Final

CHLOROPHYLL-*a* TOTAL MAXIMUM DAILY LOADS FOR CROWDER LAKE (OK310830060130_00)

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

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ACRONYMS AND ABBREVIATIONS

µg/L	Microgram per liter
BUMP	Beneficial Use Monitoring Program
CAFO	Concentrated Animal Feeding Operation
CDL	Cropland Data Layer
CFR	Code of Federal Regulations
CPP	Continuing Planning Process
CV	Coefficient of Variation
CWA	Clean Water Act
DEQ	Oklahoma Department of Environmental Quality
DMR	Discharge monitoring report
DO	Dissolved oxygen
EPA	United States Environmental Protection Agency
HUC	Hydrologic unit code
kg	Kilograms
kg/ha/yr	Kilograms per hectare per year
LA	Load allocation
mg/L	Milligram per liter
MOS	Margin of safety
MS4	Municipal separate storm sewer system
NASS	National Agricultural Statistics Service
NPDES	National Pollutant Discharge Elimination System
NSE	Nash-Sutcliffe Efficiency
O.S.	Oklahoma statutes
OAC	Oklahoma Administrative Code
OCC	Oklahoma Conservation Commission
ODAFF	Oklahoma Department of Food & Forestry
OPDES	Oklahoma Pollutant Discharge Elimination System
O.S.	Oklahoma Statute
OSWD	Onsite wastewater disposal
OWRB	Oklahoma Water Resources Board
r^2	Correlation coefficient
SH	State Highway
SWAT	Soil and Water Assessment Tool
SWS	Sensitive public and private water supply
TMDL	Total maximum daily load
TN	Total nitrogen
TP	Total phosphorus
TSI	Trophic state index
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WBID	Waterbody Identification
WLA	Wasteload allocation

WQM	Water quality monitoring
WQMP	Water quality management plan
WQS	Water quality standard
WWAQ	Warm Water Aquatic Community
WWTF	Wastewater treatment facility

Executive Summary

This report documents the data and assessment methods used to establish total maximum daily loads (TMDL) for pollutants impacting chlorophyll-*a* levels for Crowder Lake [Oklahoma Waterbody ID (OK WBID) number OK310830060130_00]. The Oklahoma Department of Environmental Quality (DEQ) placed Crowder Lake in Category 5 [303(d) list] of the *Water Quality in Oklahoma, 2022 Integrated Report* for nonsupport of the Fish and Wildlife Propagation-Warm Water Aquatic Community (WWAC) and Public and Private Water Supply designated uses (PPWS).

Crowder Lake is located in the Upper Washita sub-basin (HUC 11030302). Crowder Lake is a 158-acre lake in Washita County with a conservation pool storage of 2,094 acre-feet. It was impounded in 1958 and serves as a recreational lake and water supply (Oklahoma Water Resources Board [OWRB] 2010). Most of the 8-mile shoreline is undeveloped. The contributing watershed of Crowder Lake, displayed in Figure 1-1, is 26.8 square miles. Cobb Creek (4.5 miles long) and Possum Hollow Creek (4.1 miles long) are the primary tributaries flowing to Crowder Lake.

Based on a review of satellite imagery from Google Earth Maps there appears to be little developed land in the Crowder Lake watershed. The aggregate total of low, medium, and high density developed land accounts for less than one percent of the land use in the Crowder Lake watershed. The most common land use category in the watershed is crop land [from 2015 CDL layer (USDA 2018)]. The contributing watershed is herein after referred to as the Study Area.

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), United States Environmental Protection Agency (EPA) guidance, and Oklahoma Water Quality Standards (WQS) [Oklahoma Administrative Code (OAC) Title 252, Chapter 730]. The Oklahoma Department of Environmental Quality (DEQ) is required to submit all TMDLs to EPA for review and approval. Once EPA 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 (EPA 2003).

The purpose of this TMDL report is to establish watershed-based 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 stormwater 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

This TMDL report focuses on the waterbody identified in Table ES- 1 that DEQ placed in Category 5 of the *Water Quality in Oklahoma 2022 Integrated Report* for nonsupport of the Public Private Water Supply use. 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 such as nitrogen and phosphorus to the waterbody, a process known as eutrophication.

Table ES- 1 Excerpt from the 2022 Integrated Report – Oklahoma §303(d) List of Impaired Waters (Category 5a)

Waterbody Name and OKWBID	Waterbody Size (Acres)	TMDL Date	TMDL Priority	Causes of Impairment	Designated Use Not Supported
Crowder Lake (OK310830060130_00)	158	2033	4	▪ Chlorophyll-*a*	▪ PPWS
				▪ Turbidity	▪ WWAC

Source: 2022 Integrated Report, DEQ 2022.

Sensitive Public and Private Water Supply (SWS) lakes are defined in the Oklahoma Water Quality Standards - Oklahoma Administrative Code (OAC) 252:730-5-25(c)(4)(A). In Appendix A.3 of the WQS, Crowder Lake is listed as a SWS lake.

The numeric criterion set for chlorophyll-*a* for SWS lakes is also found in the WQS [252:730-5-10(7)] which states, "*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.*

Surface level sampling data, collected from the lake's Water Quality Monitoring (WQM) stations, was used to support the decision to place Crowder Lake on the DEQ 2018 §303(d) list for non-support of the Public and Private Water Supply Use in an SWS lake:

- Between 2006 and 2015, Crowder Lake chlorophyll-*a* samples averaged 31.2 µg/L.

Between 2006 to 2015, total nitrogen levels (TN) and total phosphorus (TP) levels were as follows for Crowder Lake.

- TN levels averaged approximately 1.09 mg/L and TP levels averaged 0.08 mg/L (Table 2-4).

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 Crowder Lake must demonstrate compliance with the numeric criterion prescribed for SWS lakes in the Oklahoma WQS (DEQ

2022g). Therefore, the water quality target established for Crowder Lake is to achieve a long-term average in-lake concentration of 10 µg/L for chlorophyll-*a*. Crowder Lake is also included in the 303(d) list for turbidity. This water quality issue will be addressed specifically at a future date.

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. 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).

E.2 Pollutant Source Assessment

This section includes an assessment of the known and suspected sources of nutrients contributing to the eutrophication of Crowder 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 discernible, 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:

- Continuous Point Source Discharges
    - NPDES municipal wastewater treatment facility (WWTF) discharges;
    - NPDES industrial WWTF discharges;
- NPDES municipal separate storm sewer system (MS4) discharges
    - Phase 1 MS4
    - Phase 2 MS4
- NPDES no-discharge WWTF
- Sanitary sewer overflow (SSO)
- NPDES concentrated animal feeding operations (CAFO)

There are no CAFOs, no-discharge facilities, MS4s and continuous discharge point sources within the contributing watersheds of Crowder Lake.

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, grasslands, and winter wheat 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.

Given the lack of in-stream water quality data and pollutant source data available to quantify nutrient and sediment loading directly from the tributaries of Crowder Lake, a watershed loading model – the Soil and Water Assessment Tool (SWAT) – was used to develop point and nonpoint source loading estimates. These estimates from SWAT were used to quantify the nutrient contributions to Crowder Lake. SWAT is a basin-scale watershed model that can be operated on a daily time step (Neitsch et al. 2011). 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. Major components of the model include weather, hydrology, soil temperature and properties, plant growth, nutrients, and land management.

There is one water quality monitoring station in the tributary to Crowder Lake. However, it was necessary to extend the modeled area to encompass watersheds with stream flow gages and nutrient concentration measurements to calibrate the SWAT model due to limited data in the Crowder Lake watershed. SWAT model was extended to USGS gaging station (Figure 3-1). Thus, this SWAT model simulated portions of Upper Washita (HUC 11130302). The modeled domain displayed in Figure 3-1 is a 234 square mile area that includes the contributing watershed of Crowder Lake. The main streams located in the modeled domain are Buck Creek, Bull Creek, Camp Creek, Cobb Creek, Crooked Creek, Fivemile Creek, Lake Creek, Possum Hollow Creek, and Spring Creek.

This modeled watershed is also predominantly rural with a few small cities and towns, including all or parts of Alfalfa, Colony, Cowden, Eakly, and Sickles. The modeled area was divided into 10 subwatersheds (Figure 3-1) based on the National Elevation Dataset (http://ned.usgs.gov) and the National Hydrography Dataset (http://nhd.usgs.gov) of the USGS. The watershed of Crowder Lake is outlined in red in Figure 3-1.

A 20-year period (1998 - 2017) was simulated in the SWAT model. However, the first two years were considered a "spin-up" period for stabilizing model initial conditions, and the model output consisted of only the latter 18 years (2000 - 2017). The variables simulated in SWAT included flow, TSS, TP, and TN.

The SWAT hydrologic calibration for the Crowder Lake model was based on flow data available at the USGS gages located on Cobb Creek near Eakly, OK (USGS Station 07325800) (Figure 3-1). Additionally, estimated daily average flow data at sub-basin 1 and 8 were compared with grab sample data collected in Cobb Creek (OWRB Station 310830060120-001RS and OCC Station OK310830-06-0050M) (Appendix Table 5). Overall, the model reproduces the annual flows slightly over the 15 percent target[1] (18.8% error). However, resulting Nash-Sutcliffe Efficiency coefficients (NSE) and percent bias (PBIAS) were 0.60 and 22.3% for monthly

[1] As stated in Section B7 of the approved QAPP for the project, total annual flows are to be calibrated so that predicted values are within 15% of the measured values ($R^2 > 0.5$ and Nash-Sutcliffe efficiency (NSE) > 0.4).

calibration (2009 – 2017) and 0.63 and 16.5% for monthly validation (2000 – 2008) (Appendix Table 4). The high resulting coefficients and low biases indicate very good model performance for annual flows.

After hydrologic calibration, same parameters were imported to the SWAT model for nutrient loads. The SWAT-predicted nutrient concentrations were calibrated to the observed nutrient concentrations at two water quality stations (Figure 3-1):

- Cobb Creek above Crowder Lake (sub-basin 1; OWRB Station 310830060120-001RS) and
- Cobb Creek, downstream of Crowder Lake (sub-basin 8; OCC Station OK310830-06-0050M).

To compare the model values, monthly average observations were estimated from linear regression model for TSS, TP and TN. Linear regression model was used because of the lack of daily WQ data to calculate monthly average. Non-detects were assumed equal to half of the detection limit in the linear regression. However, non-detect linear regression was used for TSS because there are 20 non-detects out of 37 data at OCC station. In all cases, the SWAT model reproduced the overall average concentrations within 25 percent of the estimated averages by the linear regression model[2], except TN at sub-basin 1. This exception is most likely a result of the limited amount of nutrient data available. However, this slight variance for TN at sub-basin 1 is not considered critical since the data results at sub-basins 1 and 10 are used to develop annual average loading estimates for the lake water quality model BATHTUB. It should also be 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 due to lack of the data.

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 (TN and TP) 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 Crowder Lake and the nutrient loadings from its watershed.

BATHTUB is a U.S. Army Corps of Engineers model designed to simulate eutrophication in reservoirs and lakes (Walker 1986). 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 waterbody characteristics, hydraulic characteristics, and external nutrient loadings.

The model was run under existing average, steady-state conditions. Two segmented single, well-mixed lake was assumed for Crowder Lake. Key water quality parameters for BATHTUB

[2] As stated in Section B7 of the approved QAPP for the project, nutrients are to be calibrated so that the mean of the predicted values falls within 25% of the mean of the measured values.

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 lake nutrients. Therefore, the long-term average annual loads from the SWAT-modeled period were applied as inputs to BATHTUB.

The BATHTUB model was run under average existing conditions, and calibrated to measure in-lake water quality conditions (based on 1998-2015 data) using phosphorus, nitrogen, chlorophyll-a and Secchi disk calibration factors. The model-predicted concentrations of TP, organic P, TN, organic N, chlorophyll-*a*, and Secchi depth under existing average conditions are compared to average measured concentrations from Crowder Lake in Table ES- 2 .

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

Water Quality Parameter	Calibration Factor	Crowder Lake			
		Segment 1		Segment 2	
		Modeled	Measured	Modeled	Measured
Total Phosphorus (mg/L)	1.65	107.3	101.9	73.4	71.9
Organic P (mg/L)	0.55	64.0	63.9	27.9	29.7
Total Nitrogen (mg/L)	1.3	1,285.3	1,244.9	1,058.1	1,030.8
Organic N (mg/L)	0.72	797.0	765.7	649.0	635.8
Chlorophyll-*a* (µg/L)	1.05	36.7	35.7	26.8	26.9
Secchi depth (meters)	0.8	0.40	0.42	0.77	0.74

Simulations were performed using the BATHTUB model to evaluate the effect of watershed loading reductions on chlorophyll-*a* levels. Atmospheric loads were maintained at their existing estimated levels. Simulations indicated that the water quality target of 9 µg/L chlorophyll-*a* (Appendix D) as a long-term average concentration could be achieved if the total phosphorus watershed loads to Crowder Lake were reduced by 87% from the existing loads, to 60 kg/year of TP and 828 kg/year of TN. Table ES- 3 summarizes the percent reduction goals for nutrient loading established for Crowder Lake.

Table ES- 3 Nutrient Load Reductions Needed to Meet Chlorophyll-a In-lake Water Quality Target

Constituent	LTA* (kg/yr) Existing Annual Load	Load Reduction Rate	LTA (kg/yr) Reduced Annual Load	LTA (kg/day) Reduced Daily Load
TP	464.8	87.0%	60.4	0.17
TN	6,365.7	87.0%	827.5	2.27

[a] Loads do not include atmospheric deposition

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. Furthermore, Oklahoma's implementation of WQS (OAC 252:740-13-4) prohibits new point source discharges to these lakes, except for storm water with approval from DEQ (DEQ 2022d). *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 252:730 with the limitation "SWS."*

The load allocation for watershed nonpoint sources to Crowder Lake are calculated as the difference between the TMDL, the WLA and the MOS:

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

The total allowable load to Crowder Lake was conservatively estimated as 60 kg/yr of TP and 828 kg/yr of TN, necessitating a 87 percent reduction from existing phosphorus and nitrogen loading to achieve the desired water quality target (9 µg/L).

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. EPA 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. The TMDLs for Crowder Lake include an implicit MOS using 9 µg/L chlorophyll-a target (WQS for SWS chlorophyll-a: 10 µg/L).

Load reduction scenario simulations were run using the BATHTUB model to calculate annual average phosphorus and nitrogen load (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 the lake 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 the 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 EPA's *Technical Support Document for Water Quality-Based Toxics Control* (EPA 1991a) 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 (1.645 is used for this value)
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

The LTA load and the coefficient of variation (CV) of the SWAT time series load data were used to compute the MDL. The maximum daily load correspond to the allowable annual average loads provided in Table ES- 4. In Crowder Lake the 60 kg of phosphorus per year is translated to a daily maximum load of about 0.35 kg/day of phosphorus and 828 kg of nitrogen per year is translated to a daily maximum load of about 3.37 kg/day of nitrogen. Reduction of TP and TN load in the lake watershed to this level is expected to result in achievement of WQS for chlorophyll-*a* in Crowder Lake.

Table ES- 4 TMDL for Chlorophyll-a Expressed in Kilograms of Nutrients Per Day

Constituent	LTA (kg/day) Reduced Daily Load	CV on SWAT Annual Load	MDL (kg/day) as TMDL	WLA_growth (kg/day)	LA (kg/day)	MOS
TP	0.17	0.8	0.35	0.035	0.315	Implicit
TN	2.27	0.5	3.37	0.337	3.033	

E.5 Public Participation

A public notice was sent to local newspapers, to stakeholders in the Study Area affected by these draft TMDLs, and to stakeholders who requested copies of all TMDL public notices. The public notice, draft TMDL report, and draft 208 Factsheet were posted at the following DEQ website: https://www.deq.ok.gov/water-quality-division/watershed-planning/tmdl/.

The public had 45 days (August 29, 2023 to October 13, 2023) to review the draft TMDL report and make written comments. No comments were received during the public notice period. There were no requests for a public meeting.

The Crowder Lake Chlorophyll-a TMDL Report was finalized and submitted to EPA for final approval.

SECTION 1 INTRODUCTION

1.1 TMDL Program Background

Section 303(d) of the Clean Water Act (CWA) and U.S. Environmental Protection Agency (EPA) Water Quality Planning and Management Regulations (40 Code of Federal Regulations [CFR] Part 130) require states to develop total maximum daily loads (TMDLs) for all segments and pollutants identified by the Regional Administrator as suitable for TMDL calculation. Segments and pollutants identified on the approved 303(d) list as not meeting designated uses where technology-based controls are in place will be given a higher priority for development of TMDLs. 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 (EPA 1991).

This report documents the data and assessments used to establish TMDLs for pollutants impacting chlorophyll-*a* levels for Crowder Lake (OK310830060130_00) in the Upper Washita sub-basin (HUC 11030302). Crowder Lake was placed by DEQ in Category 5 (303(d) list) of the 2022 Integrated Report for non-support of the Fish and Wildlife Propagation-Warm Water Aquatic Community (WWAC) and Public and Private Water Supply (PPWS). Figure 1-1 is location map showing this Oklahoma waterbody and its contributing watershed. The map display locations of the water quality monitoring (WQM) stations used as the basis for placement of this waterbody on the Oklahoma §303(d) list. This waterbody and its surrounding watershed are hereinafter referred to as the Study Area.

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. 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), EPA guidance, and Oklahoma Water Quality Standards (WQS) (Oklahoma Administrative Code [OAC] Title 252, Chapter 730). DEQ is required to submit all TMDLs to EPA for review and approval. Once EPA 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 WQS is achieved (EPA 2003).

The purpose of this TMDL report is to establish nutrient load allocations necessary for reducing chlorophyll-*a* levels in the lake, which is the first step toward restoring water quality and protecting public health. A TMDL determines the pollutant loading a waterbody can assimilate without exceeding applicable WQS. A TMDL also establishes 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), a 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 can be implicit and/or explicit. An implicit MOS is achieved by using conservative assumptions in the TMDL calculations. An explicit 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.

1.2 Lake and Watershed Characteristics

1.2.1 Lake Characteristics

Crowder Lake is a 158-acre lake in Washita County with a conservation pool storage of 2,094 acre-feet. Dam was constructed for flood control in 1958 and rehabilitated in 2006. Most of the 8 mile shoreline is undeveloped. The contributing watershed of Crowder Lake, displayed in Figure 1-1, is 26.8 square miles. Cobb Creek (4.5 miles long) and Possum Hollow Creek (4.1 miles long) are the primary tributaries flowing to Crowder 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
Crowder Lake	158	2,094	1,520	11.5	8.0	Southwestern Oklahoma State University

MSL = Mean Sea Level

1.2.2 General

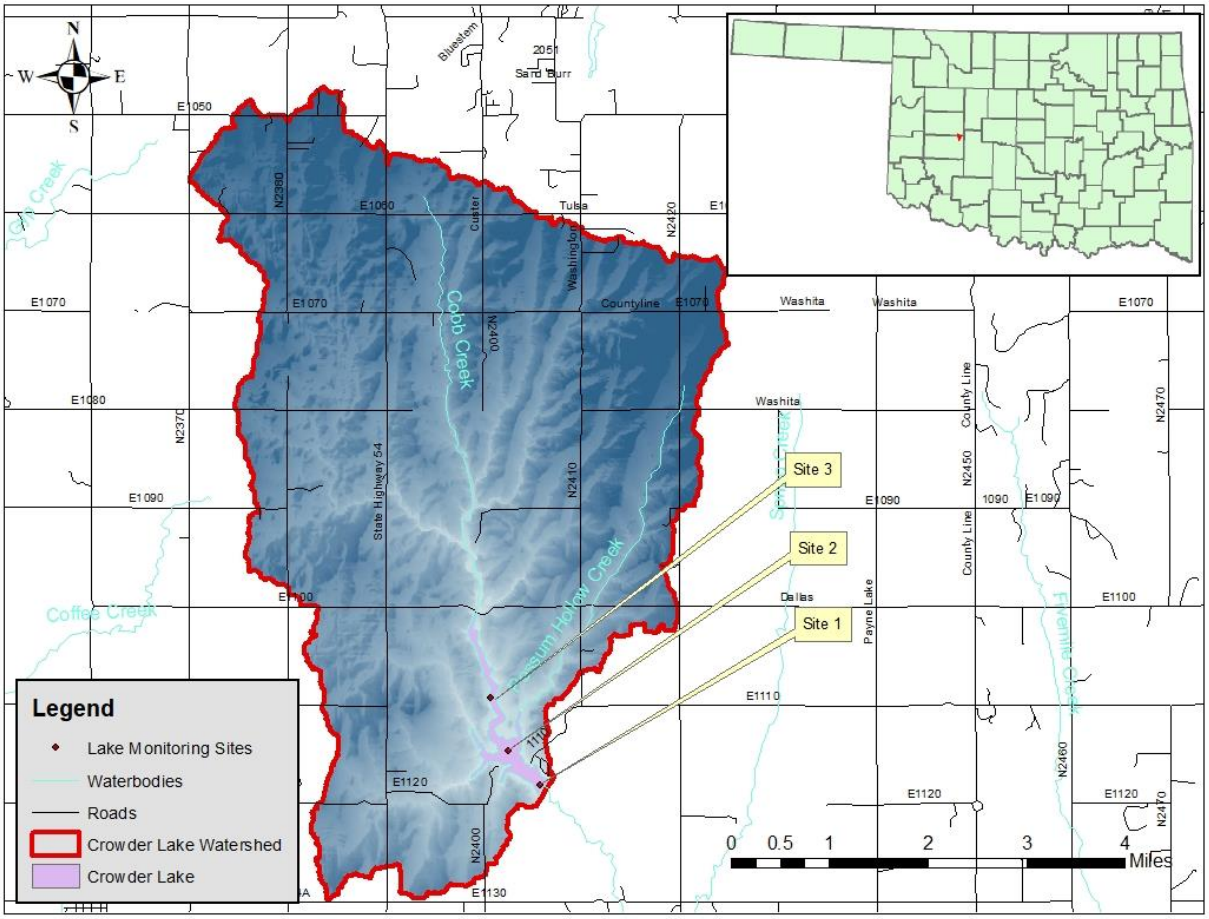
Crowder Lake is located in the Upper Washita sub-basin as well as in the Central Great Plains ecoregion (Woods et al. 2005) of central Oklahoma. Crowder Lake is specifically located 7 miles south of Weatherford, Oklahoma and it is in Washita County. The Central Great Plains ecoregion consists predominately of grassland, with scattered woodland in ravines and along streams.

Table 1-2, derived from the 2010 U.S. census, demonstrates that the counties in which the watersheds are located are sparsely populated (U.S. Census Bureau 2010).

Table 1-2 County Population and Density

County Name	Population (2010 Census)	Population Density (per square mile)
Custer	27,469	27
Washita	11,629	12

Figure 1-1 Crowder Lake



1.2.3 Climate

Table 1-3 summarizes the average annual precipitation for Crowder Lake. Average annual precipitation values were derived from the Oklahoma Mesonet Dataset (http://www.mesonet.org) based on a period of record from 2004 to 2018 from the station in the vicinity of the lake watershed (Oklahoma Mesonet 2019).

Table 1-3 Average Annual Precipitation by Watershed (2004-2018)

Waterbody Name	Waterbody ID	Station	Average Annual Precipitation (inches)
Crowder Lake	OK310830060130_00	Weatherford	34.8

1.2.4 Land Use

The contributing drainage areas of Crowder Lake are approximately 26.8 square miles. Table 1-4 summarizes the percentages and acreages of the land use categories for the contributing watersheds. Land use/land cover data were derived from the National Agricultural Statistics

Service (NASS) 2015 Cropland Data Layer (CDL). The CDL is a crop-specific land cover classification data set. Land use distributions in the watershed of Crowder Lake are displayed in Figure 1-2. The most land use categories in the watershed is crop land, followed by grassland/pasture. The aggregate total of low, medium, and high density developed land accounts for less than one percent of the land use in the Crowder Lake watershed (see summary of CDL data, Table 1-4).

Table 1-4 Land Use Summary by Watershed

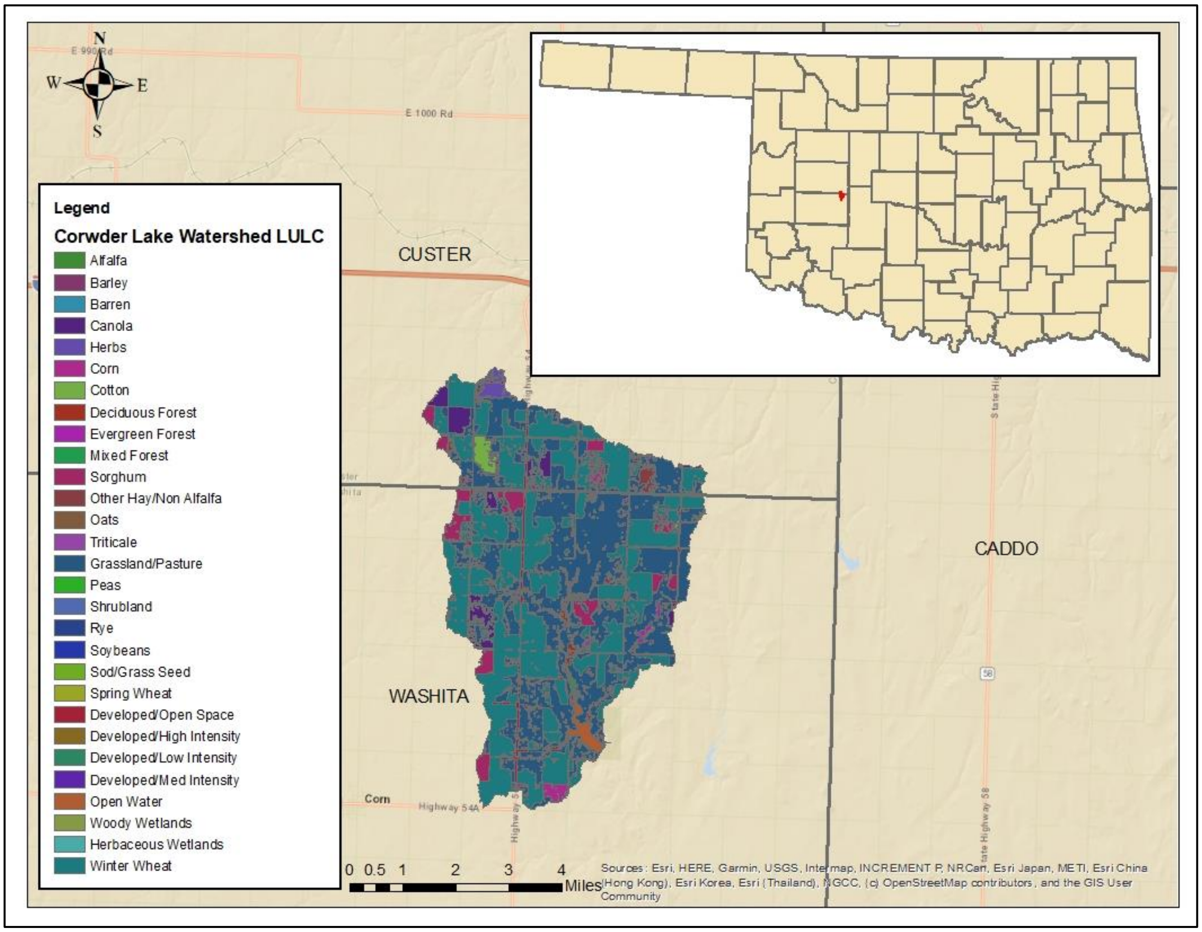
Description	SWAT Code	Area (acres)	Percent of Total Watershed Area§
Corn	CORN	201.5	1.2%
Cotton	COTP	151.0	0.9%
Sorghum	SGHY	841.9	4.9%
Soybean	SOYB	7.6	0.04%
Barley	BARL	0.2	0.001%
Spring Wheat	SWHT	0.4	0.002%
Winter Wheat	WWHT	6,884.6	40.2%
Rye	RYE	0.8	0.004%
Oats	OATS	5.7	0.03%
Canola	CANP	497.4	2.9%
Alfalfa	ALFA	15.5	0.1%
Other Hay/Non Alfalfa	HAY	176.2	1.0%
Peas	PEAS	2.5	0.0%
Herbs	CELR	137.1	0.8%
Sod/Grass Seed	BERM	0.6	0.004%
Open Water	WATR	148.6	0.9%
Develped-Open Space	URBN	679.5	4.0%
Develped- Low Density	URHD	53.4	0.3%
Develped- Medium Density	URLD	25.8	0.2%
Develped- High Density	URMD	0.8	0.005%
Barren	BARR	1.2	0.01%
Forest-Deciduous	FRSD	103.5	0.6%
Forest-Evergreen	FRSE	140.3	0.8%
Mixed Forest	FRST	95.6	0.6%
Shrubland	RNGB	286.5	1.7%
Grassland/Pasture	PAST	6,648.5	38.8%
Woody Wetlands	WETF	8.0	0.05%
Herbaceous Wetlands	WETN	1.7	0.01%
Triticale	RYE	5.7	0.03%
Sum		17,122.2	

§ Rounding of numbers accounts for percentage total not equaling 100.

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 Crowder Lake. However, OWRB collected limited flow data at the confluence where Cobb Creek (OK310830060120_00) met Crowder Lake. Given the lack of historical stream flow data, flow estimates for lake tributaries were developed using a watershed model calibrated to flow measurements at U.S. Geological Survey (USGS) gage stations in downstream. This is discussed in further detail in SECTION 3.

Figure 1-2 Land Use for the Crowder Lake Watershed



SECTION 2
PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

2.1 Oklahoma Water Quality Standards

Title 252 of the Oklahoma Administrative Code contains Oklahoma Water Quality Standards in Chapter 730 (DEQ 2022g) and implementation procedures in Chapter 740 (DEQ 2022d). The Oklahoma Department of Environmental Quality 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 DEQ 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 (DEQ 2022g). An excerpt of the Oklahoma WQS (Chapter 730, Title 252) summarizing the State of Oklahoma Antidegradation Policy is provided in Appendix A. Beneficial uses designated for Crowder Lake include aesthetics, the WWAC subcategory of the fish and wildlife propagation use, agricultural water supply, primary body contact recreation, fish consumption, and sensitive public and private water supply. The WWAC subcategory of the fish and wildlife propagation use and public and private water supply uses are not supported in Crowder Lake. 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 non-attainment of the public and private water supply use.

Table 2-1 Excerpt from the 2022 Integrated Report – Oklahoma §303(d) List of Impaired Waters (Category 5a)

Waterbody Name and OKWBID	Waterbody Size (Acres)	TMDL Date	TMDL Priority	Causes of Impairment	Designated Use Not Supported
Crowder Lake (OK310830060130_00)	158	2033	4	▪ Chlorophyll-*a*	▪ PPWS
				▪ Turbidity	▪ WWAC

Source: 2022 Integrated Report, DEQ 2022.

Crowder Lake is designated as SWS lakes. The definition of SWS is summarized by the following excerpt from the Oklahoma Administrative Code (OAC) 252:730-5-25 of the Oklahoma WQS (DEQ 2022g).

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 252:730-5-25(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 SWS lakes are defined in the Oklahoma Water Quality Standards - OAC 252:730-5-25(c)(4)(A). In Appendix A.3 of the WQS, Crowder Lake is listed as SWS lakes.

The numeric criterion for chlorophyll-a for SWS lakes is also found in the WQS (252:730-5-10(7)), which states, "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 or SWS-R in Appendix A of this Chapter. Wherever such criterion is exceeded, numerical phosphorus or nitrogen criteria or both may be promulgated."

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 Crowder Lake. These WQM stations are part of the Oklahoma Beneficial Use Monitoring Program (BUMP) network (OWRB 2012). Locations of the WQM stations for Crowder Lake are illustrated in Figure 1-1.

Table 2-2 Water Quality Monitoring Stations used for 2020 §303(d) Listing Decision

Waterbody ID	Station ID	Latitude	Longitude	Site Description
Crowder Lake				
310830060130-01	Site 1	35.39	-98.70	Near Surface
310830060130-02	Site 2	35.40	-98.71	Near Surface
310830060130-03	Site 3	35.41	-98.71	Near Surface

2.2.1 Chlorophyll-*a* Data Summary

Table 2-3 summarizes chlorophyll-*a* measurements collected from Crowder Lake from 2006 through 2015. Pooling data from surface level sites, chlorophyll-*a* levels averaged 31.2 µg/L. Nine data from Site 3 were eliminated due to extraordinary high value compared to those in Site 1 and 2. As stipulated in the Implementation Procedures for Oklahoma's Water Quality Standards (252:740-15-3(c)) the most recent 10 years of water quality data are used as the basis for evaluating the beneficial use support for lakes (DEQ 2022d). However, data older than 10 years may be utilized when minimum requirements are not met. Water quality data are provided in Appendix B.

Table 2-3 Summary of Chlorophyll-a Measurements in Crowder Lake (all values in µg/L)

Station ID	Sample Date	Number of Samples	Minimum	Maximum	Average	Median
Site 1	2/22/2006 – 12/9/2015	34	8.6	88.2	29.1	27.3
Site 2	2/22/2006 – 12/9/2015	32	8.9	76.0	29.1	24.0
Site 3	2/22/2006 – 12/9/2015	23	7.3	127.0	37.1	25.7
Overall Surface Samples		89	7.3	127.0	31.2	25.7

2.2.2 Nutrient Data Summary

During the years from 1998 to 2015, total nitrogen levels in Crowder Lake averaged approximately 1.09 mg/L, and total phosphorus levels averaged 0.08 mg/L (Table 2-4). 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.

Table 2-4 Summary of Average Nutrient Measurements in Crowder Lake (all values in mg/L)

Station ID	Data Period	Nitrogen, Nitrate + Nitrite	Nitrogen, Kjeldahl	Nitrogen, Total	Phosphorus, Ortho	Phosphorus, Total
Site 1	4/1998 – 12/2015	0.19	0.94	1.03	0.043	0.072
Site 2	4/1998 – 12/2015	0.19	0.90	0.99	0.020	0.054
Site 3	4/1998 – 12/2015	0.20	1.04	1.24	0.041	0.102
Overall Surface Samples		0.19	0.97	1.09	0.034	0.076

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 Crowder Lake must demonstrate compliance with the numeric criterion prescribed for SWS lakes in the Oklahoma WQS (DEQ

2022g). Therefore, the water quality target established for Crowder Lake is to achieve a long-term average in-lake concentration of 10 µg/L for chlorophyll-*a*. Crowder Lake is also included in the 303(d) list for turbidity. This water quality issue will be addressed specifically at a future date.

SECTION 3
POLLUTANT SOURCE ASSESSMENT

A pollutant source assessment characterizes known and suspected sources of pollutant loading to impaired waterbodies. Sources within a watershed are categorized and quantified to the extent that information is available. This section includes an assessment of the known and suspected sources of nutrients contributing to the eutrophication of Crowder 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 TMDL 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 Crowder Lake.

3.1 Assessment of Point Sources

Under 40 CFR §122.2, a point source is described as a discernible, 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:

- Continuous Point Source Dischargers
  - NPDES municipal wastewater treatment facilities (WWTF)
  - NPDES Industrial WWTF Discharges
- NPDES municipal separate storm sewer system (MS4) discharges
  - Phase 1 MS4
  - Phase 2 MS4
- NPDES No-discharge WWTF
- Sanitary sewer overflow (SSO)
- NPDES Concentrated Animal Feeding Operation (CAFO)

In the Crowder Lake watershed, there are no CAFOs, MS4s, no-discharge facilities and continuous point source dischargers.

3.2 Estimation of Existing Pollutant Loads

In the Crowder Lake watershed, there are no permitted facilities. Therefore, no WLA will be allocated for Crowder Lake TMDL. The relatively homogeneous land use/land cover categories throughout the Study Area associated with forest, grasslands, and winter wheat 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, livestock, 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 in-stream water quality data and pollutant source data available to quantify nutrient and sediment loading directly from the tributaries of Crowder Lake, a watershed loading model – the Soil and Water Assessment Tool (SWAT 2012) – was used to develop nonpoint and point source loading estimates. These estimates from SWAT were used to quantify the nutrient contributions to Crowder Lake. SWAT is a basin-scale watershed model that can be operated on a daily time step (Neitsch et al. 2011). 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. Major components of the model include weather, hydrology, soil temperature and properties, plant growth, nutrients, and land management. The SWAT model was developed to determine watershed flow and nutrient loading to Crowder Lake (Figure 3-1). The descriptions of inputs and calibration of SWAT model are presented in Appendix C. A summary of the SWAT modeling of pollutant sources is provided below.

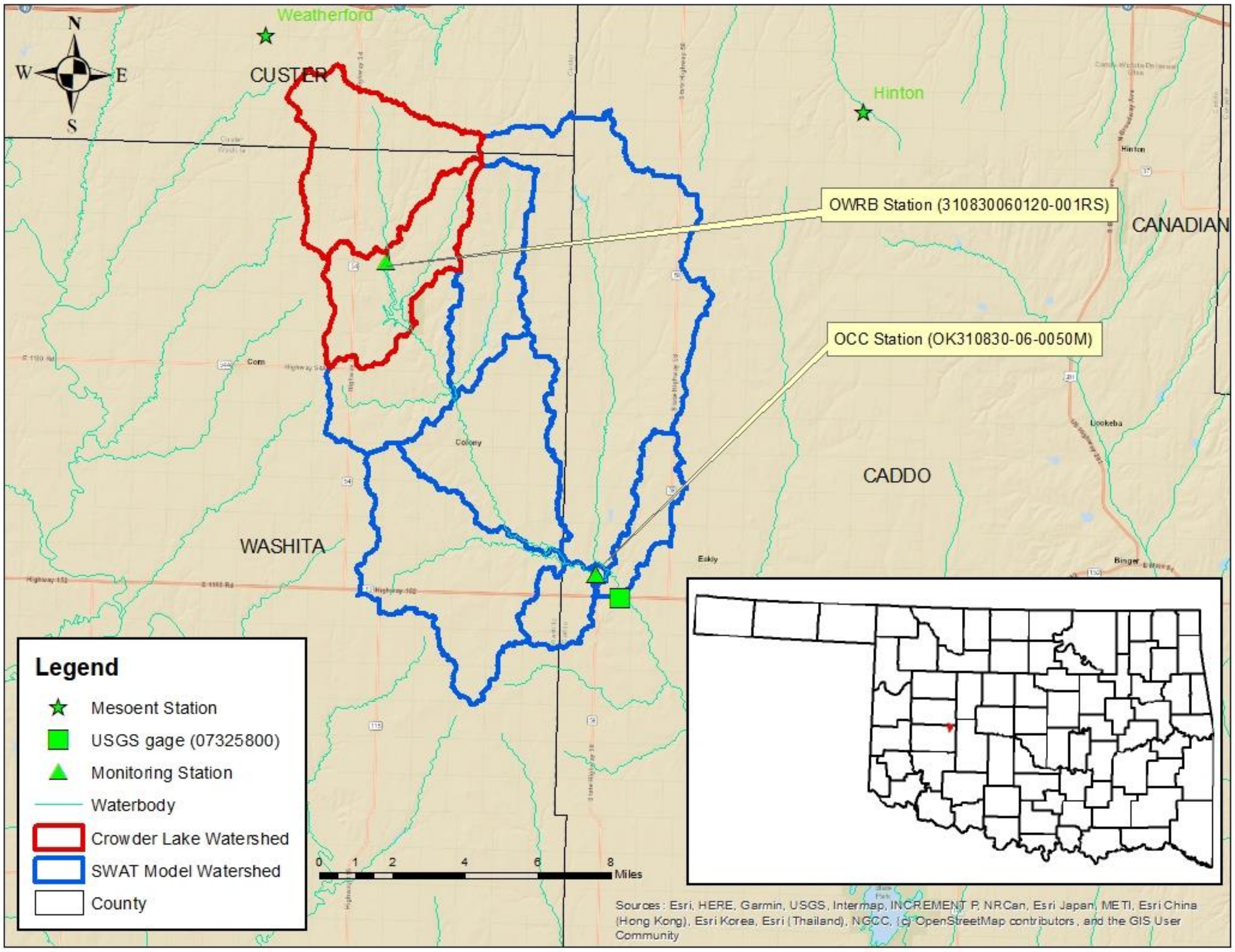
There are limited stream flow and water quality data on the tributaries to Crowder Lake. To calibrate the SWAT model, it was necessary to extend the modeled area to encompass watersheds with stream flow gages and nutrient concentration measurements. The SWAT model was extended to USGS gaging station (Figure 3-1). Thus, this SWAT model simulated portions of Upper Washita (HUC 11130302) sub-basin. The modeled domain displayed in Figure 3-1 is about 234 square mile area that includes the contributing watershed of Crowder Lake. The main streams located in the modeled domain are Buck Creek, Bull Creek, Camp Creek, Cobb Creek, Crooked Creek, Fivemile Creek, Lake Creek, Possum Hollow Creek, and Spring Creek.

This modeled watershed is predominantly rural with a few small cities and towns, including all or parts of Alfalfa, Colony, Cowden, Eakly, and Sickles. The modeled area was divided into 10 sub-watersheds (Figure 3-1) based on the National Elevation Dataset (http://ned.usgs.gov) and the National Hydrography Dataset (http://nhd.usgs.gov) of the USGS. The watershed of Crowder Lake is outlined in red in Figure 3-1.

There were no point sources in SWAT model area and OSWD systems were not included in the SWAT models. Using data from the 1990 census to estimate a density of household with OSWDs, it was estimated that there were 411 OSWD systems within the modeled watershed in Figure 3-1. Of these, approximately 54 OSWD systems were estimated to lie within the Crowder Lake watershed (about 0.003 system per acre). More recent OSWD data are not available. Because of the very low density of OSWD systems within the model watershed, they are not expected to be a major contributor of nutrient loadings and, thus, they were not included in the SWAT model of the Crowder Lake watershed.

For the SWAT model, soil data were derived from the SSURGO State Soil Geographic Database of the United States Department of Agriculture (USDA) Natural Resource Conservation Service (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053631). Land use and land cover data were derived from the USDA NASS 2015 Cropland Data Layer. County-level summaries of annual cattle population estimates from the NASS were evenly distributed across pasture land (USDA 2012).

Figure 3-1 SWAT Model Segmentation and Calibration Stations



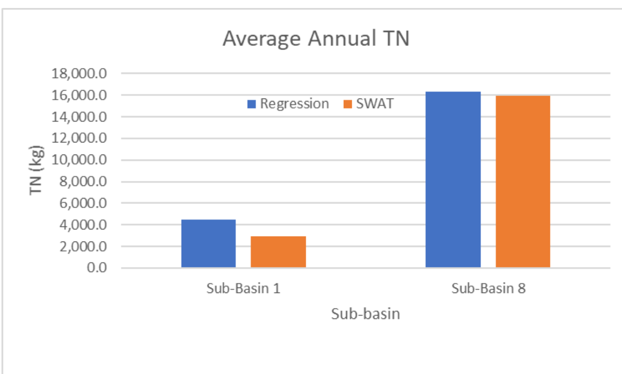
3.2.2 Model-Estimated Nutrient Loading from Point and Nonpoint Sources

The SWAT models were 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 is incorporated into the lake model BATHTUB (see SECTION 4). Fecal waste deposited in the watersheds by wildlife and pets is not considered to be a significant source of nutrient loading to the lake watersheds 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.

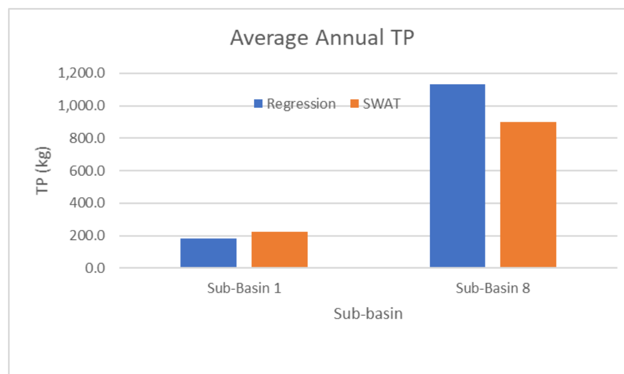
A 20-year period (1998 - 2017) was simulated in the SWAT models. However, the first two years were considered a “spin-up” period for stabilizing model initial conditions, and the model output consisted of only the latter 18 years (2000 - 2017). The variables simulated in SWAT included flow, TP, TN, and total suspended solids.

For purposes of calculating averages to compare to modeled values, non-detects were assumed equal to half of the detection limit. In all cases, the SWAT model reproduced the overall average TP and TN concentrations within 25 percent of the estimated averages (Figure 3-2), except TN at sub-basin 1 (34.4%). Linear regression estimation for observation strongly depended on flow and data were collected under low flow conditions (flow less than 1 m^3/s) at sub-basin 1. Therefore, linear regression estimation had limitation on estimating load for high flow regime and bigger errors were observed at sub-basin 1. In other word, at sub-basin 8 where flows were high compared to those at sub-basin 1, SWAT results were well agreed with linear regression estimation. Based on these observations, SWAT estimated pollutant load better for all flow range than regression method when data were limited. Therefore, these variances were not considered critical to develop annual average loading estimates for the lake water quality model, BATHTUB. It should also be noted that monitoring data available for calibration were primarily from low to moderate flow conditions. Due to limited high flow data, data comparison at high flow might not accurate and result high errors.

Figure 3-2 SWAT Model Comparison with Observed Estimation



(a) TN comparison



(b) TP comparison

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 data analysis methods used to demonstrate the linkage between chlorophyll-*a* levels in Crowder Lake and the nutrient loadings from its watershed. The subsections below summarize the inputs and results of the modeling approach used to establish TMDL calculations.

4.1 SWAT Model Description

SWAT is a river basin or watershed scale model operating a daily time step. SWAT is the acronym for Soil and Water Assessment Tool developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). It is developed to quantify and predict the impacts of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds with varying soils, land use, and management conditions over long periods of time.

4.2 SWAT Model Setup and Input Data

Model set up was described briefly in Section 3.2. Input data and model results were described in Appendix C.

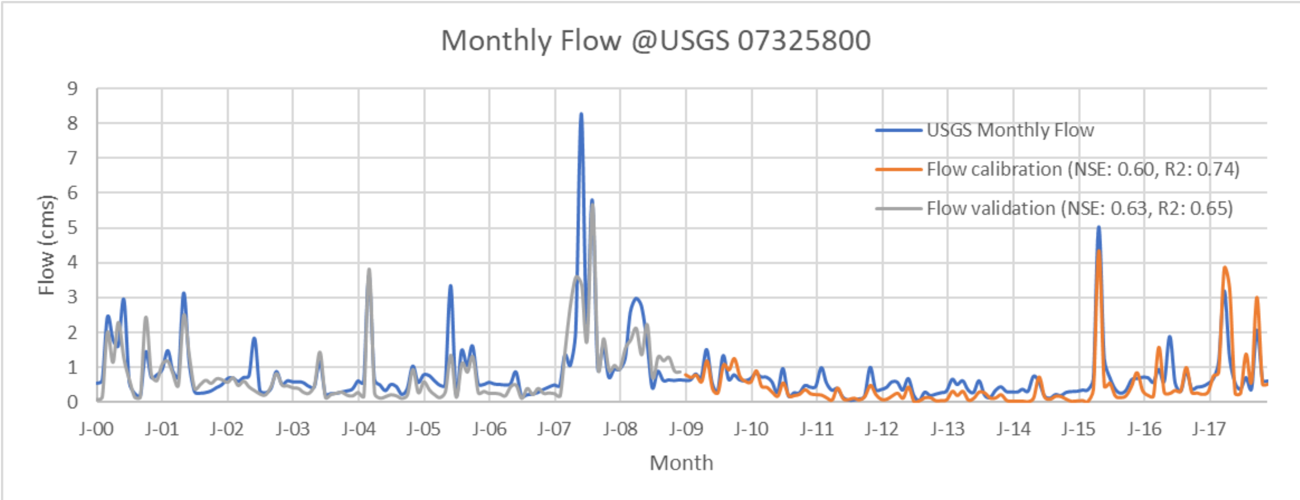
4.3 SWAT Model Calibration and Validation

<u>Calibration of SWAT Model for Crowder Lake</u>

The SWAT hydrologic calibration was primarily performed based on flow data available at the USGS gages located on Cobb Creek near Eakly, OK (USGS Station 07325800) (Figure 3-1). Additionally, estimated daily average flow data at sub-basin 1 and 8 were compared with grab sample data collected in Cobb Creek (OWRB Station 310830060120-001RS and OCC Station OK310830-06-0050M) (Appendix Table 5). The SWAT model was used to simulate annual average flows and not intended to simulate monthly or daily flows due to limited input data. However, monthly and daily model results were shown for information purpose to compare the agreement between observed and modeled data.

Primary calibration targets were annual flows, but modeled monthly flows, which are displayed in the graphs shown in Figure 4-1 and the resulting average monthly flow model results, were also compared to measured values. Overall, the model reproduces the monthly flows within 20% relative error for 18 years simulation period. Resulting NSE coefficients and R^2 values were 0.60 and 0.74 for calibration (2009 – 2017) and 0.63 and 0.65 for validation (2000 – 2008). The high resulting coefficients indicate very good model performance for monthly flows. Additional model calibration information is provided in Appendix C.

Figure 4-1 Observed and SWAT Modeled Average Monthly Flows



The SWAT-predicted nutrient concentrations were calibrated to the observed nutrient concentrations at two water quality stations (Figure 3-1):

- Cobb Creek above Crowder Lake (OWRB Station 310830060120-001RS) and
- Cobb Creek, downstream of Crowder Lake (OCC Station OK310830-06-0050M).

To compare the model values, monthly average observations were estimated from linear regression model for TSS, TN and TP. Linear regression model was used because of the lack of daily WQ data to calculate monthly average. The regression models are shown below in Table 4-1.

Table 4-1 Regression models for estimating monthly observation.

Monitoring Station	Variable	Regression Model	R^2
310830060120-001RS	TN (kg/d)	Log(TN load) 1.2561*logQ + 2.6586	0.75
	TP (kg/d)	Log(TP load) = 1.9835*logQ + 1.7317	0.76
OK310830-06-0050M	TSS (mg/L)	Log(TSS load) = 1.308*logQ + 1.667	0.55 (loglik-r)
	TN (kg/d)	Log(TN load) = 0.8295*logQ + 2.0723	0.91
	TP (kg/d)	Log(TP load) = 0.9089*logQ + 0.9355	0.52

Q=flow (m^3/s).

At 310830060120-001RS, TSS linear regression couldn't be established because of no available TSS data. All WQ linear regressions showed good correlation between WQ and flow (Q). To calibrate SWAT model, monthly load estimations from regression models were compared with monthly SWAT outputs. As mentioned earlier in the report, regression model estimations in high flow were questionable due to limited data. Therefore, estimations from the highest flow month (August 2007) were exclude from validation.

Table 4-2 SWAT WQ calibration and Validation.

Monitoring Station	Variable	Period	NSE	PBIAS	Comment
310830060120-001RS	TN	2000 - 2008	0.50	39.1%	Validation
		2009 - 2017	0.52	32.4%	Calibration
	TP	2000 - 2008	0.70	-33.8%	Validation

Monitoring Station	Variable	Period	NSE	PBIAS	Comment
		2009 - 2017	0.63	-3.8%	Calibration
OK310830-06-0050M	TSS	2000 - 2008	0.65	13.4%	Validation
		2009 - 2017	0.66	13.2%	Calibration
	TN	2000 - 2008	0.91	4.5%	Validation
		2009 - 2017	0.89	7.6%	Calibration
	TP	2000 - 2008	0.67	20.2%	Validation
		2009 - 2017	0.78	28.7%	Calibration

All NSE in Table 4-2 were greater than or equal to 0.5. These high NSE indicated that SWAT results agreed well with linear regression estimation. In another word, SWAT performed well to estimate nutrient loads from the Crowder Lake watershed. PBIAS were less than 40% and this indicated that difference between average value of SWAT results and linear regression estimations were less than 40%.

4.4 BATHTUB Model Description

The water quality linkage analysis was performed using the BATHTUB model (Walker 1986). BATHTUB is a USACE model designed to simulate eutrophication in reservoirs and lakes (USACE 2004). 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 waterbody 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 waterbody under various hydrologic and loading conditions. To do this, the model requires inputs that describe the physical characteristics (e.g., depth, surface area) of 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.

4.5 BATHTUB Model Setup and Input Data

The model was run under average, steady-state conditions. Model set up and input data were described in Appendix D.

4.6 BATHTUB Model Calibrations and Output

BATHTUB model results were compared to Crowder Lake sample data collected from 1998 to 2015. To calibrate Crowder Lake BATHTUB model, nutrients and chlorophyll-a calibration factors were adjusted to reduce the error in each water quality parameter. Table 4-3 showed less than 5% error in all parameters. Considering limited observed data, BATHTUB simulated Crowder Lake conditions very well with inputs from SWAT results. Detailed calibration parameters were described in Appendix D.

Table 4-3 Model Predicted and Measured Water Quality Parameter Concentrations

Water Quality Parameter	Calibration Factor for Segment		Crowder Lake			
			Segment 1		Segment 2	
	1	2	Modeled	Measured	Modeled	Measured
Total Phosphorus (µg/L)	3	0.95	102.5	101.9	72.3	71.9
Organic P (µg/L)	1.02	0.5	63.4	63.9	29.3	29.7
Total Nitrogen (µg/L)	3.9	0.5	1,286.7	1,244.9	1,045.2	1,030.8
Organic N (µg/L)	0.75	0.8	740.4	765.7	644.8	635.8
Chlorophyll-*a* (µg/L)	0.65	1.6	36.2	35.7	26.2	26.9
Secchi depth (meters)	0.4	0.99	0.41	0.42	0.74	0.74

4.7 BATHTUB Model Sensitivity Analysis

In BATHTUB calibration, six parameters were adjusted to reduce the difference between observed and modeled means. Sensitivity on those parameters was evaluated to determine which parameter would be the most effective to chlorophyll-a change in Crowder Lake BATHTUB model. Appendix Table 22 showed the model is the most sensitive to chlorophyll-a parameter, followed by TN and TP parameters. Other parameters (Organic P and Organic N) were adjusted to reduce an error on each parameter.

4.8 BATHTUB Uncertainty Analysis

Uncertainty is expressed in terms of the mean coefficient of variation (CV). CV is a standardized measure of dispersion of a probability distribution or frequency distribution. In this TMDL, BATHTUB model is calibrated to have similar CV values to corresponding variables (Appendix Table 21). Also, implicit MOS was accounted for model uncertainty. Adoption of a 10% MOS for more stringent target for chlorophyll- *a* will ensure an adequate determination of load reduction for Crowder Lake.

4.9 Modeled Load Reduction Scenarios

Simulations were performed using the BATHTUB model to evaluate the effect of watershed loading reductions on chlorophyll-*a* levels. Atmospheric loads were maintained at their existing estimated levels. As discussed above, a water quality target of 9 µg/L chlorophyll-*a* was set for Crowder Lake. Simulations indicate that the water quality target of 9 µg/L chlorophyll-*a* as a long-term average concentration will be achieved if the TP and TN loads to Crowder Lake from the watershed are reduced by 87 percent to about 60 kg/year of TP and 828 kg/year of TN. 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 the 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.

SECTION 5
TMDL AND LOAD ALLOCATIONS

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

5.1 Wasteload Allocation

There are no point sources in the Crowder Lake watershed. Therefore, no WLAs were allocated for the point sources. However, 10% of TMDL is set for the future growth.

5.2 Load Allocation

The LA for Crowder Lake was calculated as the difference between the TMDL, MOS, and WLA:

$$\mathbf{LA = TMDL - WLA\_growth - MOS}$$

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 applies as a long-term average concentration (OAC 252:730-5-10(7)). Oklahoma procedures to implement WQS (OAC 252:740-7-2) specify that the mean annual average outflow represents the long-term average flow in lakes (DEQ 2022d). Seasonal variation was accounted for in these TMDLs by using more than ten years of water quality data. The variation was accounted for in the watershed model (model period 18 years) and input into the BATHTUB model as annual average values obtained from the watershed model.

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. EPA 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. TMDLs for Crowder Lake include an implicit MOS not to exceed chlorophyll-a target as 9 µg/L for 10 µg/L chlorophyll-a in WQS.

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:

$$\boldsymbol{TMDL = \Sigma\, WLA + \Sigma\, LA + MOS}$$

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 (9 µg/L). The total allowable load to Crowder Lake was estimated as 60.4 kg/yr of TP and 827.5 kg/yr of TN (Table 5-1), necessitating a 87 percent reduction from existing phosphorus and nitrogen loadings to achieve the desired water quality target. A recent court decision (*Friends of the Earth, Inc. vs. EPA, et al*.) states that TMDLs must include a daily load expression. Therefore, a statistical method was used to identify a maximum daily limit based on a long-term average (LTA). This statistical method was documented in "Technical Support Document for Water Quality-Based Toxics Control (EPA, 1991a)." The MDL is computed from the LTA and the probability-based statistics of the pollutant loading data by the following equation as:

$$MDL = LTA \times e^{\left(Z \ln\left(1+CV^2\right) - 0.5\left(\ln\left(1+CV^2\right)\right)^2\right)}$$

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

For the Crowder Lake TMDL calculation, a 95% probability level of occurrence was used and the Z-score statistic was assigned a value of Z=1.645.

Table 5-1 Estimated Load to Crowder Lake

Constituent	LTA (kg/yr) Existing Annual Load	Load Reduction Rate	LTA (kg/yr) Reduced Annual Load	LTA (kg/day) Reduced Daily Load
TP	464.8	87%	60.4	0.17
TN	6,365.7	87%	827.5	2.27

The LTA load and the coefficient of variation (CV) of the SWAT time series load data were used to compute the MDL for TP given in Table 5-2.

Table 5-2 MDL for Crowder Lake

Constituent	LTA (kg/day) Reduced Daily Load	CV on SWAT Annual TP Load	MDL (kg/day) as TMDL	WLA_growth (kg/day)	LA (kg/day)	MOS
TP	0.17	0.8	0.35	0.035	0.315	Implicit
TN	2.27	0.5	3.37	0.337	3.033	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 this TMDL 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 2012). The CPP can be viewed from DEQ's website at:
http://www.deq.state.ok.us/wqdnew/305b_303d/Final%20CPP.pdf.

Table 5-3 provides a partial list of the State partner agencies DEQ will collaborate with to address point and nonpoint source reduction goals established by TMDL.

Table 5-3 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/endangeredspecies.htm
Oklahoma Department of Agriculture, Food, and Forestry	http://www.ok.gov/~okag/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, DEQ has delegation of the NPDES Program in Oklahoma, except for certain jurisdictional areas related to agriculture (retained by State Department of Agriculture, Food, and Forestry), and the oil and gas industry (retained by Oklahoma Corporation Commission), for which 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)). Point source WLAs, except stormwater WLAs, are outlined in the Oklahoma Water Quality Management Plan (also known as the 208 Plan) under the OPDES program.

5.6.2 Nonpoint Sources

Nonpoint source pollution in Oklahoma is managed by the Oklahoma Conservation Commission (OCC). The OCC works with State partners such as Oklahoma Department of Food & Forestry (ODAFF) and federal partners such as EPA and the National Resources Conservation Service of the USDA, to address water quality problems similar to those seen in the Study Area.

Primary mechanisms used for management of nonpoint source pollution are incentive-based programs that support the installation of BMPs and public education and outreach. Other programs include regulations and permits for CAFOs. The CAFO Act, as administered by the ODAFF, provides CAFO operators the necessary tools and information to deal with the manure and wastewater animals produce so streams, lakes, ponds, and groundwater sources are not polluted.

The reduction rate in nutrient loading called for in this TMDL report is 87 percent. DEQ recognizes that achieving such high reductions will be a challenge, especially since unregulated nonpoint sources are a major cause of nutrient loading.

5.6.3 Reasonable Assurance

Reasonable assurance is required by the EPA guidance for a TMDL to be approvable only when a waterbody is impaired by both point and nonpoint sources and where a point source is given a less stringent wasteload allocation based on an assumption that nonpoint source load reductions will occur. In such a case, "reasonable assurance" that the NPS load reductions will actually occur must be demonstrated.

In this report, there are no point sources in the watershed. Therefore, the impairment of this waterbody won't be caused by point sources. Reasonable assurance that nonpoint sources will meet their allocated amount in the TMDL is dependent upon the availability and implementation of nonpoint source pollutant reduction plans, controls or BMPs within the watershed. The OCC is responsible for the state's NPS program as defined in Section 319 of CWA. DEQ will work in conjunction with OCC and other federal, state, and local partners within the respective watersheds to meet the load reduction goals for NPS. All waterbodies are prioritized as part of the Unified Watershed Assessment (UWA) and that ranking will determine the likelihood of an implementation project in a watershed.

SECTION 6
PUBLIC PARTICIPATION

A public notice was sent to local newspapers, to stakeholders in the Study Area affected by these draft TMDLs, and to stakeholders who requested copies of all TMDL public notices. The public notice, draft TMDL report, and draft 208 Factsheet were posted at the following DEQ website: https://www.deq.ok.gov/water-quality-division/watershed-planning/tmdl/.

The public had 45 days (August 29, 2023 to October 13, 2023) to review the draft TMDL report and make written comments. No comments were received during the public notice period. There were no requests for a public meeting.

The Crowder Lake Chlorophyll-a TMDL Report was finalized and submitted to EPA for final approval.

SECTION 7
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Appendix A State of Oklahoma Antidegradation Policy

State of Oklahoma Antidegradation Policy

252:730-3-1. Purpose; Antidegradation policy statement

(a) Waters of the state constitute a valuable resource and shall be protected, maintained and improved for the benefit of all the citizens.

(b) It is the policy of the State of Oklahoma to protect all waters of the state from degradation of water quality, as provided in OAC 252:730-3-2 and Subchapter 13 of OAC 252:740.

252:730-3-2. Applications of antidegradation policy

(a) Application to outstanding resource waters (ORW). Certain waters of the state constitute an outstanding resource or have exceptional recreational and/or ecological significance. These waters include streams designated "Scenic River" or "ORW" in Appendix A of this Chapter, and waters of the State located within watersheds of Scenic Rivers. Additionally, these may include waters located within National and State parks, forests, wilderness areas, wildlife management areas, and wildlife refuges, and waters which contain species listed pursuant to the federal Endangered Species Act as described in 252:730-5-25(c)(2)(A) and 2525:740-13-6(c). No degradation of water quality shall be allowed in these waters.

(b) Application to high quality waters (HQW). It is recognized that certain waters of the state possess existing water quality which exceeds those levels necessary to support propagation of fishes, shellfishes, wildlife, and recreation in and on the water. These high quality waters shall be maintained and protected.

(c) Application to beneficial uses. No water quality degradation which will interfere with the attainment or maintenance of an existing or designated beneficial use shall be allowed.

(d) Application to improved waters. As the quality of any waters of the state improve, no degradation of such improved waters shall be allowed.

252:740-13-1. Applicability and scope

(a) The rules in this Subchapter provide a framework for implementing the antidegradation policy stated in OAC 252:730-3-2 for all waters of the state. This policy and framework includes three tiers, or levels, of protection.

(b) The three tiers of protection are as follows:

(1) Tier 1. Attainment or maintenance of an existing or designated beneficial use.

(2) Tier 2. Maintenance and protection Sensitive Water Supply-Reuse waterbodies.

(3) Tier 2.5 Maintenance and protection of High Quality Waters, Sensitive Public and Private Water Supply waters.

(4) Tier 3. No degradation of water quality allowed in Outstanding Resource Waters.

(c) In addition to the three tiers of protection, this Subchapter provides rules to implement the protection of waters in areas listed in Appendix B of OAC 252:730. Although Appendix B areas are not mentioned in OAC 252:730-3-2, the framework for protection of Appendix B areas is similar to the implementation framework for the antidegradation policy.

(d) In circumstances where more than one beneficial use limitation exists for a waterbody, the most protective limitation shall apply. For example, all antidegradation policy implementation rules applicable to Tier 1 waterbodies shall be applicable also to Tier 2, Tier 2.5 and Tier 3 waterbodies or areas, and implementation rules applicable to Tier 2 waterbodies shall be applicable also to Tier 2.5 and Tier 3 waterbodies.

(e) Publicly owned treatment works may use design flow, mass loadings or concentration, as appropriate, to calculate compliance with the increased loading requirements of this section if those flows, loadings or concentrations were approved by the Oklahoma Department of Environmental Quality as a portion of Oklahoma's Water Quality Management Plan prior to the application of the ORW, HQW, SWS, or SWS-R limitation.

252:740-13-2. Definitions

The following words and terms, when used in this Subchapter, shall have the following meaning, unless the context clearly indicates otherwise:

"Specified pollutants" means

(A) Oxygen demanding substances, measured as Carbonaceous Biochemical Oxygen Demand (CBOD) and/or Biochemical Oxygen Demand (BOD);

(B) Ammonia Nitrogen and/or Total Organic Nitrogen;

(C) Phosphorus;

(D) Total Suspended Solids (TSS); and

(E) Such other substances as may be determined by the Oklahoma Water Resources Board or the permitting authority.

252:740-13-3. Tier 1 protection; attainment or maintenance of an existing or designated beneficial use

(a) General.

(1) Beneficial uses which are existing or designated shall be maintained and protected.

(2) The process of issuing permits for discharges to waters of the state is one of several means employed by governmental agencies and affected persons which are designed to attain or maintain beneficial uses which have been designated for those waters. For example, Subchapters 3, 5, 7, 9 and 11 of this Chapter are rules for the permitting process. As such, the latter Subchapters not only implement numerical and narrative criteria, but also implement Tier 1 of the antidegradation policy.

(b) Thermal pollution. Thermal pollution shall be prohibited in all waters of the state. Temperatures greater than 52 degrees Centigrade shall constitute thermal pollution and shall be prohibited in all waters of the state.

(c) Prohibition against degradation of improved waters. As the quality of any waters of the state improves, no degradation of such improved waters shall be allowed.

252:740-13-4. Tier 2 protection; maintenance and protection of sensitive water supply-reuse and other tier 2 waterbodies

(a) General rules for Sensitive Water Supply – Reuse (SWS-R) Waters

(1) Classification of SWS-R Waters. DEQ may consider classification of a waterbody as an SWS-R waterbody based upon required documentation submitted by any interested party. The interested party shall submit documentation presenting background information and justification to support the classification of a waterbody as SWS-R including, but not limited to, the following:

(A) Determination of the waterbody's assimilative capacity pursuant to 252:740-13-8, including all supporting information and calculations.

(B) Documentation demonstrating that municipal wastewater discharge for the purpose of water supply augmentation has been considered as part of a local water supply plan or other local planning document.

(C) Any additional information or documentation necessary for DEQ's consideration of a request for the classification of a waterbody as SWS-R.

(D) Prior to consideration by DEQ, any interested party seeking the classification of a waterbody as SWS-R shall submit documentation to DEQ staff demonstrating that local stakeholders, including those that use the waterbody for any designated or existing beneficial uses, have been afforded notice and an opportunity for an informal public meeting, if requested, regarding the proposed classification of the waterbody as SWS-R at least one hundred eighty (180) days prior to DEQ consideration. In addition, all information or documentation submitted pursuant to this subsection shall be available for public review.

(2) The drought of record waterbody level shall be considered the receiving water critical condition for SWS-R waterbodies.

(A) All beneficial uses shall be maintained and protected during drought of record conditions.

(B) Drought of record shall be determined with the permitting authority approved monthly time step model using hydrologic data with a minimum period of record from 1950 to the present. If empirical data are not available over the minimum period of record, modeled data shall be included in the analysis, if available.

(3) In accordance with OAC 252:730-5-25(c)(8)(D), SWS-R waterbodies with a permitted discharge shall be monitored and water quality technically evaluated to ensure that beneficial uses are protected and maintained and use of assimilative capacity does not exceed that prescribed by permit. Prior to any monitoring and/or technical analysis, the permittee shall submit a Receiving Water Monitoring and Evaluation Plan to the permitting authority for review and approval.

(A) The Receiving Water Monitoring and Evaluation Plan shall include, at a minimum, the following sections:

(i) Monitoring section that meets the required spatial, temporal, and parametric coverage of this subchapter, OAC 252:740-15, and OAC 252:628-11.

(ii) Analysis and reporting section that meets the requirements of this subchapter, OAC 252:740-15, and OAC 252:628-11.

(iii) Quality Assurance Project Plan that meets the most recent requirements for United States Environmental Protection Agency Quality Assurance Project Plans.

(B) The monitoring section of the Receiving Water Monitoring and Evaluation Plan, at a minimum shall:

(i) Include parametric, temporal (including frequency of sampling events), and spatial sampling design adequate to characterize water quality related to limnological, hydrologic, seasonal, and diurnal influences and variation.

(ii) Include nutrient monitoring adequate to characterize both external and internal loading and nutrient cycling.

(iii) Include algal biomass monitoring consistent with this sub-paragraph (B) and phytoplankton monitoring sufficient to evaluate general shifts and/or trends in phytoplankton community dynamics over time.

(iv) Include in-situ monitoring of dissolved oxygen, temperature, and pH adequate to characterize diurnal changes and fluctuations during periods of thermal stratification and complete mix.

(v) Include monitoring of pollutants with a permit effluent limit and/or permit monitoring requirements.

(C) The Receiving Water Monitoring and Evaluation Plan may include special studies, as necessary.

(D) At least biennially and prior to permit renewal, the permittee shall submit a Receiving Water Monitoring and Evaluation Report to the permitting authority that includes, at a minimum:

(i) Summarized review of monitoring objectives and approach.

(ii) Presentation and evaluation of monitoring results, including an analysis of both short-term and long-term trends.

(iii) An assessment of beneficial use attainment that is at a minimum in accordance with OAC 252:740-15.

(iv) Summarized assessment of data quality objectives, including an explanation of any data quality issues.

(v) All monitoring data shall be submitted electronically.

(E) If the report documents nonattainment of a beneficial use(s) resulting from the discharge, the permitting authority shall consider actions including, but not limited to, additional permit requirements, cessation of the discharge, and/or a recommendation to DEQ to revoke the SWS-R waterbody classification.

(b) General rules for other Tier 2 Waterbodies

(1) General rules for other Tier 2 waterbodies shall be developed as waters are identified.

252:740-13-5. Tier 2.5 protection; maintenance and protection of high quality waters, sensitive water supplies, and other tier 2.5 waterbodies

(a) General rules for High Quality Waters. New point source discharges of any pollutant after June 11, 1989, and increased load or concentration 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 252:730 with the limitation "HQW". Any discharge of any pollutant to a waterbody designated "HQW" which would, if it occurred, lower existing water quality shall be prohibited. Provided however, new point source discharges or increased load or concentration of any specified pollutant from a discharge existing as of June 11, 1989, may be approved by the permitting authority in circumstances where the discharger demonstrates to the satisfaction of the permitting authority that such new discharge or increased load or concentration would result in maintaining or improving the level of water quality which exceeds that necessary to support recreation and propagation of fishes, shellfishes, and wildlife in the receiving water.

(b) General rules for sensitive public and private water supplies. 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 252:730 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, new point source discharges or increased load of any specified pollutant from a discharge existing as of June 11, 1989, may be approved by the permitting authority in circumstances where the discharger demonstrates to the satisfaction of the permitting authority that such new discharge or increased load will result in maintaining or improving the water quality in both the direct receiving water, if designated SWS, and any downstream waterbodies designated SWS.

(c) Stormwater discharges. Regardless of subsections (a) and (b) of this Section, point source discharges of stormwater to waterbodies and watersheds designated "HQW", "SWS" may be approved by the permitting authority.

(d) Nonpoint source discharges or runoff. Best management practices for control of nonpoint source discharges or runoff should be implemented in watersheds of waterbodies designated "HQW", or "SWS" in Appendix A of OAC 252:730.

252:740-13-6. Tier 3 protection; prohibition against degradation of water quality in outstanding resource waters

(a) General. New point source discharges of any pollutant after June 11, 1989, and increased load of any 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 252:730 with the limitation "ORW" and/or "Scenic River", and in any waterbody located within the watershed of any waterbody designated with the limitation "Scenic River". Any discharge of any pollutant to a waterbody designated "ORW" or "Scenic River" which would, if it occurred, lower existing water quality shall be prohibited.

(b) Stormwater discharges. Regardless of 252:740-13-6(a), point source discharges of stormwater from temporary construction activities to waterbodies and watersheds designated "ORW" and/or "Scenic River" may be permitted by the permitting authority. Regardless of 252:740-13-6(a), discharges of stormwater to waterbodies and watersheds designated "ORW" and/or "Scenic River" from point sources existing as of June 25, 1992, whether or not such stormwater discharges were permitted as point sources prior to June 25, 1992, may be permitted by the permitting authority; provided, however, increased load of any pollutant from such stormwater discharge shall be prohibited.

(c) Nonpoint source discharges or runoff. Best management practices for control of nonpoint source discharges or runoff should be implemented in watersheds of waterbodies designated "ORW" in Appendix A of OAC 252:730, provided, however, that development of conservation plans shall be required in sub-watersheds where discharges or runoff from nonpoint sources are identified as causing or significantly contributing to degradation in a waterbody designated "ORW".

(d) LMFO's. No licensed managed feeding operation (LMFO) established after June 10, 1998 which applies for a new or expanding license from the State Department of Agriculture after March 9, 1998 shall be located...[w]ithin three (3) miles of any designated scenic river area as specified by the Scenic Rivers Act in 82 O.S. Section 1451 and following, or [w]ithin one (1) mile of a waterbody [2:9-210.3(D)] designated in Appendix A of OAC 252:730 as "ORW".

252:740-13-7. Protection for Appendix B areas

(a) General. Appendix B of OAC 252:730 identifies areas in Oklahoma with waters of recreational and/or ecological significance. These areas are divided into Table 1, which includes national and state parks, national forests, wildlife areas, wildlife management areas and wildlife refuges; and Table 2, which includes areas which contain threatened or endangered species listed as such by the federal government pursuant to the federal Endangered Species Act as amended.

(b) Protection for Table 1 areas. New discharges of pollutants after June 11, 1989, or increased loading of pollutants from discharges existing as of June 11, 1989, to waters within the boundaries of areas listed in Table 1 of Appendix B of OAC 252:730 may be approved by the permitting authority under such conditions as ensure that the recreational and ecological significance of these waters will be maintained.

(c) Protection for Table 2 areas. Discharges or other activities associated with those waters within the boundaries listed in Table 2 of Appendix B of OAC 252:730 may be restricted through agreements between appropriate regulatory agencies and the United States Fish and Wildlife Service. Discharges or other activities in such areas shall not substantially disrupt the threatened or endangered species inhabiting the receiving water.

(d) Nonpoint source discharges or runoff. Best management practices for control of nonpoint source discharges or runoff should be implemented in watersheds located within areas listed in Appendix B of OAC 252:730.

Appendix B Ambient Water Quality Data

Crowder Lake Data – 1998 to 2015

Cobb Creek Data – 2004 to 2016

Appendix Table 1 Ambient Water Quality Data for Crowder Lake, 1998-2015

Date	Site	NH_3 (mg/L)	NO_3^- (mg/L)	TKN (mg/L)	TN (mg/L)	Ortho P (mg/L)	TP (mg/L)	Chl-a (µg/L)	Secchi Depth (cm)
4/21/1998	1	0.08		1.02	1.715	0.013	0.038		
	2	0.08		1.13	1.98	0.0145	0.0375		
	3			1.54	2.51	0.016	0.064		
7/13/1998	1	0.19				0.014			
	2					0.01			
	3					0.013			
10/12/1998	1			0.475	0.475	0.0055	0.047		
	2			0.98	0.98	0.005	0.087		
	3			0.45	0.45	0.007	0.044		
1/11/1999	1	0.165		0.997	1.15		0.052		
	2			1.2	1.69				
	3								
4/13/1999	1	0.06		0.38	0.627		0.043		
	2	0.07		0.41	0.68		0.041		
	3	0.14		0.42	0.73	0.01	0.086		
7/12/1999	1	0.22		0.715	0.715	0.01875	0.056		
	2			0.43	0.43	0.01	0.029		
	3			0.49	0.58	0.033	0.062		
10/10/2001	1				0.459	0.019	0.055		55
	2			0.56	0.61	0.019	0.053		50
	3			0.63	0.855	0.031	0.083		29
1/15/2002	1			0.435	0.586	0.005	0.03		88
	2			0.55	0.745	0.006	0.032		82
	3			0.58	1.055	0.007	0.034		60
4/16/2002	1	0.48		0.678	0.751	0.006	0.045		74
	2			0.85	0.925	0.007	0.055		65
	3	0.15		1.07	1.345	0.008	0.082		40
7/16/2002	1			0.735	0.785		0.105		77
	2			0.85	0.925	0.006	0.045		72
	3			0.59	0.64	0.013	0.078		32
9/17/2003	1	0.077			0.799	0.005	0.054	9.6	
	2			0.99	1.04	0.005	0.045	9.7	
	3			1.17	1.22	0.006	0.072	15.9	

Date	Site	NH_3 (mg/L)	NO_3^- (mg/L)	TKN (mg/L)	TN (mg/L)	Ortho P (mg/L)	TP (mg/L)	Chl-a (µg/L)	Secchi Depth (cm)
12/10/2003	1				2.815	0.008	0.029	17.2	
	2			3.76	3.895	0.008	0.031	18.7	
	3			0.65	0.945	0.006	0.072	10.7	
3/10/2004	1	0.267		0.83	0.855	0.045	0.082	3.0	
	2	0.31		0.42	0.785	0.008	0.031	5.6	
	3	0.37		1.2	1.84	0.084	0.169	5.0	
6/9/2004	1	0.087			0.644	0.009	0.057		
	2	0.07		0.82	0.87	0.009	0.07		
	3	0.14		0.99	1.04	0.013	0.12		
2/17/2005	1							7.1	
11/22/2005	1			0.585	0.632	0.008	0.028	23.0	28
	2			0.48	0.93	0.008	0.035	22.0	32
	3		0.19	0.55	0.74	0.011	0.046	18.0	19
2/22/2006	1		0.44	0.465	0.905	0.008	0.026	9.8	96
	2			0.58	0.605	0.007	0.026	8.9	104
	3			0.47	0.93	0.007	0.026	7.3	92
5/24/2006	1			0.53	0.555	0.008	0.03	8.6	77
	2			0.58	0.605	0.008	0.038	11.59	65
	3			0.62	0.645	0.013	0.041	10.61	38
8/23/2006	1			0.61	0.635	0.007	0.0445	14.1	82
	2			0.56	0.585	0.006	0.03	16.0	90
	3			0.72	0.745	0.011	0.053		60
11/9/2009	1			1.09	1.115		0.0675	72.6	50
	2			1.11	1.135		0.067	71.0	45
	3			1.52	1.66		0.094	61.4	44
2/9/2010	1								92
	2								89
	3								51
6/8/2010	1			0.65	0.675		0.038	18.4	72
	2			0.73	0.755		0.043		64
	3			1.06	1.085		0.096		30
8/9/2010	1			0.83	0.855		0.0465	28.5	66
	2			0.8	0.825		0.051		54
	3			0.99	1.015		0.091		29
11/25/2013	1			1.455	1.455		0.0835	64.9	32

Date	Site	NH_3 (mg/L)	NO_3^- (mg/L)	TKN (mg/L)	TN (mg/L)	Ortho P (mg/L)	TP (mg/L)	Chl-a (µg/L)	Secchi Depth (cm)
	2			1.59	1.59		0.081	59.9	32
	3		0.09	1.4	1.49		0.096	58	37
2/18/2014	1			0.915	1.045		0.0295	15.1	98
	2			0.93	0.93		0.053	11.6	48
	3		0.26	0.79	1.09		0.044	10.2	44
5/7/2014	1			0.9	0.9		0.032	13.8	91
	2			1.12	1.12		0.043	11.8	82
	3			1.27	1.27		0.082		42
7/2/2014	1			0.9125	0.9125	0.028	0.061	88.2	
	2			1.12	1.12	0.03	0.068	76	
	3			1.64	1.64	0.07	0.141	127	
7/16/2014	1			0.965	0.965	0.021	0.05	26.8	
	2			1.03	1.03	0.025	0.062	20.1	
	3			1.41	1.41	0.059	0.13	23.9	
8/6/2014	1			1.215	1.215	0.0375	0.0623	11.4	100
	2			0.78	0.78	0.016	0.041	9.51	57
	3			1.1	1.1	0.033	0.081	17.9	20
8/20/2014	1			1.675	1.675	0.071	0.100	10.5	
	2			0.81	0.81	0.024	0.041	11.7	
	3			1.2	1.2	0.057	0.094		
9/10/2014	1			0.91	0.91	0.0233	0.0435	27.8	
	2			1.04	1.04	0.036	0.053	30.7	
	3			1.4	1.4	0.036	0.121	56.9	
9/24/2014	1			0.77	0.77	0.023	0.0465	20.4	
	2			0.83	0.83	0.024	0.047	23.3	
	3			0.77	0.77	0.028	0.075	25.7	
10/8/2014	1			0.775	0.775	0.0215	0.0405	17.1	
	2			0.77	0.77	0.022	0.042	20.7	
	3			0.91	0.91	0.032	0.077	29.7	
11/19/2014	1		0.1	0.78	0.88	0.0185		27.8	
	2		0.1	0.78	0.88	0.016		24.6	
	3		0.19	0.75	0.94	0.023		18.8	
12/11/2014	1			0.725	0.725	0.019	0.032	16.5	
	2			0.64	0.64	0.019	0.029	9.95	
	3		0.3	0.71	1.01	0.023	0.057	18.5	

Date	Site	NH_3 (mg/L)	NO_3^- (mg/L)	TKN (mg/L)	TN (mg/L)	Ortho P (mg/L)	TP (mg/L)	Chl-a (µg/L)	Secchi Depth (cm)
1/14/2015	1		0.15	0.855	1.005	0.0185	0.0435	18.8	
	2		0.15	0.86	1.01	0.019	0.023	9.62	
	3		0.16	0.84	1	0.02	0.033	10.2	
2/11/2015	1		0.18	0.885	1.065	0.014	0.038	29.1	
	2		0.18	0.93	1.11	0.016	0.036	30.2	
	3		0.22	0.8	1.02	0.025	0.055	41.4	
3/11/2015	1		0.13	0.79	0.92		0.047	38.3	
	2		0.19	0.69	0.88		0.03	39.9	
	3		0.33	0.9	1.23	0.026	0.086	23	
4/1/2015	1		0.13	0.79	0.92	0.02	0.034	11.8	
	2		0.14	0.76	0.9	0.016	0.038	10.8	
	3		0.11	0.89	1	0.039	0.081	21.4	
5/6/2015	1			0.815	0.815	0.014	0.044	40.2	
	2			0.79	0.79	0.013	0.044	30.7	
	3		0.29	1.34	1.63	0.077	0.169	57.5	
5/20/2015	1			0.875	0.875	0.033	0.06	22.1	
	2			0.77	0.77	0.033	0.058	22.6	
	3		0.43	1.39	1.82	0.294	0.377	14.5	
6/10/2015	1		0.16		0.995	0.062	0.11	19.6	
	2			0.9	0.9	0.026	0.079	20.7	
	3		0.06	1.64	1.7	0.047	0.161		
6/24/2015	1			1.2025	1.2025	0.154	0.182	31.8	
	2			0.95	0.95	0.055	0.098	32.7	
	3			0.67	0.67	0.089	0.249		
7/8/2015	1		0.05		0.95	0.077	0.124	29.4	
	2		0.12	0.88	1	0.055	0.114	27.9	
	3		0.49	1.55	2.04	0.162	0.303		
7/20/2015	1			1.49	1.49	0.211	0.236	30.4	
	2			0.84	0.84	0.017	0.059	27.6	
	3		0.18	1.78	1.96	0.061	0.165		
8/5/2015	1			1.16	1.16		0.124	32.5	
	2			0.98	0.98	0.022	0.069	57.5	
	3		0.09	2.02	2.11	0.049	0.139		
8/19/2015	1			2.655	2.655	0.377	0.4	22.1	
	2			0.98	0.98	0.028	0.075	27	

Date	Site	NH_3 (mg/L)	NO_3^- (mg/L)	TKN (mg/L)	TN (mg/L)	Ortho P (mg/L)	TP (mg/L)	Chl-a (µg/L)	Secchi Depth (cm)
	3		0.2	1.29	1.49	0.045	0.101		
9/2/2015	1			1.72	1.72		0.196	31.4	
	2			1.08	1.08	0.013	0.078	38	
	3		0.2	1.59	1.79	0.018	0.151	65.5	
9/16/2015	1			1.17	1.17	0.031	0.101	46.9	
	2			1.11	1.11	0.027	0.09	55.7	
	3		0.29	1.32	1.61	0.047	0.116	64.1	
11/4/2015	1			1.075	1.075	0.019	0.0525	62.6	
	2			1.06	1.06	0.02	0.055	59.3	
	3		0.52	1.11	1.63	0.029	0.083	50	
12/9/2015	1		0.295	0.73	1.025		0.0295	30.7	
	2		0.29	0.74	1.03		0.031	23.3	
	3		0.74	0.85	1.59			40.6	

Appendix Table 2 Ambient Water Quality Data for Cobb Creek, 2004-2016

Monitoring Station	Date	Flow (cfs)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
OK310830-06-0050M	06/28/04	10.323			
OK310830-06-0050M	08/24/04	5.614	33	1.48	0.188
OK310830-06-0050M	10/04/04	9.117	35	1.52	0.13
OK310830-06-0050M	11/16/04	48.838	90	1.06	0.231
OK310830-06-0050M	12/14/04	13.025	<10	1.58	0.096
OK310830-06-0050M	01/19/05	14.587	<10	2.08	0.046
OK310830-06-0050M	02/15/05	14.551	<10	1.43	0.099
OK310830-06-0050M	03/22/05	11.195	13	1.46	0.085
OK310830-06-0050M	04/26/05	8.784	29	1.66	0.228
OK310830-06-0050M	06/01/05	11.496	58	1.67	0.167
OK310830-06-0050M	07/06/05	9.444	<10	1.48	0.119
OK310830-06-0050M	08/09/05	5.258	13	1.58	0.105
OK310830-06-0050M	09/13/05	8.274	<10	1.57	0.09
OK310830-06-0050M	10/18/05	15.137	12	1.86	0.095
OK310830-06-0050M	01/10/06	14.506	<10	1.80	0.093
OK310830-06-0050M	02/14/06	12.201	<10	1.97	0.171
OK310830-06-0050M	03/21/06	23.133	22	1.48	0.109
OK310830-06-0050M	05/02/06	13.763	46	1.35	0.148
OK310830-06-0050M	05/31/06	35.025	188		
OK310830-06-0050M	07/11/06	7.862	<10	1.55	0.088
OK310830-06-0050M	05/26/09	68.626	722		
OK310830-06-0050M	06/29/09	10.054	<10	1.96	0.098
OK310830-06-0050M	07/27/09	5.139	<10	2.17	0.314
OK310830-06-0050M	07/28/09	7.324			
OK310830-06-0050M	09/09/09	8.165	25	1.86	0.146
OK310830-06-0050M	10/06/09	10.374	<10	1.93	0.079
OK310830-06-0050M	11/03/09	16.796	<10	1.67	0.11
OK310830-06-0050M	01/26/10	14.885	<10	1.74	0.073
OK310830-06-0050M	03/02/10	15.276	<10	1.68	0.077
OK310830-06-0050M	04/06/10	14.478	26	1.33	0.127
OK310830-06-0050M	05/18/10	11.94	21	1.51	0.179
OK310830-06-0050M	6/22/2010	5.655	<10	2.18	0.161
OK310830-06-0050M	7/20/2010	2.59	<10	2.05	0.124
OK310830-06-0050M	10/13/2010	6.6	<10	2.09	0.072

Monitoring Station	Date	Flow (cfs)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
OK310830-06-0050M	11/17/2010	11.838	<10	1.70	0.07
OK310830-06-0050M	1/5/2011	10.409	<10	1.90	0.034
OK310830-06-0050M	4/20/2011	14.024	<10		0.101
310830060120-001RS	7/16/2014	1.91			
310830060120-001RS	8/6/2014	1.92			
310830060120-001RS	8/20/2014	4.43		0.79	0.05
310830060120-001RS	9/10/2014			0.99	0.077
310830060120-001RS	9/24/2014	1.01		1.29	0.175
310830060120-001RS	10/8/2014			0.8	0.036
310830060120-001RS	11/19/2014			2.76	
310830060120-001RS	12/11/2014	1.30		1.97	0.031
310830060120-001RS	1/14/2015	1.13		1.75	0.015
310830060120-001RS	2/11/2015			1.43	0.045
310830060120-001RS	3/11/2015	1.89		1.2	0.026
310830060120-001RS	4/1/2015	6.49		5.97	0.349
310830060120-001RS	5/6/2015	12.40			
310830060120-001RS	5/20/2015	18.42		2.06	0.486
310830060120-001RS	6/10/2015	2.99		4.47	0.038
310830060120-001RS	6/24/2015	5.06		4.44	0.054
310830060120-001RS	7/8/2015	8.81		3.58	0.37
310830060120-001RS	7/20/2015	2.80		4.29	0.044
310830060120-001RS	8/5/2015	2.43		4.58	0.064
310830060120-001RS	8/19/2015			4.07	0.041
310830060120-001RS	9/2/2015	3.66		4.83	0.023
310830060120-001RS	9/16/2015	4.27		3.91	0.154
310830060120-001RS	10/7/2015	2.60		3.68	0.036
310830060120-001RS	11/4/2015	3.91		2.84	0.03
310830060120-001RS	12/9/2015			4.28	0.035
310830060120-001RS	1/6/2016	6.11			
310830060120-001RS	1/13/2016			4.6	
310830060120-001RS	2/11/2016	2.69		5.19	0.013
310830060120-001RS	3/2/2016	4.74		3.65	0.114
310830060120-001RS	4/6/2016			2.98	
310830060120-001RS	5/4/2016			3.37	0.029
310830060120-001RS	6/2/2016			3.95	0.525
310830060120-001RS	6/15/2016			2.5	0.376

Monitoring Station	Date	Flow (cfs)	TSS (mg/L)	TN (mg/L)	TP (mg/L)
310830060120-001RS	7/13/2016			2.8	0.051
310830060120-001RS	7/27/2016	2.13		2.71	0.044
310830060120-001RS	8/10/2016	2.00		2.22	0.034
310830060120-001RS	8/22/2016	1.94		2.06	0.023
310830060120-001RS	9/14/2016	1.33		2.11	0.027
310830060120-001RS	9/28/2016			3.45	0.206

Appendix C SWAT Model Input and Calibration for the Crowder Lake Watershed

Appendix C
SWAT Model Input and Calibration – Crowder Lake

Given the lack of flow gage and water quality data available to quantify loadings directly from the tributary of Crowder Lake, a watershed loading model – the Soil and Water Assessment Tool (SWAT) – was used to develop nonpoint source loading estimates (there are no known point sources in the watershed). These estimates from SWAT were used to quantify the nutrient contributions to the lake. SWAT is a basin-scale watershed model that can be operated on a daily time step (Neitsch et al. 2011). 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.

C-1. Model Inputs

All the GIS layers were processed using the ArcSWAT 2012 interface for SWAT 2012 (Winchell et al. 2013). The interface was also used to change input parameters to achieve calibration and to export these parameters to a Microsoft Access database.

C-1.1 Elevation Data

Digital Elevation Model (DEM) processed by USGS after 2015 was used for watershed delineation. The highest resolution DEM of 1/3 arc-second (10 meter) was also used to calculate the slopes and determine the stream network incorporated into SWAT. Slopes were divided into four categories: 0-1.5, 1.5-5, 5-10, and > 10%.

C-1.2 Soil Data

Soil data used for this model were derived using Soil Survey Geographic Database (SSURGO). SSURGO maps are made at scales ranging from 1:12,000 to 1:63,360 and include more detailed information than STATSGO maps. STATSGO data are not detailed enough to make interpretations at a local or county scale.

C-1.3 Land Use Data

Land use and land cover data were derived from NASS 2015 Cropland Data Layer (CDL) (https://nassgeodata.gmu.edu/CropScape/) (USDA 2018). Winter wheat was the main crop in the watershed. The threshold for Landuse over subbasin area was set to 10% and subbasin areas less than 10% were eliminated and distributed to other landuses. Land uses in modeled watershed are listed in Appendix Table 3.

Appendix Table 3 Distribution of Land Cover in the modeled Watershed

Description	SWAT Code	Area (acres)	Percent of Total Watershed Area
Corn	CORN	1,717.2	2.0%
Cotton	COTP	1,798.8	2.1%
Sorghum	SGHY	2,058.7	2.4%
Soybean	SOYB	297.9	0.4%
Peanuts	PNUT	76.5	0.09%
Barley	BARL	2.3	0.00%
Spring Wheat	SWHT	4.6	0.01%
Winter Wheat	WWHT	35,119.6	41.7%
Rye	RYE	283.1	0.3%
Oats	OATS	31.5	0.0%
Canola	CANP	1,070.4	1.3%
Alfalfa	ALFA	194.2	0.2%
Other Hay/Non Alfalfa	HAY	447.7	0.5%
Peas	PEAS	5.2	0.01%
Herbs	CELR	210.0	0.2%
Sod/Grass Seed	BERM	45.1	0.1%
Open Water	WATR	315.0	0.4%
Develped-Open Space	URBN	3,721.6	4.4%
Develped- Low Density	URHD	166.1	0.2%
Develped- Medium Density	URLD	58.2	0.1%
Develped- High Density	URMD	8.5	0.01%
Barren	BARR	5.3	0.0%
Forest-Deciduous	FRSD	1,206.9	1.4%
Forest-Evergreen	FRSE	544.2	0.6%
Mixed Forest	FRST	170.4	0.2%
Shrubland	RNGB	818.5	1.0%
Grassland/Pasture	PAST	33,815.2	40.1%
Woody Wetlands	WETF	11.0	0.01%
Herbaceous Wetlands	WETN	4.1	0.005%
Triticale	RYE	17.1	0.02%
Sum		84,224.9	

C-1.4 Meteorology

The meteorological data for the simulation period of 1998 to 2017 was derived from two Oklahoma Mesonet stations (Weatherford and Hinton). Weather station locations are shown in Figure 3-1. Daily time-series of precipitation, temperature, solar radiation, wind speed, and relative humidity were imported into the SWAT model along with the station coordinates and SWAT subsequently assigned the precipitation to the various subwatersheds using the nearest station (Neitsch et al., 2011).

C-1.5 Subwatershed Delineation

The modeled area was split into 10 sub-watersheds (Figure 3-1) based on DEM. The watershed of Crowder Lake is outlined as red in Figure 3-1. This figure also shows the locations of flow gages and water quality monitoring stations at which the SWAT model was calibrated and validated.

C-1.6 Point Sources

No point sources are in the SWAT model area.

C-1.7 Management

SWAT defines management as a series of individual operations for each land cover. No modifications were made to the default management input files for urban, forest, and wetland land covers.

Cultivated Crop

The operations for winter wheat are listed below:

<u>Winter Wheat</u>

Heat Unit Fractions	Operation
0.15	Plant/begin growing season
0.01	Auto fertilization initialization (Elemental Nitrogen)
1.2	Harvest and kill operation

Pasture

<u>Pasture</u>

Heat Unit Fractions	Operation
0.15	Plant/begin growing season
1.2	Harvest and kill operation

C-1.8 Soil Nutrients

Soil nitrogen levels were estimated by the SWAT model based on the organic carbon data included in the soils database.

C-2. Calibration

C-2.1 Hydrologic Calibration

The lake was simulated as a reservoir in SWAT. The SWAT hydrologic calibration was primarily performed based on flow data available at the USGS gages located on Cobb Creek near Eakly, OK (USGS Station 07325800) (Figure 3-1). Additionally, estimated daily average flow data at sub-basin 1 and 8 were compared with grab sample data collected in Cobb Creek (OWRB Station 310830060120-001RS and OCC Station OK310830-06-0050M). Appendix Table 4 summarizes the parameters changed during flow calibration along with their typical range. The parameters were changed on a watershed level (overall change across the 10 sub-watersheds).

Appendix Table 4 List of Adjusted Parameters for Hydrologic Calibration of SWAT Model

Parameter	Units	Description	Location in SWAT Input	Typical Range	Land Use	Calibrated Value
CN2	-	SCS runoff curve number	**.mgt	35 - 98	All	41 - 68
ALPHA_BF	day	Baseflow alpha factor	**.gw	0 - 1	All	1
CANMX	-	Maximum canopy storage.	**.hru	0 - 100	All	0
SOL_AWC	mm H_2O/mm soil	Available water capacity of the soil layer	**.sol	0 - 1	All	0 – 0.23
GW_DELAY	day	Groundwater delay time	**.gw	0 - 500	All	500
GWQMN	mm	Treshold depth of water in the shallow aquifer	**.gw	0 - 5000	All	1000
ESCO	-	Soil evaporation compensation factor	**.hru	0 - 1	All	0.93
RCHRG_DP	-	Deep aquifer percolation fraction	**.gw	0 - 1	All	0.23
SURLAG	-	Surface runoff lag coefficient	**.bsn	0.05 - 24	All	4
EPCO	-	Plant uptake compensation factor	**.hru	0 - 1	All	1
GW_REVAP	-	Groundwater "revap" coefficient	**.gw	0.02 – 0.2	All	0.02
OV_N	-	Manning's "n" value for overland flow	**.hru	0.01 - 30	All	3.7 – 3.9
LAT_TTIME	-	Average slope steepness	**.hru	0 - 180	All	6.3

Daily (weather) data were input into SWAT model and SWAT can generate daily average estimation. However, comparing estimated average daily data from SWAT with grab sample data would not be adequate to evaluate model performance due to limited data. Therefore, SWAT was not intended to simulate daily results. We calibrated flows for monthly and annual periods. Flow calibration statistical and graphical output from SWAT includes measured and model-simulated total, annual, and monthly flow summaries, and statistical summaries of the quality of the fit (mean error, R^2 and NSE). Appendix Table 5 showed SWAT estimated well for monthly average flow at USGS gaging station.

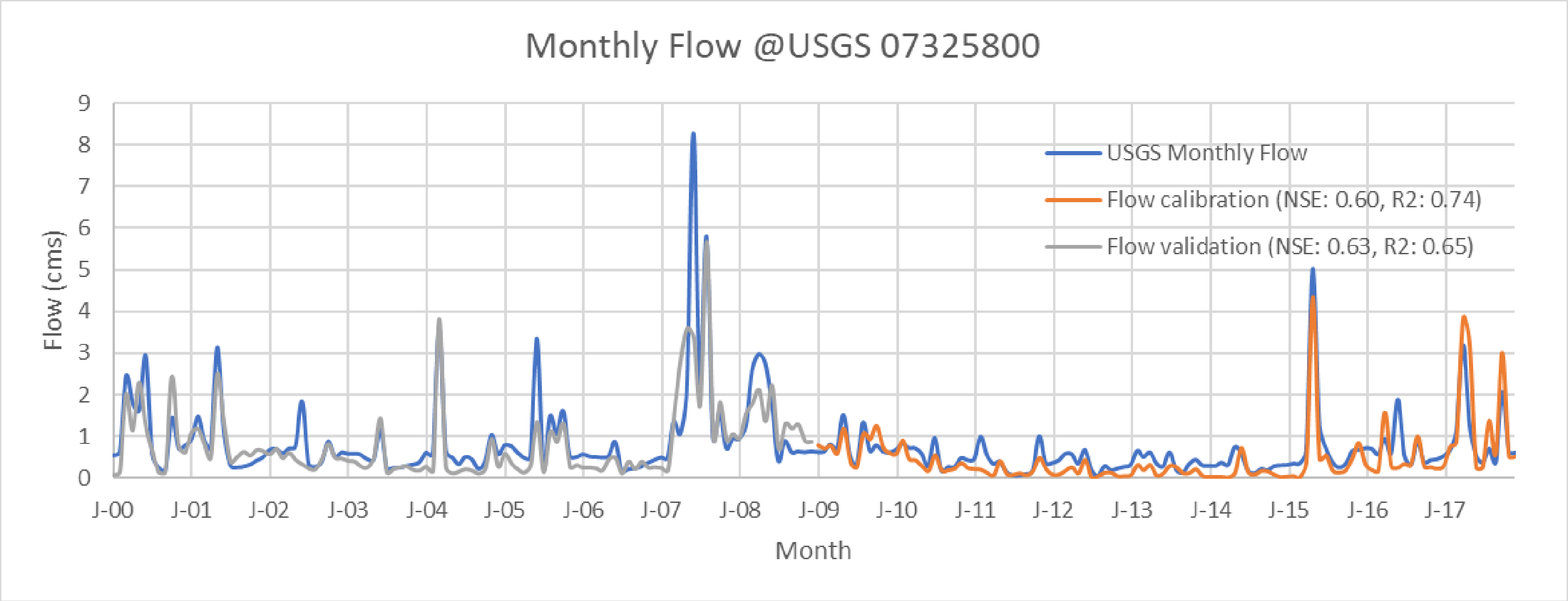
Appendix Table 5 Summary of Hydraulic Calibration and Validation

Monitoring Site	Data Period	Time Step	NSE	PBIAS	Comment
USGS 07325800	2009 - 2017	Monthly	0.60	22.3%	Calibration
USGS 07325800	2000 - 2008	Monthly	0.63	16.5%	Validation
310830060120-001RS	2014 - 2016	Daily	0.13	67.0%	sub-basin 1
OK310830-06-0050M	2004 - 2011	Daily	0.03	44.6%	sub-basin 8

The primary calibration targets were annual water balances. However, modeled monthly flows were compared to measured values for calibration and validation in Appendix Table 5.

Appendix Figure 1 displays time series of observed vs. predicted monthly flows in Cobb Creek near Eakly, OK (sub-basin 10). Appendix Table 6 summarized the statistics computed to evaluate model performance for annual flows. Overall, the model reproduces the annual flows with overall error less than 20%. Resulting Nash-Sutcliffe Efficiency coefficients (NSE) and correlation coefficient (R2) values were 0.91 and 0.96. The high resulting coefficients indicate very good model performance for annual flows.

Appendix Figure 1 Observed and Modeled Monthly Flows at sub-basin 10



Appendix Table 6 Summary of Model Performance for Water Quantity

Year	USGS 07325800 (Sub-basin 10)			
	Annual Average Flow[a] (m^3/s)		Model Error	NSE /R^2 [(b,c)]
	Observed	Modeled		
2000	1.17	0.98	16.3%	0.91/0.96
2001	0.87	0.90	-3.0%	
2002	0.70	0.48	31.5%	
2003	0.47	0.38	20.1%	
2004	0.80	0.56	29.6%	
2005	1.00	0.58	42.4%	
2006	0.44	0.29	34.1%	
2007	2.19	2.00	8.5%	
2008	1.36	1.35	1.0%	
2009	0.78	0.78	-0.2%	
2010	0.54	0.39	28.4%	
2011	0.39	0.20	48.9%	
2012	0.36	0.14	60.6%	
2013	0.40	0.19	53.3%	
2014	0.33	0.15	55.5%	
2015	0.93	0.66	29.5%	
2016	0.71	0.44	37.3%	
2017	1.03	1.30	-26.4%	
Overall	**0.80**	**0.65**	**18.8%**	

[a] Calculated using average monthly flows

[b] Nash-Sutcliffe Efficiency Coefficient = $1 - \frac{\sum(obs-mod)^2}{\sum(obs-obs_{avg})^2}$

[c] Coefficient of Determination = $\left(\frac{\sum(obs-obs_{avg})(mod-mod_{avg})}{\sqrt{\sum(obs-obs_{avg})^2}\sqrt{\sum(mod-mod_{avg})^2}}\right)^2$

C-2.2 Water Quality Calibration

There are one water quality monitoring station in the tributary (Cobb Creek) to Crowder Lake and another in downstream of Crowder Lake. SWAT model was calibrated at these two stream water quality monitoring stations in the modeled domain (Figure 3-1): sub-basin 1 (OWRB Station 310830060120-001RS) and sub-basin 8 (OCC Station OK310830-06-0050M). The goal of the water quality calibration was set 0.5 or greater of NSE to match SWAT simulated loads to Linear Regression estimated loads.

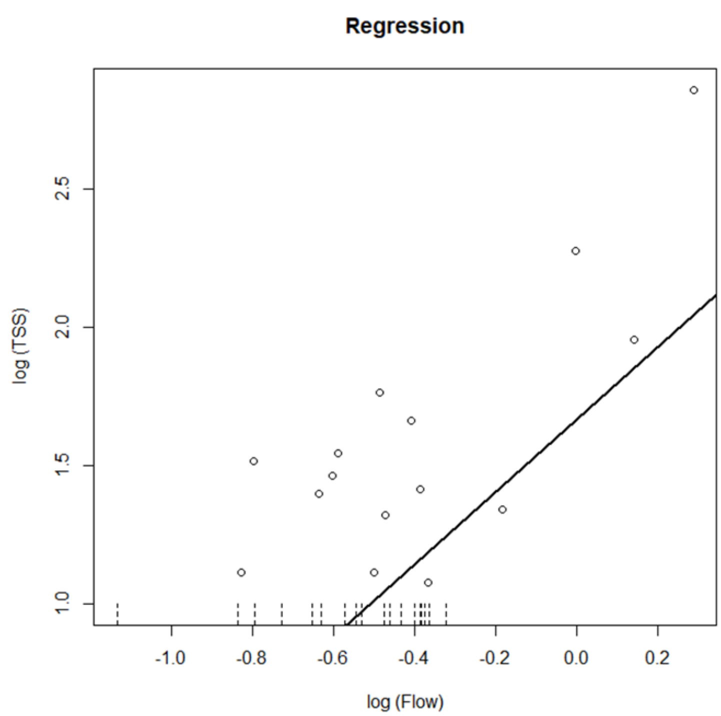
There aren't enough observed WQ data to calculate monthly average. Therefore, monthly average WQ data were estimated from linear regression method for TSS, TN and TP. From now on, we considered the linear regression estimations as observed value estimations. Appendix Table 7 summarizes the parameters changed during TSS calibration along with their typical range.

Appendix Table 7 List of Adjusted Parameters for TSS Calibration of SWAT Model

Parameter	Units	Description	Location in SWAT Input	Typical Range	Land Use	Calibrated Value
USLE_K	-	USLE equation soil erodibility (K) factor	**.sol	0 – 0.65	All	0.24 – 0.65
FILTERW	m	Width of edge-of field filter strip	**.hru	0 – 100	All	26 - 27
ADJ_PKR	-	Peak rate adjustment factor for tributary channels	**.bsn	0.5 - 2	All	1.29

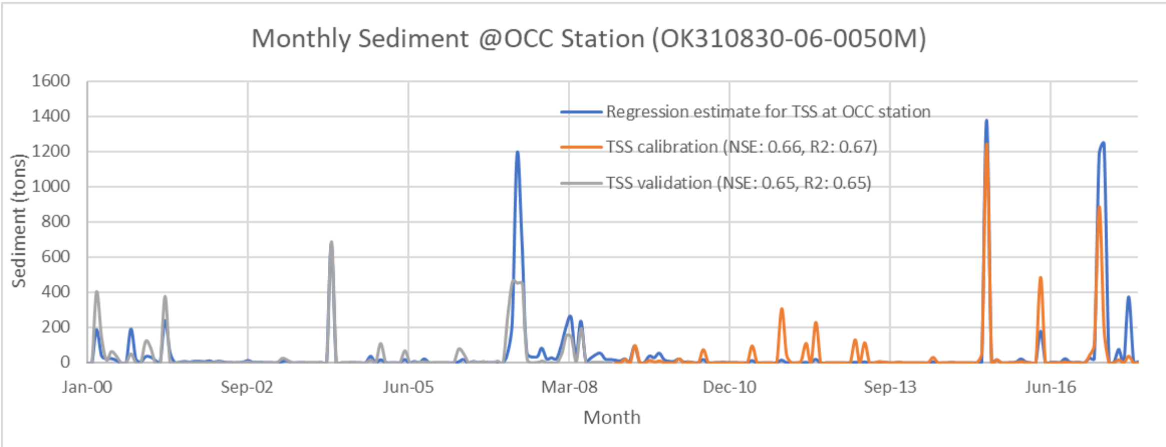
For TSS, the data were available only at OCC Station OK310830-06-0050M (sub-basin 8). Due to censored data (20 non-detect out of 37 data), non-detect MLE method was used to calculate monthly observation estimation for SWAT calibration and validation. Slope and intercept for this regression were 1.308 and 1.667, respectively.

Appendix Figure 2 Non-detect regression with MLE



Appendix Figure 2 showed moderate relationship between flow and TSS load. The likelihood r correlation coefficient (Loglik-r) was 0.55. With this linear regression, monthly average TSS data were estimated and compared to SWAT results in Appendix Figure 3.

Appendix Figure 3 TSS Calibration and Validation at sub-basin 8



Due to high number of non-detects and data collected under low-flow condition, linear regression model had high level of uncertainty on estimating monthly observed average value at high flow. Therefore, the regression estimate from the highest flow month (August 2007) was excluded from TSS, TN and TP validation. SWAT TSS calibration and Validation in Appendix Table 8 and Appendix Figure 3 showed good agreement with monthly observation regression results. NSE were greater than 0.5 for both calibration and validation and PBIAS were less than 15% for both calibration and validation. Resulting Nash-Sutcliffe Efficiency coefficients (NSE) and correlation coefficient (R^2) values for overall were 0.70 and 0.78, respectively (Appendix Table 9). The high resulting coefficients indicate very good model performance for annual TSS.

Appendix Table 8 Summary of TSS Calibration and Validation

Monitoring Site	Sub-basin	Data Period	Time Step	NSE	PBIAS	Comment
OK310830-06-0050M	8	2009 - 2017	Monthly	0.66	13.2%	Calibration
		2000 - 2008	Monthly	0.65	13.4%	Validation

Appendix Table 9 Summary of Model Performance for TSS at Sub-basin 8

Year	OK310830-06-0050M (Sub-basin 8)			
	Annual Average TSS[a] (ton)		Model Error	NSE /R^2 (b,c)
	Observed	Modeled		
2000	512.7	718.0	40.0%	0.70/0.78
2001	428.8	581.2	35.6%	
2002	68.4	13.3	80.5%	
2003	31.7	42.7	34.6%	
2004	722.0	703.6	2.6%	
2005	77.4	187.7	142.4%	
2006	46.7	139.0	197.8%	
2007	2,378.3	1,972.7	17.1%	
2008	1,041.0	554.8	46.7%	
2009	314.5	148.7	52.7%	
2010	74.9	102.9	37.5%	
2011	36.3	449.4	1,139.5%	
2012	27.6	351.7	1,172.1%	
2013	23.6	259.5	999.8%	
2014	11.5	32.2	180.5%	
2015	1,441.6	1,332.7	7.5%	
2016	234.1	494.0	111.0%	
2017	2,962.2	1,277.8	56.9%	
Overall	**579.6**	**520.1**	**10.3%**	

[a]Calculated using average monthly TSS
[b,c] Respectively same reference in Appendix Table 6

TN results were compared for the sum of organic nitrogen, nitrate, nitrite, and ammonia. Appendix Table 10 summarizes the parameters changed during TN calibration along with their typical range.

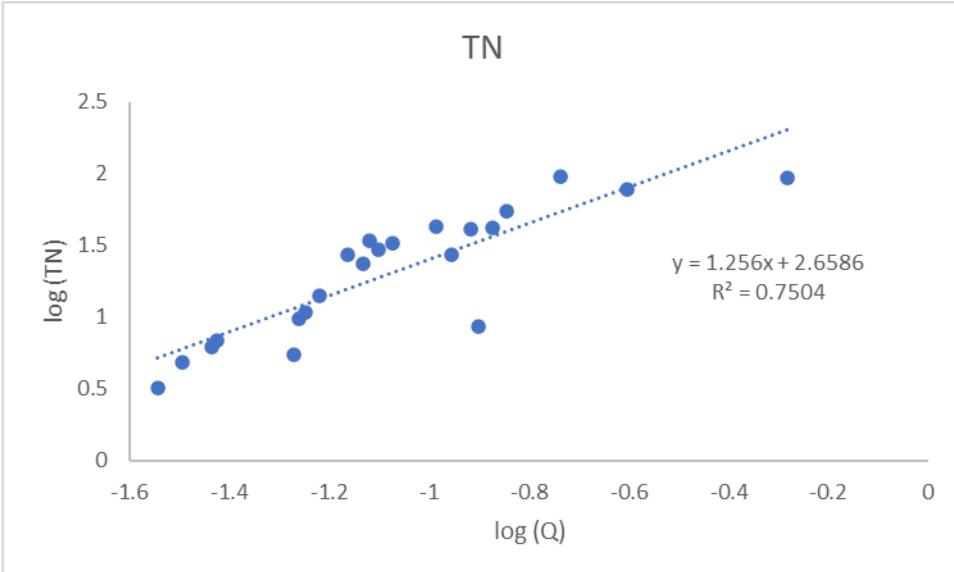
Appendix Table 10 List of Adjusted Parameters for TN Calibration of SWAT Model

Parameter	Units	Description	Location in SWAT Input	Typical Range	Land Use	Calibrated Value
SOL_NO3	mg/kg	Initial NO3 concentration in the soil layer	**.chm	0 - 100	All	9.13
LAT_ORGN	mg/L	Organic N in the baseflow	**.gw	0 - 200	All	107 - 200

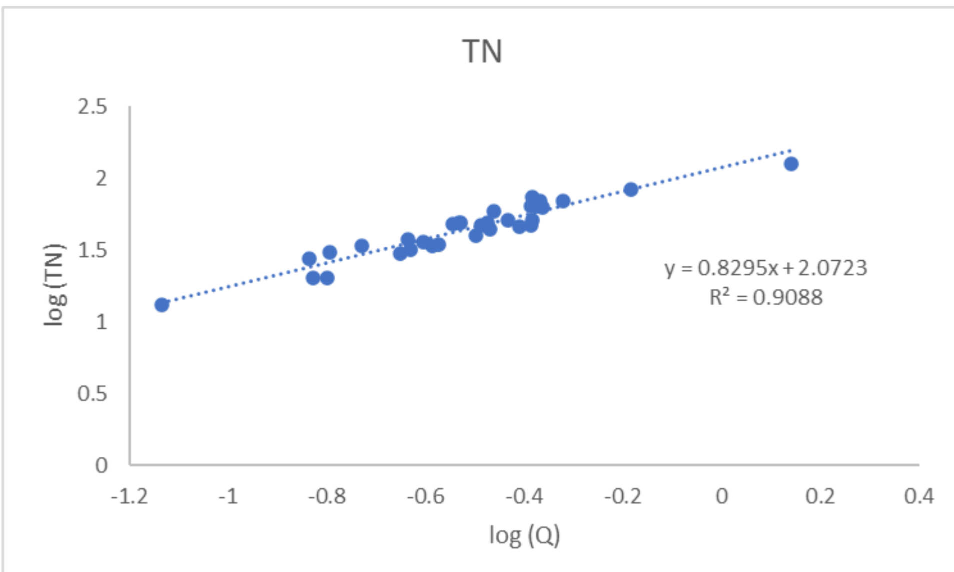
Parameter	Units	Description	Location in SWAT Input	Typical Range	Land Use	Calibrated Value
CMN	-	Rate factor for humus mineralization of active organic nitrogen	**.bsn	0.001 – 0.003	All	0.001
N_UPDIS	-	Nitrogen uptake distribution parameter	**.bsn	0 - 100	All	0
NPERCO	-	Nitrogen percolation coefficient	**.bsn	0 - 1	All	1
SDNCO	-	Denitrification threshold water content	**.bsn	0 - 1	All	1
CDN	-	Denitrification exponential rate coefficient	**.bsn	0 - 3	All	0.75
SHALLST_N	mg/L	Concentration of nitrate in groundwater contribution to streamflow from subbasin	**.gw	0 - 1000	All	0
HLIFE_NGW	days	Half-life of nitrate in the shallow aquifer	**.gw	0 - 200	All	2.5 – 200
FRT_SURFACE	-	Fraction of fertilizer applied to top 10mm of	**.mgt	0 - 1	All	0

TN were calibrated and validated at 310830060120-001RS (sub-basin 1) and OK310830-06-0050M (sub-basin 8). TN monthly observed data were estimated from log linear regression method due to limited sample data. Strong correlation with flow was observed at sub-basins 1 and 8 in Appendix Figure 4.

Appendix Figure 4 Log Linear Regression for TN estimation

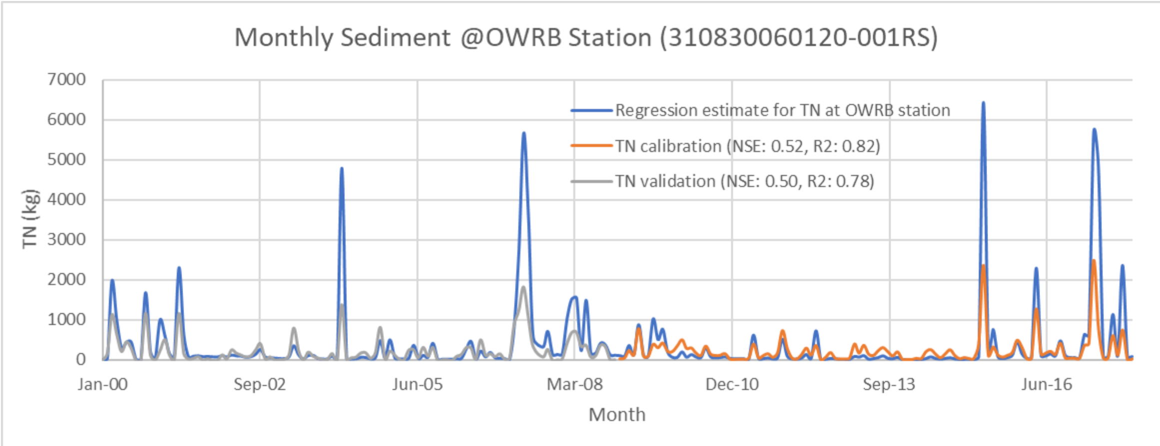


(a) Sub-basin 1

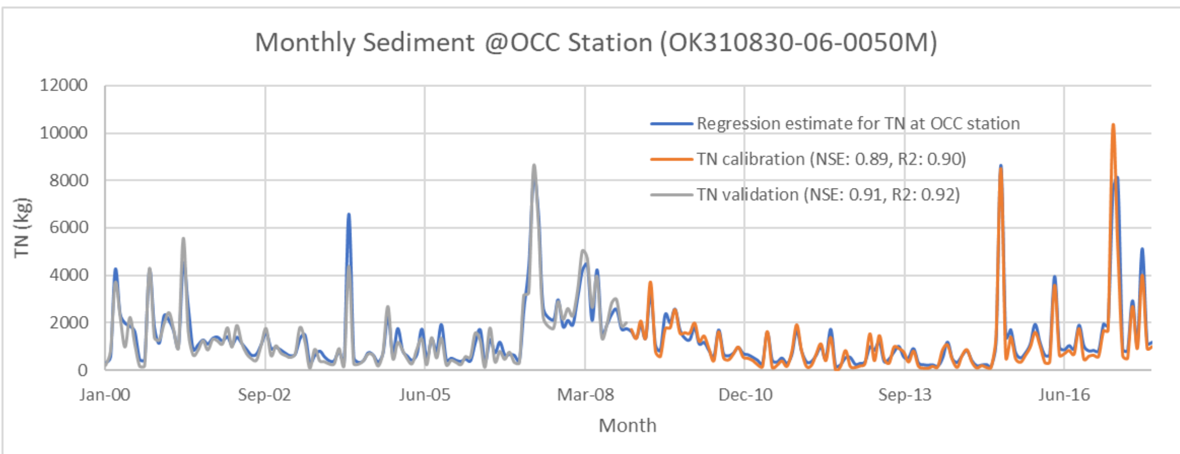


(b) Sub-basin 8

Appendix Figure 5 TN Calibration and Validation



(a) Sub-basin 1



(b) Sub-basin 8

Appendix Table 11 and Appendix Figure 5 showed good agreement between regression estimations and SWAT results at sub-basins 1 and 8. NSE ranged from 0.50 to 0.91 and PBIAS ranged from 4.5% to 39.1%.

Appendix Table 12 and Appendix Table 13 showed that SWAT estimated annual average TN load well compared to observed estimations.

Appendix Table 11 Summary of TN Calibration and Validation

Monitoring Site	Sub-basin	Data Period	Time Step	NSE	PBIAS	Comment
310830060120-001RS	1	2009 - 2017	Monthly	0.52	32.4%	Calibration
		2000 - 2008	Monthly	0.50	39.1%	Validation
OK310830-06-0050M	8	2009 - 2017	Monthly	0.89	7.6%	Calibration
		2000 - 2008	Monthly	0.91	4.5%	Validation

Appendix Table 12 Summary of Model Performance for TN at Sub-basin 1

Year	310830060120-001RS (Sub-basin 1)			
	Annual Average TN[a] (kg)		Model Error	NSE /R^2 (b,c)
	Observed	Modeled		
2000	6,091.1	4,298.7	29.4%	0.70/0.88
2001	5,186.7	2,503.6	51.7%	
2002	1,160.1	1,759.9	51.7%	
2003	920.2	1,679.4	82.5%	
2004	5,662.9	3,262.9	42.4%	
2005	1,606.5	1,785.7	11.2%	
2006	1,353.8	2,007.3	48.3%	
2007	14,602.3	7,149.7	51.0%	
2008	7,253.7	3,558.6	50.9%	
2009	4,258.7	2,834.3	33.4%	
2010	1,127.2	2,503.8	122.1%	
2011	1,469.0	1,960.0	33.4%	
2012	1,033.9	1,219.3	17.9%	
2013	551.1	2,191.1	297.6%	
2014	243.8	1,187.1	386.9%	
2015	8,211.1	4,203.9	48.8%	
2016	3,635.9	2,786.3	23.4%	
2017	15,676.0	5,602.7	64.3%	
Overall	**4,446.9**	**2,916.3**	**34.4%**	

[a]Calculated using average monthly TN
[b,c] Respectively same reference in Appendix Table 6

Appendix Table 13 Summary of Model Performance for TN at Sub-basin 8

Year	OK310830-06-0050M (Sub-basin 8)			
	Annual Average TN[a] (kg)		Model Error	NSE /R^2 (b,c)
	Observed	Modeled		
2000	21,033.9	18,612.9	11.5%	**0.98/0.98**
2001	21,318.3	20,457.9	4.0%	
2002	13,011.6	13,021.4	0.1%	
2003	8,834.1	7,832.3	11.3%	
2004	14,419.0	11,893.8	17.5%	
2005	11,491.9	9,096.9	20.8%	
2006	9,437.1	8,798.6	6.8%	
2007	34,241.8	43,088.7	25.8%	
2008	31,828.4	35,060.0	10.2%	
2009	21,354.3	21,026.1	1.5%	
2010	12,175.6	12,543.5	3.0%	
2011	8,230.9	7,549.7	8.3%	
2012	6,613.1	5,608.3	15.2%	
2013	8,323.8	8,644.7	3.9%	
2014	5,443.6	5,127.5	5.8%	
2015	18,562.2	16,601.0	10.6%	
2016	14,762.3	11,773.1	20.2%	
2017	33,413.6	30,257.3	9.4%	
Overall	**16,360.9**	**15,944.1**	**2.5%**	

[a]Calculated using average monthly TN
[b,c] Respectively same reference in Appendix Table 6

TP results were compared for the sum of organic phosphorous and ortho phosphorous. Appendix Table 14 summarizes the parameters changed during TP calibration along with their typical range.

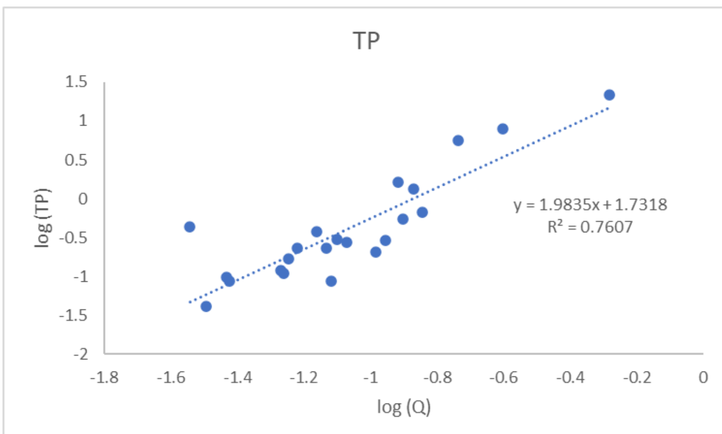
Appendix Table 14 List of Adjusted Parameters for TP Calibration of SWAT Model

Parameter	Units	Description	Location in SWAT Input	Typical Range	Land Use	Calibrated Value
ERORGP	-	Organic P enrichment ratio	**.hru	0 - 5	All	3.5 - 5
SOL_ORGP	mg/kg	Initial organic P concentration in surface soil layer	**.chm	0 - 100	All	97 - 100

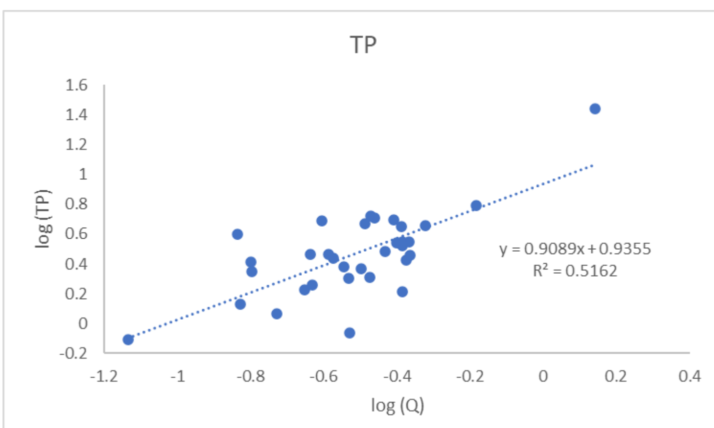
Parameter	Units	Description	Location in SWAT Input	Typical Range	Land Use	Calibrated Value
P_UPDIS	-	Phosphorus uptake distribution parameter	**.bsn	0 - 100	All	8
PHOSKD	-	Phosphorus soil partitioning coefficient.	**.bsn	100 - 200	All	100
PPERCO	-	Phosphorus percolation coefficient	**.bsn	10 – 17.5	All	12.5
LAT_ORGP	mg/L	Organic P in baseflow	**.gw	0 - 200	All	5

TP were calibrated and validated at sub-basins 1 and 8. TP monthly observed data were also estimated from log linear regression method due to limited sample data. Strong correlation with flow was observed at sub-basins 1 and 8 in Appendix Figure 6.

Appendix Figure 6 Log Linear Regression for TP estimation



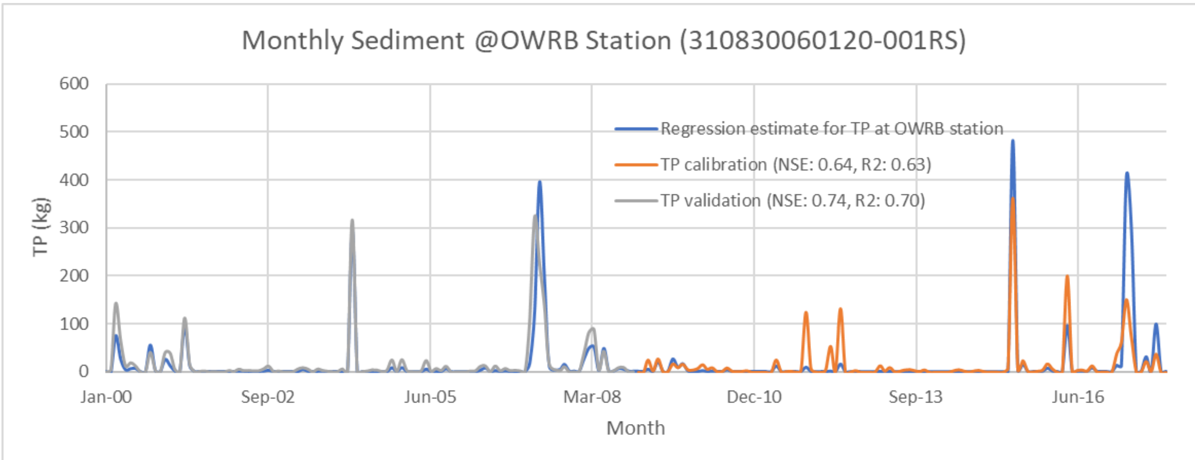
(a) Sub-basin 1



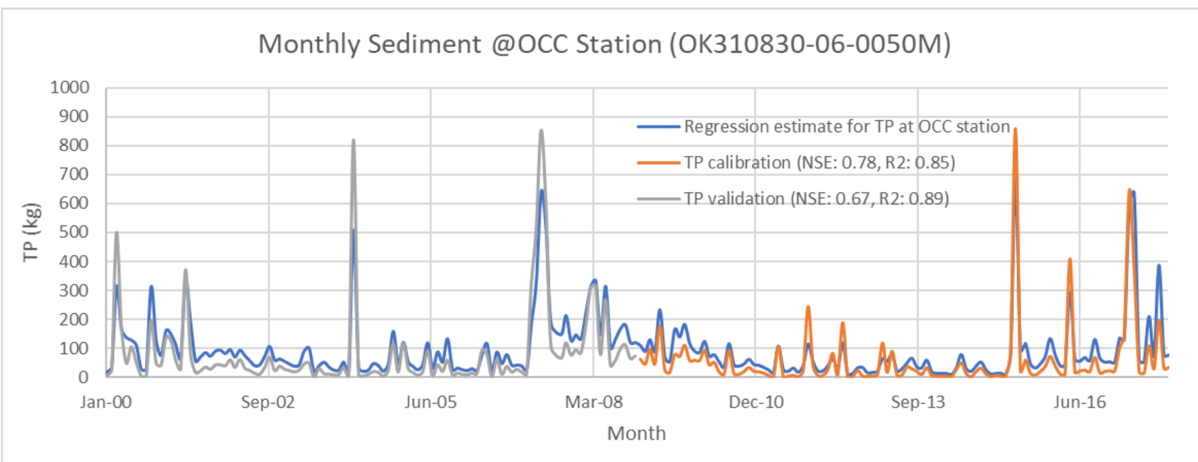
(b) Sub-basin 8

Appendix Figure 7 showed good agreement between regression estimations and SWAT results at sub-basins 1 and 8. In the Crowder Lake watershed, flow was a good independent variable to estimate sediment and nutrients.

Appendix Figure 7 TP Calibration and Validation



(a) Sub-basin 1



(b) Sub-basin 8

Appendix Table 15 showed good agreement between regression estimations and SWAT results at sub-basins 1 and 8. NSE ranged from 0.63 to 0.78 and PBIAS ranged from 3.8% to 33.8%, SWAT results were good estimation for monthly or yearly average.

Appendix Table 15 Summary of TP Calibration and Validation

Monitoring Site	Sub-basin	Data Period	Time Step	NSE	PBIAS	Comment
310830060120-001RS	1	2009 - 2017	Monthly	0.63	-3.8%	Calibration
		2000 - 2008	Monthly	0.70	-33.8%	Validation
OK310830-06-0050M	8	2009 - 2017	Monthly	0.78	28.7%	Calibration
		2000 - 2008	Monthly	0.67	20.2%	Validation

Appendix Table 16 Summary of Model Performance for TP at Sub-basin 1

Year	310830060120-001RS (Sub-basin 1)			
	Annual Average TP[a] (kg)		Model Error	NSE /R^2 (b,c)
	Observed	Modeled		
2000	174.6	299.7	71.7%	**0.786/0.80**
2001	148.5	217.1	46.2%	
2002	8.4	39.9	373.9%	
2003	7.6	32.2	322.1%	
2004	306.8	364.1	18.7%	
2005	21.3	78.1	267.3%	
2006	15.4	56.2	266.0%	
2007	760.9	961.0	26.3%	
2008	196.4	282.3	43.7%	
2009	82.4	115.9	40.7%	
2010	9.2	62.6	581.0%	
2011	22.2	168.6	658.5%	
2012	17.1	199.3	1065.0%	
2013	2.9	52.6	1703.3%	
2014	0.9	22.7	2331.8%	
2015	509.9	431.9	15.3%	
2016	109.9	237.8	116.3%	
2017	867.9	393.5	54.7%	
Overall	**181.2**	**223.1**	**23.1%**	

[a]Calculated using average monthly TP
[b,c] Respectively same reference in Appendix Table 6

Appendix Table 17 Summary of Model Performance for TP at Sub-basin 8

Year	OK310830-06-0050M (Sub-basin 8)			
	Annual Average TP[a] (kg)		Model Error	NSE /R^2 (b,c)
	Observed	Modeled		
2000	1,471.8	1,197.3	18.7%	0.90/0.90
2001	1,474.2	984.1	33.2%	
2002	849.9	434.0	48.9%	
2003	559.7	255.5	54.3%	
2004	1,008.0	1,081.8	7.3%	
2005	750.6	426.6	43.2%	
2006	604.1	368.2	39.0%	
2007	2,528.1	3,461.0	36.9%	
2008	2,273.6	1,681.5	26.0%	
2009	1,460.8	848.5	41.9%	
2010	792.7	465.1	41.3%	
2011	522.0	469.6	10.0%	
2012	413.3	358.0	13.4%	
2013	523.7	386.1	26.3%	
2014	331.7	168.7	49.2%	
2015	1,331.8	1,191.1	10.6%	
2016	989.5	681.9	31.1%	
2017	2,468.1	1,728.6	30.0%	
Overall	**1,130.8**	**899.3**	**20.5%**	

[a]Calculated using average monthly TP
[b,c] Respectively same reference in Appendix Table 6

Overall yearly averages from SWAT were well matched with linear regression estimations. These yearly average values from sub-basin 1 and 2 were input to BATHTUB for chlorophyll-a simulation. Then, reduction rate can be calculated to meet chlorophyll-a WQS in Crowder Lake.

Appendix D BATHTUB Model Input and Calibration for Crowder Lake

Appendix D
BATHTUB Model Input and Calibration – Crowder Lake

The data from SWAT is used in the BATHTUB model. BATHTUB is an empirical eutrophication reservoir water quality model that performs water and nutrient balance calculations to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network which accounts for advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (total phosphorus, total nitrogen, chlorophyll-a, and transparency) are predicted using empirical relationships derived from assessments of reservoir data (Walker, 2004). The model has been applied to U.S. Army Corps of Engineer reservoirs (e.g., Kennedy 1995), as well as a number of other lakes and reservoirs. BATHTUB was cited as an effective tool for lake and reservoir water quality assessment and management, particularly where data are limited (Ernst et al., 1994).

D-1. Model Inputs

D -1.1 Lake Morphometry

Crowder Lake is located 7 miles south from Weatherford, Oklahoma. The lake, as an artificial reservoir created by damming Cobb Creek, serves several purposes such as controlling flood and providing entertainment and recreation. Crowder Lake has a surface area of 158 acres (639,404 m^2) and conservation pool storage of 2,094 acre-feet (2,582,907 m^3). Based on t Test, difference of sample means from each site are not significant.

Appendix Table 18 Crowder Lake Chlorophyll-a Concentration at Monitoring Sites

Station ID	Sample period	Number of samples	Chlorophyll a concentration (µg/L)			
			Maximum	Minimum	Average	Median
Site 1	2013 - 2015	28	88.2	10.5	29.9	27.8
Site 2	2013 - 2015	28	76.0	9.51	29.4	25.8
Site 3	2013 - 2015	28	404.0	10.2	58.1	41.0

Crowder Lake shapes like reptile; body with tail, so BATHTUB geometry was set for two rectangular squares (segment 1 for lake tail and segment 2 for lake body). SWAT results from sub-basins 1 and 2 were used as BATHTUB model inputs.

Appendix Table 19 BATHTUB Geometry for Crowder Lake

Segment	Surface Area (m^2)	Depth (m)	Volume (m3)
1	220,610 (130 x 1,697)	0.79	174,282
2	418,800 (349 x 1,200)	5.75	2,408,100
Total	639,410		2,582,382

D -1.2 Meteorology

The BATHTUB model requires both precipitation and evaporation data. Those data were extracted from SWAT reservoir output. The rates of 0.73 m/year and 0.64 m/year were applied for precipitation and evaporation, respectively. Precipitation data, summarized in Section 1.2, were derived from the Oklahoma MESONET system.

D -1.2 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.

BATHTUB also requires an estimate of atmospheric deposition of total and inorganic nitrogen and phosphorus. Atmospheric deposition can contribute a significant amount of nitrogen directly to a lake surface when the ratio of watershed area to lake surface area is low. Total atmospheric deposition of nitrogen was extracted from annual depositions of the National Atmospheric Deposition Program (http://nadp.sws.uiuc.edu/) at site OK00 (Salt Plains National Wildlife Refuge). The annual depositions for the years 1983 to 2018 were averaged for Crowder Lake. Inorganic nitrogen deposition was estimated as the sum of the average nitrate and ammonia nitrogen deposition. Appendix Table 20 listed atmospheric N inputs for BATHTUB.

Appendix Table 20 Atmospheric N Loads

Atmospheric Loads	Averaged Aannual Deposition (mg/m^2-yr)	Estimated Load to Crowder Lake (kg/year)	CV
Total Nitrogen	435	278.0	0.3
Inorganic Nitrogen	435	278.0	0.3

Reliable estimates of atmospheric loads of phosphorus are not available; the atmosphere is not expected to be a major source of phosphorus. The estimation of 0.3 kg/ha-year P from Anderson and Downing (2006) was input to BATHTUB.

D -1.3 Empirical Equations

BATHTUB consists of a series of empirical equations calibrated and tested for lake application (for a description of the equations, see Model Documentation available online at http://www.walker.net/bathtub/help/bathtubWebMain.html). 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

D-2. Model Calibration and Results

Due to limited sample data on Crowder Lake, BATHTUB was only calibrated. The model was run under average existing conditions and calibrated to measure in-lake water quality conditions (based on 1998-2015 data) using phosphorus, nitrogen, chlorophyll-a and Secchi disk calibration factors. Appendix Table 21 includes the calibration factors used for Crowder Lake.

Appendix Table 21 BATHTUB Calibration Factors and Results

Segment	Parameter	Calibration Factor	BATHTUB Results		Observed data	
			Mean	CV	Mean	CV
1	Total Phosphorus (µg/L)	3	102.5	0.58	101.9	0.68
	Organic P (µg/L)	1.02	63.4	0.83	63.9	0.55
	Total Nitrogen (µg/L)	3.9	1,286.7	0.44	1,244.9	0.37
	Organic N (µg/L)	0.75	740.4	0.67	765.7	0.55
	Chlorophyll-*a* (µg/L)	0.65	36.2	0.78	35.7	0.77
	Secchi Disk (m)	0.4	0.41	0.71	0.42	0.43
2	Total Phosphorus (µg/L)	0.95	72.3	0.82	71.9	0.93
	Organic P (µg/L)	0.5	29.3	0.50	29.7	0.45
	Total Nitrogen (µg/L)	0.5	1,045.2	0.36	1,030.8	0.46
	Organic N (µg/L)	0.8	644.8	0.49	635.8	0.42
	Chlorophyll-*a* (µg/L)	1.6	26.2	0.67	26.9	0.69
	Secchi Disk (m)	0.99	0.74	0.44	0.74	0.30

The model-predicted concentrations of total nitrogen, total phosphorus, chlorophyll-*a*, and Secchi depth under existing average conditions are compared to average measured concentrations. Model error for each parameter was less than 5%.

D-3. Sensitivity Analysis

To determine the most sensitive parameters, a one-at-a time sensitivity analysis will be conducted comparing default and calibration values for each of the parameters selected. Then, the model output difference of average chlorophyll-a concentration is compared with the parameter range. Then, rates were ranked for sensitive parameters. These ranked parameters are adjusted in the calibration process to meet calibration criteria. All calibration factors were kept as default (1) except calibration parameters shown in Appendix Table 22.

Appendix Table 22 BATHTUB Sensitivity Analysis on Calibration Factors

Parameter	Calibration Factor		BATHTUB Chl-a Results		Absolute % Change	Sensitivity[a]	Rank
	Default	Calibration	Default	Calibration			
TP (Segment 1)	1	3	61.3	57.4	6.5%	1.98	5
TP (Segment 2)	1	0.95	61.3	61.4	0.1%	0.8	6
Organic P (Segment 1)	1	1.02	61.3	61.3	0%	0	-
Organic P (Segment 2)	1	0.5	61.3	61.3	0%	0	-
TN (Segment 1)	1	3.9	61.3	47.8	22.1%	4.7	4
TN (Segment 2)	1	0.5	61.3	64.2	4.7%	5.7	3
Organic N (Segment 1)	1	0.75	61.3	61.3	0%	0	-
Organic N (Segment 2)	1	0.8	61.3	61.3	0%	0	-
Chlorophyll-*a* (Segment 1)	1	0.65	61.3	45.0	26.6%	46.7	1
Chlorophyll-a (Segment 2)	1	1.6	61.3	70.2	14.5%	14.8	2
Secchi Depth (Segment 1)	1	0.4	61.3	61.3	0%	0	-
Secchi Depth (Segment 2)	1	0.99	61.3	61.3	0%	0	-

[a] Sensitivity =abs(chl-a change)/abs(Factor change)

Chlorophyll-a calibration factor was the most sensitive parameter in Crowder Lake BATHTUB model, followed by TN calibration factor. Model coefficients and other calibration factors were kept as default value (1).

D-4. Uncertainty Analysis

Coefficient of Variation (CV) refers to the spread of a sample or a population as a proportion of the mean. Chlorophyll-*a* samples from Crowder Lake have 0.72 of CV, so BATHTUB model is calibrated to have similar value of CV.

In addition, implicit MOS was applied for load reduction calculation to account model uncertainty. An implicit 10% margin of safety was incorporated by using an in-lake water quality target of 9 µg/L, instead of using 10 µg/L chlorophyll- *a* WQS.

Appendix Table 23 Uncertainty Analysis for BATHTUB Results

Reduction		Overall BATHTUB Chlorophyll-a Result		Comments
TP	TN	Mean	CV	
80%	80%	12.2	0.63	As reduction increases, CV increases
85%	85%	9.9	0.67	
87%	87%	8.9	0.69	
90%	90%	7.3	0.75	

TP and TN reductions are shown in Appendix Table 23. BATHTUB results showed 87% reduction would meet water quality target.