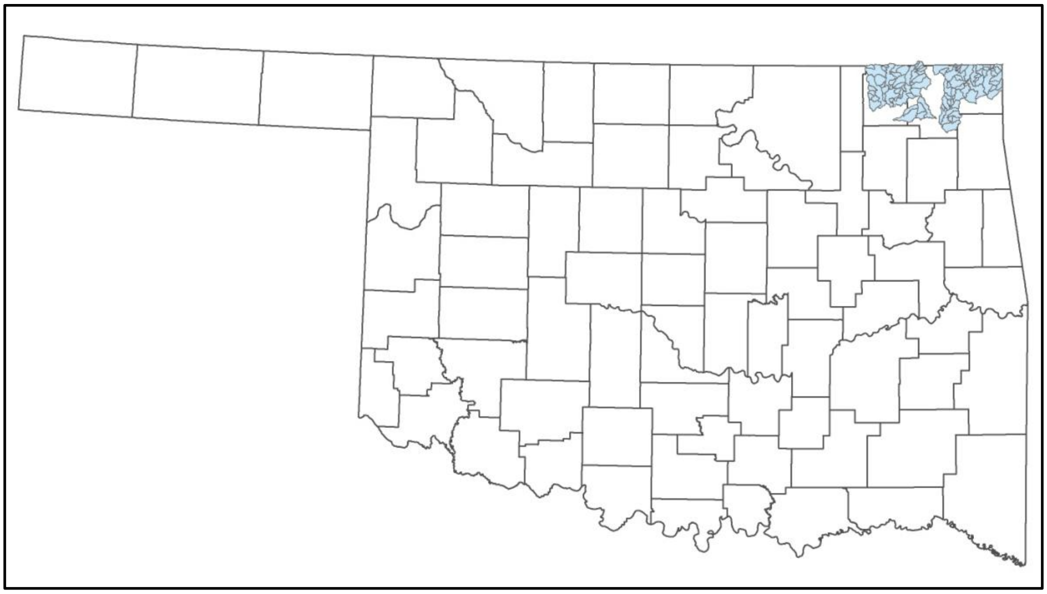
FINAL

BACTERIAL AND TURBIDITY TOTAL MAXIMUM DAILY LOADS FOR STREAMS IN THE VERDIGRIS-NEOSHO RIVER STUDY AREA, OKLAHOMA (OK121510, OK121600)



Prepared by:

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

SEPTEMBER 2012

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BACTERIAL AND TURBIDITY

TOTAL MAXIMUM DAILY LOADS FOR STREAMS IN THE VERDIGRIS-NEOSHO RIVER AREA, OKLAHOMA (OK121510, OK121600)

OKWBID

Verdigris River	**OK121510020010_00**
California Creek	**OK121510020050_00**
Big Creek	**OK121510030010_00**
Neosho River	**OK121600040010_00**
Hudson Creek	**OK121600040040_00**
Cow Creek	**OK121600040130_00**
Neosho River	**OK121600040220_00**
Little Cabin Creek	**OK121600060080_00**
Spring River	**OK121600070010_00**
Fivemile Creek	**OK121600070110_00**

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SEPTEMBER 2012

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ACRONYMS AND ABBREVIATIONS

AEMS	Agricultural Environmental Management Service
ASAE	American Society of Agricultural Engineers
BMP	Best management practices
BOD	Biochemical Oxygen Demand
CAFO	Concentrated Animal Feeding Operation
CBOD	Carbonaceous Biochemical Oxygen Demand
CFR	Code of Federal Regulations
cfs	cubic feet per second
cfu	colony-forming unit
CPP	Continuing Planning Process
CWA	Clean Water Act
DEQ	Oklahoma Department of Environmental Quality
DMR	Discharge monitoring report
E. coli	Escherichia coli
ENT	Enterococci
EPA	U.S. Environmental Protection Agency
HUC	Hydrologic unit code
IQR	Interquartile range
LA	Load allocation
LDC	Load duration curve
LOC	Line of organic correlation
mg	Million gallons
mgd	Million gallons per day
mg/L	Milligram per liter
mL	Milliliter
MOS	Margin of safety
MS4	Municipal separate storm sewer system
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRMSE	Normalized root mean square error
NTU	Nephelometric turbidity unit
OAC	Oklahoma Administrative Code

OLS	Ordinary least square
O.S.	Oklahoma statute
ODAFF	Oklahoma Department of Agriculture, Food and Forestry
OKWBID	Oklahoma Waterbody Identification Number
OPDES	Oklahoma Pollutant Discharge Elimination System
OSWD	Onsite wastewater disposal
OWQS	Oklahoma Water Quality Standards
OWRB	Oklahoma Water Resources Board
PBCR	Primary Body Contact Recreation
PRG	Percent reduction goal
RMSE	Root mean square error
SH	State Highway
SSO	Sanitary sewer overflow
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WWAC	warm water aquatic community
WLA	wasteload allocation
WQM	Water quality monitoring
WQMP	Water Quality Management Plan
WQS	Water quality standard
WWTP	wastewater treatment plant

Executive Summary

This report documents the data and assessment used to establish TMDLs for the pathogen indicator bacteria [*Escherichia coli (E. coli),* Enterococci] and turbidity for certain waterbodies in the Verdigris-Neosho River Area. Elevated levels of pathogen indicator bacteria in aquatic environments indicate that a waterbody is contaminated with human or animal feces and that a potential health risk exists for individuals exposed to the water. Elevated turbidity levels caused by excessive sediment loading and stream bank erosion impact aquatic communities. Data assessment and total maximum daily load (TMDL) calculations are conducted in accordance with requirements of Section 303(d) of the Clean Water Act (CWA), Water Quality Planning and Management Regulations (40 CFR Part 130), U.S. Environmental Protection Agency (EPA) guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to EPA for review. Approved 303(d) listed waterbody-pollutant pairs or surrogates TMDLs will receive notification of the approval or disapproval action. Once the 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 pollutant load allocations for indicator bacteria and turbidity in impaired waterbodies, which is the first step toward restoring water quality and protecting public health. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding the WQS for that pollutant. TMDLs also establish the pollutant load allocation necessary to meet the WQS established for a waterbody based on the relationship between pollutant sources and instream water quality conditions. 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. MOS can be implicit and/or explicit. The 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 process 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 bacteria or turbidity within each watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process.

E.1 Problem Identification and Water Quality Target

This TMDL report focuses on waterbodies in the Verdigris-Neosho River Area, identified in Table ES-1, that DEQ placed in Category 5 [303(d) list] of the *Water Quality in Oklahoma, 2008 Integrated Report* (aka 2008 Integrated Report) for nonsupport of primary body contact recreation (PBCR) or warm water aquatic community (WWAC).

Elevated levels of bacteria or turbidity above the WQS necessitates the development of a TMDL. The TMDLs established in this report are a necessary step in the process to develop the pollutant loading controls needed to restore the PBCR or fish and wildlife propagation beneficial uses designated for each waterbody.

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

Waterbody ID	Waterbody Name	Stream Miles	TMDL Date	Priority	ENT	*E. coli*	Designated Use Primary Body Contact Recreation	Turbidity	Designated Use Warm Water Aquatic Life
OK121510010130_00	Lightning Creek	14.40	2012	1		X	N		
OK121510020010_00	Verdigris River	37.43	2012	1	X		N	X	N
OK121510020050_00	California Creek	25.39	2021	4	X		N		N
OK121510030010_00	Big Creek	34.74	2021	4	X	X	N		N
OK121600030560_00	Lost Creek	10.23	2021	4		X	N		
OK121600040010_00	Neosho River	16.57	2021	4			F	X	N
OK121600040040_00	Hudson Creek	8.28	2021	4			I	X	N
OK121600040130_00	Cow Creek	12.42	2021	4			N	X	N
OK121600040220_00	Neosho River	13.97	2021	4	X		N	X	N
OK121600060080_00	Little Cabin Creek	32.31	2021	4	X	X	N		N
OK121600060200_00	Bull Creek	10.83	2021	4		X	N		N
OK121600060240_00	Pawpaw Creek	18.40	2021	4		X	N		N
OK121600070010_00	Spring River	22.11	2018	3	X		N	X	
OK121600070110_00	Fivemile Creek	5.81	2018	3	X		N		

ENT = Enterococci; N = Not attaining; X = Criterion exceeded
Source: 2008 Integrated Report, DEQ 2008.

Table ES-2 summarizes water quality data collected during primary contact recreation season from the water quality monitoring (WQM) stations between 2000 and 2008 for each bacterial indicator. The data summary in Table ES-2 provides a general understanding of the amount of water quality data available and the severity of exceedances of the water quality criteria. This data collected during the primary contact recreation season includes the data used to support the decision to place specific waterbodies within the Study Area on the DEQ 2008 303(d) list (DEQ 2008). It also includes the new date collected after the data cutoff date for the 2008 303(d) list.

Table ES-2 Summary of Indicator Bacterial Samples from Primary Body Contact Recreation Subcategory Season May 1 to September 30, 2000-2008

Waterbody ID	Waterbody Name	Indicator	Number of samples	Geometric Mean Conc (cfu/100 ml)	Assessment Results
OK121510010130_00	Lightning Creek	EC	2	148	De-list: Not enough data available
OK121510020010_00	Verdigris River	ENT	22	120	TMDL Required
OK121510020050_00	California Creek	ENT	17	95	TMDL Required
OK121510030010_00	Big Creek	ENT	18	92	TMDL Required
		EC	2	148	TMDL Required
OK121600030560_00	Lost Creek	EC	2	96	De-list: Not enough data available
OK121600040220_00	Neosho River	ENT	27	85	TMDL Required
OK121600060080_00	Little Cabin Creek	EC	15	366	TMDL Required
		ENT	15	287	TMDL Required
OK121600060200_00	Bull Creek	EC	3	73	Delist: Not enough data available
OK121600060240_00	Pawpaw Creek	EC	2	134	Delist: Not enough data available
OK121600070010_00	Spring River	ENT	30	35	TMDL Required
OK121600070110_00	Fivemile Creek	ENT	16	64	TMDL Required

E. coli (EC) water quality criterion = Geometric Mean of 126 counts/100 mL
Enterococci (ENT) water quality criterion = Geometric Mean of 33 counts/100 mL

The definition of PBCR and the bacterial WQSs for PBCR are summarized by the following excerpt from Chapter 45 of the Oklahoma WQSs.

(a) Primary Body Contact Recreation involves direct body contact with the water where a possibility of ingestion exists. In these cases the water shall not contain chemical, physical or biological substances in concentrations that are irritating to skin or sense organs or are toxic or cause illness upon ingestion by human beings.

(b) In waters designated for Primary Body Contact Recreation...limits...shall apply only during the recreation period of May 1 to September 30. The criteria for Secondary Body Contact Recreation will apply during the remainder of the year.

(c) Compliance with 785:45-5-16 shall be based upon meeting the requirements of one of the toptions specified in (1) or (2) of this subsection (c) for bacteria. Upon selection of one (1) group or test method, said method shall be used exclusively over the time period prescribed therefore. Provided, where concurrent data exist for multiple bacterial indicators on the same waterbody or waterbody segment, no criteria exceedances shall be allowed for any indicator group.

(1) Escherichia coli (E. coli): The E. coli geometric mean criterion is 126/100 ml. For swimming advisory and permitting purposes, E. coli shall not exceed a monthly geometric mean of 126/100 ml based upon a minimum of not less than five (5) samples collected over a period of not more than thirty (30) days. For swimming advisory and permitting purposes, no sample shall exceed a 75% one-sided confidence level of 235/100 ml in lakes and high use waterbodies and the 90% one-sided confidence level of 406/100 ml in all other Primary Body Contact Recreation beneficial use areas. These values are based upon all samples collected over the recreation period. For purposes of sections 303(d) and 305(b) of the federal Clean Water Act as amended, beneficial use support status shall be assessed using only the geometric mean criterion of 126/100 milliliters compared to the geometric mean of all samples collected over the recreation period.

(2) Enterococci: The Enterococci geometric mean criterion is 33/100 ml. For swimming advisory and permitting purposes, Enterococci shall not exceed a monthly geometric mean of 33/100 ml based upon a minimum of not less than five (5) samples collected over a period of not more than thirty (30) days. For swimming advisory and permitting purposes, no sample shall exceed a 75% one-sided confidence level of 61/100 ml in lakes and high use waterbodies and the 90% one-sided confidence level of 108/100 ml in all other Primary Body Contact Recreation beneficial use areas. These values are based upon all samples collected over the recreation period. For purposes of sections 303(d) and 305(b) of the federal Clean Water Act as amended, beneficial use support status shall be assessed using only the geometric mean criterion of 33/100 milliliters compared to the geometric mean of all samples collected over the recreation period.

To implement Oklahoma's WQS for PBCR, the Oklahoma Water Resources Board (OWRB) promulgated Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2011a). The abbreviated excerpt below from Chapter 46: 785:46-15-6, stipulates how water quality data will be assessed to determine support of the PBCR use as well as how the water quality target for TMDLs will be defined for each bacterial indicator.

(a) Scope.

The provisions of this Section shall be used to determine whether the subcategory of Primary Body Contact of the beneficial use of Recreation designated in OAC 785:45 for a waterbody is supported during the recreation season from May 1 through September 30 each year. Where data exist for multiple bacterial indicators on the same waterbody or waterbody segment, the determination of use support shall be based upon the use and application of all applicable tests and data.

(b) Escherichia coli (E. coli):

(1) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be fully supported with respect to E. coli if the geometric mean of 126 colonies per 100 ml is met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

(2) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be not supported with respect to E. coli if the geometric mean of 126 colonies per 100 ml is not met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

(c) Enterococci.

(1) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be fully supported with respect to Enterococci if the geometric mean of 33 colonies per 100 ml is met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

(2) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be not supported with respect to Enterococci if the geometric mean of 33 colonies per 100 ml is not met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

Where concurrent data exist for multiple bacterial indicators on the same waterbody, each indicator group must demonstrate compliance with the numeric criteria prescribed (OWRB 2011).

As stipulated in the WQS, only the geometric mean of all samples collected over the recreation period shall be used to assess the impairment status of a stream. Therefore, only the geometric mean criteria will be used to develop TMDLs for *E. coli* and Enterococci bacterial indicators.

It is worth noting that the Oklahoma Water Quality Standards (OWQS) prior to July 1, 2011 contains three bacterial indicators (fecal coliform, *E. coli* and Enterococci) and the new OWQS effective on July 1, 2011 contains only *E. coli* and Enterococci. Because the new OWQS no longer have a standard for fecal coliform, fecal coliform TMDLs will not be developed for any stream in this report listed for fecal coliform impairment in the 2008 303(d) list. Bacterial TMDLs will be developed only for *E. coli* and/or Enterococci impaired streams.

The beneficial use of WWAC is one of several subcategories of the Fish and Wildlife Propagation use established to manage the variety of communities of fish and shellfish throughout the state (OWRB 2011). The numeric criteria for turbidity to maintain and protect the use of "Fish and Wildlife Propagation" from Title 785:45-5-12 (f) (7) is as follows:

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

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

2. Lakes: 25 NTU; and

3. Other surface waters: 50 NTUs.

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

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

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

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

Assessment of Fish and Wildlife Propagation support

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

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

785:46-15-4. Default protocols

(b) Short term average numerical parameters.

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

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

Turbidity is a measure of water clarity and is caused by suspended particles in the water column. Because turbidity cannot be expressed as a mass load, total suspended solids (TSS) are used as a surrogate for the TMDLs in this report. Therefore, both turbidity and TSS data are presented.

Table ES-3 summarizes a subset of water quality data collected for turbidity and TSS under base flow conditions, which DEQ considers to be all flows less than the 25^{th} flow exceedance percentile (i.e., the lower 75% of flows). Water quality samples collected under flow conditions greater than the 25^{th} flow exceedance percentile (highest flows) were therefore excluded from the data set used for TMDL analysis.

Table ES-3 Summary of Turbidity and TSS Data Excluding High Flow Samples, 1998-2011

Waterbody ID	Waterbody Name	WQM Stations	Number of turbidity samples	Number of samples greater than 50 NTU	% samples exceeding criterion	Average Turbidity (NTU)	Assessment Results
OK121510020010_00	Verdigris River	121510020010-001AT	71	15	21%	39	TMDL Required
OK121600040010_00	Neosho River	121600040010-001AT	55	15	27%	34	TMDL Required
OK121600040040_00	Hudson Creek	OK121600-04-0040G	18	4	22%	23	TMDL Required
OK121600040130_00	Cow Creek	OK121600-04-0130G	16	5	31%	35	TMDL Required
OK121600040220_00	Neosho River	121600040220-001AT	74	28	38%	86	TMDL Required

TMDLs for turbidity in streams designated as WWAC must take into account that no more than 10% of the samples may exceed the numeric criterion of 50 nephelometric turbidity units (NTU). However, as described above, because turbidity cannot be expressed as a mass load, TSS is used as a surrogate in this TMDL. Since there is no numeric criterion in the Oklahoma WQS for TSS, a regression method to convert the turbidity criterion to TSS based on a relationship between turbidity and TSS was used to establish TSS goals as surrogates. Table ES-4 provides the results of the waterbody specific regression analysis.

Table ES-4 Regression Statistics and TSS Goals

Waterbody ID	Waterbody Name	R-square	NRMSE	TSS Goal (mg/L)	MOS
OK121510020010_00	Verdigris River	0.906	7.5%	40	10%
OK121600040010_00	Neosho River	0.846	8.7%	45	10%
OK121600040040_00	Hudson Creek	0.793	12.1%	43	10%
OK121600040130_00	Cow Creek	0.866	8.8%	33	10%
OK121600040220_00	Neosho River	0.846	8.7%	45	10%

After re-evaluating bacterial/turbidity data for the streams listed in Table ES-1, bacterial impairments on Lightning Creek, Lost Creek, Bull Creek and Pawpaw Creek are recommended for delisting. TMDLs are not required for these delisted creeks. Table ES-5 shows the bacterial and turbidity TMDLs that will be developed in this report.

Table ES-5 Stream and Pollutants for TMDL Development

Waterbody ID	Waterbody Name	Stream Miles	TMDL Date	Priority	ENT	*E. coli*	Turbidity
OK121510020010_00	Verdigris River	37.43	2012	1	X		X
OK121510020050_00	California Creek	25.39	2021	4	X		
OK121510030010_00	Big Creek	34.74	2021	4	X	X	
OK121600040010_00	Neosho River	16.57	2021	4			X
OK121600040040_00	Hudson Creek	8.28	2021	4			X
OK121600040130_00	Cow Creek	12.42	2021	4			X
OK121600040220_00	Neosho River	13.97	2021	4	X		X
OK121600060080_00	Little Cabin Creek	32.31	2021	4	X	X	
OK121600070010_00	Spring River	22.11	2018	3	X		
OK121600070110_00	Fivemile Creek	5.81	2018	3	X		

E.2 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. Bacteria originate from warm-blooded animals and sources may be point or nonpoint in nature. Turbidity may originate from NPDES-permitted facilities, fields, construction sites, quarries, stormwater runoff and eroding stream banks.

Point sources are permitted through the NPDES program. NPDES-permitted facilities that discharge treated sanitary wastewater are required to monitor fecal coliform under the current permits and will be required to monitor *E. coli* when their permits come to renew. These facilities are also required to monitor TSS in accordance with their permits. 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 bacteria or TSS to surface water as a result of rainfall runoff. For the TMDLs in this report, all sources of pollutant loading not regulated by NPDES permits are considered nonpoint sources. Sediment loading of streams can originate from natural erosion processes, including the weathering of soil, rocks, and uncultivated land; geological abrasion; and other natural phenomena. There is insufficient data available to quantify contributions of TSS from these natural processes. TSS or sediment loading can also occur under non-runoff conditions as a result of anthropogenic activities in riparian corridors which cause erosive conditions. Given the lack of data to establish the background conditions for TSS/turbidity, separating background loading from nonpoint sources whether it is from natural or anthropogenic processes is not feasible in this TMDL development. Table ES-6 summarizes the point and nonpoint sources that contribute bacteria or TSS to each respective waterbody.

Table ES-6 Summary of Potential Pollutant Sources by Category

Waterbody ID	Waterbody Name	Municipal NPDES Facility	Industrial NPDES Facility	MS4	NPDES No Discharge Facility	CAFO/ PFO	Mines	Construction Stormwater Permit	Nonpoint Source
Verdigris River	OK121510020010_00								Bacteria/ Turbidity
California Creek	OK121510020050_00								Bacteria
Big Creek	OK121510030010_00								Bacteria
Neosho River	OK121600040010_00								Turbidity
Hudson Creek	OK121600040040_00								Turbidity
Cow Creek	OK121600040130_00								Turbidity
Neosho River	OK121600040220_00								Bacteria/ Turbidity
Little Cabin Creek	OK121600060080_00								Bacteria
Spring River	OK121600070010_00								Bacteria
Fivemile Creek	OK121600070110_00								Bacteria

Facility present in watershed and potential as contributing pollutant source.

Facility present in watershed, but not recognized as pollutant source.

No facility present in watershed.

E.3 Using Load Duration Curves to Develop TMDLs

The TMDL calculations presented in this report are derived from load duration curves (LDC). LDCs facilitate rapid development of TMDLs, and as a TMDL development tool can provide some information for identifying whether impairments are associated with point or nonpoint sources. The efficiency and simplicity of the LDC method should not be considered as bad descriptors of this powerful tool for displaying the changing water quality over changing flows that provides information as to the sources of the pollutant that is not apparent in the raw data. The LDC has additional valuable uses in the post-TMDL implementation phase of the restoration of the water quality for a waterbody. Plotting future monitoring information on the LDC can show trends of improvement to sources that will identify areas for revision to the watershed restoration plan. The low cost of the LDC method allows accelerated development of TMDL plans on more waterbodies and the evaluation of the implementation of WLAs and BMPs. The technical approach for using LDCs for TMDL development includes the following steps:

- Preparing flow duration curves for gaged and ungaged WQM stations;
- Estimating existing loading in the waterbody using ambient bacterial water quality data; and estimating loading in the waterbody using measured TSS water quality data and turbidity-converted data; and
- Using LDCs to identify the critical condition that will dictate loading reductions and the overall percent reduction goal (PRG) necessary to attain WQS.

Use of the LDC obviates the need to determine a design storm or selected flow recurrence interval with which to characterize the appropriate flow level for the assessment of critical conditions. For waterbodies impacted by both point and nonpoint sources, the “nonpoint source critical condition” would typically occur during high flows, when rainfall runoff would contribute the bulk of the pollutant load, while the “point source critical condition” would typically occur during low flows, when wastewater treatment plant (WWTP) effluents would dominate the base flow of the impaired water. However, flow range is only a general indicator of the relative proportion of point/nonpoint contributions. Violations have been noted under low flow conditions in some watersheds that contain no point sources.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by a water quality criterion. The TMDL can be expressed as a continuous function of flow, equal to the line, or as a discrete value derived from a specific flow condition.

The basic steps to generating an LDC involve:

- Obtaining daily flow data for the site of interest from the U.S. Geological Survey (USGS), or if unavailable, projected from a nearby USGS site;
- Sorting the flow data and calculating flow exceedance percentiles;
- Obtaining the water quality data from the primary contact recreation season (May 1 through September 30); or obtaining available turbidity and TSS water quality data;

- Matching the water quality observations with the flow data from the same date;
- Displaying a curve on a plot that represents the allowable load determined by multiplying the actual or estimated flow by the WQS for each respective bacterial indicator; or displaying a curve on a plot that represents the allowable load determined by multiplying the actual or estimated flow by the WQ_{goal} for TSS;
- For bacterial TMDLs, displaying and differentiating another curve derived by plotting the geometric mean of all existing bacterial samples continuously along the full spectrum of flow exceedance percentiles which represents the observed load in the stream; or
- For turbidity TMDLs, matching the water quality observations with the flow data from the same date and determining the corresponding exceedance percentile. Plotting the flow exceedance percentiles and daily load observations in a load duration plot (See Section 5).

For bacterial TMDLs the culmination of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve:

TMDL (cfu/day) = WQS * flow (cfs) * unit conversion factor

Where: WQS = 126 cfu/100 mL (E. coli); or 33 cfu/100 mL (Enterococci)

unit conversion factor = 24,465,525

For turbidity (TSS) TMDLs the culmination of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve:

TMDL (lb/day) = WQ_{goal} * flow (cfs) * unit conversion factor

where: WQ_{goal} = waterbody specific TSS concentration derived from regression analysis results presented in Table 5-1

unit conversion factor = 5.39377

Historical observations of bacteria were plotted as a separate LDC based on the geometric mean of all samples. Historical observations of TSS and/or turbidity concentrations are paired with flow data and are plotted on the LDC for a stream. It is noted that the LDCs for bacteria were based on the geometric mean standards or geometric mean of all samples. It is inappropriate to compare single sample bacterial observations to a geometric mean water quality criterion in the LDC; therefore individual bacterial samples are not plotted on the LDCs.

E.4 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 lack of knowledge concerning the relationship between pollutant loading and water quality.

This definition can be expressed by the following equation:

$$TMDL = WLA\_{WWTP} + WLA\_{MS4} + LA + MOS$$

For each waterbody the TMDLs presented in this report are expressed as colony forming units per day across the full range of flow conditions. For information purpose, percent reductions are also provided. The difference between existing loading and the water quality target is used to calculate the loading reductions required. For bacteria, the PRG is calculated by reducing all samples by the same percentage until the geomean of the reduced sample values meets the corresponding bacterial geomean standard (126 cfu/100 ml for *E. coli* and 33 cfu/100 ml for Enterococci) with 10% of MOS. For turbidity, the PRG is the load reduction that ensures that no more than 10% of the samples under flow-base conditions exceed the TMDL.

Table ES-7 presents the percent reductions necessary for each bacterial indicator causing nonsupport of the PBCR use in each waterbody of the Study Area.

Table ES-7 Percent Reductions Required to Meet Water Quality Standards for Indicator Bacteria

Waterbody ID	Waterbody Name	Required Reduction Rate	
		EC	ENT
OK121510020010_00	Verdigris River		72.5%
OK121510020050_00	California Creek		65.3%
OK121510030010_00	Big Creek	4.8%	64.2%
OK121600040220_00	Neosho River		61.2%
OK121600060080_00	Little Cabin Creek	65.6%	88.5%
OK121600070010_00	Spring River		4.6%
OK121600070110_00	Fivemile Creek		48.1%

Similarly, PRGs for TSS are calculated as the required overall reduction so that no more than 10% of the samples exceed the water quality target for TSS. The PRGs for the waterbodies requiring turbidity TMDLs in this report are summarized in Table ES-8 and range from 16% to 57%.

Table ES-8 TMDL Percent Reductions Required to Meet Water Quality Targets for Total Suspended Solids

Waterbody ID	Waterbody Name	Required Reduction Rate
OK121510020010_00	Verdigris River	16%
OK121600040010_00	Neosho River	57%

Waterbody ID	Waterbody Name	Required Reduction Rate
OK121600040040_00	Hudson Creek	37%
OK121600040130_00	Cow Creek	41%
OK121600040220_00	Neosho River	35%

The TMDL, WLA, LA, and MOS vary with flow condition, and are calculated at every 5th flow interval percentile. The WLA component of each TMDL is the sum of all WLAs within each contributing watershed. The LA can then be calculated as follows:

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

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs include an MOS and account for seasonal variability. The MOS, which can be implicit or explicit, 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.

For bacterial TMDLs, an explicit MOS was set at 10%.

For turbidity, the TMDLs are calculated for TSS instead of turbidity. Thus, the quality of the regression has a direct impact on confidence of the TMDL calculations. The better the regression is, the more confidence there is in the TMDL targets. As a result, it leads to a smaller MOS. The selection of MOS is based on the normalized root mean square error (NRMSE) for each waterbody (Table ES-4).

The bacterial TMDLs established in this report adhere to the seasonal application of the Oklahoma WQS which limits the PBCR use to the period of May 1st through September 30th. Similarly, the TSS TMDLs established in this report adhere to the seasonal application of the Oklahoma WQS for turbidity, which applies to seasonal base flow conditions only. Seasonal variation was also accounted for in these TMDLs by using more than five years of water quality data and by using the longest period of USGS flow records when estimating flows to develop flow exceedance percentiles.

E.5 Reasonable Assurance

Reasonable assurance is required by the EPA rules 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 WLA based on an assumption that nonpoint source load reductions will occur. In such a case, "reasonable assurances" that nonpoint (NPS) load reductions will actually occur must be demonstrated. In this report, all point source discharges either already have or will be given discharge limitations less than or equal to the water quality standard numerical criteria. This ensures that the impairments of the waterbodies in this report will not be caused by point sources. Since the point source WLAs in this TMDL report are not dependent on NPS load reduction, reasonable assurance does not apply.

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 (TMDL) for all waterbodies and pollutants identified by the Regional Administrator as suitable for TMDL calculation. Waterbodies 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 instream water quality conditions, so states can implement water quality-based controls to reduce pollution from point and nonpoint sources and restore and maintain water quality (EPA 1991).

This report documents the data and assessment used to establish TMDLs for the pathogen indicator bacteria [*Escherichia coli (E. coli)*, Enterococci] and turbidity for selected waterbodies in the Verdigris-Neosho River basin. (All future references to bacteria in this document imply these two fecal pathogen indicator bacterial groups unless specifically stated otherwise.) Elevated levels of pathogen indicator bacteria in aquatic environments indicate that a waterbody is contaminated with human or animal feces and that a potential health risk exists for individuals exposed to the water. Elevated turbidity levels caused by excessive sediment loading and stream bank erosion impact aquatic biological communities. 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 Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to EPA for review. Approved 303(d) listed waterbody-pollutant pairs or surrogates TMDLs will receive notification of the approval or disapproval action. Once the 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 pollutant load allocations for indicator bacteria and turbidity in impaired waterbodies, which is the first step toward restoring water quality and protecting public health. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding the WQS for that pollutant. TMDLs also establish the pollutant load allocation necessary to meet the WQS established for a waterbody based on the relationship between pollutant sources and instream water quality conditions. 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). The LA is the fraction of the total pollutant load apportioned to nonpoint sources. 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 process in aquatic systems, model assumptions, and data limitations.

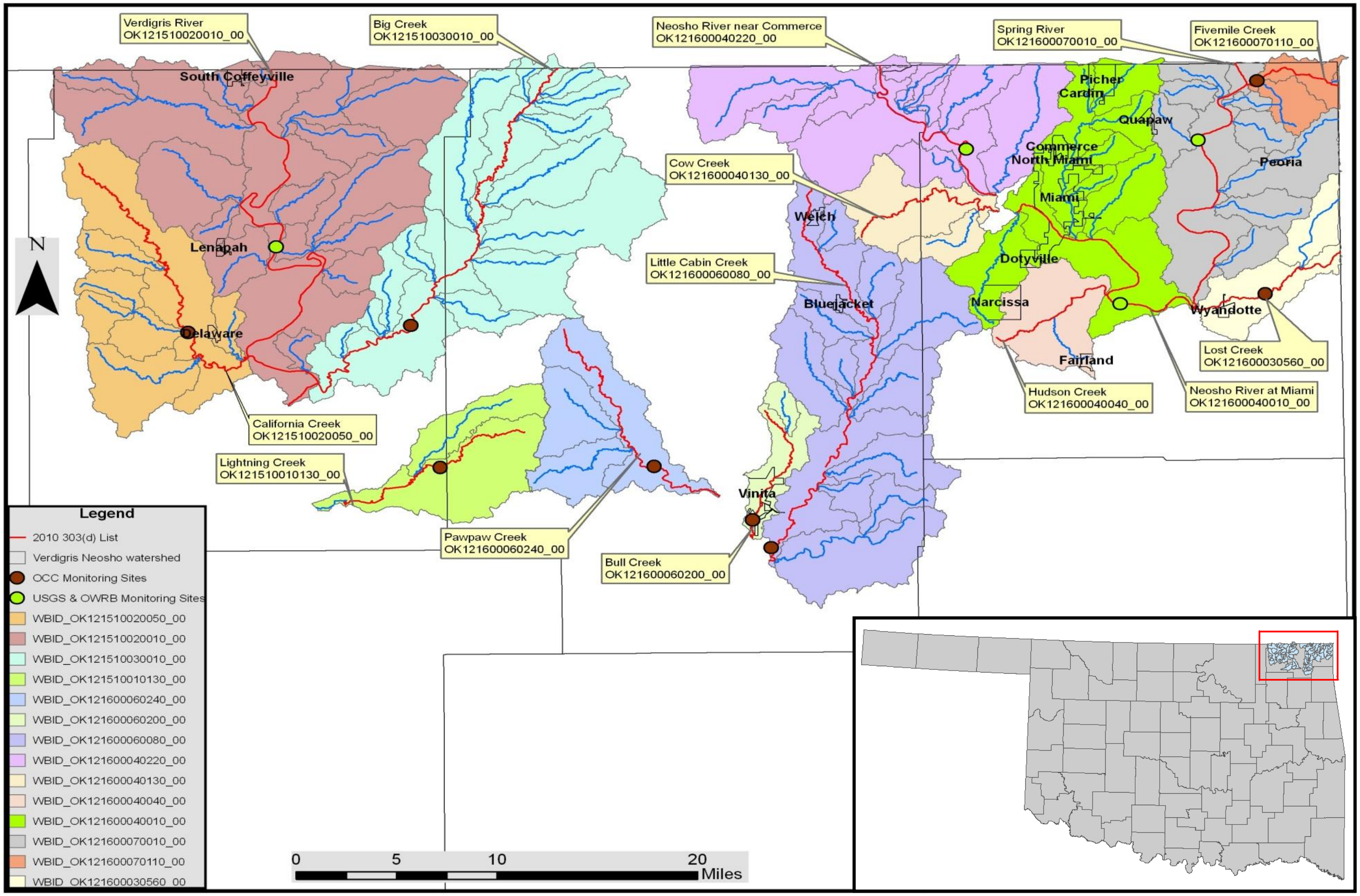
This report does not stipulate specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce bacteria or turbidity within each watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented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

This TMDL report focuses on waterbodies that DEQ placed in Category 5 [303(d) list] of the *Water Quality in Oklahoma, 2008 Integrated Report* (aka 2008 Integrated Report) for nonsupport of primary body contact recreation (PBCR) or Fish and Wildlife Propagation beneficial uses. The waterbodies considered for TMDL development in this report include:

- Lightning Creek OK121510010130_00
- Verdigris River OK121510020010_00
- California Creek OK121510020050_00
- Big Creek OK121510030010_00
- Lost Creek OK121600030560_00
- Neosho River OK121600040010_00
- Hudson Creek OK121600040040_00
- Cow Creek OK121600040130_00
- Neosho River OK121600040220_00
- Little Cabin Creek OK121600060080_00
- Bull Creek OK121600060200_00
- Pawpaw Creek OK121600060240_00
- Spring River OK121600070010_00
- Fivemile Creek OK121600070110_00

Figure 1-1 shows these Oklahoma waterbodies and their contributing watersheds. These maps also display locations of the water quality monitoring (WQM) stations used as the basis for placement of these waterbodies on the Oklahoma 303(d) list. These waterbodies and their surrounding watersheds are hereinafter referred to as the Study Area.

Figure 1-1 Verdigris-Neosho River Watersheds Not Supporting Primary Body Contact Recreation or Fish and Wildlife Propagation Use



Elevated levels of pathogen indicator bacteria or turbidity above the WQS numeric criterion result in the requirement that a TMDL be developed. The TMDLs established in this report are a necessary step in the process to develop the pollutant loading controls needed to restore the PBCR or fish and wildlife propagation use designated for each waterbody. Table 1-1 provides a description of the locations of WQM stations on the 303(d)-listed waterbodies.

Table 1-1 Water Quality Monitoring Stations used for Assessment of Streams

WQM Station	Waterbody Name	Station Location	Waterbody ID
OK121510-01-0130M	Lightning Creek	Section 15/14 T25N-R17E	OK121510010130_00
121510020010-001AT	Verdigris River	Section 03 - T27N - R16E	OK121510020010_00
OK121510-02-0050C	California Creek	Section 36/35 T27N-R15E	OK121510020050_00
OK121510-03-0010D OK121510-03-0010G	Big Creek	NW¼ Section 35-T27N-R17E Section 13/24 T27N-R17E	OK121510030010_00
OK121600-03-0560G	Lost Creek	SE¼ NE¼ SE¼ S21-T27N-R24E SE¼ Section 22-T27N-R24E	OK121600030560_00
121600040010-001AT	Neosho River	Section 22-T27N-R23E	OK121600040010_00
OK121600-04-0040G	Hudson Creek	Section 20/21 T27N-R23E	OK121600040040_00
OK121600-04-0130G	Cow Creek	Section 27/28 T28N-R22E	OK121600040130_00
121600040220-001AT	Neosho River	Section 09-T28N-R22EI	OK121600040220_00
OK121600-06-0080C OK121600-06-0080G OK121600-06-0080M	Little Cabin Creek	N.B. Section 2-T24N-R20E SW¼ Section 35-T25N-R20E SE¼ Section 16-T24N-R21E	OK121600060080_00
OK121600-06-0200G	Bull Creek	NW¼ Section 34-T25N-R20E	OK121600060200_00
OK121600-06-0240G	Pawpaw Creek	W½ Section 13-T25N-19E	OK121600060240_00
121600070010-001AT	Spring River	S05 - T28N - R24E	OK121600070010_00
OK121600-07-0110G	Fivemile Creek	NW¼ NE¼ S22-T29N-R24E	OK121600070110_00

1.2 Watershed Description

1.2.1 General

The Verdigri-Neosho River basin is located in the northeastern portion of Oklahoma. The majority of the waterbodies addressed in this report are located in Craig, Nowata, Montgomery, Washington, Ottawa, Delaware and Cherokee Counties. These counties are part of the Central Irregular Plains and Ozark Highlands Level III ecoregions (Woods, A.J, Omerik, J.M., et al 2005). The watersheds in the Study Area are located in the Cherokee Platform and the Ozark Uplift geological provinces. Table 1-2, derived from the 2010 U.S. Census, demonstrates that the counties in which these watersheds are located are sparsely populated (U.S. Census Bureau 2010). Table 1-3 lists the towns and cities located in each watershed.

Table 1-2 County Population and Density

County Name	Population (2010 Census)	Population Density (per square mile)
Craig	15,029	20
Nowata	10,536	19
Montgomery	35,471	55
Washington	50,976	123
Ottawa	31,848	68
Delaware	41,487	56
Cherokee	31,848	68

Table 1-3 Towns and Cities by Watershed

Waterbody Name	Waterbody ID	Municipalities
Verdigris River	OK121510020010_00	Lenepah, South Coffeyville
California Creek	OK121510020050_00	Delaware
Lost Creek	OK121600030560_00	Wyandotte
Neosho River	OK121600040010_00	Miami, Dotyville, Picher
Hudson Creek	OK121600040040_00	Fairland
Little Cabin Creek	OK121600060080_00	Bluejacket, Welch
Bull Creek	OK121600060200_00	Vinita
Spring River	OK121600070010_00	Quapaw, Peoria

1.2.2 Climate

Table 1-4 summarizes the average annual precipitation for each Oklahoma waterbody derived from a geospatial layer developed to display annual precipitation using data collected from Oklahoma weather stations between 1971 through 2000. Average annual precipitation values among the watersheds in this portion of Oklahoma range between 41 and 45 inches (Oklahoma Climatological Survey 2005).

Table 1-4 Average Annual Precipitation by Watershed

Waterbody Name	Waterbody ID	Average Annual Precipitation (inches)
Lightning Creek	OK121510010130_00	42.8
Verdigris River	OK121510020010_00	41.9
California Creek	OK121510020050_00	41.3
Big Creek	OK121510030010_00	43.2
Lost Creek	OK121600030560_00	44.7
Neosho River	OK121600040010_00	45.3
Hudson Creek	OK121600040040_00	45.0
Cow Creek	OK121600040130_00	44.8
Neosho River	OK121600040220_00	44.6
Little Cabin Creek	OK121600060080_00	44.4
Bull Creek	OK121600060200_00	44.2
Pawpaw Creek	OK121600060240_00	43.5
Spring River	OK121600070010_00	45.0
Fivemile Creek	OK121600070110_00	45.2

1.2.3 Land Use

Tables 1-5a and 1-5b summarize the percentages and acreages of the land use categories for the contributing watershed associated with each respective Oklahoma waterbody addressed in the Study Area. The land use/land cover data were derived from the U.S. Geological Survey (USGS) 2001 National Land Cover Dataset (USGS 2007). The percentages provided in Tables 1-5a and 1-5b are rounded so in some cases may not total exactly 100%. The land use categories are displayed in Figure 1-3. The two most dominant land use category throughout the Verdigris-Neosho River Study Area is pasture/hay and grasslands/herbaceous. Two watersheds in the Study Area that have a significant percentage of land use classified as deciduous forest and pasture/hay are Lost Creek (OK121600030560_00) and Fivemile Creek (OK121600070110_00). The watersheds targeted for TMDL development in this Study Area range in size from 8,960 acres (Fivemile Creek, OK121600070110_00) to 142,659 acres (Verdigris River, OK121510020010_00).

Figure 1-3 Land Use Map

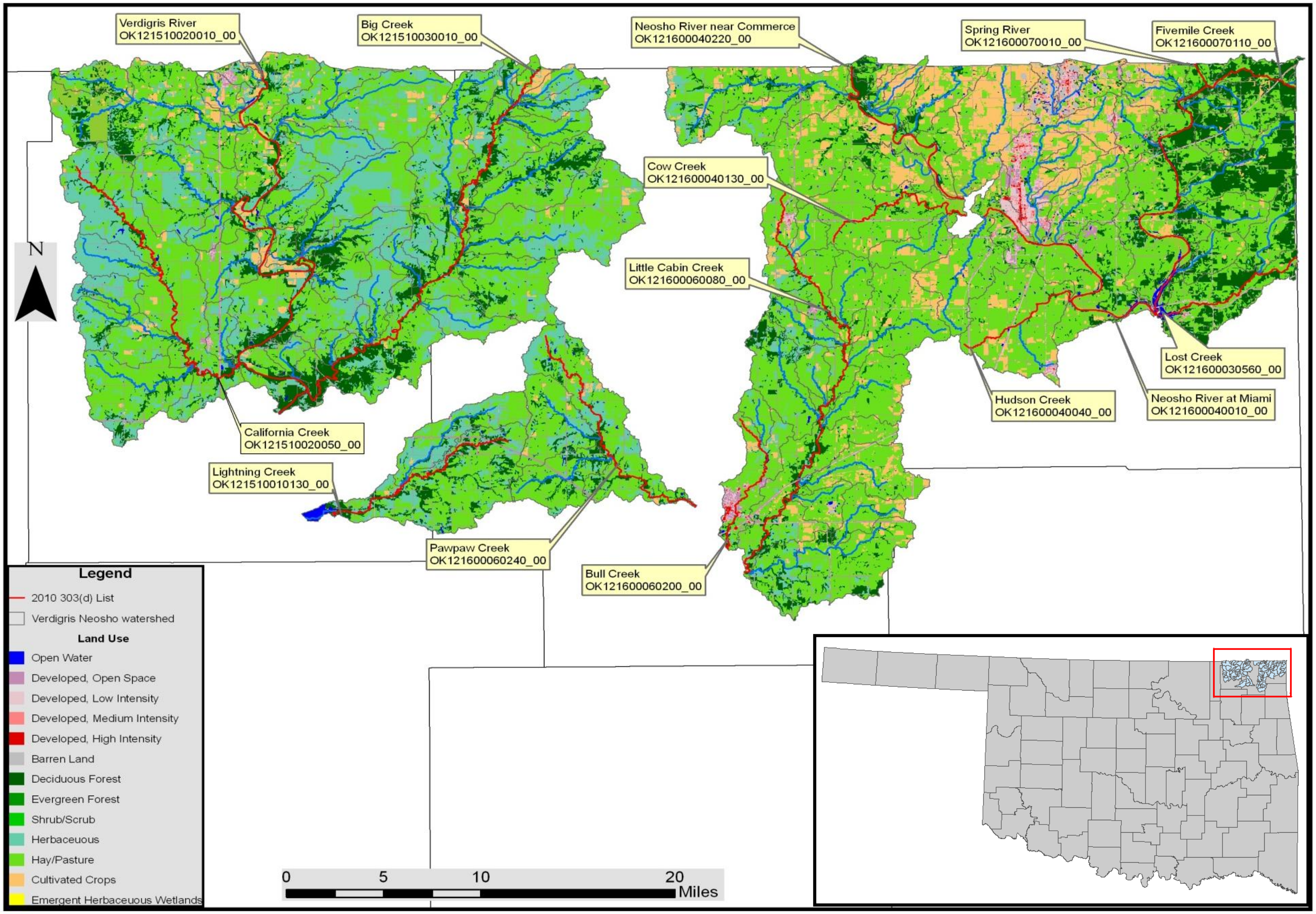


Table 1-5a Land Use Summaries by Watershed

Landuse Category	Watershed						
	Lightning Creek	Verdigris River	California Creek	Big Creek	Lost Creek	Neosho River	Hudson Creek
Waterbody ID	**OK121510010130_00**	**OK121510020010_00**	**OK121510020050_00**	**OK121510030010_00**	**OK121600030560_00**	**OK121600040010_00**	**OK121600040040_00**
Open Water	664	1,560	180	294	126	2,348	195
Medium Intensity Residential	41	1,565	184	26	212	4,288	500
High Intensity Residential	7	133	0	0	15	444	5
Bare Rock/Sand/Clay	0	51	0	0	5	1,495	4
Deciduous Forest	5,178	17,447	5,000	17,828	6,313	3,319	315
Evergreen Forest	103	221	46	422	73	2	0
Mixed Forest	0	352	0	0	4	39	6
Shrubland	2	8	0	0	92	19	0
Grasslands/Herbaceous	8,629	34,382	20,476	30,178	141	340	17
Pasture/Hay	13,895	69,520	29,969	56,981	9,370	27,305	12,494
Cultivated Crops	80	11,204	714	2,552	64	15,654	1,885
Urban/Recreational Grasses	1,500	6,000	2,463	3,620	804	4,159	917
Woody Wetlands	0	171	0	0	51	3,246	131
Emergent Herbaceous Wetlands	4	44	0	0	0	182	23
Total (Acres)	**30,102**	**142,659**	**59,032**	**111,900**	**17,270**	**62,839**	**16,492**
Open Water	2.20%	1.09%	0.31%	0.26%	0.73%	3.74%	1.18%
Medium Intensity Residential	0.14%	1.10%	0.31%	0.02%	1.23%	6.82%	3.03%
High Intensity Residential	0.02%	0.09%	0.00%	0.00%	0.09%	0.71%	0.03%
Bare Rock/Sand/Clay	0.00%	0.04%	0.00%	0.00%	0.03%	2.38%	0.02%
Deciduous Forest	17.20%	12.23%	8.47%	15.93%	36.56%	5.28%	1.91%
Evergreen Forest	0.34%	0.15%	0.08%	0.38%	0.42%	0.00%	0.00%
Mixed Forest	0.00%	0.25%	0.00%	0.00%	0.02%	0.06%	0.04%
Shrubland	0.01%	0.01%	0.00%	0.00%	0.53%	0.03%	0.00%
Grasslands/Herbaceous	28.67%	24.10%	34.69%	26.97%	0.82%	0.54%	0.10%
Pasture/Hay	46.16%	48.73%	50.77%	50.92%	54.25%	43.45%	75.76%
Cultivated Crops	0.26%	7.85%	1.21%	2.28%	0.37%	24.91%	11.43%
Urban/Recreational Grasses	4.98%	4.21%	4.17%	3.23%	4.66%	6.62%	5.56%
Woody Wetlands	0.00%	0.12%	0.00%	0.00%	0.29%	5.16%	0.79%
Emergent Herbaceous Wetlands	0.01%	0.03%	0.00%	0.00%	0.00%	0.29%	0.14%
Total Percentage:	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 1-5b Land Use Summaries by Watershed

Landuse Category	Watershed						
	Cow Creek	**Neosho River**	**Little Cabin Creek**	**Bull Creek**	**Pawpaw Creek**	**Spring River**	**Fivemile Creek**
Waterbody ID	**OK121600040130_00**	**OK121600040220_00**	**OK121600060080_00**	**OK121600060200_00**	**OK121600060240_00**	**OK121600070010_00**	**OK121600070110_00**
Open Water	151	637	494	268	171	1,201	52
Medium Intensity Residential	134	326	846	474	28	1,407	117
High Intensity Residential	0	10	11	148	0	99	23
Bare Rock/Sand/Clay	0	275	95	6	0	204	1
Deciduous Forest	746	5,663	9,747	420	4,452	11,325	4,213
Evergreen Forest	0	4	54	16	41	55	5
Mixed Forest	4	33	32	0	0	56	3
Shrubland	68	33	337	0	0	195	152
Grasslands/Herbaceous	34	1,618	6,313	970	7,279	603	72
Pasture/Hay	15,022	31,942	72,322	6,382	18,722	26,717	3,540
Cultivated Crops	1,636	25,740	8,131	395	601	10,027	114
Urban/Recreational Grasses	894	2,882	4,342	965	1,345	2,891	626
Woody Wetlands	502	1,785	183	0	0	876	42
Emergent Herbaceous Wetlands	7	37	42	0	0	26	0
Total (Acres)	**19,199**	**70,983**	**102,949**	**10,045**	**32,639**	**55,680**	**8,960**
Open Water	0.79%	0.90%	0.48%	2.67%	0.52%	2.16%	0.58%
Medium Intensity Residential	0.70%	0.46%	0.82%	4.72%	0.09%	2.53%	1.31%
High Intensity Residential	0.00%	0.01%	0.01%	1.48%	0.00%	0.18%	0.25%
Bare Rock/Sand/Clay	0.00%	0.39%	0.09%	0.06%	0.00%	0.37%	0.01%
Deciduous Forest	3.89%	7.98%	9.47%	4.18%	13.64%	20.34%	47.02%
Evergreen Forest	0.00%	0.01%	0.05%	0.16%	0.12%	0.10%	0.05%
Mixed Forest	0.02%	0.05%	0.03%	0.00%	0.00%	0.10%	0.04%
Shrubland	0.35%	0.05%	0.33%	0.00%	0.00%	0.35%	1.70%
Grasslands/Herbaceous	0.18%	2.28%	6.13%	9.65%	22.30%	1.08%	0.80%
Pasture/Hay	78.24%	45.00%	70.25%	63.54%	57.36%	47.98%	39.51%
Cultivated Crops	8.52%	36.26%	7.90%	3.93%	1.84%	18.01%	1.27%
Urban/Recreational Grasses	4.66%	4.06%	4.22%	9.61%	4.12%	5.19%	6.99%
Woody Wetlands	2.61%	2.51%	0.18%	0.00%	0.00%	1.57%	0.47%
Emergent Herbaceous Wetlands	0.04%	0.05%	0.04%	0.00%	0.00%	0.05%	0.00%
Total Percentage:	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

1.3 Stream Flow Conditions

Stream flow characteristics and data are key information when conducting water quality assessments such as TMDLs. The USGS operates flow gages throughout Oklahoma, from which long-term stream flow records can be obtained. At various WQM stations additional flow measurements are available which were collected at the same time bacteria, total suspended solids (TSS) and turbidity water quality samples were collected. Not all of the waterbodies in this Study Area have historical flow data available. Flow data from the surrounding USGS gage stations and the instantaneous flow measurement data taken with water quality samples have been used to estimate flows for ungaged streams. Flow data collected at the time of water quality sampling are included in Appendix A along with corresponding water chemistry data results. A summary of the method used to project flows for ungaged streams and flow exceedance percentiles from projected flow data are provided in Appendix B.

SECTION 2
PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

2.1 Oklahoma Water Quality Standards

Title 785 of the Oklahoma Administrative Code contains Oklahoma Water Quality Standards (OWQS) and implementation procedures (OWRB 2011). The Oklahoma Water Resources Board (OWRB) has statutory authority and responsibility concerning establishment of State WQS, as provided under 82 Oklahoma Statute [O.S.], §1085.30. This statute authorizes the OWRB to promulgate rules …*which establish classifications of uses of waters of the state, criteria to maintain and protect such classifications, and other standards or policies pertaining to the quality of such waters.* [O.S. 82:1085:30(A)]. Beneficial uses are designated for all waters of the State. Such uses are protected through restrictions imposed by the antidegradation policy statement, narrative water quality criteria, and numerical criteria (OWRB 2011). An excerpt of the Oklahoma WQS (Title 785) summarizing the State of Oklahoma Antidegradation Policy is provided in Appendix C. Table 2-1, an excerpt from the 2008 Integrated Report (DEQ 2008), lists beneficial uses designated for each bacterial and/or turbidity impaired stream segment in the Study Area. The beneficial uses include:

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

Table 2-1 Designated Beneficial Uses for Each Stream Segment in This Report

Waterbody ID	Waterbody Name	AES	AG	CWAC	WWAC	FISH	PBCR	PPWS
OK121510010130_00	Lightning Creek	I	N		I	X	N	I
OK121510020010_00	Verdigris River	I	F		N	N	N	I
OK121510020050_00	California Creek	F	F		N	X	N	I
OK121510030010_00	Big Creek	F	F		N	X	N	I
OK121600030560_00	Lost Creek	F	F	F		X	N	I
OK121600040010_00	Neosho River	I	F		N	F	F	I
OK121600040040_00	Hudson Creek	F	F		N	X	I	
OK121600040130_00	Cow Creek	F	F		N	X	N	
OK121600040220_00	Neosho River	I	F		N	N	N	I
OK121600060080_00	Little Cabin Creek	I	N		N	X	N	
OK121600060200_00	Bull Creek	F	N		N	X	N	
OK121600060240_00	Pawpaw Creek	F	N		N	X	N	
OK121600070010_00	Spring River	I	F	N		N	N	I
OK121600070110_00	Fivemile Creek	F	F	F		F	N	F

F – Fully supporting; N – Not supporting; I – Insufficient information; X – Not assessed
Source: 2008 Integrated Report, DEQ 2008

Table 2-2 summarizes the PBCR and WWAC use attainment status and the bacterial and turbidity impairment status for streams in the Study Area. The TMDL priority shown in Table 2-2 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 bacterial and/or turbidity impairments that affect the PBCR and WWAC beneficial uses.

The definition of PBCR and the bacterial WQSs for PBCR are summarized by the following excerpt from Chapter 45 of the Oklahoma WQSs.

(a) Primary Body Contact Recreation involves direct body contact with the water where a possibility of ingestion exists. In these cases the water shall not contain chemical, physical or biological substances in concentrations that are irritating to skin or sense organs or are toxic or cause illness upon ingestion by human beings.

(b) In waters designated for Primary Body Contact Recreation...limits...shall apply only during the recreation period of May 1 to September 30. The criteria for Secondary Body Contact Recreation will apply during the remainder of the year.

(c) Compliance with 785:45-5-16 shall be based upon meeting the requirements of one of the options specified in (1) or (2) of this subsection (c) for bacteria. Upon selection of one (1) group or test method, said method shall be used exclusively over the time period prescribed therefore. Provided, where concurrent data exist for multiple bacterial indicators on the same waterbody or waterbody segment, no criteria exceedances shall be allowed for any indicator group.

(1) Escherichia coli (E. coli): The E. coli geometric mean criterion is 126/100 ml. For swimming advisory and permitting purposes, E. coli shall not exceed a monthly geometric mean of 126/100 ml based upon a minimum of not less than five (5) samples collected over a period of not more than thirty (30) days. For swimming advisory and permitting purposes, no sample shall exceed a 75% one-sided confidence level of 235/100 ml in lakes and high use waterbodies and the 90% one-sided confidence level of 406/100 ml in all other Primary Body Contact Recreation beneficial use areas. These values are based upon all samples collected over the recreation period. For purposes of sections 303(d) and 305(b) of the federal Clean Water Act as amended, beneficial use support status shall be assessed using only the geometric mean criterion of 126/100 milliliters compared to the geometric mean of all samples collected over the recreation period.

(2) Enterococci: The Enterococci geometric mean criterion is 33/100 ml. For swimming advisory and permitting purposes, Enterococci shall not exceed a monthly geometric mean of 33/100 ml based upon a minimum of not less than five (5) samples collected over a period of not more than thirty (30) days. For swimming advisory and permitting purposes, no sample shall exceed a 75% one-sided confidence level of 61/100 ml in lakes and high use waterbodies and the 90% one-sided confidence level of 108/100 ml in all other Primary Body Contact Recreation beneficial use areas. These values are based upon all samples collected over the recreation period. For purposes of sections 303(d) and 305(b) of the federal Clean Water Act as amended, beneficial use support status shall be assessed using only the geometric mean criterion of 33/100 milliliters compared to the geometric mean of all samples collected over the recreation period.

To implement Oklahoma's WQS for PBCR, OWRB promulgated Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2011a). The excerpt below from Chapter 46: 785:46-15-6, stipulates how water quality data will be assessed to determine support of the PBCR use as well as how the water quality target for TMDLs will be defined for each bacterial indicator.

(a) ***Scope.***

The provisions of this Section shall be used to determine whether the subcategory of Primary Body Contact of the beneficial use of Recreation designated in OAC 785:45 for a waterbody is supported during the recreation season from May 1 through September 30 each year. Where data exist for multiple bacterial indicators on the same waterbody or waterbody segment, the determination of use support shall be based upon the use and application of all applicable tests and data.

(b) ***Escherichia coli (E. coli).***

(1) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be fully supported with respect to E. coli if the geometric mean of 126 colonies per 100 ml is met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

(2) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be not supported with respect to E. coli if the geometric mean of 126 colonies per 100 ml is not met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

(c) ***Enterococci.***

(1) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be fully supported with respect to Enterococci if the geometric mean of 33 colonies per 100 ml is met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

(2) The Primary Body Contact Recreation subcategory designated for a waterbody shall be deemed to be not supported with respect to Enterococci if the geometric mean of 33 colonies per 100 ml is not met. These values are based upon all samples collected over the recreation period in accordance with OAC 785:46-15-3(c).

Table 2-2 Excerpt from the 2010 Integrated Report – Oklahoma 303(d) List of Impaired Waters (Category 5)

Waterbody ID	Waterbody Name	Stream Miles	TMDL Date	Priority	ENT	*E. coli*	Designated Use Primary Body Contact Recreation	Turbidity	Designated Use Warm Water Aquatic Life
OK121510010130_00	Lightning Creek	14.40	2012	1		X	N		
OK121510020010_00	Verdigris River	37.43	2012	1	X		N	X	N
OK121510020050_00	California Creek	25.39	2021	4	X		N		N
OK121510030010_00	Big Creek	34.74	2021	4	X	X	N		N
OK121600030560_00	Lost Creek	10.23	2021	4		X	N		
OK121600040010_00	Neosho River	16.57	2021	4			F	X	N
OK121600040040_00	Hudson Creek	8.28	2021	4			I	X	N
OK121600040130_00	Cow Creek	12.42	2021	4			N	X	N
OK121600040220_00	Neosho River	13.97	2021	4	X		N	X	N
OK121600060080_00	Little Cabin Creek	32.31	2021	4	X	X	N		N
OK121600060200_00	Bull Creek	10.83	2021	4		X	N		N
OK121600060240_00	Pawpaw Creek	18.40	2021	4		X	N		N
OK121600070010_00	Spring River	22.11	2018	3	X		N	X	
OK121600070110_00	Fivemile Creek	5.81	2018	3	X		N		

ENT = Enterococci; N = Not attaining; X = Criterion exceeded
Source: 2008 Integrated Report, DEQ 2008

Compliance with the Oklahoma WQS is based on meeting requirements for both *E. coli* and Enterococci bacterial indicators in addition to the minimum sample requirements for assessment. Where concurrent data exist for multiple bacterial indicators on the same waterbody or waterbody segment, each indicator group must demonstrate compliance with the numeric criteria prescribed (OWRB 2011).

As stipulated in the WQS, only the geometric mean of all samples collected over the primary recreation period shall be used to assess the impairment status of a stream segment. Therefore, only the geometric mean criteria will be used to develop TMDLs for *E. coli* and Enterococci.

It is worth noting that the Oklahoma WQS prior to July 1, 2011 contains three bacterial indicators (fecal coliform, *E. coli* and Enterococci) and the new Oklahoma WQS effective on July 1, 2011 contains only *E. coli* and Enterococci. Because the new Oklahoma WQS no longer have a standard for fecal coliform, fecal coliform TMDLs will not be developed for any stream segment in this report even though some stream segments were listed for fecal coliform impairment in the 2008 303(d) list. Bacterial TMDLs will be developed only for *E. coli* and/or Enterococci impaired streams.

The beneficial use of WWAC is one of several subcategories of the Fish and Wildlife Propagation use established to manage the variety of communities of fish and shellfish throughout the state (OWRB 2011). The numeric criteria for turbidity to maintain and protect the use of "Fish and Wildlife Propagation" from Title 785:45-5-12 (f) (7) is as follows:

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

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

ii. Lakes: 25 NTU; and

iii. Other surface waters: 50 NTUs.

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

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

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

To implement Oklahoma's WQS for Fish and Wildlife Propagation, promulgated Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2011a). The excerpt below from Chapter 46: 785:46-15-5, stipulates how water quality data will be assessed to determine support of fish and wildlife propagation as well as how the water quality target for TMDLs will be defined for turbidity.

Assessment of Fish and Wildlife Propagation support

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

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

785:46-15-4. Default protocols

(b) Short term average numerical parameters.

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

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

(3) A beneficial use shall be deemed to be fully supported but threatened if the use is supported currently but the appropriate state environmental agency determines that available data indicate that during the next five years the use may become not supported due to anticipated sources or adverse trends of pollution not prevented or controlled. If data from the preceding two year period indicate a trend away from impairment, the appropriate agency shall remove the threatened status.

(4) A beneficial use shall be deemed to be not supported for a given parameter whose criterion is based upon a short term average if at least 10% of the samples for that parameter exceed the applicable screening level prescribed in this Subchapter.

2.2 Problem Identification

In this subsection water quality data summarizing waterbody impairments caused by elevated levels of bacteria are summarized first followed by the data summarizing impairments caused by elevated levels of turbidity.

2.2.1 Bacterial Data Summary

Table 2-3 summarizes water quality data collected during primary contact recreation season from the WQM stations between 2000 and 2008 for each indicator bacteria. The data summary in Table 2-3 provides a general understanding of the amount of water quality data available and the severity of exceedances of the water quality criteria. This data collected during the primary contact recreation season was used to support the decision to place specific waterbodies within the Study Area on the DEQ 2010 303(d) list (DEQ 2010). Water quality data from the primary contact recreation season are provided in Appendix A. For the data collected between 2000 and 2008, evidence of nonsupport of the PBCR use based on elevated *E. coli* and Enterococci concentrations was observed in two waterbodies: Big Creek (OK121510030010_00) and Little Cabin Creek (OK121600060080_00). Evidence of nonsupport of the PBCR use based on Enterococci exceedances was observed in five waterbodies: Verdigris River (OK121510020010_00), California Creek (OK121510020050_00), Neosho River (OK121600040220_00), Spring River (OK121600070010_00), and Fivemile Creek (OK121600070110_00). Rows highlighted in green in Table 2-3 require TMDLs.

Four waterbodies within the Study Area will be removed from further consideration for bacterial TMDL development in this report. Detailed review of the data collected between 2000 and 2008 for Lightning Creek (OK121510010130_00), Lost Creek (OK121600030560_00), Bull Creek (OK121600060200_00) and Pawpaw Creek (OK121600060240_00) indicated an insufficient number of samples were available. As a result, no bacterial TMDLs are included in this report for any of these four waterbodies.

2.2.2 Turbidity Data Summary

Turbidity is a measure of water clarity and is caused by suspended particles in the water column. Because turbidity cannot be expressed as a mass load, total suspended solids (TSS) are used as a surrogate in this TMDL. Therefore, both turbidity and TSS data are presented in this subsection.

Table 2-4 summarizes water quality data collected from the WQM stations between 1998 and 2011 for turbidity. However, as stipulated in Title *785:45-5-12 (f) (7) (C),* numeric criteria for turbidity only apply under base flow conditions. While the base flow condition is not specifically defined in the OWQS, DEQ considers base flow conditions to be all flows greater than the 25th flow exceedance frequency (i.e., the lower 75% of flows) which is consistent with the USGS Streamflow Conditions Index (USGS 2009). Therefore, Table 2-5 was prepared to represent the subset of these data when samples under high flow conditios were excluded.

Water quality samples collected under flow conditions less than the 25th flow exceedance frequency (highest flows) were therefore excluded from the data set used for TMDL analysis. Only six of the fourteen waterbodies were listed on the DEQ 2008 303(d) list (DEQ 2008) for nonsupport of the Fish and Wildlife Propagation use based on turbidity levels observed in the waterbody. The data in Table 2-5 were used to support the decision to place these six on the DEQ 2008 303(d) list. Table 2-6 summarizes TSS data collected from the WQM stations between 1998 and 2011. Table 2-7 presents a subset of these data when samples under high flow conditions were excluded. Water quality data for turbidity and TSS are provided in Appendix A.

Table 2-3 Summary of Assessment of Indicator Bacterial Samples from Primary Body Contact Recreation Subcategory Season May 1 to September 30, 2000-2008

Waterbody ID	Waterbody Name	Indicator	Number of samples	Geometric Mean Conc (cfu/100 ml)	Assessment Results
OK121510010130_00	Lightning Creek	EC	2	148	Delist: Not enough data available
OK121510020010_00	Verdigris River	ENT	22	120	TMDL Required
OK121510020050_00	California Creek	ENT	17	95	TMDL Required
OK121510030010_00	Big Creek	ENT	18	92	TMDL Required
		EC	2	148	TMDL Required
OK121600030560_00	Lost Creek	EC	2	96	De-list; Insufficient number of samples
OK121600040220_00	Neosho River	ENT	27	85	TMDL Required
OK121600060080_00	Little Cabin Creek	EC	15	366	TMDL Required
		ENT	15	287	TMDL Required
OK121600060200_00	Bull Creek	EC	3	73	Delist: Not enough data available
OK121600060240_00	Pawpaw Creek	EC	2	134	Delist: Not enough data available
OK121600070010_00	Spring River	ENT	30	35	TMDL Required
OK121600070110_00	Fivemile Creek	ENT	16	64	TMDL Required

E. coli (EC) water quality criterion = Geometric Mean of 126 counts/100 mL
Enterococci (ENT) water quality criterion = Geometric Mean of 33 counts/100 mL
TMDLs will be developed for waterbodies highlighted in green

Table 2-4 Summary of All Turbidity Samples, 1998-2011

Waterbody ID	Waterbody Name	WQM Stations	Number of turbidity samples	Number of samples greater than 50 NTU	% samples exceeding criterion	Average Turbidity (NTU)
OK121510020010_00	Verdigris River	121510020010-001AT	113	53	47%	124
OK121600040010_00	Neosho River	121600040010-001AT	69	27	39%	86
OK121600040040_00	Hudson Creek	OK121600-04-0040G	21	7	33%	31
OK121600040130_00	Cow Creek	OK121600-04-0130G	20	9	45%	46
OK121600040220_00	Neosho River	121600040220-001AT	89	42	47%	95

Table 2-5 Summary of Turbidity Samples Excluding High Flow Samples, 1998-2011

Waterbody ID	Waterbody Name	WQM Stations	Number of turbidity samples	Number of samples greater than 50 NTU	% samples exceeding criterion	Average Turbidity (NTU)	Assessment Results
OK121510020010_00	Verdigris River	121510020010-001AT	71	15	21%	39	TMDL Required
OK121600040010_00	Neosho River	121600040010-001AT	55	15	27%	34	TMDL Required
OK121600040040_00	Hudson Creek	OK121600-04-0040G	18	4	22%	23	TMDL Required
OK121600040130_00	Cow Creek	OK121600-04-0130G	16	5	31%	35	TMDL Required
OK121600040220_00	Neosho River	121600040220-001AT	74	28	38%	86	TMDL Required

Table 2-6 Summary of All TSS Samples, 1998-2011

Waterbody ID	Waterbody Name	WQM Stations	Number of TSS samples	Average TSS (mg/L)
OK121510020010_00	Verdigris River	121510020010-001AT	22	140
OK121600040010_00	Neosho River	121600040010-001AT	20	94
OK121600040040_00	Hudson Creek	OK121600-04-0040G	19	26
OK121600040130_00	Cow Creek	OK121600-04-0130G	19	32
OK121600040220_00	Neosho River	121600040220-001AT	2	59

Table 2-7 Summary of TSS Samples Excluding High Flow Samples, 1998-2011

Waterbody ID	Waterbody Name	WQM Stations	Number of TSS samples	Average TSS (mg/L)
OK121510020010_00	Verdigris River	121510020010-001AT	16	30
OK121600040010_00	Neosho River	121600040010-001AT	14	37
OK121600040040_00	Hudson Creek	OK121600-04-0040G	16	17
OK121600040130_00	Cow Creek	OK121600-04-0130G	14	23
OK121600040220_00	Neosho River	121600040220-001AT	2	59

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 targets for *E. coli* and Enterococci are geometric mean standards of 126 cfu/100ml and 33 cfu/100ml, respectively. The TMDL for bacteria will incorporate an explicit 10% margin of safety.

An individual water quality target established for turbidity must demonstrate compliance with the numeric criteria prescribed in the Oklahoma WQS (OWRB 2011). According to the Oklahoma WQS [785:45-5-12(f)(7)], the turbidity criterion for streams with WWAC beneficial use is 50 NTUs (OWRB 2011). The turbidity of 50 NTUs applies only to seasonal base flow conditions. Turbidity levels are expected to be elevated during, and for several days after, a storm event.

TMDLs for turbidity in streams designated as WWAC must take into account that no more than 10% of the samples may exceed the numeric criterion of 50 NTU. However, as described above, because turbidity cannot be expressed as a mass load, TSS is used as a surrogate for TMDL development. Since there is no numeric criterion in the Oklahoma WQS for TSS, a specific method must be developed to convert the turbidity criterion to TSS based on a relationship between turbidity and TSS. The method for deriving the relationship between turbidity and TSS and for calculating a water body specific water quality goal using TSS is summarized in Section 4 of this report.

The MOS for the TSS TMDLs varies by waterbody and is related to the goodness-of-fit metrics of the turbidity-TSS regressions. The method for defining MOS percentages is described in Section 5 of this report.

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. Pathogen indicator bacteria originate from the digestive tract of warm-blooded animals, and sources may be point or nonpoint in nature. Turbidity may originate from NPDES-permitted facilities, fields, construction sites, quarries, stormwater runoff and eroding stream banks.

Point sources are permitted through the NPDES program. NPDES-permitted facilities that discharge treated wastewater are currently required to monitor for fecal coliform and TSS in accordance with their permits. The discharges with bacterial limits will be required to monitor for *E. coli* when their permits come to renew. 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 bacteria or TSS to surface water as a result of rainfall runoff. For the TMDLs in this report, all sources of pollutant loading not regulated by NPDES permits are considered nonpoint sources.

The potential nonpoint sources for bacteria were compared based on the fecal coliform load produced in each subwatershed. Although fecal coliform is no longer used as a bacterial indicator in the Oklahoma WQS, it is still valid to use fecal coliform concentration or loading estimates to compare the potential contributions of different nonpoint sources because *E. coli* is a subset of fecal coliform. Currently there is insufficient data available in the scientific arena to quantify counts of *E. coli* in feces from warm-blooded animals discussed in Section 3.

The following nonpoint sources were considered in this report:

- Wildlife (deer)
- Non-Permitted Agricultural Activities and Domesticated Animals
- Failing Onsite Wastewater Disposal (OSWD) Systems and Illicit Discharges
- Pets (dogs and cats)

The 2008 Integrated Water Quality Assessment Report (DEQ 2008) listed potential sources of turbidity as clean sediment, grazing in riparian corridors of streams and creeks, highway/road/bridge runoff (non-construction related), non-irrigated crop production, petroleum/natural gas activities, rangeland grazing, as well as other unknown sources. The following discussion describes what is known regarding point and nonpoint sources of bacteria in the impaired watersheds. Where information was available on point and nonpoint sources of indicator bacteria or TSS, data were provided and summarized as part of each category.

3.1 NPDES-Permitted Facilities

Under 40 CFR, §122.2, a point source is described as a discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Certain municipal plants are classified as no-discharge facilities. These facilities are required to sign an affidavit of no discharge. NPDES-permitted facilities classified as point sources that may contribute bacterial or TSS loading includes:

- NPDES municipal wastewater treatment plant (WWTP);
- NPDES Industrial WWTP Discharges;
- Municipal no-discharge WWTP;
- NPDES Concentrated Animal Feeding Operation (CAFO);
- NPDES municipal separate storm sewer system (MS4) discharges;
- NPDES multi-sector general permits; and
- NPDES construction stormwater discharges.

Continuous point source discharges such as WWTPs could result in discharge of elevated concentrations of indicator bacteria if the disinfection unit is not properly maintained, is of poor design, or if flow rates are above the disinfection capacity. While the no-discharge facilities do not discharge wastewater directly to a waterbody, it is possible that continuous point source discharges from municipal and industrial WWTPs could result in discharge of elevated concentrations of TSS if a facility is not properly maintained, is of poor design, or flow rates exceed capacity. However, in most cases suspended solids discharged by WWTPs consist primarily of organic solids rather than inorganic suspended solids (i.e., soil and sediment particles from erosion or sediment resuspension). Discharges of organic suspended solids from WWTPs are addressed by DEQ through its permitting of point sources to maintain WQS for dissolved oxygen and are not considered a potential source of turbidity in this TMDL. Discharges of TSS will be considered to be organic suspended solids if the discharge permit includes a limit for Biochemical Oxygen Demand (BOD) or Carbonaceous Biochemical Oxygen Demand (CBOD). Only WWTP discharges of inorganic suspended solids will be considered and will receive WLAs.

While the no-discharge facilities do not discharge wastewater directly to a waterbody, it is possible that the collection systems associated with each facility may be a source of bacterial loading to surface waters. CAFOs are recognized by EPA as potential significant sources of pollution, and may have the potential to cause serious impacts to water quality if not properly managed.

Stormwater runoff from MS4 areas, which is now regulated under the EPA NPDES Program, can also contain high fecal coliform bacterial concentrations. Stormwater runoff from MS4 areas, facilities under multi-sector general permits, and NPDES construction stormwater discharges, which are regulated under the EPA NPDES Program, can contain TSS. 40 C.F.R. § 130.2(h) requires that NPDES-regulated stormwater discharges must be addressed by the WLA component of a TMDL. However, any stormwater discharge by definition occurs during or immediately following periods of rainfall and elevated flow conditions when Oklahoma Water Quality Standard for turbidity does not apply. OWQS specify that the criteria for turbidity "apply only to seasonal base flow conditions" and go on to say "Elevated turbidity levels may be expected during, and for several days after, a runoff event" [OAC 785:45-5-12(f)(7)]. In other words, the turbidity impairment status is limited to base flow conditions and stormwater discharges from MS4 areas or construction sites do not contribute to the violation of Oklahoma's turbidity standard. Therefore, WLAs for NPDES-regulated stormwater discharges is essentially considered unnecessary in this TMDL report and will not be included in the TMDL calculations.

There is at least one NPDES-permitted facility in each of the contributing watersheds with the exception of Big Creek (OK121510030010_00), Neosho River (OK121600040220_00), Cow Creek (OK121600040130_00) and Fivemile Creek (OK121600070110_00). There is one MS4 permitted entity within the watersheds addressed in the Study Area.

3.1.1 Continuous Point Source Dischargers

The locations of the NPDES-permitted facilities that discharge wastewater to surface waters addressed in these TMDLs are listed in Table 3-1 and displayed in Figure 3-1. Municipal WWTPs designated with a Standard Industrial Code number 4952 in Table 3-1 discharges organic TSS and therefore are not considered a potential source of turbidity. DMR data for Boron Products, LLC (OK0040142) are provided in Appendix D.

3.1.2 No-Discharge Facilities and Sanitary Sewer Overflows

For the purposes of these TMDLs, it is assumed that no-discharge facilities do not contribute indicator bacterial or TSS loading. However, it is possible the wastewater collection systems associated with these no-discharge facilities could be a source of indicator bacterial loading, or that discharges from the wastewater plant may occur during large rainfall events that exceed the systems' storage capacities. There are two municipal no-discharge facilities in the Study Area which are listed in Table 3-2. The no-discharge facilities located in Verdigris River (OK121510020010_00) and California Creek (OK121510020050_00) watersheds could be contributing to the elevated levels of instream indicator bacterial loading.

Sanitary sewer overflow (SSO) from wastewater collection systems, although infrequent, can be a major source of indicator bacterial loading to streams. SSOs have existed since the introduction of separate sanitary sewers, and most are caused by blockage of sewer pipes by grease, tree roots, and other debris that clog sewer lines, by sewer line breaks and leaks, cross connections with storm sewers, and inflow and infiltration of groundwater into sanitary sewers. SSOs are permit violations that must be addressed by the responsible NPDES permittee. The reporting of SSOs has been strongly encouraged by EPA, primarily through enforcement and fines. While not all sewer overflows are reported, DEQ has some data on SSOs available. SSOs were reported between 1991 and 2012. During that period 55 overflows were reported ranging from 30 to over 6 million gallons. Table 3-3 summarizes the SSO occurrences by NPDES facility. Historical data of reported SSOs are provided in Appendix E.

Table 3-1 Point Source Discharges in the Study Area

Waterbody ID & Waterbody Name	OPDES Permit No.	Facility	SIC code	Facility Type	Design Flow (mgd)	Ave/Max FC cfu/100mL	Avg/Max TSS mg/L	Expiration Date	Notes
Verdigris River OK121510020010_00	OK0020117	South Coffeyville PWA	4952	Sewerage systems	0.159	200/400	30/45	12/31/2016	Active
California Creek OK121510020050_00	OK0020796	City of Delaware	4952	Sewerage systems	0.55	200/400	30/45	07/3/2012	Active
Hudson Creek OK121600040040_00	OK0021504	Fairland PWA (Lagoon)	4952	Sewerage systems	0.086	200/400	90/135	10/31/2012	Active
Neosho River OK121600040010_00	OK0020320	City of Commerce	4952	Sewerage systems	0.48	200/400	90/135	09/30/2015	Active
	OK0031798	City of Miami,Southeast	4952	Sewerage systems	3.50	200/400	30/45	01/3/2015	Active
	OK0031801	City of Miami, Miami	4952	Sewerage systems	NA	NA	NA	01/6/2007	Inactive
	OK0032263	City of Picher	4952	Sewerage systems	0.18	200/400	90/135		Active
	OK0038962	Cardin Special Utilities	4952	Sewerage systems	0.05	NA	90/135		Active
Little Cabin Creek OK121600060080_00	OK0028657	Town of Welch PWA	4952	Sewerage systems	NA	NA	NA	NA	Inactive
	OK0031771	Bluejacket PWA	4952	Sewerage systems	0.025	NA	90/135		Active
Spring River OK121600070010_00	OK0001261	Eagle Picher Ottawa	3339	Primary Smelting Refining	NA	NA	NA	NA	Inactive
	OK0028258	Quapaw PWA	4952	Sewerage systems	0.137	NA	90/135	12/31/2016	Active
	OK0040142	Boron Products, LLC	2819	Industrial Inorganic	0.053	NA	6	04/30/2014	Active

NA = not available.

Table 3-2 NPDES No-Discharge Facilities in the Study Area

Facility	Facility ID	County	Facility Type	Type	Waterbody ID	Waterbody Name
Coweta WWTP	S20410	Wagoner	Land Application	Municipal	OK121510020010_00	Verdigris River
Bartlesville WWTP	S21402	Washington	Land Application	Municipal	OK121510020050_00	California Creek

Table 3-3 Sanitary Sewer Overflow Summary

Facility Name	NPDES Permit No.	Receiving Water	Facility ID	Number of Occurrences	Date Range		Amount (Gallons)	
					From	To	Min	Max
South Coffeyville PWA WWTP	OK0020117	OK121510020010_00	S21501	6	7/13/1992	12/25/2007	NA	6,000,000+
City of Delaware WWTP	OK0020796	OK121510020050_00	S21502	20	12/9/1992	4/30/2012	NA	600,000
Bluejacket PWA WWTP	OK0031771	OK121600060080_00	S21677	6	9/19/1991	2/23/2010	NA	10,000
Quapaw PWA WWTP	OK0028258	OK121600070010_00	S21609	23	9/14/1993	3/21/2010	NA	645,000

Figure 3-1 Locations of NPDES-Permitted Facilities and Land Application Sites in the Study Area

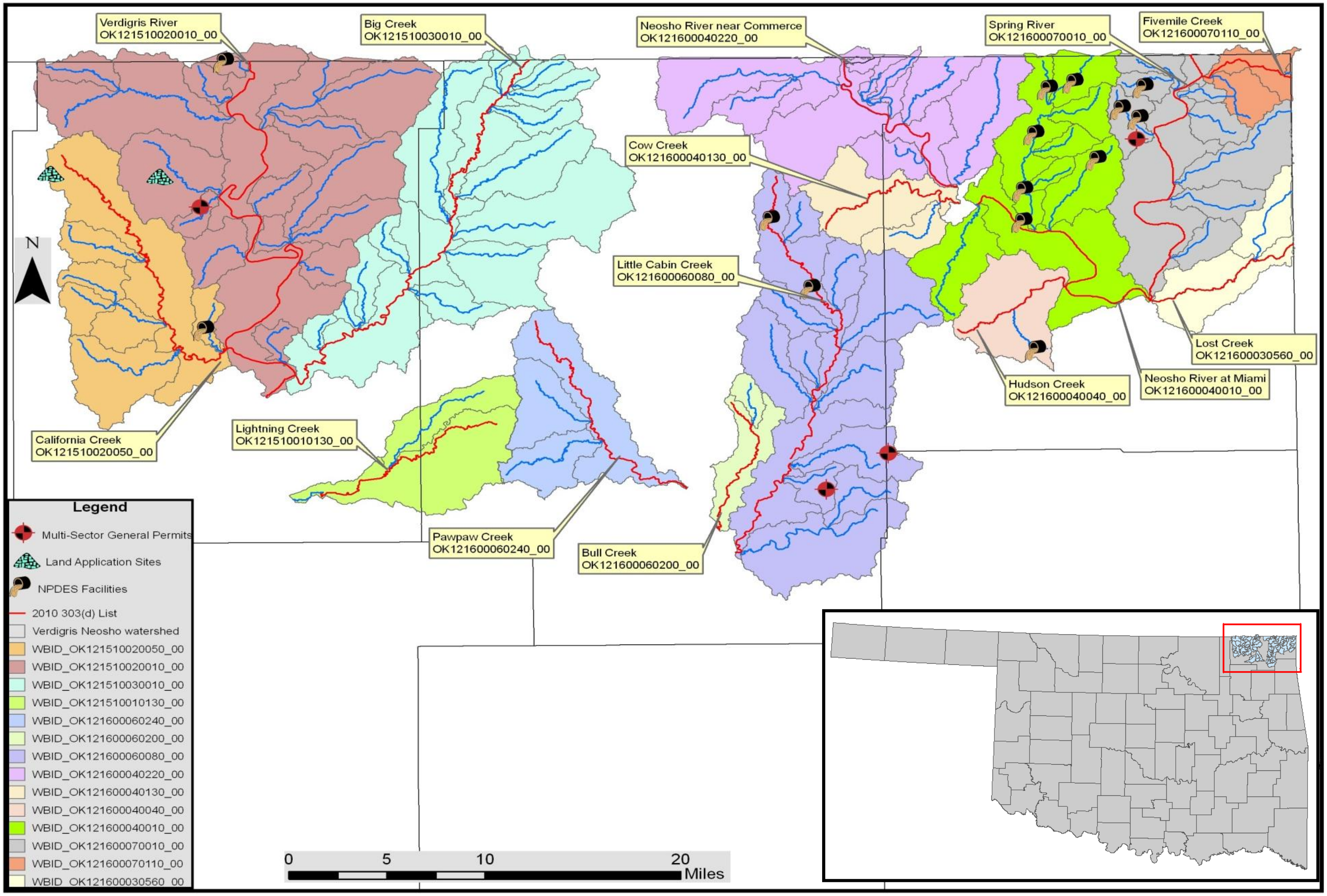
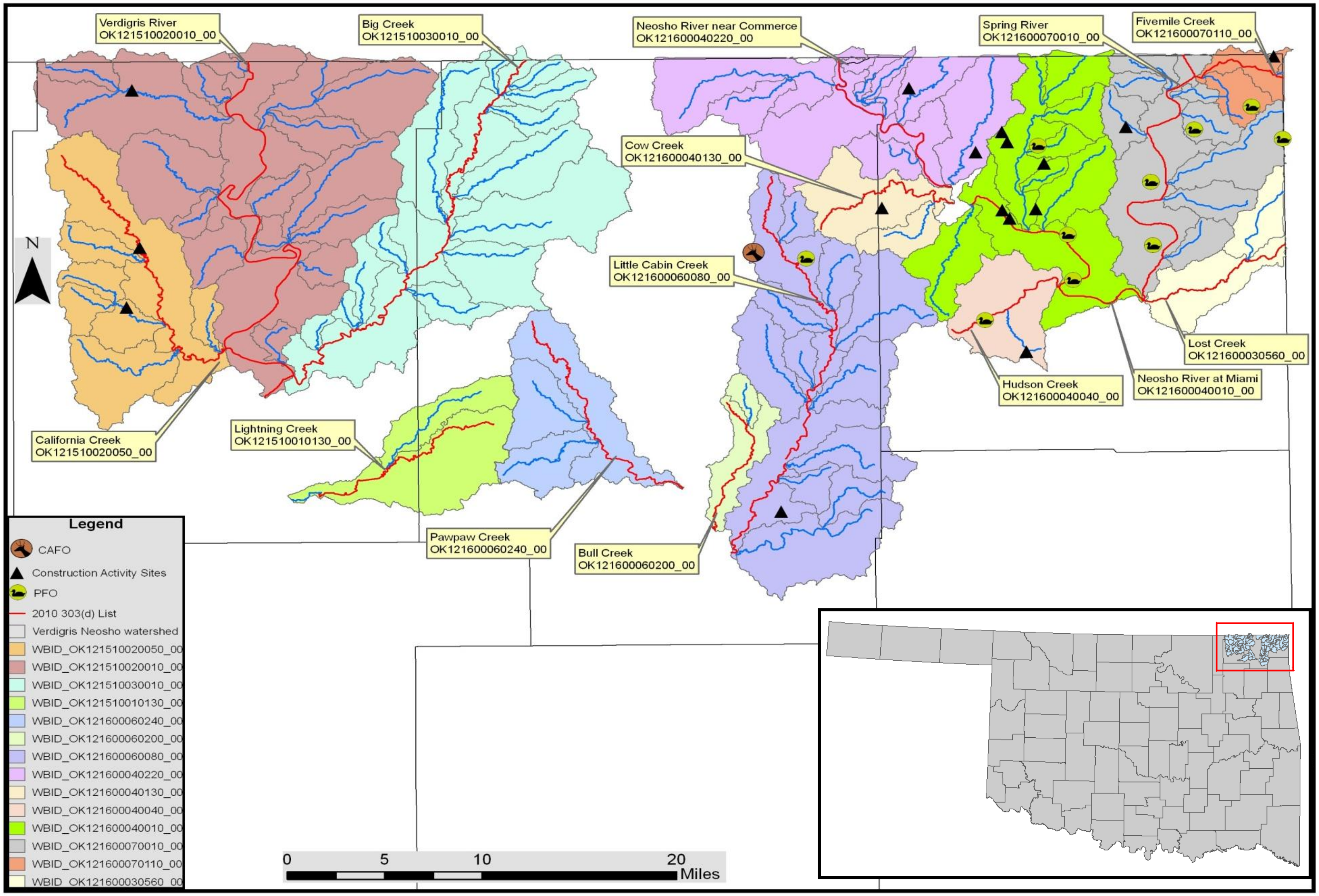


Figure 3-2 Locations of NPDES-Permitted CAFOs, Construction Activities Sites, and Registered PFOs in the Study Area



3.1.3 NPDES Municipal Separate Storm Sewer System

Phase I MS4

In 1990 the EPA developed rules establishing Phase I of the NPDES Stormwater Program, designed to prevent harmful pollutants from being washed by stormwater runoff into MS4s (or from being dumped directly into the MS4) and then discharged into local waterbodies (EPA 2005). Phase I of the program required operators of medium and large MS4s (those generally serving populations of 100,000 or greater) to implement a stormwater management program as a means to control polluted discharges. Approved stormwater management programs for medium and large MS4s are required to address a variety of water quality-related issues, including roadway runoff management, municipal-owned operations, and hazardous waste treatment. There are no Phase I MS4 permits in the Study Area.

Phase II MS4

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

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

The small MS4 General Permit for communities in Oklahoma became effective on February 8, 2005. DEQ provides information on the current status of the MS4 program on its website, which can be found at: http://www.deq.state.ok.us/WQDnew/stormwater/ms4/.

The only permitted Phase II MS4 in the Study Area is the City of Miami, OKR040032, which is located in the Neosho River (OK121600040010_00) watershed.

3.1.4 Concentrated Animal Feeding Operations

The Agricultural Environmental Management Services (AEMS) of the Oklahoma Department of Agriculture, Food and Forestry (ODAFF) was created to help develop, coordinate, and oversee environmental policies and programs aimed at protecting the Oklahoma environment from pollutants associated with agricultural animals and their waste. Through regulations established by the Oklahoma Concentrated Animal Feeding Operation (CAFO) Act, Swine Feeding Operation (SFO) Act and Poultry Feeding Operation (PFO) Registration Act, AEMS works with producers and concerned citizens to ensure that animal waste does not impact the waters of the state.

(1) CAFO

A CAFO is an animal feeding operation that confines and feeds at least 1,000 animal units for 45 days or more in a 12-month period (ODAFF 2005). The CAFO Act is designed to protect water quality through the use of best management practices (BMP) such as dikes, berms, terraces, ditches, or other similar structures used to isolate animal waste from outside surface drainage, except for a 25-year, 24–hour rainfall event (ODAFF 2005). CAFOs are considered no-discharge facilities for the purpose of the TMDL calculations in this report.

CAFOs are designated by EPA as significant sources of pollution, and may have the potential to cause serious impacts to water quality if not managed properly (ODAFF 2009a). Potential problems for CAFOs can include animal waste discharges to waters of the state and failure to properly operate wastewater lagoons. CAFOs are not considered a source of TSS loading. The location of each CAFO is shown in Figure 3-1 and is listed in Table 3-4.

Regulated CAFOs within the Study Area operate under state CAFO licenses issued and overseen by ODAFF and NPDES permits by EPA. In order to comply with this TMDL, those CAFO permits in the watershed and their associated management plans must be reviewed. Further actions to reduce bacterial loads and achieve progress toward meeting the specified reduction goals must be implemented. This provision will be forwarded to EPA and ODAFF for follow up.

Table 3-4 NPDES-Permitted CAFOs in Study Area

ODAFF Owner ID	EPA Facility ID	ODAFF ID	ODAFF License Number	Max # of Slaughter Feeder Cattle units at Facility	Total # of Animal Units at Facility	County	Waterbody ID and Waterbody Name
AGR002429	OKG010065	183	67	6000	6000	Craig	OK121600060080_00 Little Cabin Creek

(2) PFO

Poultry feeding operations not licensed under the Oklahoma Concentrated Animal Feeding Operation Act must register with the State Board of Agriculture. A registered PFO is an animal feeding operation which raises poultry and generates more than 10 tons of poultry waste (litter) per year. PFOs are required to develop an Animal Waste Management Plan (AWMP) or an equivalent document such as a Nutrient Management Plan (NMP). These plans describe how litter will be stored and applied properly in order to protect water quality of streams and lakes located in the watershed. Applicable BMPs shall be included in the Plan.

In order to comply with this TMDL, the registered PFOs in the watershed and their associated management plans must be reviewed. Further actions to reduce bacterial loads and achieve progress toward meeting the specified reduction goals must be implemented. This provision will be forwarded to EPA and ODAFF for follow up.

Per data provided by ODAFF in May 2011, there are ten PFOs located in the watershed as shown in Table 3-5. These PFOs are small animal feeding oerations and are not required to get NPDES permits; they are required only to register with ODAFF. They generate dry litter and do not have any significant impact on the watershed.

Table 3-5 Registered PFOs in Study Area

Waterbody Name	Waterbody ID	Company Name	Poultry ID	County	Type	Total Birds
Hudson Creek	OK121600040040_00	Simmons Foods	761	Ottawa	Broilers	200,000
Lilttle Cabin Creek	OK121600060080_00	Cargill	1457	Craig	Broilers	240,000
		Cargill	1696	Craig	Broilers	50,000
Neosho River	OK121600040010_00	Simmons Foods	1480	Ottawa	Broilers	95,000
		Simmons Foods	836	Ottawa	Broilers	100,000
		Simmons Foods	815	Ottawa	Broilers	100,000
Spring River	OK121600070010_00	Tyson foods	207	Ottawa	Broilers	80,000
		Simmons Foods	1234	Ottawa	Broilers	88,000
		Butterball	681	Ottawa	Turkeys	30,000
Fivemile Creek	OK121600070110_00	Simmons Foods	1454	Ottawa	Broilers	92,000

3.1.5 Stormwater Permits

Construction Activities

A general stormwater permit (OKR10) is required by the DEQ for any stormwater discharges associated with construction activities that result in land disturbance of equal to or greater than one (1) acre, or less than one (1) acre if they are part of a larger common plan of development or sale that totals at least one (1) acre. The permit also authorizes any stormwater discharges from support activities (e.g. concrete or asphalt batch plants, equipment staging yards, material storage areas, excavated material disposal areas, and borrow areas) that are directly related to a construction site that is required to have permit coverage, and is not a commercial operation serving unrelated different sites (DEQ 2007). Stormwater discharges occur only during or immediately following periods of rainfall and elevated flow conditions when the turbidity criteria do not apply and are not considered potential contributors to turbidity impairment. The permits for construction projects that were active during the time period that samples were taken are summarized in Table 3-6.

Multi-Sector General Permits

A multi-sector industrial general permit (OKR05) is also required by the DEQ for stormwater discharges from industrial facilities (DEQ 2011). Stormwater discharges from all industrial facilities, except mine dewatering discharges at crushed stone, construction sand and gravel, or industrial sand mining facilities, occur only during or immediately following periods of rainfall and elevated flow conditions when the turbidity criteria do not apply and therefore are not considered potential contributors of turbidity impairment. Mine dewatering discharges can happen at any time and have the following specific effluent limitations for TSS:

- Daily Maximum: 45 mg/L
- Monthly Average: 25 mg/L

If the TMDL shows that a TSS limit more stringent than 45 mg/L is required, additional TSS limitations and monitoring requirements will be required. These additional requirements will be implemented under the multi-sector general permit. There are two facilities within the Study Area with multi-sector general permits – Apac Oklahoma (OKR050967) and Apac Central (OKR052052) in the Little Cabin Creek (OK121600060080_00) watershed. There is one OKR05 pending - Midwest Minerals Inc. (OKR050483) in the Neosho River

(OK121600040010_00) watershed. Both Apac Oklahoma and Apac Central (OKR050967 & OKR052052) in the Little Cabin Creek (OK121600060080_00) watershed will not require a wasteload allocation as a contributing source of TSS since the receiving stream is not impaired for TSS.

3.1.6 Rock, Sand and Gravel Quarries

Operators of rock, sand and gravel quarries in Oklahoma are regulated with a general permit (OKG950000) issued by the DEQ. The general permit does not allow discharge of wastewater to waterbodies included in Oklahoma's 303(d) List of impaired waterbodies listed for turbidity for which a TMDL has not been performed or the result of the TMDL indicates that discharge limits more stringent than 45 mg/l for TSS are required (DEQ 2009).

There is one rock/sand/gravel quarry located in the Study Area. It is Midwest Minerals Inc. (OKG950040) in the Neosho River (OK121600040010_00) watershed. Table 3-7 summarizes the permit for that quarry located within the Study Area.

3.1.7 Section 404 permits

Section 404 of the CWA establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Activities in waters of the United States regulated under this program include fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports) and mining projects. Section 404 requires a permit before dredged or fill material may be discharged into waters of the United States, unless the activity is exempt from Section 404 regulation (e.g. certain farming and forestry activities).

Section 404 Permits are administrated by the U.S. Army Corps of Engineers (USACE). EPA reviews and provides comments on each permit application to make sure it adequately protects water quality and complies with applicable guidelines. Both USACE and EPA can take enforcement actions for violations of Section 404.

Discharge of dredged or fill material in waters can be a significant source of turbidity/TSS. The federal CWA requires that a permit be issued for activities which discharge dredged or fill materials into the waters of the United States, including wetlands. The State of Oklahoma will use its Section 401 Certification authority to ensure Section 404 Permits protect Oklahoma WQS.

Table 3-6 Construction Permits Summary

Company Name	County	Permit ID	Date Issued	Waterbody ID	Receiving Water (Permit)	Estimated Acres
ODOT JP#21781(04)	Nowata	OKR109020	5/2/2008	OK121510020010_00	Opossum Creek	3
ODOT JP#22158(04)	Nowata	OKR109018	6/10/2008	OK121510020050_00	Wolf Creek	2
ODOT JP#23420(04)	Nowata	OKR109097	6/10/2008	OK121510020050_00	California Creek	3
Francis Morgan Ballpark/Lots	Ottawa	OKR107231	3/11/2008	OK121600040010_00	Neosho River	1
ODOT JP#22562(04)	Ottawa	OKR109007	5/23/2008	OK121600040010_00	Neosho River	2
Miami Activity Center	Ottawa	OKR109250		OK121600040010_00	Little Elm Creek	1
Northeast Industrial Park	Ottawa	OKR108314	2/11/2008	OK121600040010_00	Tar Creek	1
Southeast Commerce Tar Creek	Ottawa	OKR106248	3/31/2008	OK121600040010_00	Unnamed tributary to Neosho River	36
West Commerce Tar Creek AML	Ottawa	OKR106247	N/A	OK121600040010_00	Tar Creek	220
NEW 19.5 MG WW LAGOON	Ottawa	OKR108451	10/30/2007	OK121600040040_00	Unnamed tributary to Neosho River	14
Myaamia Elder Complex	Ottawa	OKR107290	12/27/2007	OK121600040220_00	Elm Creek to Neosho River	15
Duck Creek Waterfowl Refuge	Delaware	OKR107039	5/8/2008	OK121600040220_00	Duck Creek	56
NEOEC Water Lagoon	Craig	OKR107779	1/10/2008	OK121600060080_00	Unnamed tribuatry of Little Cabin Creek	3
Kingston Farm	Ottawa	OKR105865	10/1/2007	OK121600070010_00	Rock Creek	N/A
Downstream Casino & Resort	Ottawa	OKR108918	4/18/2008	OK121600070110_00	Fivemile Creek	15

Table 3-7 Rock, Sand and Gravel Quarry

Company Name	County	Permit ID	Product	Permitted Acres	Permit Issue Date	Permit Renewal Date	Mining Expiration Date	Waterbody Name & ID
Midwest Minerals Inc., #32	Ottawa	L.E.-1452-C	Limestone	106	2/1/1996	1/31/2009	1/31/2026	Neosho River (OK121600040010_00)

3.2 Nonpoint Sources

Nonpoint sources include those sources that cannot be identified as entering the waterbody at a specific location. The relatively homogeneous land use/land cover categories throughout the Study Area associated with rural agricultural, forest and range management activities has an influence on the origin and pathways of pollutant sources to surface water. Bacteria originate from warm-blooded animals in rural, suburban, and urban areas. These sources include wildlife, various agricultural activities and domesticated animals, land application fields, urban runoff, failing OSWD systems and domestic pets. Water quality data collected from streams draining urban communities often show existing concentrations of fecal coliform bacteria at levels greater than a state's water quality standards. A study under EPA's National Urban Runoff Project indicated that the average fecal coliform concentration from 14 watersheds in different areas within the United States was approximately 15,000/100 mL in stormwater runoff (EPA 1983). Runoff from urban areas not permitted under the MS4 program can be a significant source of fecal coliform bacteria. Water quality data collected from streams draining many of the non-permitted communities show a high level of fecal coliform bacteria. Various potential nonpoint sources of TSS as indicated in the 2008 Integrated Report include sediments originating from grazing in riparian corridors of streams and creeks, highway/road/bridge runoff, non-irrigated crop production, rangeland grazing and other sources of sediment loading (DEQ 2008). Elevated turbidity measurements can be caused by stream bank erosion processes, stormwater runoff events and other channel disturbances. The following section provides general information on nonpoint sources contributing bacteria or TSS loading within the Study Area.

3.2.1 Wildlife

Fecal coliform bacteria are produced by all warm-blooded animals, including wildlife such as mammals and birds. In developing bacterial TMDLs it is important to identify the potential for bacterial contributions from wildlife by watershed. Wildlife is naturally attracted to riparian corridors of streams and rivers due to habitat and resource availability. With direct access to the stream channel, wildlife can be a concentrated source of bacterial loading to a waterbody. Fecal coliform bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff. Currently there are insufficient data available to estimate populations of wildlife and avian species by watershed. Consequently it is difficult to assess the magnitude of bacterial contributions from wildlife species as a general category.

However, adequate data are available by county to estimate the number of deer by watershed. This report assumes that deer habitat includes forests, croplands, and pastures. Using Oklahoma Department of Wildlife and Conservation (ODWC) county data, the population of deer can be roughly estimated from the actual number of deer harvested and harvest rate estimates. Because harvest success varies from year to year based on weather and other factors, the average harvest from 2005 to 2009 was combined with an estimated annual harvest rate of 20% to predict deer population by county. Using the estimated deer population by county and the percentage of the watershed area within each county, a wild deer population can be calculated for each watershed.

According to a study conducted by the American Society of Agricultural Engineers (ASAE), deer release approximately $5x10^8$ fecal coliform units per animal per day

(ASAE 1999). Although only a fraction of the total fecal coliform loading produced by the deer population may actually enter a waterbody, the estimated fecal coliform production based on the estimated deer population provided in Table 3-8 in cfu/day provides a relative magnitude of loading in each watershed.

Table 3-8 Estimated Population and Fecal Coliform Production for Deer

Waterbody ID	Waterbody Name	Watershed Area (acres)	Wild Deer Population	Estimated Wild Deer per acre	Fecal Production (x 10^9 cfu/day) of Deer Population
OK121510020010_00	Verdigris River	142,659	2,753	0.019	1377
OK121510020050_00	California Creek	59,032	1,184	0.020	592
OK121510030010_00	Big Creek	111,900	790	0.007	395
OK121600040010_00	Neosho River	62,839	1,175	0.019	588
OK121600040040_00	Hudson Creek	16,492	301	0.018	151
OK121600040130_00	Cow Creek	19,199	198	0.010	99
OK121600040220_00	Neosho River	70,983	976	0.014	488
OK121600060080_00	Little Cabin Creek	102,949	472	0.005	236
OK121600070010_00	Spring River	55,680	1,281	0.023	640
OK121600070110_00	Fivemile Creek	8,960	147	0.016	74

3.2.2 Non-Permitted Agricultural Activities and Domesticated Animals

There are a number of non-permitted agricultural activities that can also be sources of bacterial or TSS loading. Agricultural activities of greatest concern are typically those associated with livestock operations (Drapcho and Hubbs 2002). Examples of commercially raised farm animal activities that can contribute to bacterial sources include:

- Processed commercially raised farm animal manure is often applied to fields as fertilizer, and can contribute to fecal bacterial loading to waterbodies if washed into streams by runoff.
- Animals grazing in pastures deposit manure containing fecal bacteria onto land surfaces. These bacteria may be washed into waterbodies by runoff.
- Animals often have direct access to waterbodies and can provide a concentrated source of fecal bacterial loading directly into streams or can cause unstable stream banks which can contribute TSS.

Table 3-9 provides estimated numbers of selected livestock by watershed based on the 2007 U.S. Department of Agriculture (USDA) county agricultural census data (USDA 2007). The estimated commercially raised farm animal populations in Table 3-9 were derived by using the percentage of the watershed within each county. Because the watersheds are generally much smaller than the counties, and commercially raised farm animals are not evenly distributed across counties or constant with time, these are rough estimates only. Cattle are clearly the most abundant species of commercially raised farm animals in the Study Area and often have direct access to the waterbodies and their tributaries.

Detailed information is not available to describe or quantify the relationship between instream concentrations of bacteria and land application or direct deposition of manure from commercially raised farm animal. Nor is sufficient information available to describe or quantify the contributions of sediment loading caused by commercially raised farm animal responsible for destabilizing stream banks or erosion in pasture fields. The estimated acreage by watershed where manure was applied in 2007 is shown in Table 3-9. These estimates are also based on the county level reports from the 2007 USDA county agricultural census, and thus, represent approximations of the commercially raised farm animal populations in each watershed. Despite the lack of specific data, for the purpose of these TMDLs, land application of commercially raised farm animal manure is considered a potential source of bacterial loading to the watersheds in the Study Area.

According to a livestock study conducted by the ASAE, the daily fecal coliform production rates by livestock species were estimated as follows (ASAE 1999):

- Beef cattle release approximately 1.04E+11 fecal coliform counts per animal per day;
- Dairy cattle release approximately 1.01E+11 per animal per day
- Swine release approximately 1.08E+10 per animal per day
- Chickens release approximately 1.36E+08 per animal per day
- Sheep release approximately 1.20E+10 per animal per day
- Horses release approximately 4.20E+08 per animal per day;
- Turkey release approximately 9.30E+07 per animal per day
- Ducks release approximately 2.43E+09 per animal per day
- Geese release approximately 4.90E+10 per animal per day

Using the estimated animal populations and the fecal coliform production rates from ASAE, an estimate of fecal coliform production from each group of commercially raised farm animal was calculated in each watershed of the Study Area. These estimates are presented in Table 3-10. Note that only a small fraction of these fecal coliform are expected to represent loading into waterbodies, either washed into streams by runoff or by direct deposition from wading animals. Because of their numbers, cattle again appear to represent the most likely commercially raised farm animal source of fecal bacteria.

Table 3-9 Commercially Raised Farm Animals and Manure Application Area Estimates by Watershed

Waterbody ID	Waterbody Name	Cattle	Dairy Cows	Horses	Goats	Sheep	Hogs & Pigs	Ducks & Geese	Acres of Manure Application
OK121510020010_00	Verdigris River	19,750	91	445	0	107	1,492	16	435
OK121510020050_00	California Creek	10,592	57	301	0	62	48	10	218
OK121510030010_00	Big Creek	23,832	210	611	1	80	82	95	2,288
OK121600040010_00	Neosho River	10,532	342	340	0	101	481	102	2,708
OK121600040040_00	Hudson Creek	2,894	86	84	0	25	146	28	729
OK121600040130_00	Cow Creek	3,867	72	105	0	20	91	27	690
OK121600040220_00	Neosho River	11,860	333	409	0	105	211	85	2,395
OK121600060080_00	Little Cabin Creek	22,538	279	592	1	72	148	121	3,055
OK121600070010_00	Spring River	7,932	312	327	0	94	268	74	2,144
OK121600070110_00	Fivemile Creek	896	19	21	0	7	68	6	194

Table 3-10 Fecal Coliform Production Estimates for Commercially Raised Farm Animals ($x10^9$ number/day)

Waterbody ID	Waterbody Name	Cattle	Dairy Cows	Horses	Goats	Sheep	Hogs & Pigs	Ducks & Geese	Total
OK121510020010_00	Verdigris River	2,054,019	9,163	187	0	1,282	16,112	407	2,081,169
OK121510020050_00	California Creek	1,101,583	5,796	127	0	746	514	264	1,109,030
OK121510030010_00	Big Creek	2,478,551	21,256	257	12	959	890	2,449	2,504,374
OK121600040010_00	Neosho River	1,095,340	34,492	143	0	1,213	5,196	2,630	1,139,014
OK121600040040_00	Hudson Creek	300,980	8,731	35	0	306	1,572	728	312,352
OK121600040130_00	Cow Creek	402,163	7,280	44	0	240	983	707	411,419
OK121600040220_00	Neosho River	1,233,467	33,628	172	0	1,261	2,284	2,183	1,272,998
OK121600060080_00	Little Cabin Creek	2,343,923	28,132	249	12	862	1,597	3,110	2,377,887
OK121600070010_00	Spring River	824,926	31,537	137	0	1,128	2,891	1,897	862,518
OK121600070110_00	Fivemile Creek	93,232	1,902	9	0	85	731	154	96,113

3.2.3 Failing Onsite Wastewater Disposal Systems and Illicit Discharges

DEQ is responsible for implementing the regulations of Title 252, Chapter 641 of the Oklahoma Administrative Code, which defines design standards for individual and small public onsite sewage disposal systems (DEQ 2011a). OSWD systems and illicit discharges can be a source of bacterial loading to streams and rivers. Bacterial loading from failing OSWD systems can be transported to streams in a variety of ways, including runoff from surface ponding or through groundwater. Fecal coliform-contaminated groundwater may discharge to creeks through springs and seeps.

To estimate the potential magnitude of OSWDs fecal bacterial loading, the number of OSWD systems was estimated for each watershed. The estimate of OSWD systems was derived by using data from the 1990 U.S. Census which was the last year in which there were Census questions about plumbing facilities (U.S. Department of Commerce, Bureau of the Census 1990). The density of OSWD systems within each watershed was estimated by dividing the number of OSWD systems in each census block by the number of acres in each census block. This density was then applied to the number of acres of each census block within a WQM station watershed. Census blocks crossing a watershed boundary required additional calculation to estimate the number of OSWD systems based on the proportion of the census block falling within each watershed. This step involved adding all OSWD systems for each whole or partial census block.

Over time, most OSWD systems operating at full capacity will fail. OSWD system failures are proportional to the adequacy of a state's minimum design criteria (Hall 2002). The 1990 American Housing Survey for Oklahoma conducted by the U.S. Census Bureau estimates that, nationwide, 10% of occupied homes with OSWD systems experience malfunctions during the year (U.S. Department of Commerce, Bureau of the Census 1990). A study conducted by Reed, Stowe & Yanke, LLC (2001) reported that approximately 12% of the OSWD systems in east Texas and 8% in the Texas Panhandle were chronically malfunctioning. Most studies estimate that the minimum lot size necessary to ensure against contamination is roughly one-half to one acre (Hall 2002). Some studies, however, found that lot sizes in this range or even larger could still cause contamination of ground or surface water (University of Florida 1987). It is estimated that areas with more than 40 OSWD systems per square mile (6.25 septic systems per 100 acres) can be considered to have potential contamination problems (Canter and Knox 1986). Table 3-11 summarizes estimates of sewered and unsewered households and the average number of septic tanks per square mile for each watershed in the Study Area.

For the purpose of estimating fecal coliform loading in watersheds, an OSWD failure rate of 8% was used in the calculations made to characterize fecal coliform loads in each watershed.

Fecal coliform loads were estimated using the following equation (EPA 2001):

$$\#\frac{counts}{day} = \left(\#Failing\_systems\right) \times \left(\frac{10^6\,counts}{100ml}\right) \times \left(\frac{70gal}{personday}\right) \times \left(\#\frac{person}{household}\right) \times \left(3785.2\frac{ml}{gal}\right)$$

Table 3-11 Estimates of Sewered and Unsewered Households

Waterbody ID	Waterbody Name	Public Sewer	Septic Tank	Other Means	Housing Units	# of Septic Tanks / Mile^2
OK121510020010_00	Verdigris River	2496	915	38	3448	4
OK121510020050_00	California Creek	378	251	13	642	3
OK121510030010_00	Big Creek	168	442	22	632	3
OK121600040010_00	Neosho River	5218	749	11	5978	8
OK121600040040_00	Hudson Creek	134	239	1	374	9
OK121600040130_00	Cow Creek	70	176	3	249	6
OK121600040220_00	Neosho River	1061	432	23	1516	4
OK121600060080_00	Little Cabin Creek	901	876	21	1798	5
OK121600070010_00	Spring River	1702	863	27	2592	10
OK121600070110_00	Fivemile Creek	64	261	8	333	19

The average of number of people per household was calculated to be 2.08 for counties in the Study Area (U.S. Census Bureau 2010). Approximately 70 gallons of wastewater were estimated to be produced on average per person per day (Metcalf and Eddy 1991). The fecal coliform concentration in septic tank effluent was estimated to be 10^6 per 100 mL of effluent based on reported concentrations from a number of publications (Metcalf and Eddy 1991; Canter and Knox 1985; Cogger and Carlile 1984). Using this information, the estimated load from failing septic systems within the watersheds was summarized below in Table 3-12.

Table 3-12 Estimated Fecal Coliform Load from OSWD Systems

Waterbody ID	Waterbody Name	Acres	Septic Tank	# of Failing Septic Tanks	Estimated Loads from Septic Tanks (x 10^9 counts/day)
OK121510020010_00	Verdigris River	142,659	915	73	481
OK121510020050_00	California Creek	59,032	251	20	132
OK121510030010_00	Big Creek	111,900	442	35	232
OK121600040010_00	Neosho River	62,839	749	60	394
OK121600040040_00	Hudson Creek	16,492	239	19	126
OK121600040130_00	Cow Creek	19,199	176	14	93
OK121600040220_00	Neosho River	70,983	432	35	227
OK121600060080_00	Little Cabin Creek	102,949	876	70	461
OK121600070010_00	Spring River	55,680	863	69	454
OK121600070110_00	Fivemile Creek	8,960	261	21	137

3.2.4 Domestic Pets

Fecal matter from dogs and cats, which is transported to streams by runoff from urban and suburban areas, can be a potential source of bacterial loading. On average 37.2% of the nation's households own dogs and 32.4% own cats and in these households the average number of dogs is 1.7 and 2.2 cats per household (American Veterinary Medical Association 2007). Using the U.S. Census data at the block level (U.S. Census Bureau 2010), dog and cat populations can be estimated for each watershed. Table 3-13 summarizes the estimated number of dogs and cats for the watersheds of the Study Area.

Table 3-13 Estimated Numbers of Pets

Waterbody ID	Waterbody Name	Dogs	Cats
OK121510020010_00	Verdigris River	5,862	7,586
OK121510020050_00	California Creek	1,091	1,412
OK121510030010_00	Big Creek	1,074	1,390
OK121600040010_00	Neosho River	10,162	13,151
OK121600040040_00	Hudson Creek	636	823
OK121600040130_00	Cow Creek	423	548
OK121600040220_00	Neosho River	2,578	3,336
OK121600060080_00	Little Cabin Creek	3,057	3,956
OK121600070010_00	Spring River	4,406	5,702
OK121600070110_00	Fivemile Creek	565	732

Table 3-14 provides an estimate of the fecal coliform production from pets. These estimates are based on estimated fecal coliform production rates of $5.4x10^8$ per day for cats and $3.3x10^9$ per day for dogs (Schueler 2000).

Table 3-14 Estimated Fecal Coliform Daily Production by Pets ($x10^9$ counts/day)

Waterbody ID	Waterbody Name	Dogs	Cats	Total
OK121510020010_00	Verdigris River	19,345	4,097	43,791
OK121510020050_00	California Creek	3,602	763	8,155
OK121510030010_00	Big Creek	3,546	751	8,028
OK121600040010_00	Neosho River	33,536	7,102	75,914
OK121600040040_00	Hudson Creek	2,098	444	4,758
OK121600040130_00	Cow Creek	1,397	296	3,168
OK121600040220_00	Neosho River	8,508	1,802	19,260
OK121600060080_00	Little Cabin Creek	10,087	2,136	22,836
OK121600070010_00	Spring River	14,540	3,079	32,920
OK121600070110_00	Fivemile Creek	1,866	395	4,242

3.3 Summary of Sources of Impairment

3.3.1 Bacteria

There are five continuous, permitted point sources in the Neosho River (OK121600040010_00) and Hudson Creek (OK121600040040_00) watersheds that will not require a waste load allocation because the receiving waterbodies are not impaired for bacteria. Four of the nine watersheds requiring a bacterial TMDL have one or more continuous point source discharges. There is one CAFO in the Study Area and ten PFOs scattered in the upper eastern portion of the Study Area. All the stream segments in Table 3-15 require bacterial TMDLs. That table provides a summary of the estimated fecal coliform loads in cfu/day for the four major nonpoint source categories (commercially raised farm animals, pets, deer, and septic tanks) that contribute to the elevated bacterial concentrations in each watershed. Because of their numbers and animal unit production of bacteria, livestock are estimated to be the largest contributors of fecal coliform loading to land surfaces. It must be noted that while no data are available to estimate populations and fecal loading of wildlife other than deer, a number of bacterial source tracking studies around the nation demonstrate that wild birds and mammals represent a major source of the fecal bacteria found in streams.

Table 3-15 Percentage Contribution of Fecal Coliform Load Estimates from Nonpoint Sources to Land Surfaces

Waterbody ID	Waterbody Name	Commercially Raised Farm Animals	Pets	Deer	Estimated Loads from Septic Tanks
OK121510020010_00	Verdigris River	97.85%	2.06%	0.06%	0.02%
OK121510020050_00	California Creek	99.21%	0.73%	0.05%	0.01%
OK121510030010_00	Big Creek	99.66%	0.32%	0.02%	0.01%
OK121600040010_00	Neosho River	93.68%	6.24%	0.05%	0.03%
OK121600040040_00	Hudson Creek	98.41%	1.50%	0.05%	0.04%
OK121600040130_00	Cow Creek	99.19%	0.76%	0.02%	0.02%
OK121600040220_00	Neosho River	98.46%	1.49%	0.04%	0.02%
OK121600060080_00	Little Cabin Creek	99.02%	0.95%	0.01%	0.02%
OK121600070010_00	Spring River	96.21%	3.67%	0.07%	0.05%
OK121600070110_00	Fivemile Creek	95.57%	4.22%	0.07%	0.14%

The magnitude of loading to a stream may not reflect the magnitude of loading to land surfaces. While no studies have quantified these effects, bacteria may die off or survive at different rates depending on the manure characteristics and a number of other environmental conditions. Also, the structural properties of some manure, such as cow patties, may limit their washoff into streams by runoff. In contrast, malfunctioning septic tank effluent may be present in standing water on the surface, or in shallow groundwater, which may enhance its conveyance to streams.

3.3.2 Turbidity

Of the five watersheds in the Study Area that require turbidity TMDLs, only one of them, Neosho River (OK121600040010_00) has an industrial permitted source of TSS that will necessitate a WLA. These five watersheds have other permitted activities such as construction and/or mining that contribute some TSS loading. Therefore, nonsupport of WWAC use in all but one watershed is caused primarily by nonpoint sources of TSS. Sediment loading of streams can originate from natural erosion processes, including the weathering of soil, rocks, and uncultivated land; geological abrasion; and other natural phenomena. There is insufficient data available to quantify contributions of TSS from these natural processes. TSS or sediment loading can also occur under non-runoff conditions as a result of anthropogenic activities in riparian corridors which cause erosive conditions. Given the lack of data to establish the background conditions for TSS/turbidity, separating background loading from nonpoint sources whether it is from natural or anthropogenic processes is not feasible in this TMDL development.

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. A TMDL is expressed as the sum of three elements as described in the following mathematical equation:

$$TMDL = WLA\_{WWTP} + WLA\_{MS4} + LA + MOS$$

The WLA is the portion of the TMDL allocated to existing and future point sources. The LA is the portion of the TMDL allocated to nonpoint sources, including natural background sources. The MOS is intended to ensure that WQSs will be met.

For *E. coli* or Enterococci bacteria, TMDLs are expressed as colony-forming units per day, and represent the maximum one-day load the stream can assimilate while still attaining the WQS. Percent reduction goals are also calculated to aid to characterizing the possible magnitude of the effort to restore the segment to meeting water quality criterion. Turbidity TMDLs will be derived from TSS calculations and expressed in pounds (lbs) per day which will represent the maximum one-day load the stream can assimilate while still attaining the WQS, as well as a PRG.

4.1 Determining a Surrogate Target for Turbidity

Turbidity is a commonly measured indicator of the suspended solids load in streams. However, turbidity is an optical property of water, which measures scattering of light by suspended solids and colloidal matter. To develop TMDLs, a gravimetric (mass-based) measure of solids loading is required to express loads. There is often a strong relationship between the total suspended solids concentration and turbidity. Therefore, the TSS load, which is expressed as mass per time, is used as a surrogate for turbidity.

To determine the relationship between turbidity and TSS, a linear regression between TSS and turbidity was developed using data collected from 1998 to 2011 at stations within the Study Area. Prior to developing the regression the following steps were taken to refine the dataset:

- Replace TSS samples of “<10” with 9.99;
- Remove data collected under high flow conditions exceeding the base-flow criterion. This means that measurements corresponding to flow exceedance frequency lower than 25^{th} were not used in the regression;
- Check rainfall data on the day when samples were collected and on the previous two days. If there was a significant rainfall event (>= 1.0 inch) in any of these days, the sample will be excluded from regression analysis with one exception. If the significant rainfall happened on the sampling day and the turbidity reading was less than 25 NTUs (half of turbidity standard for streams), the sample will not be excluded from analysis because most likely the rainfall occurred after the sample was taken; and
- Log-transform both turbidity and TSS data to minimize effects of their non-linear data distributions.

When ordinary least squares (OLS) regression is applied to ascertain the best relationship between two variables (i.e., X and Y), one variable (Y) is considered "dependent" on the other variable (X), but X must be considered "independent" of the other, and known without measurement error. OLS minimizes the differences, or residuals, between measured Y values and Y values predicted based on the X variable.

For current purposes, a relationship is necessary to predict TSS concentrations from measured turbidity values, but also to translate the TSS-based TMDL back to instream turbidity values. For this purpose, an alternate regression fitting procedure known as the line of organic correlation (LOC) was applied. The LOC has three advantages over OLS (Helsel and Hirsch 2002):

- LOC minimizes fitted residuals in both the X and Y directions;
- It provides a unique best-fit line regardless of which parameter is used as the independent variable; and
- Regression-fitted values have the same variance as the original data.

The LOC minimizes the areas of the right triangles formed by horizontal and vertical lines drawn from observations to the fitted line. The slope of the LOC line equals the geometric mean of the Y on X (TSS on turbidity) and X on Y (turbidity on TSS) OLS slopes, and is calculated as:

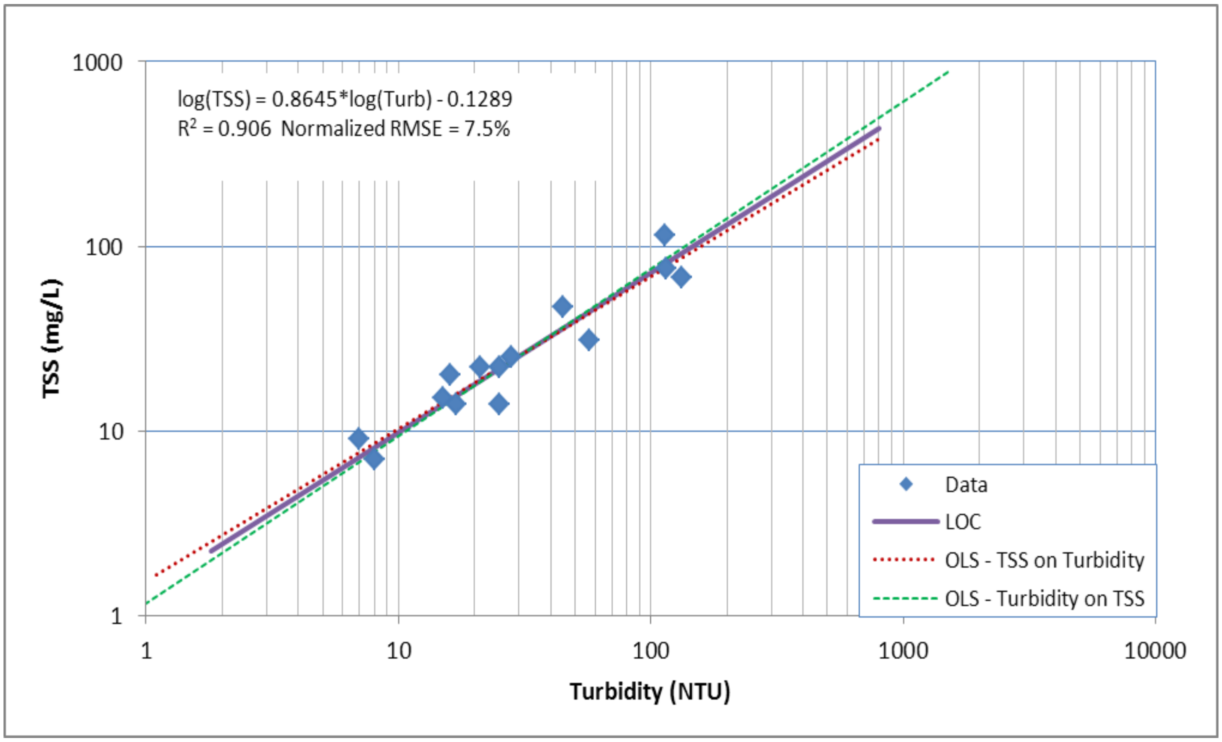
$$m1 = \sqrt{m \cdot m'} = sign[r] \cdot \frac{s_y}{s_x}$$

where *m*1 is the slope of the LOC line, *m* is the TSS on turbidity OLS slope, *m'* is the turbidity on TSS OLS slope, *r* is the TSS-turbidity correlation coefficient, s_y is the standard deviation of the TSS measurements, and s_x is the standard deviation of the turbidity measurements.

The intercept of the LOC (*b*1) is subsequently found by fitting the line with the LOC slope through the point (mean turbidity, mean TSS). Figure 4-1 shows an example of the correlation between TSS and turbidity, along with the LOC and the OLS lines.

The NRMSE and R-square (r^2) were used as the primary measures of goodness-of-fit. As shown in Figure 4-1, the LOC yields a NRMSE value of 8 which means the root mean square error (RMSE) is 8% of the average of the measured TSS values. The R-square (r^2) value indicates the fraction of the total variance in TSS or turbidity observations that is explained by the LOC. The regression equation can be used to convert the turbidity standard of 50 NTUs to TSS goals.

Figure 4-1 Linear Regression for TSS-Turbidity for Verdigris River (OK121510020010_00)



It was noted that there were a few outliers that exerted undue influence on the regression relationship. These outliers were identified by applying the Tukey's Boxplot method (Tukey 1977) to the dataset of the distances from observed points to the regression line. The Tukey Method is based on the interquartile range (IQR), the difference between the 75th percentile (Q_3) and 25th percentile (Q_1) of distances between observed points and the LOC. Using the Tukey method, any point with an error greater than Q_3 + 1.5* IQR or less than Q_1 – 1.5*IQR was identified as an outlier and removed from the regression dataset. The above regressions were calculated using the dataset with outliers removed.

The Tukey Method is equivalent to using three times the standard deviation to identify outliers if the residuals (observed - predicted) follow a normal distribution. The probability of sampling results being within three standard deviations of the mean is 99.73% while the probability for the Tukey Method is 99.65%. If three times the standard deviation is used to identify outliers, it is necessary to first confirm that the residuals are indeed normally distributed. This is difficult to do because of the size limitations of the existing turbidity & TSS dataset. Tukey's method does not rely on any assumption about the distribution of the residuals. It can be used regardless of the shape of distribution.

Outliers were removed from the dataset only for calculating the turbidity-TSS relationship, not from the dataset used to develop the TMDL.

The regression between TSS and turbidity and its statistics for each turbidity impaired stream segment is provided in Section 5.1.

4.2 Using Load Duration Curves to Develop TMDLs

The TMDL calculations presented in this report are derived from load duration curves (LDC). LDCs facilitate rapid development of TMDLs, and as a TMDL development tool can help identifying whether impairments are associated with point or nonpoint sources. The technical approach for using LDCs for TMDL development includes the three following steps that are described in Subsections 4.3 through 4.5 below:

- Preparing flow duration curves for gaged and ungaged WQM stations;
- Estimating existing loading in the waterbody using ambient bacterial water quality data; and estimating loading in the waterbody using measured TSS water quality data and turbidity-converted data; and
- Using LDCs to identify if there is a critical condition.

Historically, in developing WLAs for pollutants from point sources, it was customary to designate a critical low flow condition (*e.g.*, 7Q2) at which the maximum permissible loading was calculated. As water quality management efforts expanded in scope to quantitatively address nonpoint sources of pollution and types of pollutants, it became clear that this single critical low flow condition was inadequate to ensure adequate water quality across a range of flow conditions. Use of the LDC obviates the need to determine a design storm or selected flow recurrence interval with which to characterize the appropriate flow level for the assessment of critical conditions. For waterbodies impacted by both point and nonpoint sources, the “nonpoint source critical condition” would typically occur during high flows, when rainfall runoff would contribute the bulk of the pollutant load, while the “point source critical condition” would typically occur during low flows, when WWTP effluents would dominate the base flow of the impaired water. However, flow range is only a general indicator of the relative proportion of point/nonpoint contributions. It is not used in this report to quantify point source or nonpoint source contributions. Violations that occur during low flows may not be caused exclusively by point sources. Violations during low flows have been noted in some watersheds that contain no point sources.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by a water quality criterion. The TMDL can be expressed as a continuous function of flow, equal to the line, or as a discrete value derived from a specific flow condition.

4.3 Development of Flow Duration Curves

Flow duration curves (FDC) serve as the foundation of LDCs and are graphical representations of the flow characteristics of a stream at a given site. Flow duration curves utilize the historical hydrologic record from stream gages to forecast future recurrence frequencies. Many WQM stations throughout Oklahoma do not have long-term flow data and therefore, flow frequencies must be estimated. Nine of the fourteen waterbodies in the Study Area do not have USGS gage stations. The default approach used to develop flow frequencies necessary to establish flow duration curves considers watershed differences in rainfall, land use, and the hydrologic properties of soil that govern runoff and retention. A detailed explanation of the methods for estimating flow for ungaged streams is provided in Appendix B. The most basic method to estimate flows at an ungaged site involves 1) identifying an upstream or downstream flow gage; 2) calculating the contributing drainage areas of the ungaged sites and the flow gage; and 3) calculating daily flows at the ungaged site by using the flow at the gaged site multiplied by the drainage area ratio.

Flow duration curves are a type of cumulative distribution function. The flow duration curve represents the fraction of flow observations that exceed a given flow at the site of interest. The observed flow values are first ranked from highest to lowest, then, for each observation, the percentage of observations exceeding that flow is calculated. The flow value is read from the ordinate (y-axis), which is typically on a logarithmic scale since the high flows would otherwise overwhelm the low flows. The flow exceedance frequency is read from the abscissa (x-axis), which is numbered from 0% to 100%, and may or may not be logarithmic. The lowest measured flow occurs at an exceedance frequency of 100% indicating that flow has equaled or exceeded this value 100% of the time, while the highest measured flow is found at an exceedance frequency of 0%. The median flow occurs at a flow exceedance frequency of 50%. The flow exceedance percentiles for each waterbody addressed in this report are provided in Appendix B.

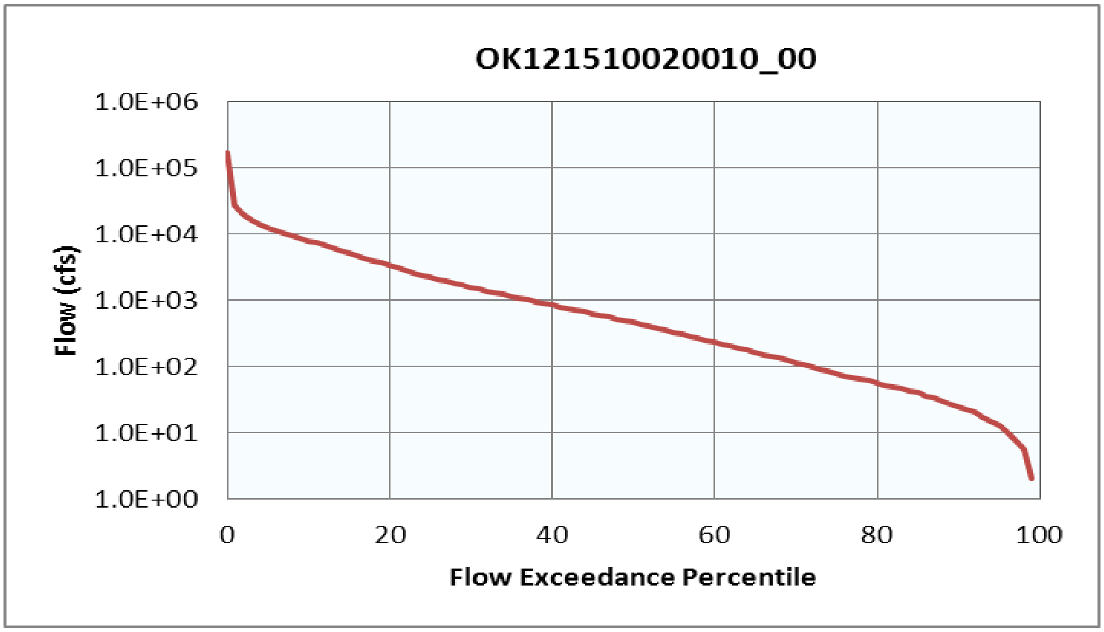
While the number of observations required to develop a flow duration curve is not rigorously specified, a flow duration curve is usually based on more than one year of observations, and encompasses inter-annual and seasonal variation. Ideally, the drought of record and flood of record are included in the observations. For this purpose, the long-term flow gaging stations operated by the USGS are utilized (USGS 2009) to support the Oklahoma TMDL Toolbox.

The USGS National Water Information System serves as the primary source of flow measurements for the Oklahoma TMDL Toolbox. All available daily average flow values for all gages in Oklahoma, as well as the nearest upstream and downstream gages in adjacent states, were retrieved for use in the Oklahoma TMDL Toolbox to generate flow duration curves for gaged and ungaged waterbodies. The application includes a data update module that automatically downloads the most recent USGS data and appends it to the existing flow database.

Some instantaneous flow measurements were available from various agencies. These were not combined with the daily average flows or used in calculating flow percentiles, but were matched turbidity, or TSS grab measurements collected at the same site and time. When available, these instantaneous flow measurements were used in lieu of projected flows to calculate pollutant loads.

A typical semi-log flow duration curve exhibits a sigmoidal shape, bending upward near a flow exceedance frequency value of 0% and downward at a frequency near 100%, often with a relatively constant slope in between. For sites that on occasion exhibit no flow, the curve will intersect the abscissa at a frequency less than 100%. As the number of observations at a site increases, the line of the LDC tends to appear smoother. However, at extreme low and high flow values, flow duration curves may exhibit a "stair step" effect due to the USGS flow data rounding conventions near the limits of quantization. An example of a typical flow duration curve is shown in Figure 4-2.

Figure 4-2 Flow Duration Curve for Verdigris River (OK121510020010_00)



Flow duration curves for each impaired waterbody in the Study Area are provided in Section 5.2.

4.4 Estimating Existing Loading

Existing instream loads can be estimated using FDCs. For bacteria, this is accomplished by:

- Calculating the geometric mean of all water quality observations from the period of record selected for the waterbody;
- Converting the geometric mean concentration value to loads by multiplying the flow duration curve by the geometric mean of the ambient water quality data for each bacterial indicator.

For TSS, this is accomplished by:

- Matching the water quality observations with the flow data from the same date;
- Converting measured concentration values to loads by multiplying the flow at the time the sample was collected by the water quality parameter concentration (for sampling events with both tss and turbidity data, the measured tss value is used; if only turbidity was measured, the value was converted to tss using the regression equations described); or multiplying the flow by the bacterial indicator concentration to calculate daily loads.

4.5 Development of TMDLs Using Load Duration Curves

The final step in the TMDL calculation process involves a group of additional computations derived from the preparation of LDCs. These computations are necessary to derive a PRG (which is one method of presenting how much pollutant loads must be reduced to meet WQSs in the impaired watershed).

Step 1: Generate LDCs. LDCs are similar in appearance to flow duration curves; however, for bacteria the ordinate is expressed in terms of a bacterial load in cfu/day, and for TSS the ordinate is expressed in terms of a load in lbs/day. The bacterial curve represents the geometric mean water quality criterion for *E. coli* or Enterococci bacteria expressed in terms of a load through multiplication by the continuum of flows historically observed at the site. Bacterial TMDLs are not easily expressed in mass per day, the following equation calculates a load in the units of cfu per day. The cfu is a total for the day at a specific flow for bacteria, which is the best equivalent to a mass per day of a pollutant such as sulfate. Expressing bacterial TMDLs as cfu per day is consistent with EPA's Protocol for Developing Pathogen TMDLs (EPA 2001).

For turbidity, the curve represents the water quality target for TSS from Table 5-1 expressed in terms of a load obtained through multiplication of the TSS goal by the continuum of flows historically observed at the site. The basic steps to generating an LDC involve:

- Obtaining daily flow data for the site of interest from the USGS;
- Sorting the flow data and calculating flow exceedance percentiles;
- Obtaining the water quality data from the primary contact recreation season (May 1 through September 30); or obtaining available turbidity and TSS water quality data;
- Displaying a curve on a plot that represents the allowable load determined by multiplying the actual or estimated flow by the WQS numerical criterion for each parameter (geometric mean standard for bacterial and TSS goal for turbidity); and
- For bacterial TMDLs, displaying another curve derived by plotting the geometric mean of all existing bacteria samples continuously along the full spectrum of flow exceedance percentiles which represents LDC (See Section 5); or
- For turbidity TMDLs, matching the water quality observations with the flow data from the same date and determining the corresponding exceedance percentile (See Section 5).

For bacterial TMDLs the culmination of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve:

TMDL (cfu/day) = WQS * flow (cfs) * unit conversion factor

Where: WQS = 126 cfu/100 mL (E. coli); or 33 cfu/100 mL (Enterococci)

unit conversion factor = 24,465,525

For turbidity (TSS) TMDLs the culmination of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve:

TMDL (lb/day) = WQ_{goal} * flow (cfs) * unit conversion factor

where: WQ_{goal} = waterbody specific TSS concentration derived from regression analysis results presented in Table 5-1

unit conversion factor = 5.39377

The flow exceedance frequency (x-value of each point) is obtained by looking up the historical exceedance frequency of the measured or estimated flow, in other words, the percent of historical observations that are equal to or exceed the measured or estimated flow. Historical observations of bacteria were plotted as a separate LDC based on the geometric mean of all samples. Historical observations of TSS and/or turbidity concentrations are paired with flow data and are plotted on the LDC for a stream. TSS loads representing exceedance of water quality criteria fall above the TMDL line. It is noted that the LDCs for bacteria were based on the geometric mean standards or geometric mean of all samples. It is inappropriate to compare single sample bacterial observations to a geometric mean water quality criterion in the LDC; therefore individual bacterial samples are not plotted on the LDCs.

As noted earlier, runoff has a strong influence on loading of nonpoint pollution. Yet flows do not always correspond directly to runoff; high flows may occur in dry weather (e.g., lake release to provide water downstream) and runoff influence may be observed with low or moderate flows (e.g., persistent high turbidity due to previous storm).

Step 2: Define MOS. The MOS may be defined explicitly or implicitly. A typical explicit approach would reserve some specific fraction of the TMDL as the MOS. In an implicit approach, conservative assumptions used in developing the TMDL are relied upon to provide an MOS to assure that WQSs are attained. For bacterial TMDLs in this report, an explicit MOS of 10% was selected. The 10% MOS has been used in other approved bacterial TMDLs. For turbidity (TSS) TMDLs an explicit MOS is derived from the NRMSE established by the turbidity/TSS regression analysis conducted for each waterbody. This approach for setting an explicit MOS has been used in other approved turbidity TMDLs.

Step 3: Calculate WLA. As previously stated, the pollutant load allocation for point sources is defined by the WLA. For bacterial TMDLs a point source can be either a wastewater (continuous) or stormwater (MS4) discharge. Stormwater point sources are typically associated with urban and industrialized areas, and recent EPA guidance includes NPDES-permitted stormwater discharges as point source discharges and, therefore, part of the WLA. For TMDL development purposes when addressing turbidity or TSS, a WLA will be established for wastewater (continuous) discharges in impaired watersheds that do not have a BOD or CBOD permit limit but do have a TSS limit. These point source discharges of inorganic suspended solids will be assigned a TSS WLA as part of turbidity TMDLs to ensure WQS can be maintained. As discussed in Section 3.1, a WLA for TSS is not necessary for MS4s.

The LDC approach recognizes that the assimilative capacity of a waterbody depends on the flow, and that maximum allowable loading will vary with flow condition. WLAs can be expressed in terms of a single load, or as different loads allowable under different flows. WLAs may be set to zero in cases of watersheds with no existing or planned continuous permitted point sources. For turbidity (TSS) TMDLs a load-based approach also meets the requirements of 40 CFR, 130.2(i) for expressing TMDLs “in terms of mass per time, toxicity, or other appropriate measures.”

WLA for WWTP. For watersheds with permitted point sources discharging the pollutant of concern, NPDES permit limits are used to derive WLAs for evaluation as appropriate for use in the TMDL. The permitted flow rate used for each point source discharge and the water quality concentration defined in a permit are used to estimate the WLA for each wastewater facility. In cases where a permitted flow rate is not available for a WWTP, then the average of monthly flow rates derived from DMRs can be used. WLA values for each NPDES wastewater discharger are then summed to represent the total WLA for a given segment. Using this information bacterial and TSS WLAs can be calculated using the approach as shown in the equations below.

WLA for bacteria:

WLA = WQS * flow * unit conversion factor (cfu/day)

Where:

WQS = 126 cfu/100 mL (E. coli); or 33 cfu/100 mL (Enterococci)

flow (mgd) = permitted flow unit conversion factor = 37,854,120

WLA for TSS:

WLA = WQ goal * flow * unit conversion factor (lb/day)

Where:

WQ goal= Waterbody specific water quality goal provided in Table 5-1, or monthly

TSS limit in the current permit, whichever is smaller

flow (mgd) = permitted flow or average monthly flow

unit conversion factor = 8.3445

Step 4: Calculate LA and WLA for MS4s. Given the lack of data and the variability of storm events and discharges from storm sewer system discharges, it is difficult to establish numeric limits on stormwater discharges that accurately address projected loadings. As a result, EPA regulations and guidance recommend expressing NPDES permit limits for MS4s as BMPs.

LAs can be calculated under different flow conditions. The LA at any particular flow exceedance is calculated as shown in the equation below.

LA = TMDL - WLA_WWTP - WLA_MS4 – MOS

WLA for MS4s. For bacterial TMDLs, if there are no permitted MS4s in the Study Area, WLA_MS4 is set to zero. When there are permitted MS4s in a watershed, first calculate the sum of LA + WLA_MS4 using the above formula, then separate WLA for MS4s from the sum based on the percentage of a watershed that is under a MS4 jurisdiction. This WLA for MS4s may not be the total load allocated for permitted MS4s unless the whole MS4 area is located within the study watershed boundary. However, in most case the study watershed intersects only a portion of the permitted MS4 coverage areas.

For turbidity TMDLs, WLAs for permitted stormwater such as MS4s, construction, and multi-sector general permits are not calculated since these discharges occur under high flow conditions when the turbidity criteria do not apply.

Step 5: Estimate Percent Load Reduction. Percent load reductions are not required items and are provided for informational purposes when making inferences about individual TMDLs or between TMDLs usually in regard to implementation of the TMDL.

The LDC approach recognizes that the assimilative capacity of a waterbody depends on stream flow and that the maximum allowable loading varies with flow condition. Existing loading and load reductions required to meet the TMDL can also be calculated under different flow conditions. The difference between existing loading and the TMDL is used to calculate the loading reductions required. Percent reduction goals are calculated through an iterative process of taking a series of percent reduction values applying each value uniformly to the measured concentrations of samples and verifying if the geometric mean of the reduced values of all samples is less than the geomean standards.

WLA Load Reduction: The WLA load reduction for bacteria was not calculated as it was assumed that continuous dischargers (NPDES-permitted WWTPs) are adequately regulated under existing permits to achieve WQS at the end-of-pipe and, therefore, no WLA reduction would be required. Currently, bacterial limits are not required for lagoon systems. Lagoon systems located within a sub-watershed of bacterially-impaired stream segment will be required to meet *E. coli* standards at the discharge when the permits are renewed.

MS4s are classified as point sources, but they are nonpoint sources in nature. Therefore, the percent reduction goal calculated for LA will also apply to the MS4 area within the bacterially-impaired sub-watershed. If there are no MS4s located within the Study Area requiring a TMDL, then there is no need to establish a PRG for permitted stormwater.

The WLA load reduction for TSS for dischargers without BOD/CBOD limits can be determined as follows:

- If permitted TSS limit is less than TSS goal for the receiving stream, there will be no reductions;
- If permitted TSS limit is greater than TSS goal for the receiving stream, the permit limit will be set at the TSS goal.

LA Load Reduction. After existing loading estimates are computed for each pollutant, nonpoint load reduction estimates for each segment are calculated by using the difference between the estimate of existing loading and the allowable loading (TMDL) under all flow conditions. This difference is expressed as the overall PRG for the impaired waterbody. The PRG serves as a guide for the amount of pollutant reduction necessary to meet the TMDL. For *E. coli* and Enterococci, because WQSs are considered to be met if the geometric mean of all future data is maintained below the geometric mean criteria (TMDL). For turbidity, the PRG is the load reduction that ensures that no more than 10% of the samples under flow-base conditions exceed the TMDL.

SECTION 5
TMDL CALCULATIONS

5.1 Surrogate TMDL Target for Turbidity

Using the LOC method described in Section 4.1, correlations between TSS and turbidity were developed for establishing the statistics of the regressions and the resulting TSS goals were provided in Table 5-1. The regression analysis for each impaired waterbody in the Study Area using the LOC method is displayed in Figures 5-1 through 5-4. There was not enough TSS data available for Neosho River (OK121600040220_00) so the regression for Neosho River (OK121600040010_00) was used.

Table 5-1 Regression Statistics and TSS Goals

Waterbody ID	Waterbody Name	R-square	NRMSE	TSS Goal (mg/L)[a]	MOS[b]
OK121510020010_00	Verdigris River	0.906	7.5%	40	10%
OK121600040010_00	Neosho River	0.846	8.7%	45	10%
OK121600040040_00	Hudson Creek	0.696	12.1%	43	15%
OK121600040130_00	Cow Creek	0.866	8.8%	33	10%
OK121600040220_00	Neosho River	0.846	8.7%	45	10%

[a] Calculated using the regression equation and the turbidity standard (50 NTU)
[b] Based on the goodness-of-fit of the turbidity-TSS regression (NRMSE)

Figure 5-1 Linear Regression for TSS-Turbidity for Verdigris River (OK121510020010_00)

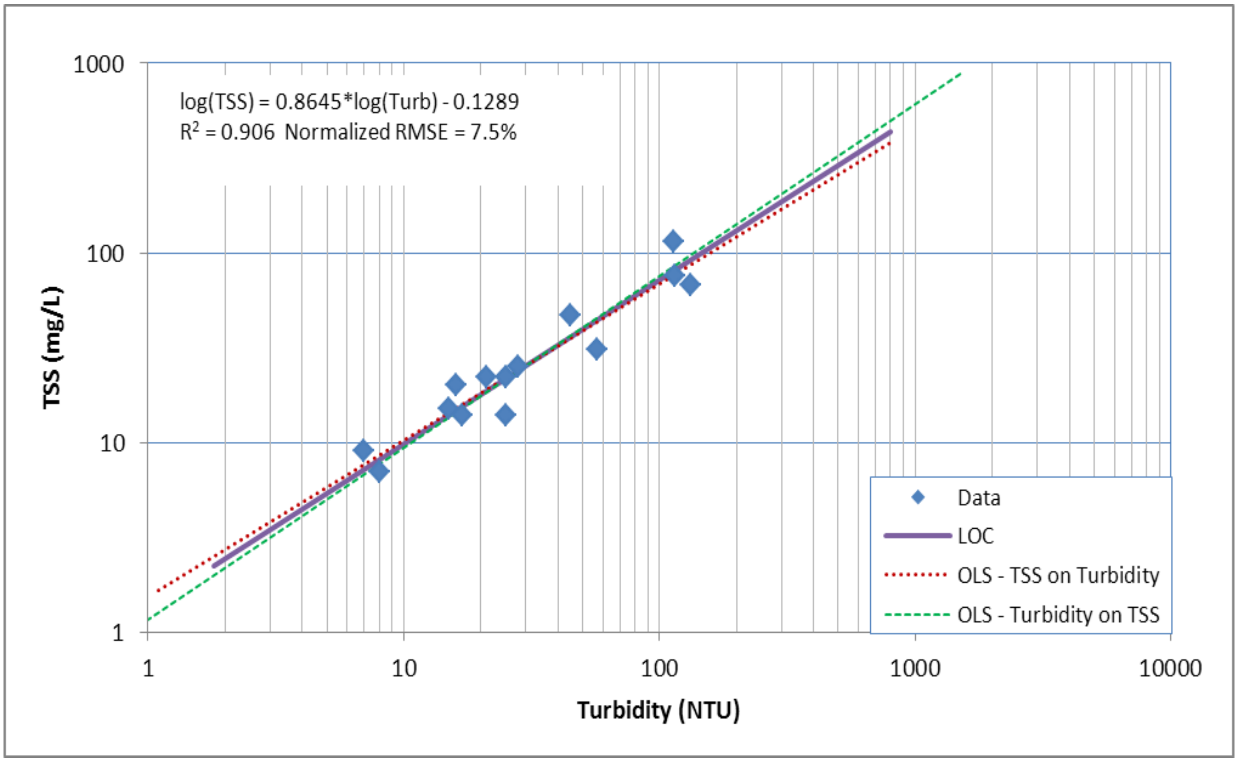


Figure 5-2 Linear Regression for TSS-Turbidity for Neosho River (OK121600040010_00)

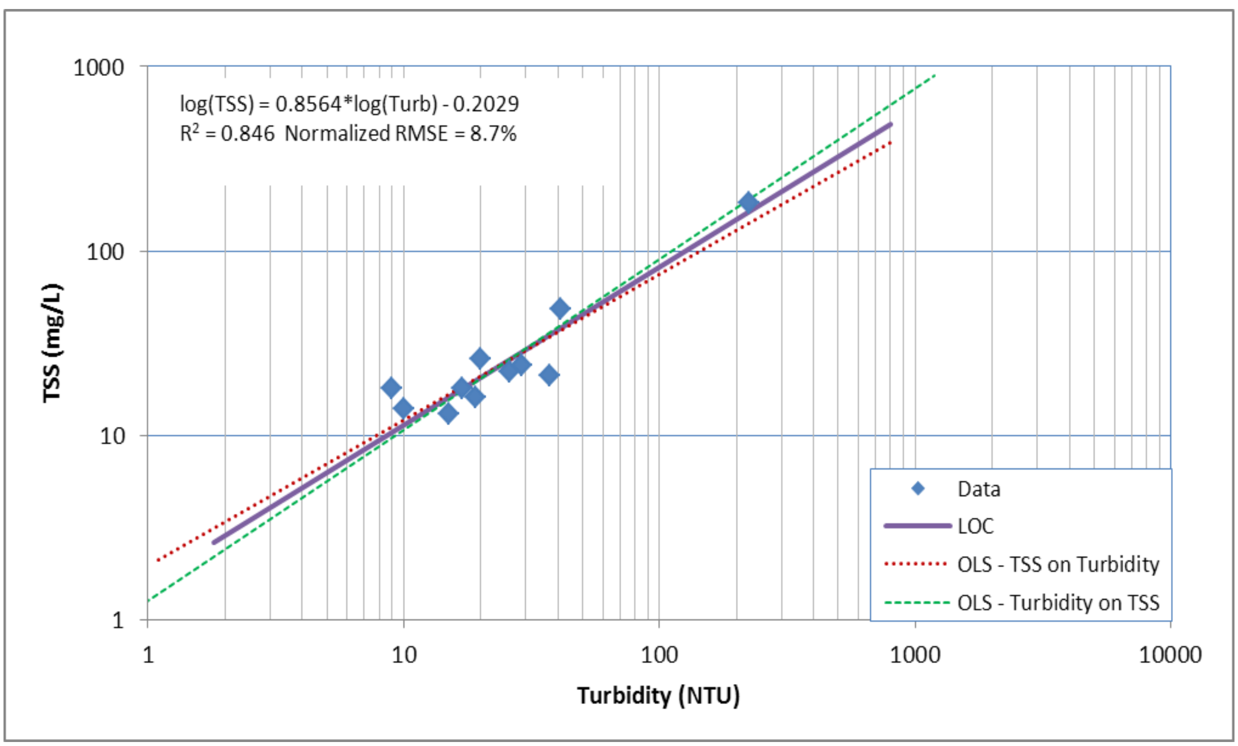


Figure 5-3 Linear Regression for TSS-Turbidity for Hudson Creek (OK121600040040_00)

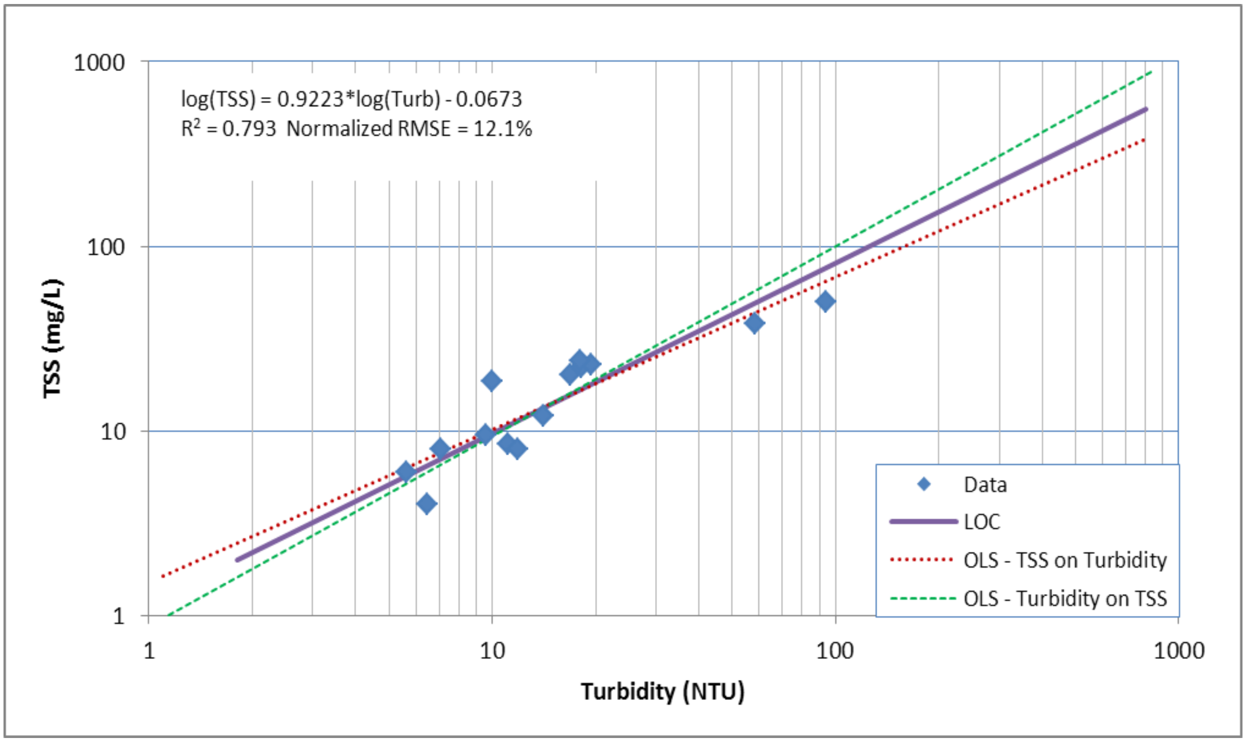
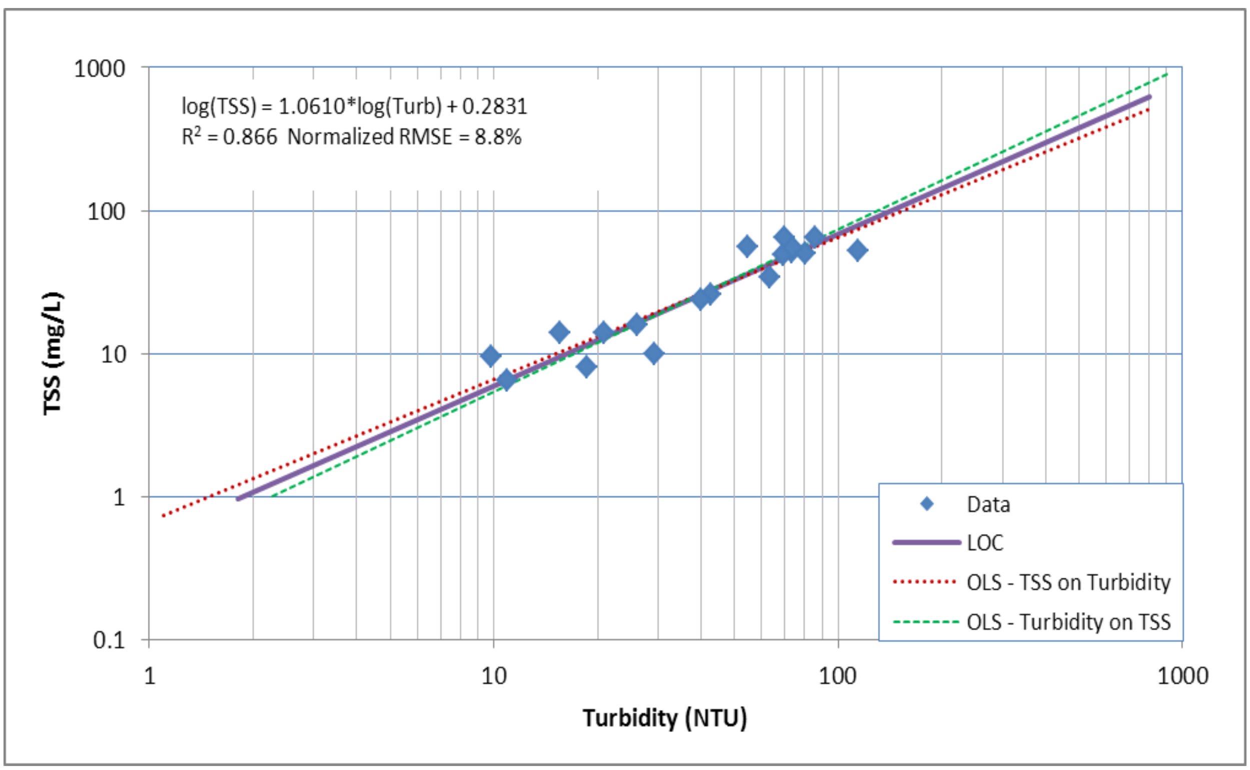


Figure 5-4 Linear Regression for TSS-Turbidity for Cow Creek (OK121600040130_00)



5.2 Flow Duration Curve

Following the same procedures described in Section 4.3, a flow duration curve for each stream segment in this study was developed. These are shown in Figures 5-5 through Figure 5-14.

No flow gage exists on California Creek (OK121510020050_000) and Big Creek (OK121510030010_00). Therefore, flows for these waterbodies were estimated using the watershed area ration method based on measured flows for Verdigris River (OK121510020010_00) at USGS gage station 07171000. The flow duration curves were based on measured flows from 1938 to 2012.

No flow gage exists on Cow Creek (OK121510020050_000), Little Cabin Creek (OK121510030010_00), Hudson Creek (OK121600040040_00), or Neosho River (OK121600040010_00). Therefore, flows for these waterbodies were estimated using the watershed area ration method based on measured flows for Neosho River (OK121600040220_00) at USGS gage station 07185000. The flow duration curves were based on measured flows from 1939 to 2012.

Since no flow gage exists on Fivemile Creek (OK121600070110_00), flows were estimated using the watershed area ration method based on measured flows for Spring River (OK121600070010_00) at USGS gage station 07188000. The flow duration curves were based on measured flows from 1939 to 2012.

Figure 5-5 Flow Duration Curve for Verdigris River (OK121510020010_00)

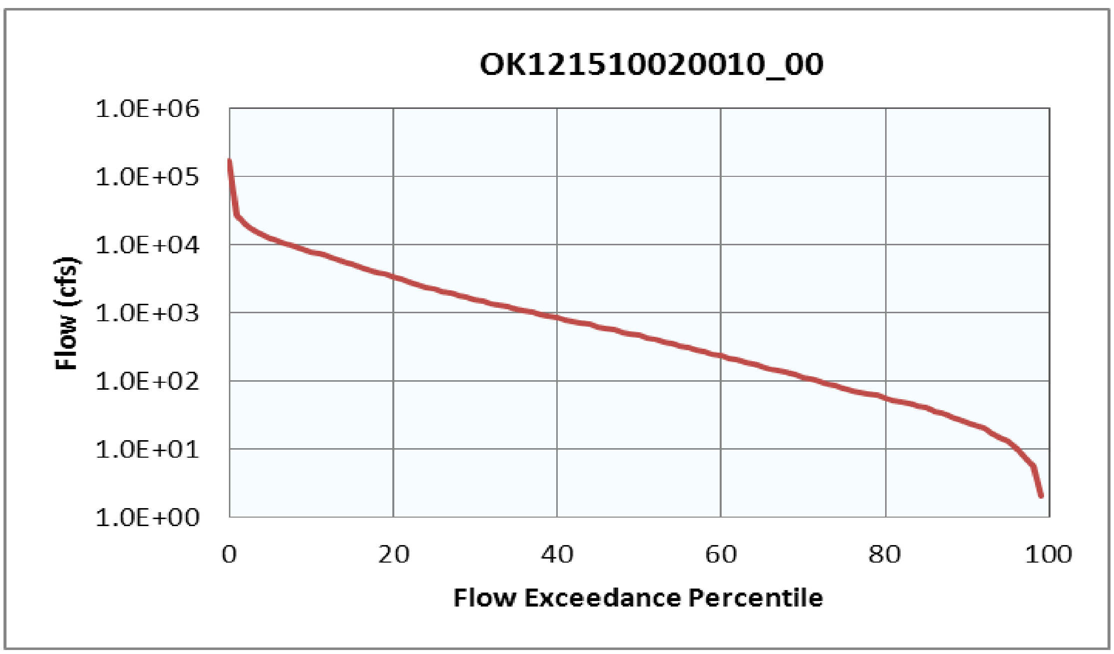


Figure 5-6 Flow Duration Curve for California Creek (OK121510020050_00)

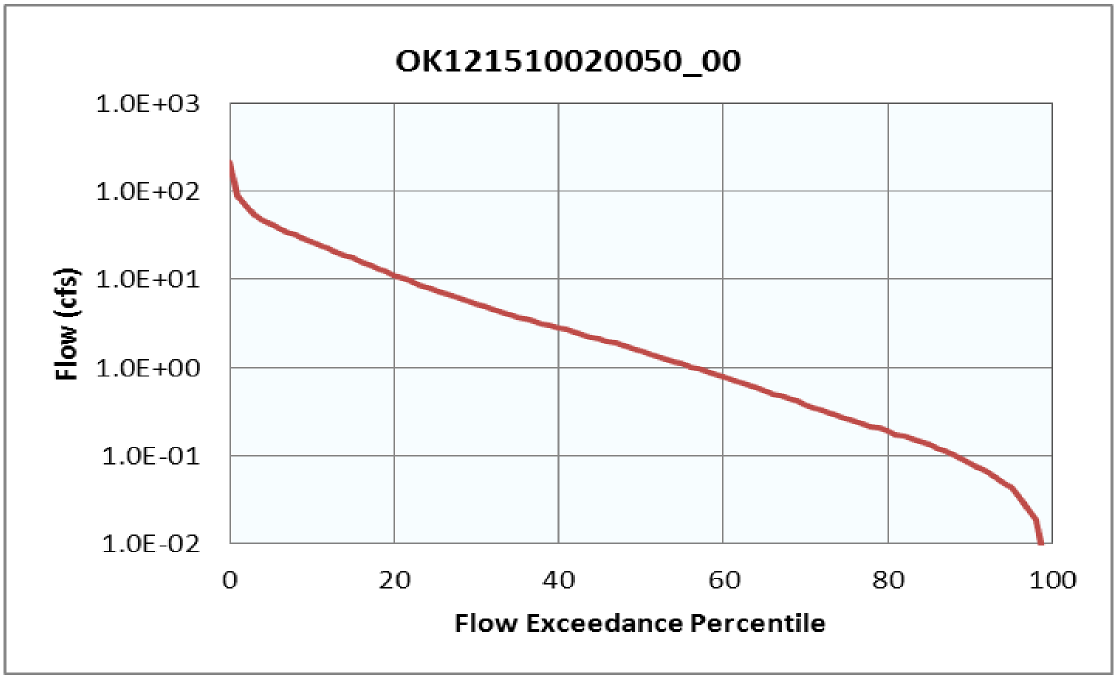


Figure 5-7 Flow Duration Curve for Big Creek (OK121510030010_00)

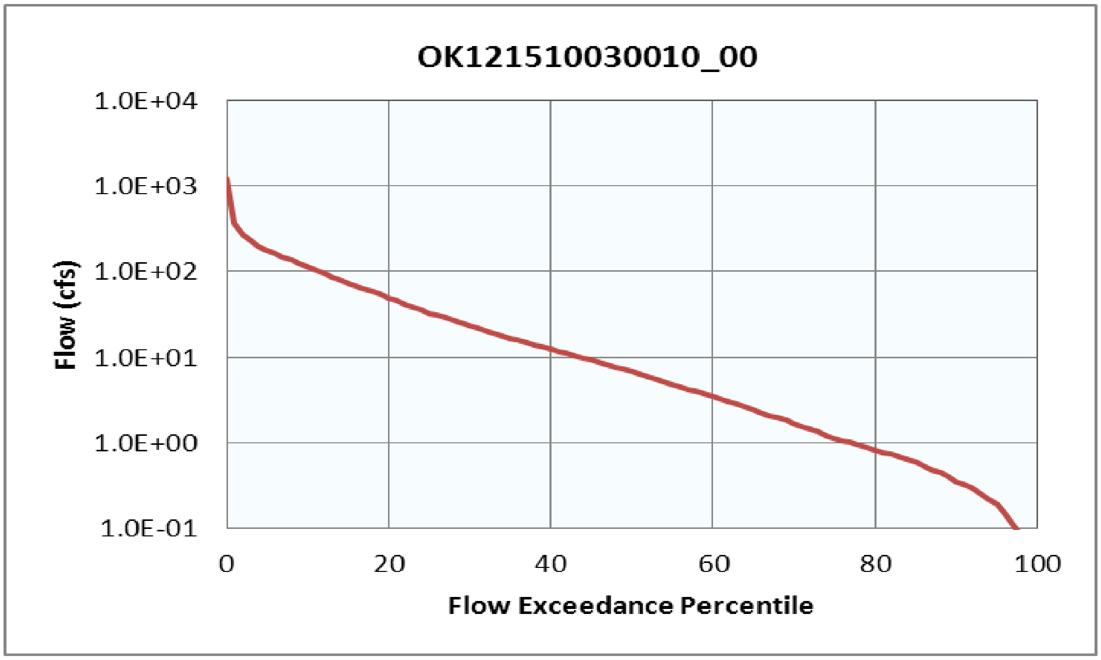


Figure 5-8 Flow Duration Curve for Neosho River (OK121600040010_00)

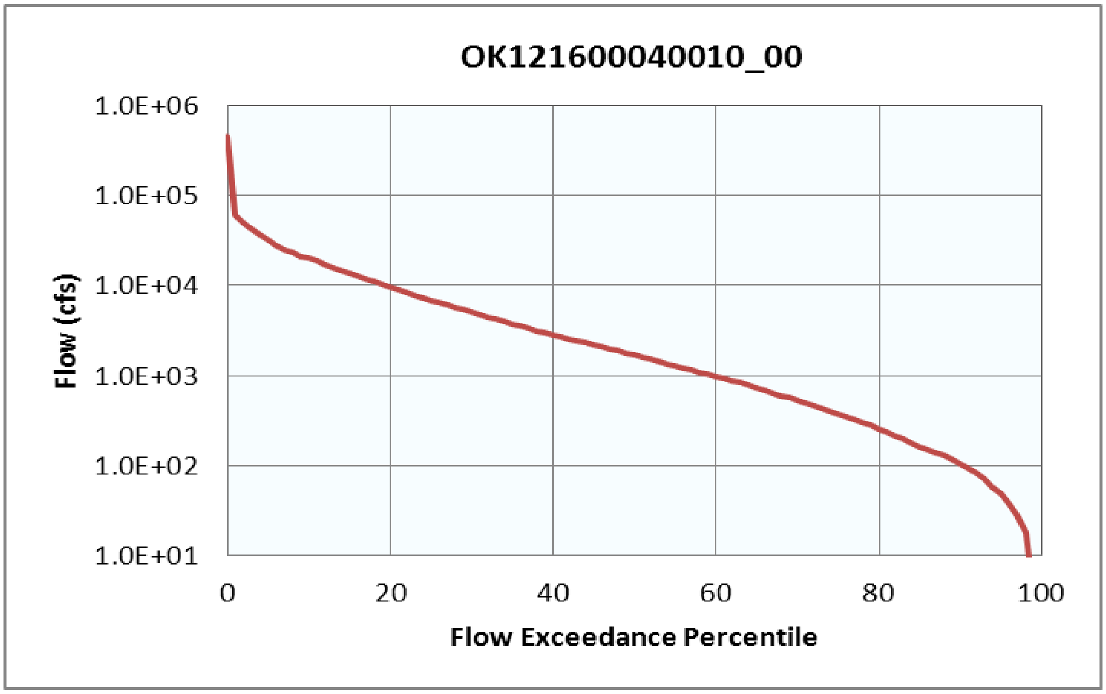


Figure 5-9 Flow Duration Curve for Hudson Creek (OK121600040040_00)

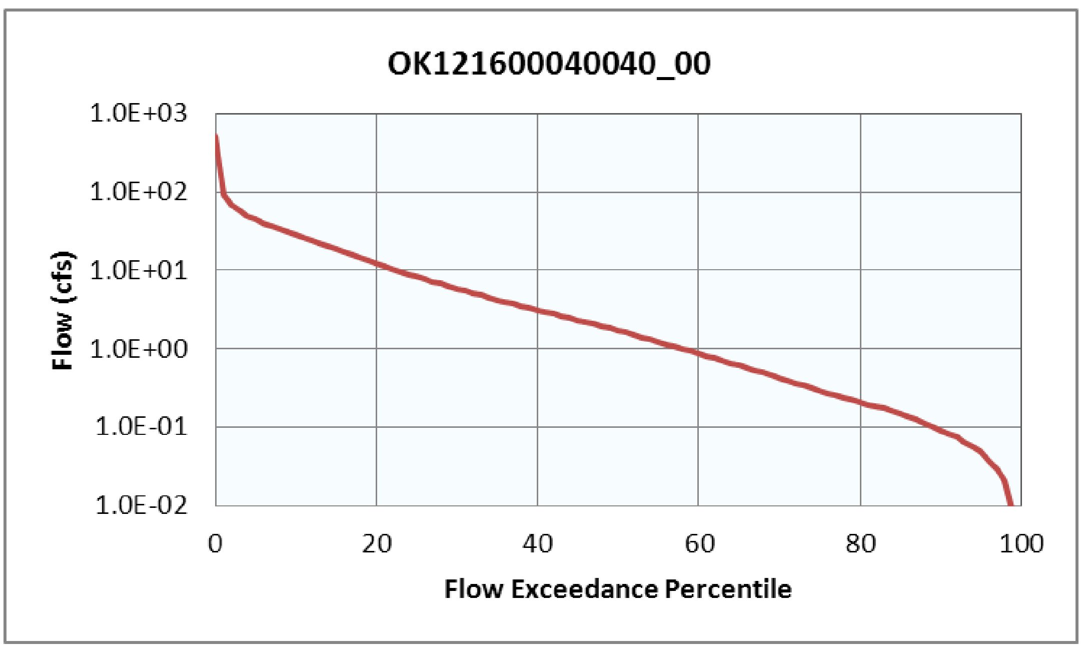


Figure 5-10 Flow Duration Curve for Cow Creek (OK121600040130_00)

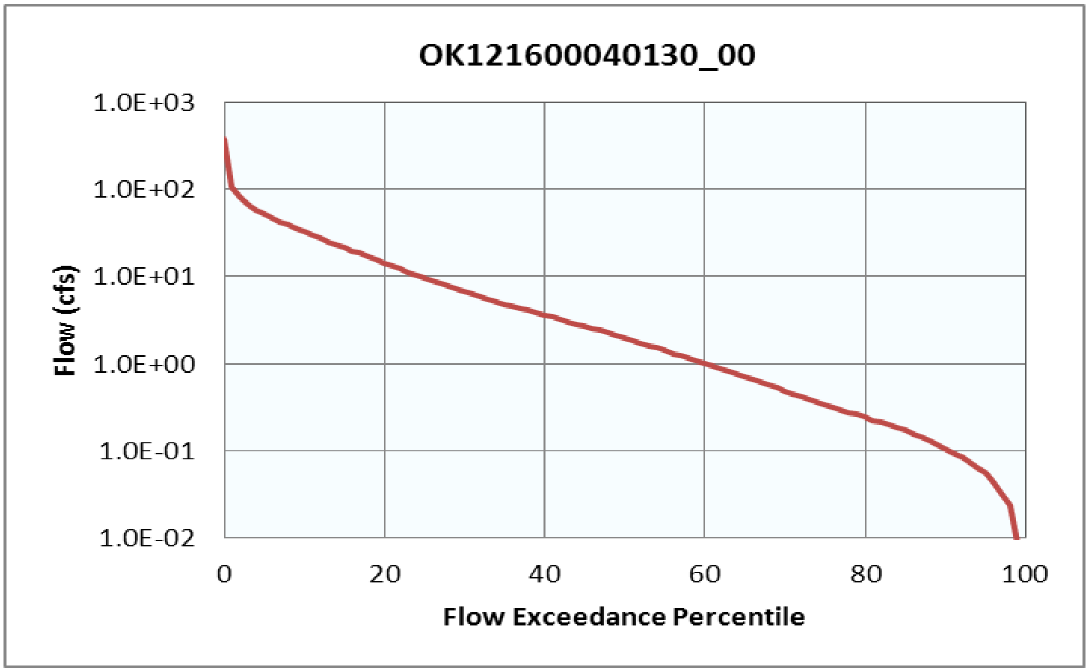


Figure 5-11 Flow Duration Curve for Neosho River (OK121600040220_00)

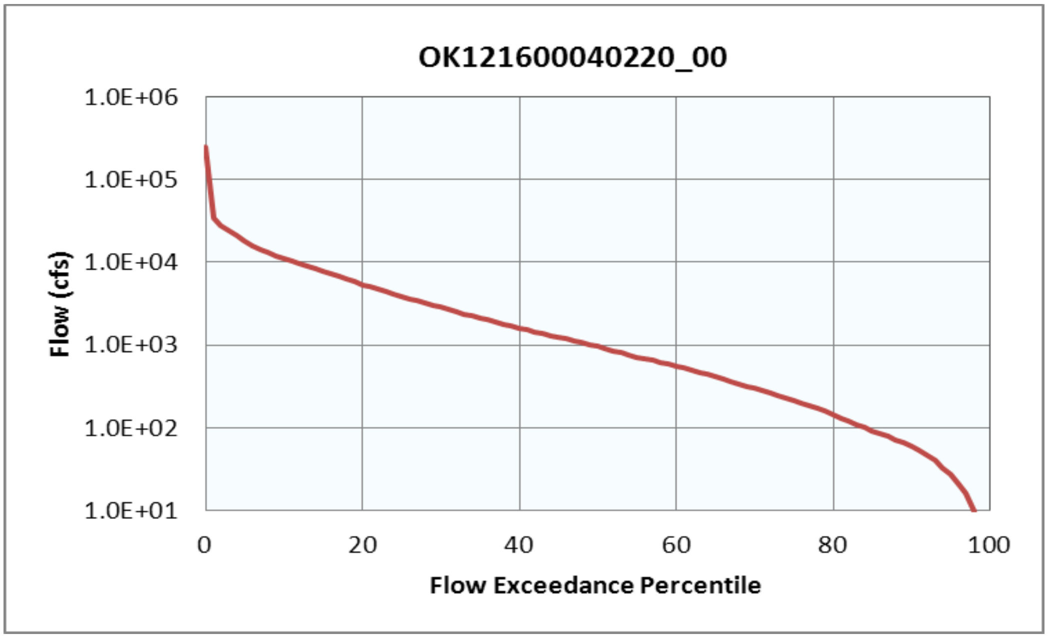


Figure 5-12 Flow Duration Curve for Little Cabin Creek (OK121600060080_00)

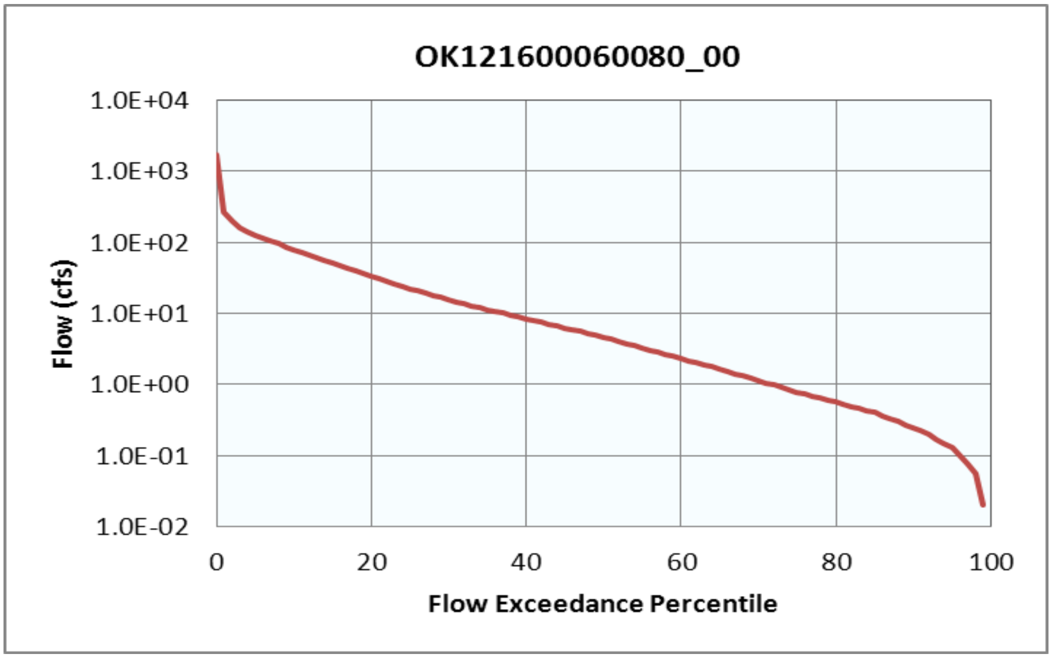


Figure 5-13 Flow Duration Curve for Spring River (OK121600070010_00)

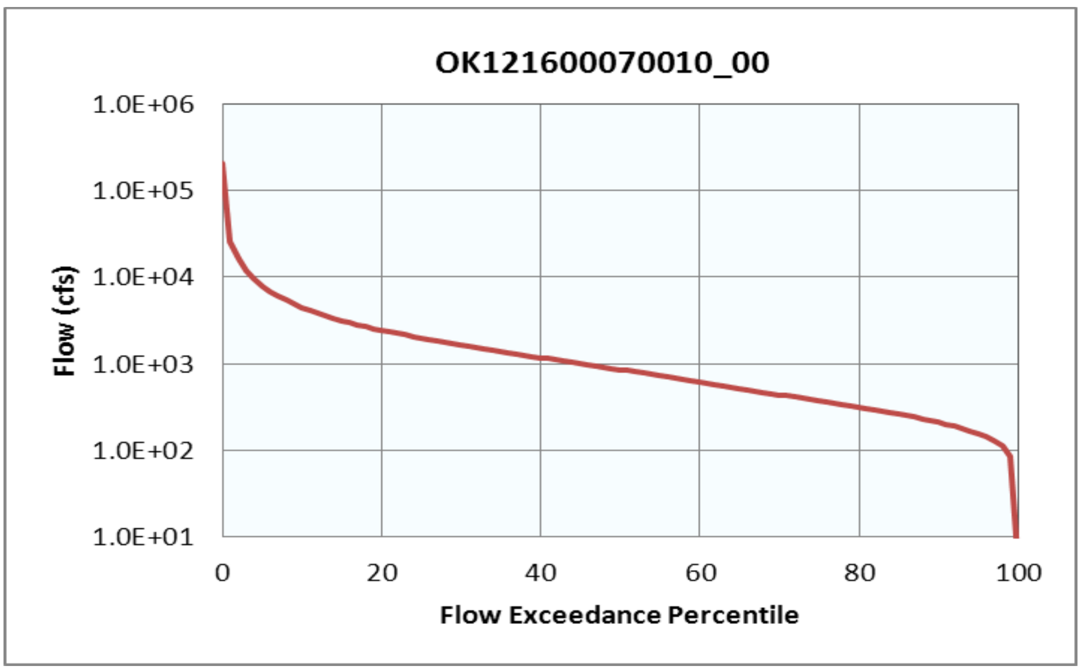
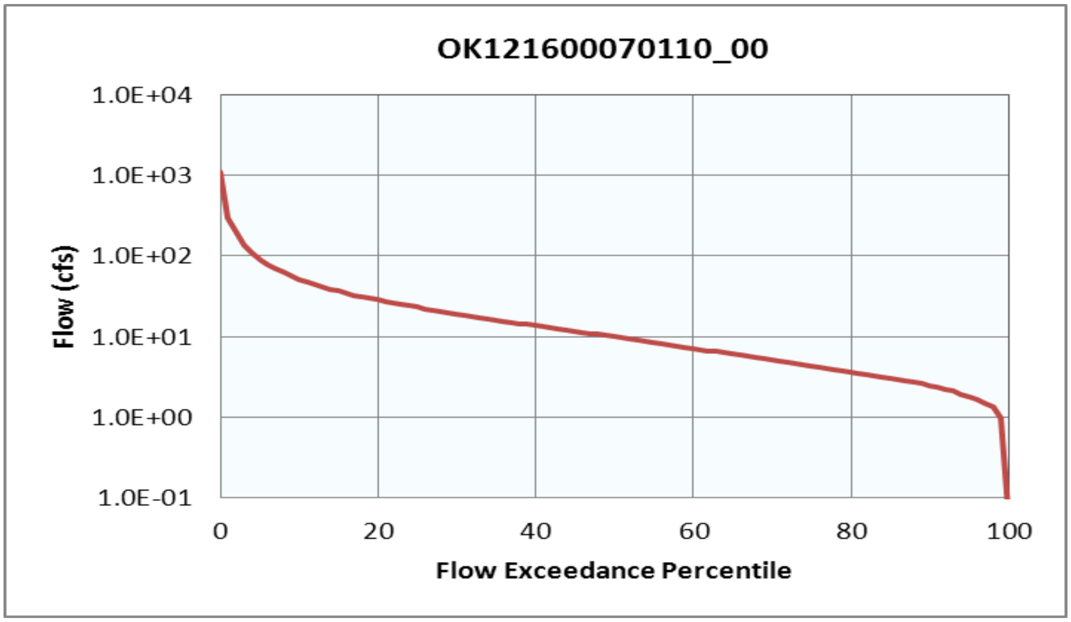


Figure 5-14 Flow Duration Curve for Fivemile Creek (OK121600070110_00)



5.3 Estimated Loading and Critical Conditions

EPA regulations at 40 CFR 130.7(c) (1) require TMDLs to take into account critical conditions for stream flow, loading, and all applicable WQS. To accomplish this, available instream WQM data were evaluated with respect to flows and magnitude of water quality criteria exceedance using LDCs.

5.3.1 Bacterial LDC

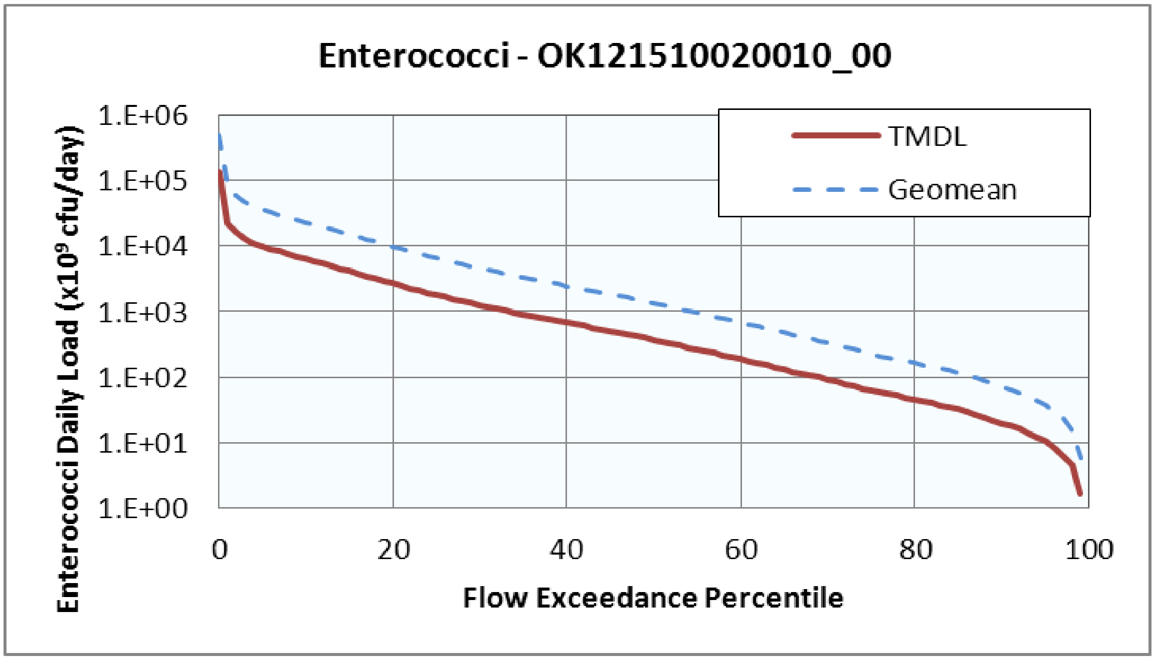
To calculate the allowable bacterial load, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (*24,465,525*) and the geometric mean water quality criterion for each bacterial indicator. This calculation produces the maximum bacterial load in the stream over the range of flow conditions. The allowable bacterial (*E. coli* or Enterococci) loads at the WQS establish the TMDL and are plotted versus flow exceedance percentile as a LDC. The x-axis indicates the flow exceedance percentile, while the y-axis is expressed in terms of a bacterial load.

To estimate existing loading, the geometric mean of all bacterial observations (concentrations) for the primary contact recreation season (May 1st through September 30th) from 2000 to 2008 are paired with the flows measured or estimated in that waterbody. Pollutant loads are then calculated by multiplying the measured bacterial concentration by the flow rate and the unit conversion factor of *24,465,756*.

The bacterial LDCs developed for each impaired waterbody are shown in Figures 5-15 through 5-23. Each waterbody had an LDC for either *E. coli*, Enterococci or both. This is because for the PBCR use to be supported, criteria for each bacterial indicator must be met in each impaired waterbody.

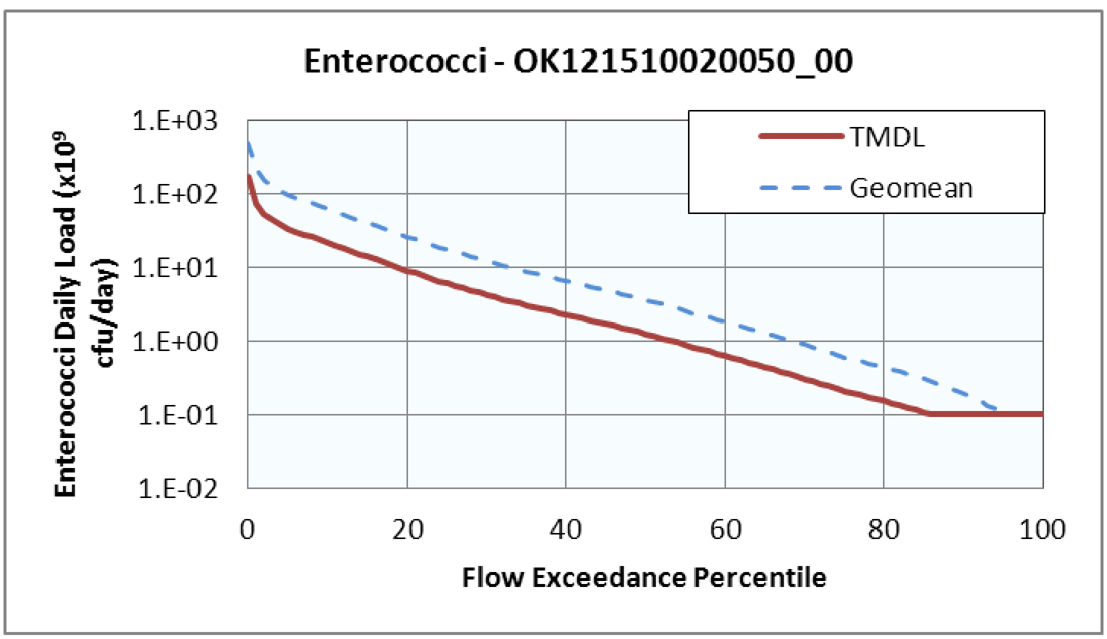
The LDC for Verdigris River (Figure 5-15) is based on Enterococci bacterial measurements collected during primary contact recreation season at WQM station 121510020010-001AT.

Figure 5-15 Load Duration Curve for Enterococci in Verdigris River (OK121510020010_00)



The LDC for California Creek (Figure 5-16) is based on Enterococci bacterial measurements collected during primary contact recreation season at WQM station OK121510-02-0050C.

Figure 5-17 Load Duration Curve for Enterococci in California Creek (OK121510020050_00)



The LDCs for Big Creek (Figures 5-17 and 5-18) are based on *E. coli* and Enterococci measurements during primary contact recreation season at WQM stations OK121510-03-0010G0090G and OK121510-03-0010D.

Figure 5-17 Load Duration Curve for *E. coli* in Big Creek (OK121510030010_00)

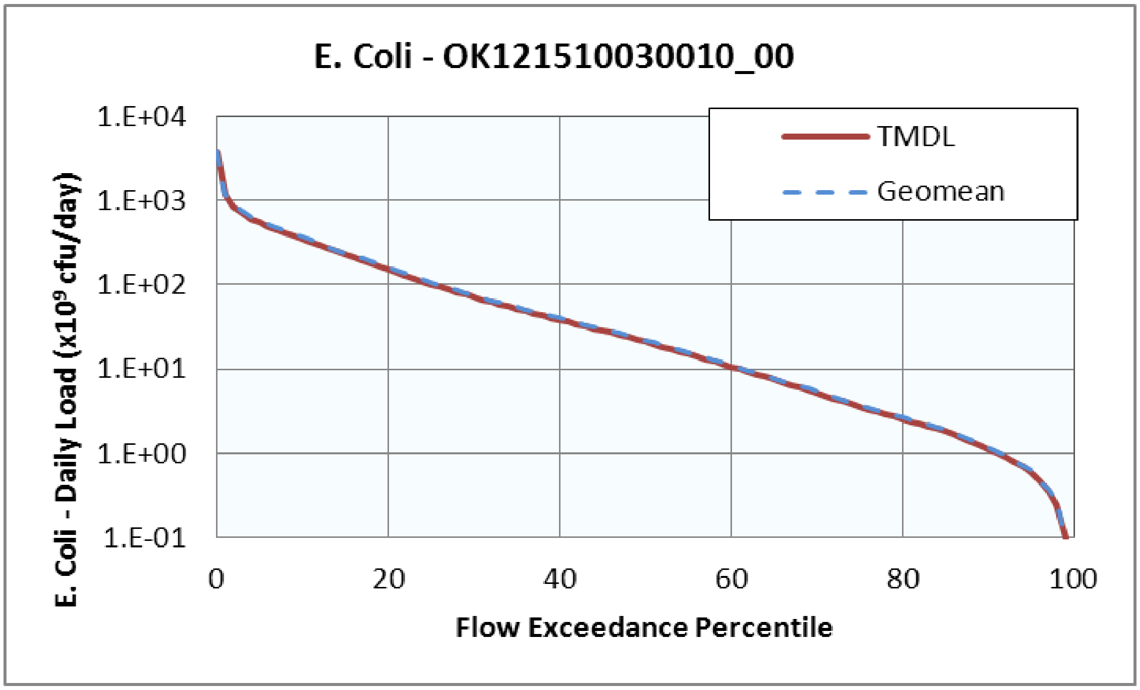
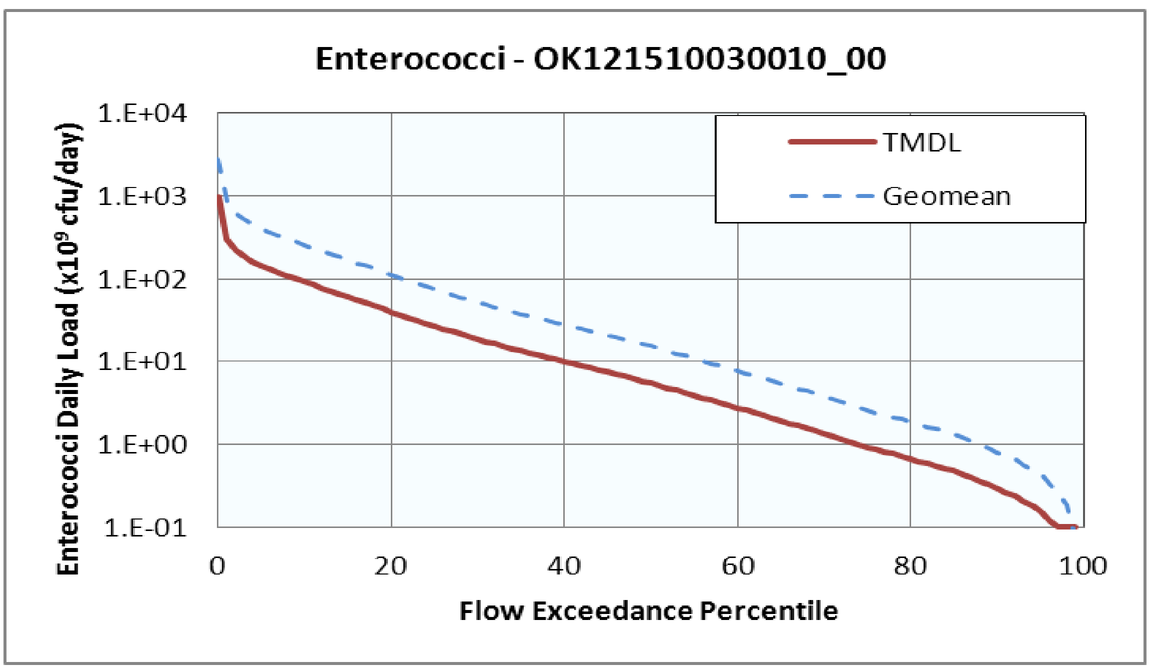
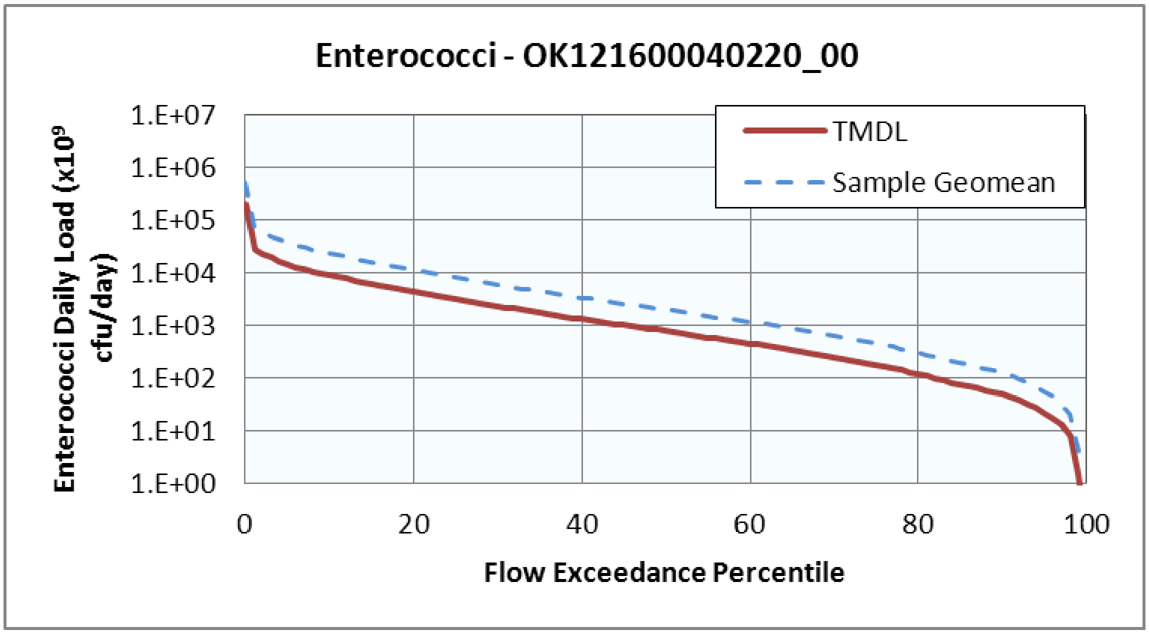


Figure 5-18 Load Duration Curve for Enterococci in Big Creek (OK121510030010_00)



The LDC for Neosho River (Figure 5-19) is based on Enterococci bacterial measurements collected during primary contact recreation season at WQM station 121600040220-001AT.

Figure 5-19 Load Duration Curve for Enterococci in Neosho River (OK121600040220_00)



The LDCs for the Little Cabin Creek (Figures 5-20 and 5-21) are based on *E. coli* and Enterococci measurements during primary contact recreation season at WQM stations OK121600-06-0080C.

Figure 5-20 Load Duration Curve for *E. coli* in Little Cabin Creek (OK121600060080_00)

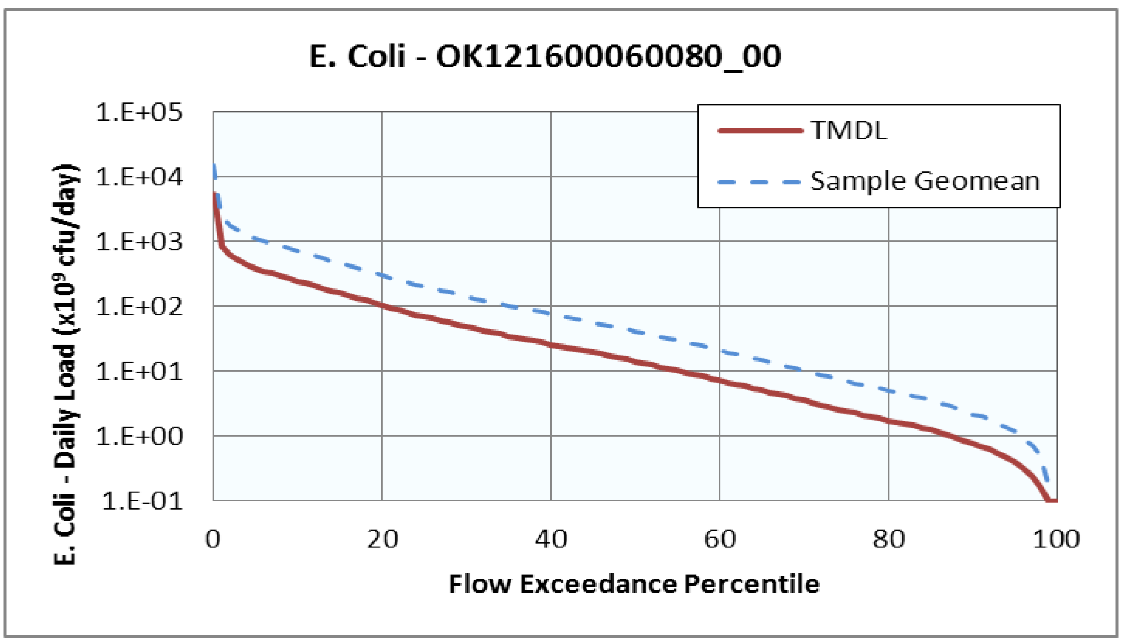
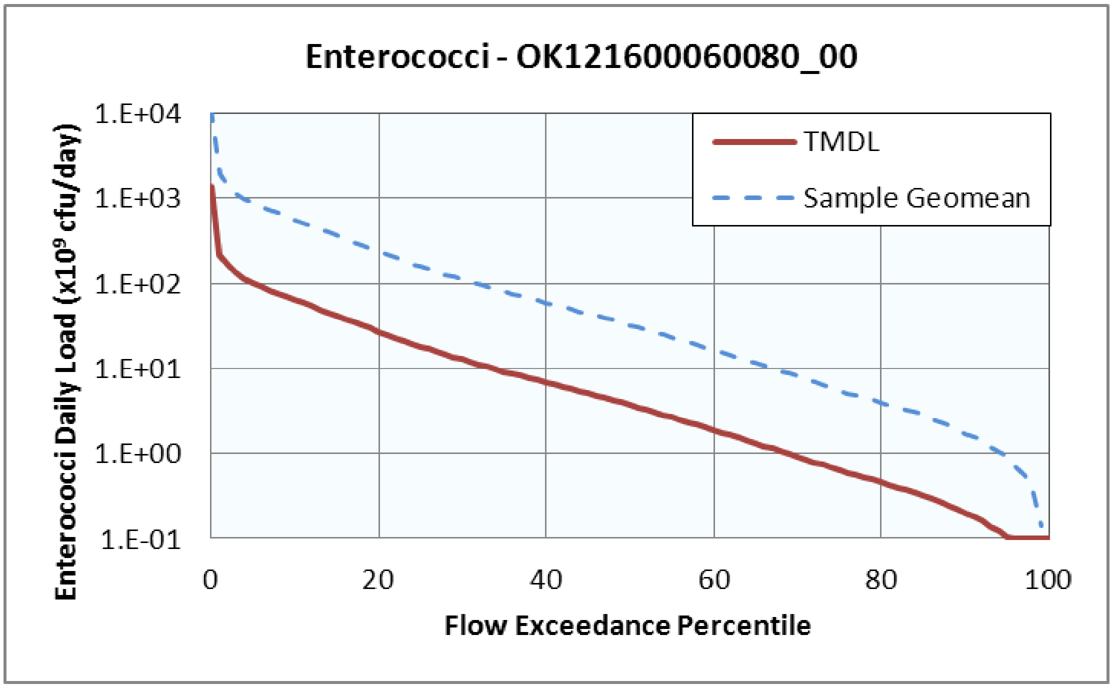
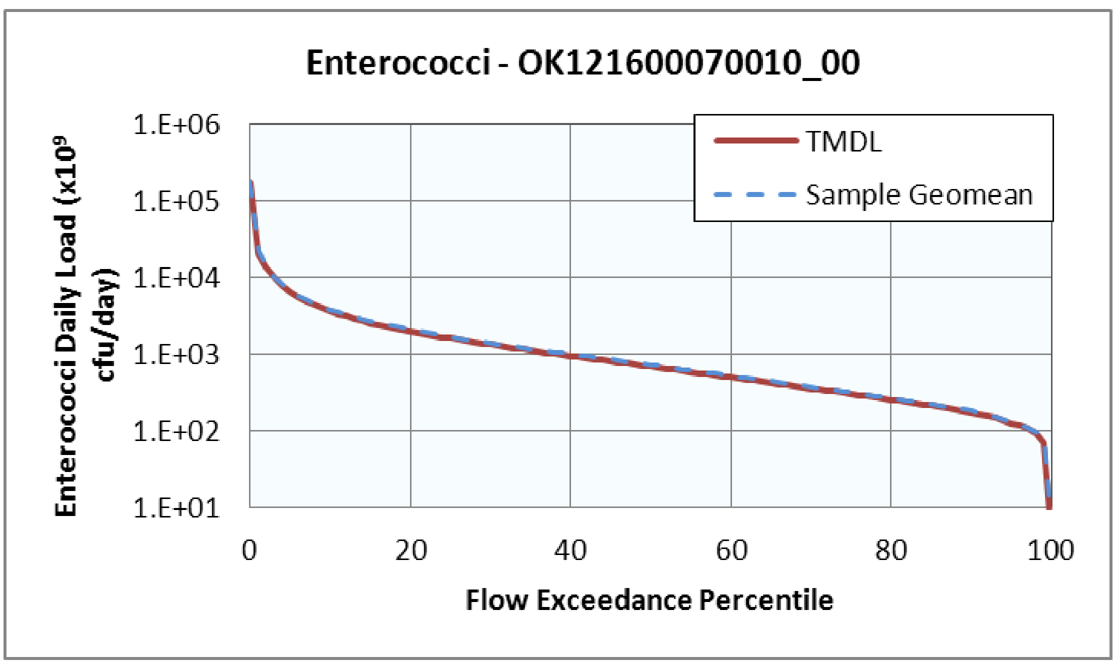


Figure 5-21 Load Duration Curve for Enterococci in Little Cabin Creek (OK121600060080_00)



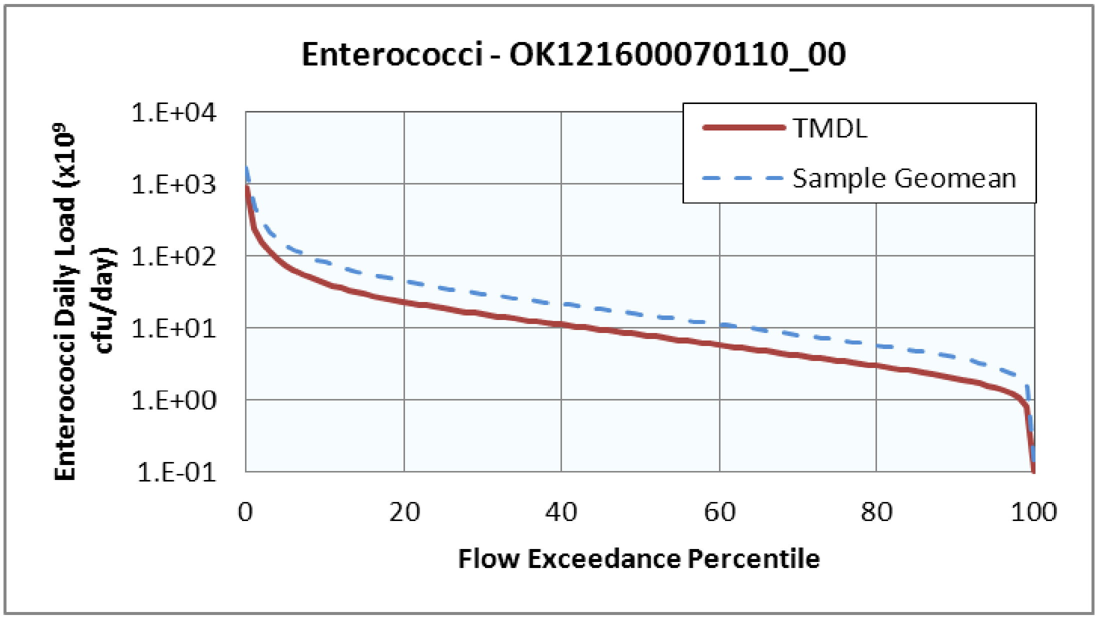
The LDC for Spring River (Figures 5-22) is based on Enterococci bacterial measurements collected during primary contact recreation season at WQM station 121600070010-001AT.

Figure 5-22 Load Duration Curve for Enterococci in Spring River (OK121600070010_00)



The LDC for Fivemile Creek (Figure 5-23) is based on Enterococci measurements during primary contact recreation season at WQM station OK121600-07-0110G.

Figure 5-23 Load Duration Curve for Enterococci in Fivemile Creek (OK121600070110_00)



5.3.2 TSS LDC

To calculate the TSS load at the WQ target, the flow rate (cfs) at each flow exceedance percentile is multiplied by a unit conversion factor (*5.39377*) and the TSS goal (mg/L) for each waterbody. This calculation produces the maximum TSS load in the waterbody that will result in attainment of the 50 NTU target for turbidity. The allowable TSS loads at the WQS establish the TMDL and are plotted versus flow exceedance percentile as a LDC. The x-axis indicates the flow exceedance percentile, while the y-axis is expressed in terms of a TSS load in pounds per day.

To estimate existing loading, TSS and turbidity observations from 1998 to 2011 are paired with the flows measured or projected on the same date for the waterbody. For sampling events with both TSS and turbidity data, the measured TSS value is used. Pollutant loads are then calculated by multiplying the TSS concentration by the flow rate and the unit conversion factor. The associated flow exceedance percentile is then matched with the flow from the tables provided in Appendix B. The observed TSS or converted turbidity loads are then added to the LDC plot as points. These points represent individual ambient water quality samples of TSS. Points above the LDC indicate the TSS goal was exceeded at the time of sampling. Conversely, points under the LDC indicate the sample did not exceed the TSS goal.

Figures 5-24 through Figure 5-28 show the TSS LDCs developed for the waterbodies addressed in this TMDL report. Data in the figures indicate that for most waterbodies, TSS levels exceed the water quality target during all flow conditions, indicating water quality impairments due to nonpoint sources or a combination of point and nonpoint sources. Wet weather influenced samples found during low flow conditions can be caused by an isolated rainfall event during dry weather conditions. It is noted that the LDC plots include data under all flow conditions to show the overall condition of the waterbody. However, the turbidity standard only applies for base-flow conditions. Thus, when interpreting the LDC to derive TMDLs for TSS, only the portion of the graph corresponding to flows above the 25th flow exceedance percentile should be used. WLAs for point sources discharges (continuous) of inorganic TSS are shown on a LDC as a horizontal line which represents the sum of all WLAs for TSS in a given watershed.

Figure 5-24 Load Duration Curve for Total Suspended Solids in Verdigris River (OK121510020010_00)

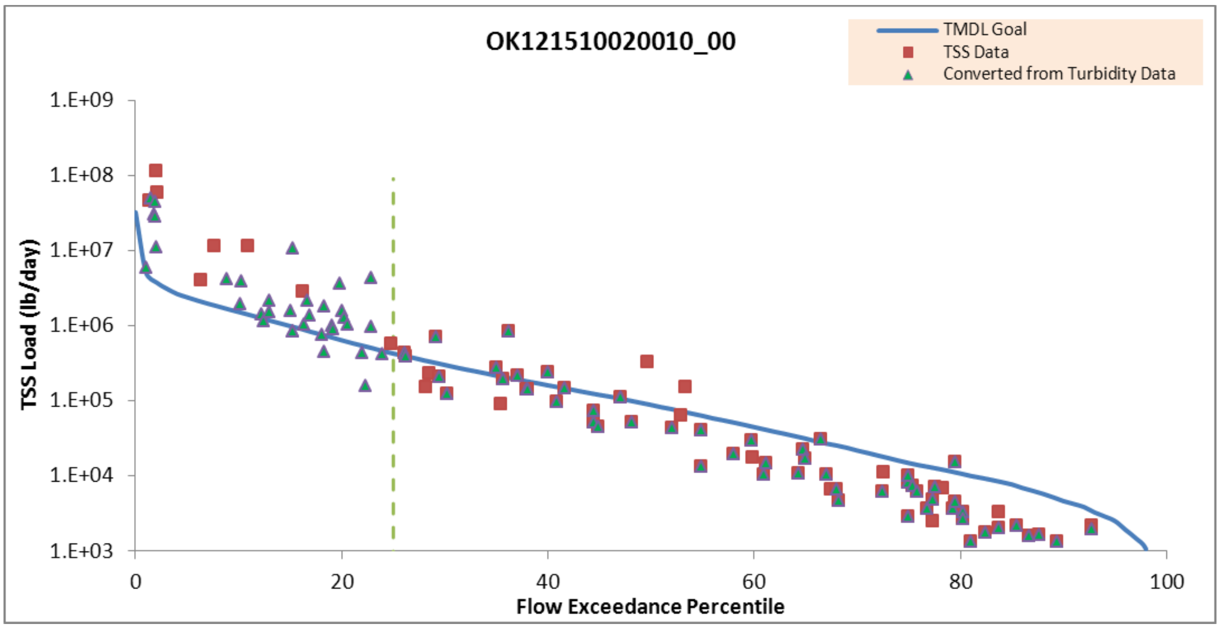


Figure 5-25 Load Duration Curve for Total Suspended Solids in Neosho River (OK121600040010_00)

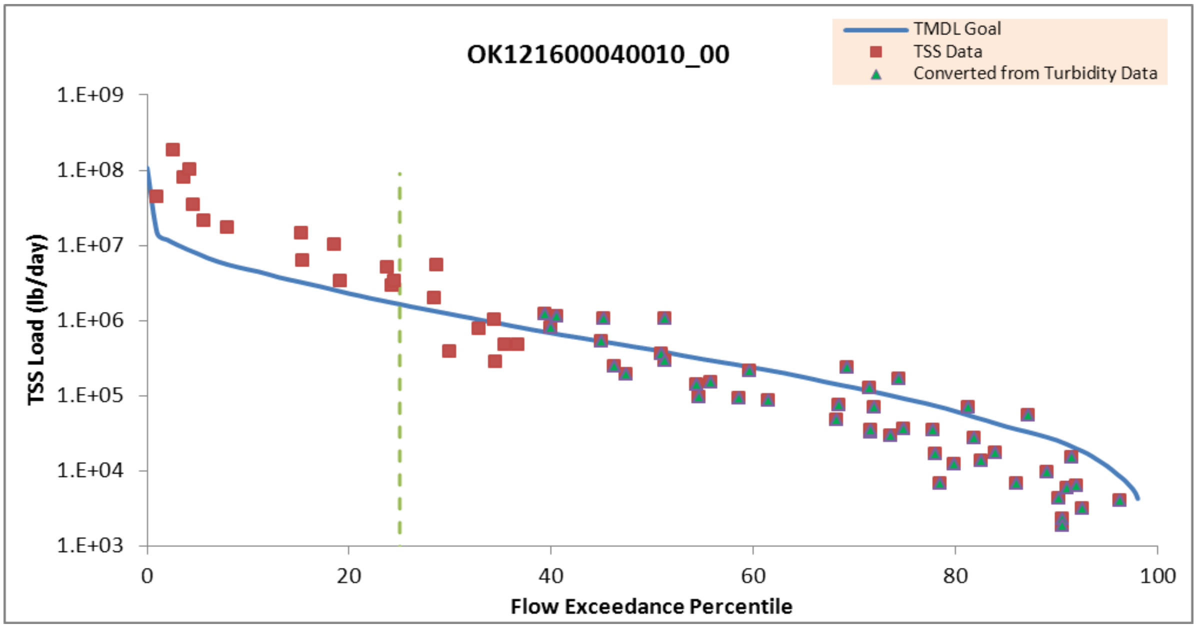


Figure 5-26 Load Duration Curve for Total Suspended Solids in Hudson Creek (OK121600040040_00)

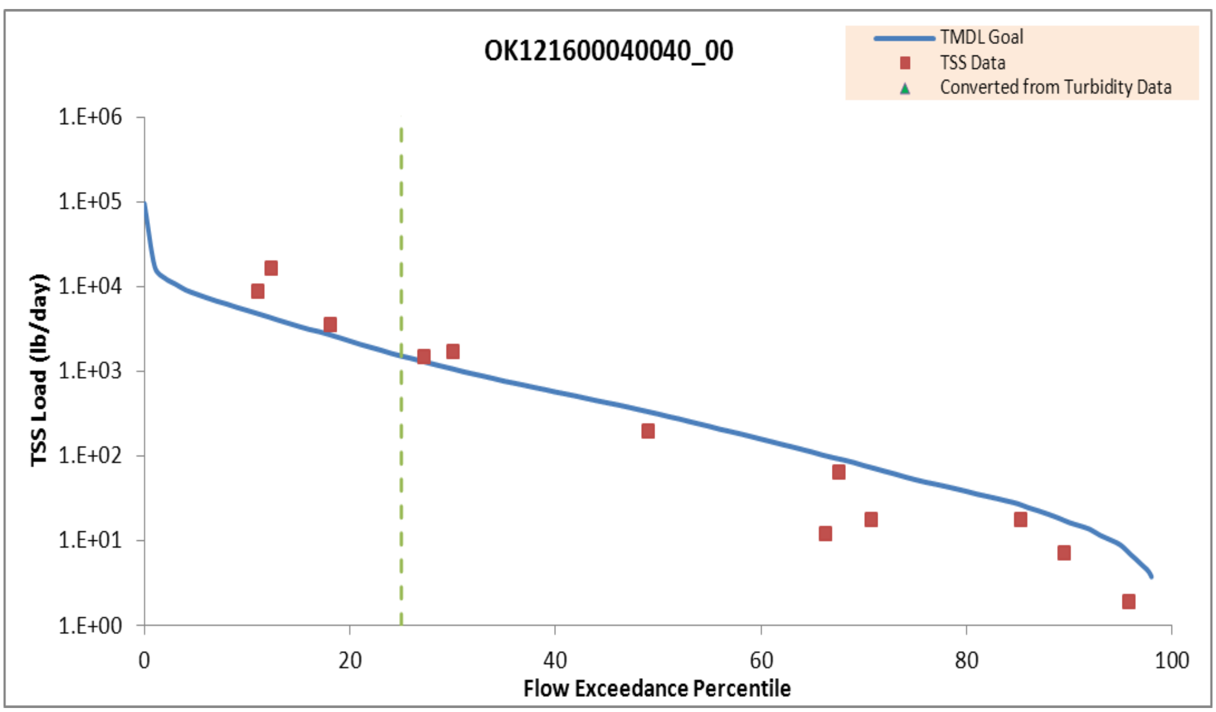


Figure 5-27 Load Duration Curve for Total Suspended Solids in Cow Creek (OK121600040130_00)

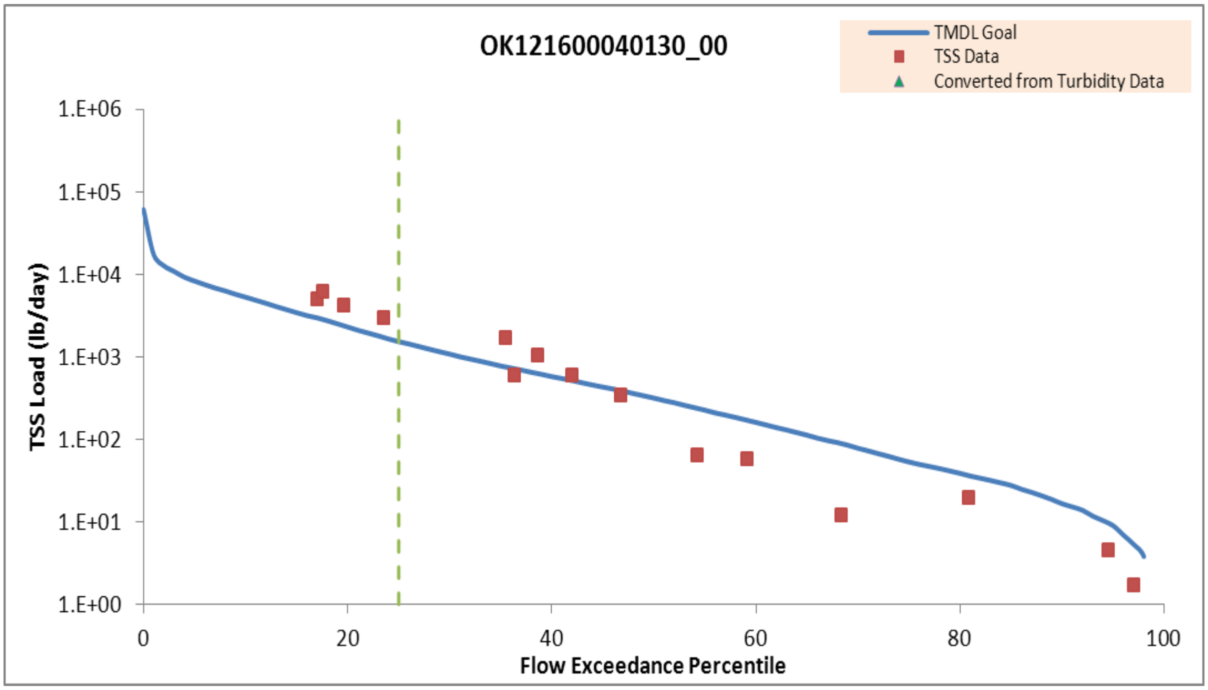
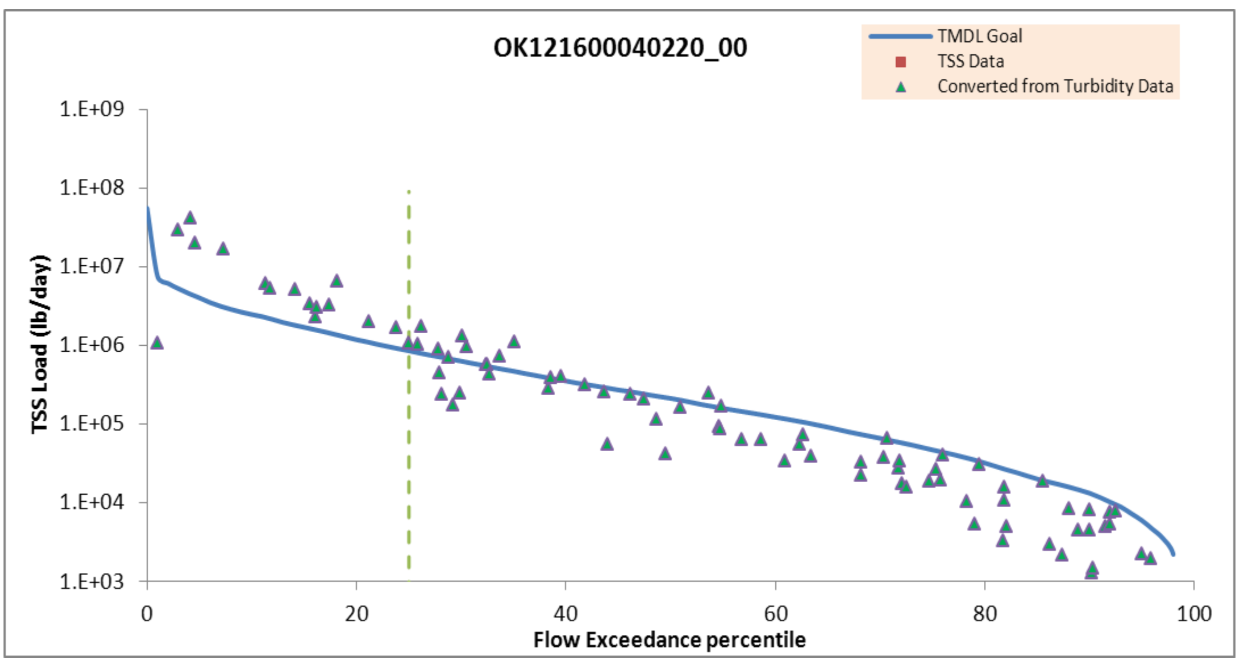


Figure 5-28 Load Duration Curve for Total Suspended Solids in Neosho River (OK311200000010_00)



5.3.3 Establishing Percent Reduction Goals

The LDC approach recognizes that the assimilative capacity of a waterbody depends on the flow, and that maximum allowable loading varies with flow condition. Existing loading and load reductions required to meet the TMDL can also be calculated under different flow conditions. The difference between existing loading and the TMDL is used to calculate the loading reductions required. PRGs are calculated through an iterative process of taking a series of percent reduction values, applying each value uniformly to the concentrations of samples and verifying if the geometric mean of the reduced values of all samples is less than the WQS geometric mean. Table 5-2 represents the percent reductions necessary to meet the TMDL water quality target for each bacterial indicator in each of the impaired waterbodies in the Study Area. The PRGs range from 4.6% to 88.5%.

Table 5-2 TMDL Percent Reductions Required to Meet Water Quality Standards for Indicator Bacteria

Waterbody ID	Waterbody Name	Required Reduction Rate	
		EC	ENT
OK121510020010_00	Verdigris River		72.5%
OK121510020050_00	California Creek		65.3%
OK121510030010_00	Big Creek	4.8%	64.2%
OK121600040220_00	Neosho River		61.2%
OK121600060080_00	Little Cabin Creek	65.6%	88.5%
OK121600070010_00	Spring River		4.6%
OK121600070110_00	Fivemile Creek		48.1%

PRGs for TSS are calculated as the required overall reduction so that no more than 10% of the samples exceed the water quality target for TSS. The PRGs for the seven waterbodies included in this TMDL report are summarized in Table 5-3 and range from 16% to 57%.

Table 5-3 TMDL Percent Reductions Required to Meet Water Quality Targets for Total Suspended Solids

Waterbody ID	Waterbody Name	Required Reduction Rate
OK121510020010_00	Verdigris River	16%
OK121600040010_00	Neosho River	57%
OK121600040040_00	Hudson Creek	37%
OK121600040130_00	Cow Creek	41%
OK121600040220_00	Neosho River	35%

5.4 Wasteload Allocation

5.4.1 Indicator Bacteria

For bacterial TMDLs, NPDES-permitted facilities are allocated a daily wasteload calculated as their permitted flow rate multiplied by the instream geometric mean water quality criterion. In other words, the facilities are required to meet instream criteria in their discharge. Table 5-4 summarizes the WLA for the NPDES-permitted facilities within the Verdigris-Neosho River Study Area. The WLA for each facility discharging to a bacterially-impaired waterbody is derived from the following equation:

WLA = WQS * flow * unit conversion factor (cfu/day)

Where:

WQS = 33 and 126 cfu/100 mL for Enterococci and E. coli respectively

flow (mgd) = permitted flow

unit conversion factor = 37,854,120

When multiple NPDES facilities occur within a watershed, individual WLAs are summed and the total WLA for continuous point sources is included in the TMDL calculation for the corresponding waterbody. When there are no NPDES WWTPs discharging into the contributing watershed of a stream segment, then the WLA is zero. Compliance with the WLA will be achieved by adhering to the fecal coliform or *E. coli* limits and disinfection requirements of NPDES permits. Currently, facilities that discharge treated wastewater are currently required to monitor for fecal coliform. These discharges or any other discharges with a bacterial WLA will be required to monitor for *E. coli* as their permits are renewed.

Table 5-4 indicates which point source dischargers within the Study Area currently have a disinfection requirement in their permit. Certain facilities that utilize lagoons for treatment have not been required to provide disinfection since storage time and exposure to ultraviolet radiation from sunlight should reduce bacterial levels. In the future, all point source dischargers which are assigned a wasteload allocation but do not currently have a bacterial limit in their permit will receive a permit limit consistent with the wasteload allocation as their permits are reissued. Regardless of the magnitude of the WLA calculated in these TMDLs, future new discharges of bacteria or increased bacterial load from existing discharges will be considered consistent with the TMDL provided that the NPDES permit requires instream criteria to be met.

Table 5-4 Bacterial Wasteload Allocations for NPDES-Permitted Facilities

Waterbody ID	NPDES Permit No.	Name	Dis-infection?	Design Flow (mg/d)	Wasteload Allocation (cfu/day)	
					E.coli	ENT
OK121510020010_00	OK0020117	South Coffeyville Public Works	Yes	0.159		1.99E+08
OK121510020050_00	OK0020796	City of Delaware	Yes	0.550		6.87E+07
OK121600060080_00	OK0031771	Bluejacket PWA	No	0.025	1.19E+08	3.12E+07
OK121600070010_00	OK0028258	Quapaw PWA	No	0.137		2.37E+08

Permitted stormwater discharges are considered point sources; however, there are no areas designated as MS4s within the watersheds of the Study Area impaired for contact recreation, so the WLA for MS4 is zero.

5.4.2 Total Suspended Solids

NPDES-permitted facilities discharging inorganic TSS are allocated a daily wasteload calculated by using the average of self-reported monthly flow multiplied by the water quality target. In other words, the facilities are required to meet instream criteria in their discharge. If the current monthly TSS limits of a facility are greater than instream TSS criteria, the new limits equal to instream criteria will be applied to the facility as their permit is renewed. Table 5-5 summarizes the WLA for the NPDES-permitted facilities within the Verdigris-Neosho Study Area. The WLA for each facility is derived as follows:

WLA_WWTP = WQ goal * flow * unit conversion factor (lb/day)

Where:

WQ goal = Waterbody specific water quality goal provided in Table 5-1, or monthly TSS limit in the current permit, whichever is smaller

flow (mgd) = average monthly flow

unit conversion factor = 8.3445

Table 5-5
Total Suspended Solids Wasteload Allocations for NPDES-Permitted Facilities

Waterbody ID	Instream TSS Criteria (mg/L)	NPDES Permit No.	Name	Average Monthly Flow (mgd)	Wasteload Allocation (lb/day)
OK121600040010_00	45	OKG950040	Midwest Minerals, Inc.- # 32	0.039	14.6

No TSS WLAs are needed for MS4s in the Study Area. By definition, any stormwater discharge occurs during periods of rainfall and elevated flow conditions. Oklahoma's Water Quality Standards specify that the criteria for turbidity "apply only to seasonal base flow conditions" and go on to say "Elevated turbidity levels may be expected during, and for several days after, a runoff event" [OAC 785:45-5-12(f)(7)]. To accommodate the potential for future growth in those watersheds with no WLA for TSS, 1% of TSS loading is reserved as part of the WLA.

5.4.3 Section 404 permits

No TSS WLAs were set aside for Section 404 Permits. The State will use its Section 401 Certification authority to ensure Section 404 Permits protect Oklahoma WQS and comply with TSS TMDLs in this report. Section 401 Certification will be conditioned to meet one of the following two conditions to be certified by the state:

- Include TSS limits in the permit and establish a monitoring requirement to ensure compliance with turbidity standards and TSS TMDLs; or
- Submit to the DEQ a BMP turbidity reduction plan which should include all practicable turbidity control techniques. The turbidity reduction plan must be approved first before a Section 401 Certification can be issued.

Compliance with the Section 401 Certification condition will be considered compliance with this TMDL.

5.5 Load Allocation

As discussed in Section 3, nonpoint source bacterial loading to each waterbody emanate from a number of different sources. The data analysis and the LDCs indicate that exceedances for each waterbody are the result of a variety of nonpoint source loading. The LAs for each bacterial indicator in waterbodies not supporting the PBCR use are calculated as the difference between the TMDL, MOS, and WLA, as follows:

LA = TMDL – WLA_WWTP – WLA_MS4 – MOS

This equation is used to calculate the LA for TSS however the LA is further reduced by allocating 1% of the TMDL as part of the WLA:

LA = TMDL – WLA_WWTP – WLA_MS4 – WLA_growth – MOS

5.6 Seasonal Variability

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. The bacterial TMDLs established in this report adhere to the seasonal application of the Oklahoma WQS which limits the PBCR use to the period of May 1st through September 30th. Similarly, the turbidity TMDLs established in this report adhere to the seasonal application of the Oklahoma WQS for turbidity, which applies to seasonal base flow conditions only. Seasonal variation was also accounted for in these TMDLs by using five years of water quality data and by using the longest period of USGS flow records when estimating flows to develop flow exceedance percentiles.

5.7 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. For bacterial TMDLs, an explicit MOS was set at 10%.

For turbidity, the TMDLs are calculated for TSS instead of turbidity. Thus, the quality of the regression has a direct impact on confidence of the TMDL calculations. The better the regression is, the more confidence there is in the TMDL targets. As a result, it leads to a smaller MOS. The selection of MOS is based on the NRMSE for each waterbody. The explicit MOS ranged from 10% to 15%. Table 5-6 shows the MOS for each waterbody.

Table 5-6 Explicit Margin of Safety for Total Suspended Solids TMDLs

Waterbody ID	Waterbody Name	NRMSE	Margin of Safety
OK121510020010_00	Verdigris River	7.5%	10%
OK121600040010_00	Neosho River	8.7%	10%
OK121600040040_00	Hudson Creek	12.1%	15%
OK121600040130_00	Cow Creek	8.8%	10%
OK121600040220_00	Neosho River	8.7%	10%

5.8 TMDL Calculations

The TMDLs for the 303(d)-listed waterbodies covered in this report were derived using LDCs. 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 lack of knowledge concerning the relationship between pollutant loading and water quality.

This definition can be expressed by the following equation:

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

The TMDL represents a continuum of desired load over all flow conditions, rather than fixed at a single value, because loading capacity varies as a function of the flow present in the stream. The higher the flow is, the more wasteload the stream can handle without violating WQS. Regardless of the magnitude of the WLA calculated in these TMDLs, future new discharges or increased load from existing discharges will be considered consistent with the TMDL provided the NPDES permit requires instream criteria to be met.

The TMDL, WLA, LA, and MOS will vary with flow condition, and are calculated at every 5^{th} flow interval percentile. Tables 5-7 and 5-8 summarize the TMDL, WLA, LA and MOS loadings at the 50% flow percentile. Tables 5-9 through 5-17 summarize the allocations for indicator bacteria. The bacterial TMDLs calculated in these tables apply to the recreation season (May 1 through September 30) only. Tables 5-18 to 5-22 present the allocations for total suspended solids.

Table 5-7 Summaries of Bacterial TMDLs

Stream Name	Waterbody ID	Pollutant	TMDL (cfu/day)	WLA_WWTP (cfu/day)	WLA_MS4 (cuf/day)	LA (cfu/day)	MOS (cfu/day)
Verdigris River	OK121510020010_00	ENT	3.70E+11	1.99E+08	0	3.33E+11	3.70E+10
California Creek	OK121510020050_00	ENT	1.24E+09	6.87E+07	0	1.05E+09	1.24E+08
Big Creek	OK121510030010_00	ENT	5.48E+09	0	0	4.93E+09	5.48E+08
		EC	2.09E+10	0	0	1.88E+10	2.09E+09
Neosho River	OK121600040220_00	ENT	7.76E+11	0	0	6.98E+11	7.76E+10
Little Cabin Creek	OK121600060080_00	ENT	3.73E+09	3.12E+07	0	3.32E+09	3.73E+08
		EC	1.42E+10	1.19E+08	0	1.27E+10	1.42E+09
Spring River	OK121600070010_00	ENT	6.91E+11	1.71E+08	0	6.22E+11	6.91E+10
Fivemile Creek	OK121600070110_00	ENT	8.04E+09	0	0	7.24E+09	8.04E+08

Table 5-8 Summaries of TSS TMDLs

Stream Name	Waterbody ID	Pollutant	TMDL (lbs/day)	WLA (lbs/day)	WLA_MS4 (cuf/day)	WLA_Growth (lbs/day)	LA (lbs/day)	MOS (lbs/day)
Verdigris River	OK121510020010_00	TSS	2.52E+05	0	0	2.52E+03	2.24E+05	2.52E+04
Neosho River	OK121600040010_00	TSS	9.36E+05	1.46E+01	0	9.36E+03	8.33E+05	9.36E+04
Hudson Creek	OK121600040040_00	TSS	9.43E+02	0	0	9.43E+00	7.92E+02	1.41E+02
Cow Creek	OK121600040130_00	TSS	1.09E+03	0	0	1.09E+01	9.66E+02	1.09E+02
Neosho River	OK121600040220_00	TSS	5.28E+05	0	0	5.28E+03	4.70E+05	5.28E+04

Table 5-9 Enterococci TMDL Calculations for Verdigris River (OK121510020010_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	168000	1.36E+14	1.99E+08	0	1.22E+14	1.36E+13
5	12400	1.00E+13	1.99E+08	0	9.01E+12	1.00E+12
10	7890	6.37E+12	1.99E+08	0	5.73E+12	6.37E+11
15	5130	4.14E+12	1.99E+08	0	3.73E+12	4.14E+11
20	3320	2.68E+12	1.99E+08	0	2.41E+12	2.68E+11
25	2210	1.78E+12	1.99E+08	0	1.61E+12	1.78E+11
30	1560	1.26E+12	1.99E+08	0	1.13E+12	1.26E+11
35	1120	9.04E+11	1.99E+08	0	8.14E+11	9.04E+10
40	834	6.73E+11	1.99E+08	0	6.06E+11	6.73E+10
45	623	5.03E+11	1.99E+08	0	4.52E+11	5.03E+10
50	458	3.70E+11	1.99E+08	0	3.33E+11	3.70E+10
55	327	2.64E+11	1.99E+08	0	2.37E+11	2.64E+10
60	232	1.87E+11	1.99E+08	0	1.68E+11	1.87E+10
65	163	1.32E+11	1.99E+08	0	1.18E+11	1.32E+10
70	113	9.12E+10	1.99E+08	0	8.19E+10	9.12E+09
75	77	6.22E+10	1.99E+08	0	5.58E+10	6.22E+09
80	56	4.52E+10	1.99E+08	0	4.05E+10	4.52E+09
85	40	3.23E+10	1.99E+08	0	2.89E+10	3.23E+09
90	24	1.94E+10	1.99E+08	0	1.72E+10	1.94E+09
95	13	1.05E+10	1.99E+08	0	9.25E+09	1.05E+09
100	0	1.99E+08	1.99E+08	0	0.00E+00	0.00E+00

Table 5-10 Enterococci TMDL Calculations for California Creek (OK121510020050_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	213.57	1.72E+11	6.87E+07	0	1.55E+11	1.72E+10
5	41.73	3.37E+10	6.87E+07	0	3.03E+10	3.37E+09
10	26.55	2.14E+10	6.87E+07	0	1.92E+10	2.14E+09
15	17.26	1.39E+10	6.87E+07	0	1.25E+10	1.39E+09
20	11.17	9.02E+09	6.87E+07	0	8.05E+09	9.02E+08
25	7.44	6.00E+09	6.87E+07	0	5.34E+09	6.00E+08
30	5.25	4.24E+09	6.87E+07	0	3.75E+09	4.24E+08
35	3.77	3.04E+09	6.87E+07	0	2.67E+09	3.04E+08
40	2.81	2.27E+09	6.87E+07	0	1.97E+09	2.27E+08
45	2.09	1.69E+09	6.87E+07	0	1.45E+09	1.69E+08
50	1.54	1.24E+09	6.87E+07	0	1.05E+09	1.24E+08
55	1.10	8.88E+08	6.87E+07	0	7.31E+08	8.88E+07
60	0.78	6.30E+08	6.87E+07	0	4.99E+08	6.30E+07
65	0.55	4.43E+08	6.87E+07	0	3.30E+08	4.43E+07
70	0.38	3.07E+08	6.87E+07	0	2.08E+08	3.07E+07
75	0.26	2.09E+08	6.87E+07	0	1.20E+08	2.09E+07
80	0.19	1.52E+08	6.87E+07	0	6.82E+07	1.52E+07
85	0.13	1.09E+08	6.87E+07	0	2.91E+07	1.09E+07
90	0.08	6.52E+07	6.87E+07	0	0.00E+00	6.52E+06
95	0.04	3.53E+07	6.87E+07	0	0.00E+00	3.53E+06
100	0.00	6.87E+07	6.87E+07	0	0.00E+00	0.00E+00

Table 5-11 *E. coli* TMDL Calculations for Big Creek (OK121510030010_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	1200	3.70E+12	0	0	3.33E+12	3.70E+11
5	178	5.48E+11	0	0	4.93E+11	5.48E+10
10	113	3.49E+11	0	0	3.14E+11	3.49E+10
15	74	2.27E+11	0	0	2.04E+11	2.27E+10
20	49	1.52E+11	0	0	1.37E+11	1.52E+10
25	33	1.01E+11	0	0	9.09E+10	1.01E+10
30	23	7.13E+10	0	0	6.42E+10	7.13E+09
35	17	5.12E+10	0	0	4.61E+10	5.12E+09
40	12	3.81E+10	0	0	3.43E+10	3.81E+09
45	9.23	2.85E+10	0	0	2.56E+10	2.85E+09
50	6.79	2.09E+10	0	0	1.88E+10	2.09E+09
55	4.85	1.49E+10	0	0	1.35E+10	1.49E+09
60	3.44	1.06E+10	0	0	9.54E+09	1.06E+09
65	2.42	7.45E+09	0	0	6.70E+09	7.45E+08
70	1.68	5.16E+09	0	0	4.65E+09	5.16E+08
75	1.14	3.52E+09	0	0	3.17E+09	3.52E+08
80	0.83	2.56E+09	0	0	2.30E+09	2.56E+08
85	0.59	1.83E+09	0	0	1.65E+09	1.83E+08
90	0.36	1.10E+09	0	0	9.87E+08	1.10E+08
95	0.19	5.94E+08	0	0	5.35E+08	5.94E+07
100	0.00	0.00E+00	0	0	0.00E+00	0.00E+00

Table 5-12 Enterococci TMDL Calculations for Big Creek (OK121510030010_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	1200	9.69E+11	0	0	8.72E+11	9.69E+10
5	178	1.44E+11	0	0	1.29E+11	1.44E+10
10	113	9.13E+10	0	0	8.22E+10	9.13E+09
15	74	5.94E+10	0	0	5.35E+10	5.94E+09
20	49	3.97E+10	0	0	3.58E+10	3.97E+09
25	33	2.65E+10	0	0	2.38E+10	2.65E+09
30	23	1.87E+10	0	0	1.68E+10	1.87E+09
35	17	1.34E+10	0	0	1.21E+10	1.34E+09
40	12	9.98E+09	0	0	8.98E+09	9.98E+08
45	9.23	7.45E+09	0	0	6.71E+09	7.45E+08
50	6.79	5.48E+09	0	0	4.93E+09	5.48E+08
55	4.85	3.91E+09	0	0	3.52E+09	3.91E+08
60	3.44	2.78E+09	0	0	2.50E+09	2.78E+08
65	2.42	1.95E+09	0	0	1.76E+09	1.95E+08
70	1.68	1.35E+09	0	0	1.22E+09	1.35E+08
75	1.14	9.22E+08	0	0	8.30E+08	9.22E+07
80	0.83	6.70E+08	0	0	6.03E+08	6.70E+07
85	0.59	4.79E+08	0	0	4.31E+08	4.79E+07
90	0.36	2.87E+08	0	0	2.59E+08	2.87E+07
95	0.19	1.56E+08	0	0	1.40E+08	1.56E+07
100	0.00	0	0	0	0	0

Table 5-13 Enterococci TMDL Calculations for Neosho River (OK121600040220_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	251000	2.03E+14	0	0	1.82E+14	2.03E+13
5	18200	1.47E+13	0	0	1.32E+13	1.47E+12
10	11200	9.04E+12	0	0	8.14E+12	9.04E+11
15	7700	6.22E+12	0	0	5.60E+12	6.22E+11
20	5350	4.32E+12	0	0	3.89E+12	4.32E+11
25	3870	3.12E+12	0	0	2.81E+12	3.12E+11
30	2860	2.31E+12	0	0	2.08E+12	2.31E+11
35	2130	1.72E+12	0	0	1.55E+12	1.72E+11
40	1600	1.29E+12	0	0	1.16E+12	1.29E+11
45	1230	9.93E+11	0	0	8.94E+11	9.93E+10
50	961	7.76E+11	0	0	6.98E+11	7.76E+10
55	718	5.80E+11	0	0	5.22E+11	5.80E+10
60	554	4.47E+11	0	0	4.03E+11	4.47E+10
65	414	3.34E+11	0	0	3.01E+11	3.34E+10
70	300	2.42E+11	0	0	2.18E+11	2.42E+10
75	213	1.72E+11	0	0	1.55E+11	1.72E+10
80	145	1.17E+11	0	0	1.05E+11	1.17E+10
85	91	7.35E+10	0	0	6.61E+10	7.35E+09
90	60	4.84E+10	0	0	4.36E+10	4.84E+09
95	27	2.18E+10	0	0	1.96E+10	2.18E+09
100	0	0.00E+00	0	0	0.00E+00	0.00E+00

Table 5-14 *E. coli* TMDL Calculations for the Little Cabin Creek (OK121600060080_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	1693.19	5.22E+12	1.19E+08	0	4.70E+12	5.22E+11
5	124.97	3.85E+11	1.19E+08	0	3.47E+11	3.85E+10
10	79.52	2.45E+11	1.19E+08	0	2.21E+11	2.45E+10
15	51.70	1.59E+11	1.19E+08	0	1.43E+11	1.59E+10
20	33.46	1.03E+11	1.19E+08	0	9.27E+10	1.03E+10
25	22.27	6.87E+10	1.19E+08	0	6.17E+10	6.87E+09
30	15.72	4.85E+10	1.19E+08	0	4.35E+10	4.85E+09
35	11.29	3.48E+10	1.19E+08	0	3.12E+10	3.48E+09
40	8.41	2.59E+10	1.19E+08	0	2.32E+10	2.59E+09
45	6.27	1.93E+10	1.19E+08	0	1.73E+10	1.93E+09
50	4.62	1.42E+10	1.19E+08	0	1.27E+10	1.42E+09
55	3.30	1.02E+10	1.19E+08	0	9.02E+09	1.02E+09
60	2.34	7.21E+09	1.19E+08	0	6.37E+09	7.21E+08
65	1.64	5.06E+09	1.19E+08	0	4.44E+09	5.06E+08
70	1.14	3.51E+09	1.19E+08	0	3.04E+09	3.51E+08
75	0.78	2.39E+09	1.19E+08	0	2.03E+09	2.39E+08
80	0.56	1.74E+09	1.19E+08	0	1.45E+09	1.74E+08
85	0.40	1.24E+09	1.19E+08	0	9.99E+08	1.24E+08
90	0.24	7.46E+08	1.19E+08	0	5.52E+08	7.46E+07
95	0.13	4.04E+08	1.19E+08	0	2.44E+08	4.04E+07
100	0.00	1.19E+08	1.19E+08	0	0.00E+00	0.00E+00

Table 5-15 Enterococci TMDL Calculations for Little Cabin Creek (OK121600060080_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	1693.19	1.37E+12	3.12E+07	0	1.23E+12	1.37E+11
5	124.97	1.01E+11	3.12E+07	0	9.08E+10	1.01E+10
10	79.52	6.42E+10	3.12E+07	0	5.78E+10	6.42E+09
15	51.70	4.17E+10	3.12E+07	0	3.75E+10	4.17E+09
20	33.46	2.70E+10	3.12E+07	0	2.43E+10	2.70E+09
25	22.27	1.80E+10	3.12E+07	0	1.62E+10	1.80E+09
30	15.72	1.27E+10	3.12E+07	0	1.14E+10	1.27E+09
35	11.29	9.11E+09	3.12E+07	0	8.17E+09	9.11E+08
40	8.41	6.79E+09	3.12E+07	0	6.08E+09	6.79E+08
45	6.27	5.07E+09	3.12E+07	0	4.53E+09	5.07E+08
50	4.62	3.73E+09	3.12E+07	0	3.32E+09	3.73E+08
55	3.30	2.66E+09	3.12E+07	0	2.36E+09	2.66E+08
60	2.34	1.89E+09	3.12E+07	0	1.67E+09	1.89E+08
65	1.64	1.33E+09	3.12E+07	0	1.16E+09	1.33E+08
70	1.14	9.19E+08	3.12E+07	0	7.96E+08	9.19E+07
75	0.78	6.27E+08	3.12E+07	0	5.33E+08	6.27E+07
80	0.56	4.56E+08	3.12E+07	0	3.79E+08	4.56E+07
85	0.40	3.25E+08	3.12E+07	0	2.62E+08	3.25E+07
90	0.24	1.95E+08	3.12E+07	0	1.45E+08	1.95E+07
95	0.13	1.06E+08	3.12E+07	0	6.40E+07	1.06E+07
100	0.00	3.12E+07	3.12E+07	0	0.00E+00	0.00E+00

Table 5-16 Enterococci TMDL Calculations for Spring River (OK121600070010_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	210000	1.70E+14	1.71E+08	0	1.53E+14	1.70E+13
5	7794	6.29E+12	1.71E+08	0	5.66E+12	6.29E+11
10	4450	3.59E+12	1.71E+08	0	3.23E+12	3.59E+11
15	3140	2.54E+12	1.71E+08	0	2.28E+12	2.54E+11
20	2460	1.99E+12	1.71E+08	0	1.79E+12	1.99E+11
25	1980	1.60E+12	1.71E+08	0	1.44E+12	1.60E+11
30	1650	1.33E+12	1.71E+08	0	1.20E+12	1.33E+11
35	1380	1.11E+12	1.71E+08	0	1.00E+12	1.11E+11
40	1170	9.45E+11	1.71E+08	0	8.50E+11	9.45E+10
45	1000	8.07E+11	1.71E+08	0	7.26E+11	8.07E+10
50	856	6.91E+11	1.71E+08	0	6.22E+11	6.91E+10
55	723	5.84E+11	1.71E+08	0	5.25E+11	5.84E+10
60	613	4.95E+11	1.71E+08	0	4.45E+11	4.95E+10
65	519	4.19E+11	1.71E+08	0	3.77E+11	4.19E+10
70	438	3.54E+11	1.71E+08	0	3.18E+11	3.54E+10
75	375	3.03E+11	1.71E+08	0	2.72E+11	3.03E+10
80	315	2.54E+11	1.71E+08	0	2.29E+11	2.54E+10
85	264	2.13E+11	1.71E+08	0	1.92E+11	2.13E+10
90	212	1.71E+11	1.71E+08	0	1.54E+11	1.71E+10
95	155	1.25E+11	1.71E+08	0	1.12E+11	1.25E+10
100	6	4.68E+09	1.71E+08	0	4.04E+09	4.68E+08

Table 5-17 Enterococci TMDL Calculations for Fivemile Creek (OK121600070110_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTP} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	1085.90	8.77E+11	0	0	7.89E+11	8.77E+10
5	90.68	7.32E+10	0	0	6.59E+10	7.32E+09
10	51.77	4.18E+10	0	0	3.76E+10	4.18E+09
15	36.53	2.95E+10	0	0	2.65E+10	2.95E+09
20	28.62	2.31E+10	0	0	2.08E+10	2.31E+09
25	23.04	1.86E+10	0	0	1.67E+10	1.86E+09
30	19.20	1.55E+10	0	0	1.39E+10	1.55E+09
35	16.06	1.30E+10	0	0	1.17E+10	1.30E+09
40	13.61	1.10E+10	0	0	9.89E+09	1.10E+09
45	11.63	9.39E+09	0	0	8.45E+09	9.39E+08
50	9.96	8.04E+09	0	0	7.24E+09	8.04E+08
55	8.42	6.79E+09	0	0	6.12E+09	6.79E+08
60	7.13	5.76E+09	0	0	5.18E+09	5.76E+08
65	6.04	4.88E+09	0	0	4.39E+09	4.88E+08
70	5.10	4.11E+09	0	0	3.70E+09	4.11E+08
75	4.36	3.52E+09	0	0	3.17E+09	3.52E+08
80	3.66	2.96E+09	0	0	2.66E+09	2.96E+08
85	3.07	2.48E+09	0	0	2.23E+09	2.48E+08
90	2.47	1.99E+09	0	0	1.79E+09	1.99E+08
95	1.80	1.46E+09	0	0	1.31E+09	1.46E+08
100	0.07	5.45E+07	0	0	4.90E+07	5.45E+06

Table 5-18 Total Suspended Solids TMDL Calculations for Verdigris River (OK121510020010_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)			LA (lb/day)	MOS (lb/day)
			WWTP	MS4	Future growth		
0	168000	N/A	0	0	N/A	N/A	N/A
5	12400	N/A	0	0	N/A	N/A	N/A
10	7890	N/A	0	0	N/A	N/A	N/A
15	5130	N/A	0	0	N/A	N/A	N/A
20	3320	N/A	0	0	N/A	N/A	N/A
25	2210	1.21E+06	0	0	1.21E+04	1.08E+06	1.21E+05
30	1560	8.57E+05	0	0	8.57E+03	7.63E+05	8.57E+04
35	1120	6.15E+05	0	0	6.15E+03	5.48E+05	6.15E+04
40	834	4.58E+05	0	0	4.58E+03	4.08E+05	4.58E+04
45	623	3.42E+05	0	0	3.42E+03	3.04E+05	3.42E+04
50	458	2.52E+05	0	0	2.52E+03	2.24E+05	2.52E+04
55	327	1.80E+05	0	0	1.80E+03	1.60E+05	1.80E+04
60	232	1.27E+05	0	0	1.27E+03	1.13E+05	1.27E+04
65	163	8.96E+04	0	0	8.96E+02	7.97E+04	8.96E+03
70	113	6.21E+04	0	0	6.21E+02	5.53E+04	6.21E+03
75	77	4.23E+04	0	0	4.23E+02	3.77E+04	4.23E+03
80	56	3.08E+04	0	0	3.08E+02	2.74E+04	3.08E+03
85	40	2.20E+04	0	0	2.20E+02	1.96E+04	2.20E+03
90	24	1.32E+04	0	0	1.32E+02	1.17E+04	1.32E+03
95	13	7.14E+03	0	0	7.14E+01	6.36E+03	7.14E+02
100	0	0.00E+00	0	0	0.00E+00	0.00E+00	0.00E+00

NA = Not Applicable

Table 5-19 Total Suspended Solids TMDL Calculations for Neosho River (OK121600040010_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)			LA (lb/day)	MOS (lb/day)
			WWTP	MS4	Future growth		
0	444786.69	N/A	1.46E+01	0	N/A	N/A	N/A
5	32251.47	N/A	1.46E+01	0	N/A	N/A	N/A
10	19847.06	N/A	1.46E+01	0	N/A	N/A	N/A
15	13644.85	N/A	1.46E+01	0	N/A	N/A	N/A
20	9480.51	N/A	1.46E+01	0	N/A	N/A	N/A
25	6857.87	3.77E+06	1.46E+01	0	3.77E+04	3.35E+06	3.77E+05
30	5068.09	2.79E+06	1.46E+01	0	2.79E+04	2.48E+06	2.79E+05
35	3774.48	2.07E+06	1.46E+01	0	2.07E+04	1.85E+06	2.07E+05
40	2835.29	1.56E+06	1.46E+01	0	1.56E+04	1.39E+06	1.56E+05
45	2179.63	1.20E+06	1.46E+01	0	1.20E+04	1.07E+06	1.20E+05
50	1702.95	9.36E+05	1.46E+01	0	9.36E+03	8.33E+05	9.36E+04
55	1272.34	6.99E+05	1.46E+01	0	6.99E+03	6.22E+05	6.99E+04
60	981.72	5.39E+05	1.46E+01	0	5.39E+03	4.80E+05	5.39E+04
65	733.63	4.03E+05	1.46E+01	0	4.03E+03	3.59E+05	4.03E+04
70	530.91	2.92E+05	1.46E+01	0	2.92E+03	2.60E+05	2.92E+04
75	377.45	2.07E+05	1.46E+01	0	2.07E+03	1.85E+05	2.07E+04
80	256.95	1.41E+05	1.46E+01	0	1.41E+03	1.26E+05	1.41E+04
85	161.26	8.86E+04	1.46E+01	0	8.86E+02	7.89E+04	8.86E+03
90	106.32	5.84E+04	1.46E+01	0	5.84E+02	5.20E+04	5.84E+03
95	47.85	2.63E+04	1.46E+01	0	2.63E+02	2.34E+04	2.63E+03
100	0.00	1.46E+01	1.46E+01	0	0.00E+00	0.00E+00	0.00E+00

NA = Not Applicable

Table 5-20 Total Suspended Solids TMDL Calculations for Hudson Creek (OK121600040040_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)			LA (lb/day)	MOS (lb/day)
			WWTP	MS4	Future growth		
0	522.00	N/A	0	0	N/A	N/A	N/A
5	44.93	N/A	0	0	N/A	N/A	N/A
10	28.59	N/A	0	0	N/A	N/A	N/A
15	18.59	N/A	0	0	N/A	N/A	N/A
20	12.44	N/A	0	0	N/A	N/A	N/A
25	8.28	4550.07	0	0	45.50	3822.06	682.51
30	5.84	3211.81	0	0	32.12	2697.92	481.77
35	4.20	2305.92	0	0	23.06	1936.97	345.89
40	3.12	1717.09	0	0	17.17	1442.35	257.56
45	2.33	1281.74	0	0	12.82	1076.66	192.26
50	1.72	942.96	0	0	9.43	792.08	141.44
55	1.23	673.25	0	0	6.73	565.53	100.99
60	0.87	477.65	0	0	4.78	401.23	71.65
65	0.61	335.59	0	0	3.36	281.90	50.34
70	0.42	232.65	0	0	2.33	195.43	34.90
75	0.29	158.53	0	0	1.59	133.17	23.78
80	0.21	115.30	0	0	1.15	96.85	17.29
85	0.15	82.35	0	0	0.82	69.18	12.35
90	0.09	49.41	0	0	0.49	41.51	7.41
95	0.05	26.77	0	0	0.27	22.48	4.01
100	0.00	0.00	0	0	0.00	0.00	0.00

NA = Not Applicable

Table 5-21 Total Suspended Solids TMDL Calculations for Cow Creek (OK121600040130_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)			LA (lb/day)	MOS (lb/day)
			WWTP	MS4	Future growth		
0	380.00	N/A	0	0	N/A	N/A	N/A
5	51.71	N/A	0	0	N/A	N/A	N/A
10	32.90	N/A	0	0	N/A	N/A	N/A
15	21.39	N/A	0	0	N/A	N/A	N/A
20	14.32	N/A	0	0	N/A	N/A	N/A
25	9.53	5236.54	0	0	52.37	4660.52	523.65
30	6.73	3696.38	0	0	36.96	3289.78	369.64
35	4.83	2653.81	0	0	26.54	2361.89	265.38
40	3.60	1976.14	0	0	19.76	1758.77	197.61
45	2.68	1475.12	0	0	14.75	1312.85	147.51
50	1.97	1085.22	0	0	10.85	965.85	108.52
55	1.41	774.82	0	0	7.75	689.59	77.48
60	1.00	549.72	0	0	5.50	489.25	54.97
65	0.70	386.22	0	0	3.86	343.74	38.62
70	0.49	267.75	0	0	2.68	238.30	26.78
75	0.33	182.45	0	0	1.82	162.38	18.24
80	0.24	132.69	0	0	1.33	118.09	13.27
85	0.17	94.78	0	0	0.95	84.35	9.48
90	0.10	56.87	0	0	0.57	50.61	5.69
95	0.06	30.80	0	0	0.31	27.41	3.08
100	0.00	0.00	0	0	0.00	0.00	0.00

NA = Not Applicable

Table 5-22 Total Suspended Solids TMDL Calculations for Neosho River (OK121600040220_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)			LA (lb/day)	MOS (lb/day)
			WWTP	MS4	Future growth		
0	251000	N/A	0	0	N/A	N/A	N/A
5	18200	N/A	0	0	N/A	N/A	N/A
10	11200	N/A	0	0	N/A	N/A	N/A
15	7700	N/A	0	0	N/A	N/A	N/A
20	5350	N/A	0	0	N/A	N/A	N/A
25	3870	2.13E+06	0	0	2.13E+04	1.89E+06	2.13E+05
30	2860	1.57E+06	0	0	1.57E+04	1.40E+06	1.57E+05
35	2130	1.17E+06	0	0	1.17E+04	1.04E+06	1.17E+05
40	1600	8.79E+05	0	0	8.79E+03	7.83E+05	8.79E+04
45	1230	6.76E+05	0	0	6.76E+03	6.02E+05	6.76E+04
50	961	5.28E+05	0	0	5.28E+03	4.70E+05	5.28E+04
55	718	3.95E+05	0	0	3.95E+03	3.51E+05	3.95E+04
60	554	3.04E+05	0	0	3.04E+03	2.71E+05	3.04E+04
65	414	2.28E+05	0	0	2.28E+03	2.02E+05	2.28E+04
70	300	1.65E+05	0	0	1.65E+03	1.47E+05	1.65E+04
75	213	1.17E+05	0	0	1.17E+03	1.04E+05	1.17E+04
80	145	7.97E+04	0	0	7.97E+02	7.09E+04	7.97E+03
85	91	5.00E+04	0	0	5.00E+02	4.45E+04	5.00E+03
90	60	3.30E+04	0	0	3.30E+02	2.93E+04	3.30E+03
95	27	1.48E+04	0	0	1.48E+02	1.32E+04	1.48E+03
100	0	0.00E+00	0	0	0.00E+00	0.00E+00	0.00E+00

NA = Not Applicable

5.9 TMDL Implementation

DEQ will collaborate with a host of other state agencies and local governments working within the boundaries of state and local regulations to target available funding and technical assistance to support implementation of pollution controls and management measures. Various water quality management programs and funding sources will be utilized so that the pollutant reductions as required by these TMDLs can be achieved and water quality can be restored to maintain designated uses. DEQ's Continuing Planning Process (CPP), required by the CWA §303(e)(3) and 40 CFR 130.5, summarizes Oklahoma's commitments and programs aimed at restoring and protecting water quality throughout the State (DEQ 2006). The CPP can be viewed from DEQ's website at http://www.deq.state.ok.us/wqdnew/pubs/2006_CPP_final.pdf. Table 5-27 provides a partial list of the state partner agencies DEQ will collaborate with to address point and nonpoint source reduction goals established by TMDLs.

Table 5-27 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

5.9.1 Point Sources

As authorized by Section 402 of the CWA, the DEQ has delegation of the NPDES Program in Oklahoma, except for certain jurisdictional areas related to agriculture (retained by State Department of Agriculture, Food, and Forestry), and the oil & gas industry (retained by the Oklahoma Corporation Commission) for which the EPA has retained permitting authority. The NPDES Program in Oklahoma, in accordance with an agreement between DEQ and EPA relating to administration and enforcement of the delegated NPDES Program, is implemented via the Oklahoma Pollutant Discharge Elimination System (OPDES) Act [Title 252, Chapter 606 (http://www.deq.state.ok.us/rules/611.pdf)]. Point source WLAs are outlined in the Oklahoma Water Quality Management Plan (aka the 208 Plan) under the OPDES program.

5.9.2 Nonpoint Sources

Nonpoint source pollution in Oklahoma is managed by the Oklahoma Conservation Commission. The Oklahoma Conservation Commission works with state partners such as ODAFF and federal partners such as the EPA and the National Resources Conservation Service of the USDA, to address water quality problems similar to those seen in the Study Area. The primary mechanisms used for management of nonpoint source pollution are incentive-based programs that support the installation of BMPs and public education and outreach. 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 rates called for in this TMDL report are as high as 88.5%. The DEQ recognizes that achieving such high reductions will be a challenge, especially since unregulated nonpoint sources are a major cause of both bacterial and TSS loading. The high reduction rates are not uncommon for pathogen- or TSS-impaired waters. Similar reduction rates are often found in other pathogen and TSS TMDLs around the nation. The suitability of the current criteria for pathogens and the beneficial uses of a waterbody should be reviewed. For example, the Kansas Department of Environmental Quality has proposed to exclude certain high flow conditions during which pathogen standards will not apply, although that exclusion was not approved by the EPA. Additionally, EPA has been conducting new epidemiology studies and may develop new recommendations for pathogen criteria in the near future.

Revisions to the current pathogen provisions of Oklahoma's WQSs should be considered. There are three basic approaches to such revisions that may apply.

- Removing the PBCR use: This revision would require documentation in a Use Attainability Analysis that the use is not an existing use and cannot be attained. It is unlikely that this approach would be successful since there is evidence that people do swim in this segment of the river, thus constituting an existing use. Existing uses cannot be removed.

- Modifying application of the existing criteria: This approach would include considerations such as an exemption under certain high flow conditions, an allowance for wildlife or "natural conditions," a sub-category of the use or other special provision for urban areas, or other special provisions for storm flows. Since large bacterial violations occur over all flow ranges, it is likely that large reductions would still be necessary. However, this approach may have merit and should be considered.

- Revising the existing numeric criteria: Oklahoma's current pathogen criteria, revised in 2011, are based on EPA guidelines (See the *2012 Draft Recreational Water Quality Criteria*, December 2011; Implementation Guidance for Ambient Water Quality Criteria for Bacteria, May 2002 Draft; and Ambient Water Quality Criteria for Bacteria-1986, January 1986). However, those guidelines have received much criticism and EPA studies that could result in revisions to their recommendations are ongoing. The numeric criteria values should also be evaluated using a risk-based method such as that found in EPA guidance.

Unless or until the WQSs are revised and approved by EPA, federal rules require that the TMDLs in this report must be based on attainment of the current standards. If revisions to the pathogen standards are approved in the future, reductions specified in these TMDLs will be re-evaluated.

5.10 Reasonable Assurances

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, all point source discharges either already have or will be given discharging discharge limitations less than or equal to the water quality standards numerical criteria. This ensures that the impairments of the waterbodies in this report will not be caused by point sources. Since the point source WLAs in this TMDL report are not dependent on NPS load reduction, reasonable assurance does not apply.

SECTION 6
PUBLIC PARTICIPATION

This report was preliminarily reviewed by EPA prior to the public notice. The public notice was then sent to local newspapers, to stakeholders in the area affected by the TMDLs in this Study Area, and to stakeholders who have requested all copies of TMDL public notices. The public notice was also posted at the DEQ website:
http://www.deq.state.ok.us/wqdnew/index.htm.

The public comment period lasted 45 days. During that time, the public had the opportunity to review the TMDL report and make written comments. No comments were received from the public during the public notice period, and there were no requests for a public meeting. There was one staff-identified change. The details about that can be found in Appendix F.

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

SECTION 7
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APPENDIX A

AMBIENT WATER QUALITY DATA

Table A-1 Bacterial Data-2000 to 2008

Waterbody Name	WQM Station	Date	EC[1]	ENT[1]
Lightning Creek	OK121510-01-0130M	8/22/2000	703	
Lightning Creek	OK121510-01-0130M	9/25/2000	31	160
Verdigris River	121510020010-001AT	6/4/2001		49000
Verdigris River	121510020010-001AT	7/9/2001		70
Verdigris River	121510020010-001AT	8/6/2001		100
Verdigris River	121510020010-001AT	5/8/2002		247000
Verdigris River	121510020010-001AT	6/4/2002		250
Verdigris River	121510020010-001AT	7/10/2002		20
Verdigris River	121510020010-001AT	9/4/2002		25
Verdigris River	121510020010-001AT	5/16/2006		41
Verdigris River	121510020010-001AT	5/22/2006		20
Verdigris River	121510020010-001AT	6/12/2006		31
Verdigris River	121510020010-001AT	7/5/2006		20
Verdigris River	121510020010-001AT	7/24/2006		4106
Verdigris River	121510020010-001AT	8/7/2006		10
Verdigris River	121510020010-001AT	8/21/2006		299
Verdigris River	121510020010-001AT	8/28/2006		52
Verdigris River	121510020010-001AT	9/5/2006		10
Verdigris River	121510020010-001AT	9/18/2006		10
Verdigris River	121510020010-001AT	5/29/2008		826
Verdigris River	121510020010-001AT	6/17/2008		393
Verdigris River	121510020010-001AT	7/8/2008		30
Verdigris River	121510020010-001AT	7/29/2008		31
Verdigris River	121510020010-001AT	8/19/2008		52
California Creek	OK121510-02-0050C	8/22/2000	20	
California Creek	OK121510-02-0050C	8/13/2001	105	10
California Creek	OK121510-02-0050C	9/17/2001	70	100
California Creek	OK121510-02-0050C	5/28/2002	340	375
California Creek	OK121510-02-0050C	7/8/2002	310	240
California Creek	OK121510-02-0050C	8/5/2002	50	10
California Creek	OK121510-02-0050C	9/16/2002	20	20
California Creek	OK121510-02-0050C	5/12/2003	10	60
California Creek	OK121510-02-0050C	6/16/2003	20	20
California Creek	OK121510-02-0050C	6/19/2006	80	40
California Creek	OK121510-02-0050C	8/14/2006	50	260
California Creek	OK121510-02-0050C	9/18/2006	710	610
California Creek	OK121510-02-0050C	5/14/2007	390	300
California Creek	OK121510-02-0050C	6/19/2007	1960	1900
California Creek	OK121510-02-0050C	7/10/2007	160	320

Waterbody Name	WQM Station	Date	EC[1]	ENT[1]
California Creek	OK121510-02-0050C	7/23/2007	120	50
California Creek	OK121510-02-0050C	8/27/2007	60	170
California Creek	OK121510-02-0050C	5/6/2008	80	20
Big Creek	OK121510-03-0010G	8/22/2000	10	
Big Creek	OK121510-03-0010D	8/13/2001	180	15
Big Creek	OK121510-03-0010D	9/17/2001	650	830
Big Creek	OK121510-03-0010D	5/28/2002	910	330
Big Creek	OK121510-03-0010D	7/8/2002	70	220
Big Creek	OK121510-03-0010D	8/5/2002	140	70
Big Creek	OK121510-03-0010D	9/16/2002	20	20
Big Creek	OK121510-03-0010D	5/12/2003	80	9.99
Big Creek	OK121510-03-0010D	6/16/2003	180	60
Big Creek	OK121510-03-0010D	6/19/2006	410	510
Big Creek	OK121510-03-0010D	8/14/2006	50	40
Big Creek	OK121510-03-0010D	9/18/2006	290	310
Big Creek	OK121510-03-0010D	5/14/2007	120	150
Big Creek	OK121510-03-0010D	6/19/2007	140	240
Big Creek	OK121510-03-0010D	7/23/2007	30	10
Big Creek	OK121510-03-0010D	8/27/2007	540	400
Big Creek	OK121510-03-0010D	5/6/2008	240	40
Lost Creek	OK121600-03-0560G	8/14/2000	223	
Lost Creek	OK121600-03-0560G	9/19/2000	41	40
Neosho River	121600040220-001AT	6/6/2001		4000
Neosho River	121600040220-001AT	8/8/2001		10
Neosho River	121600040220-001AT	6/4/2002		500
Neosho River	121600040220-001AT	9/4/2002		50
Neosho River	121600040220-001AT	5/8/2002		282000
Neosho River	121600040220-001AT	7/10/2002		10
Neosho River	121600040220-001AT	7/8/2003		10
Neosho River	121600040220-001AT	7/22/2003		2100
Neosho River	121600040220-001AT	6/17/2003		20
Neosho River	121600040220-001AT	8/12/2003		10
Neosho River	121600040220-001AT	5/13/2003		190
Neosho River	121600040220-001AT	6/3/2003		30
Neosho River	121600040220-001AT	9/16/2003		400
Neosho River	121600040220-001AT	8/26/2003		40
Neosho River	121600040220-001AT	7/18/2006		41
Neosho River	121600040220-001AT	8/7/2006		100
Neosho River	121600040220-001AT	9/25/2006		10
Neosho River	121600040220-001AT	8/28/2006		450
Neosho River	121600040220-001AT	6/7/2006		160

Waterbody Name	WQM Station	Date	EC[1]	ENT[1]
Neosho River	121600040220-001AT	7/24/2006		52
Neosho River	121600040220-001AT	5/22/2006		41
Neosho River	121600040220-001AT	8/14/2006		10
Neosho River	121600040220-001AT	7/31/2006		30
Neosho River	121600040220-001AT	8/19/2008		51
Neosho River	121600040220-001AT	5/28/2008		1191
Neosho River	121600040220-001AT	6/17/2008		10
Neosho River	121600040220-001AT	7/8/2008		10
Little Cabin Creek	OK121600-06-0080C	8/13/2001	250	300
Little Cabin Creek	OK121600-06-0080C	9/17/2001	1680	400
Little Cabin Creek	OK121600-06-0080C	5/28/2002	800	860
Little Cabin Creek	OK121600-06-0080C	7/8/2002	110	230
Little Cabin Creek	OK121600-06-0080C	8/5/2002	40	10
Little Cabin Creek	OK121600-06-0080C	9/16/2002	120	200
Little Cabin Creek	OK121600-06-0080C	5/12/2003	330	650
Little Cabin Creek	OK121600-06-0080C	6/16/2003	80	60
Little Cabin Creek	OK121600-06-0080C	6/19/2006	450	510
Little Cabin Creek	OK121600-06-0080C	8/7/2006	500	255
Little Cabin Creek	OK121600-06-0080C	9/11/2006	850	90
Little Cabin Creek	OK121600-06-0080C	5/7/2007	6100	10000
Little Cabin Creek	OK121600-06-0080C	6/11/2007	2000	2000
Little Cabin Creek	OK121600-06-0080C	7/16/2007	220	170
Little Cabin Creek	OK121600-06-0080C	8/20/2007	120	100
Bull Creek	OK121600-06-0200G	8/21/2000	10	
Bull Creek	OK121600-06-0200G	8/22/2000	10	
Bull Creek	OK121600-06-0200G	9/25/2000	3873	1600
PawPaw Creek	OK121600-06-0240G	8/22/2000	31	
PawPaw Creek	OK121600-06-0240G	9/25/2000	581	300
Spring River	121600070010-001AT	6/6/2001		1700
Spring River	121600070010-001AT	8/8/2001		9.99
Spring River	121600070010-001AT	5/22/2002		340
Spring River	121600070010-001AT	6/4/2002		65
Spring River	121600070010-001AT	7/9/2002		20
Spring River	121600070010-001AT	9/4/2002		9.99
Spring River	121600070010-001AT	5/12/2003		33000
Spring River	121600070010-001AT	6/3/2003		20
Spring River	121600070010-001AT	6/17/2003		30
Spring River	121600070010-001AT	7/8/2003		20
Spring River	121600070010-001AT	7/22/2003		23000
Spring River	121600070010-001AT	8/12/2003		10
Spring River	121600070010-001AT	8/26/2003		20

Waterbody Name	WQM Station	Date	EC[1]	ENT[1]
Spring River	121600070010-001AT	9/16/2003		10
Spring River	121600070010-001AT	9/30/2003		20
Spring River	121600070010-001AT	5/17/2006		9.99
Spring River	121600070010-001AT	5/22/2006		10
Spring River	121600070010-001AT	6/7/2006		20
Spring River	121600070010-001AT	7/18/2006		10
Spring River	121600070010-001AT	7/24/2006		10
Spring River	121600070010-001AT	7/31/2006		10
Spring River	121600070010-001AT	8/7/2006		9.99
Spring River	121600070010-001AT	8/14/2006		10
Spring River	121600070010-001AT	8/28/2006		10
Spring River	121600070010-001AT	9/25/2006		10
Spring River	121600070010-001AT	5/28/2008		663
Spring River	121600070010-001AT	6/17/2008		41
Spring River	121600070010-001AT	7/8/2008		10
Spring River	121600070010-001AT	7/29/2008		10
Spring River	121600070010-001AT	8/19/2008		10
Fivemile Creek	OK121600-07-0110G	5/28/2002	10	10
Fivemile Creek	OK121600-07-0110G	5/12/2003	10	40
Fivemile Creek	OK121600-07-0110G	7/8/2002	10	9.99
Fivemile Creek	OK121600-07-0110G	8/5/2002	10	20
Fivemile Creek	OK121600-07-0110G	8/21/2000	10	
Fivemile Creek	OK121600-07-0110G	9/9/2002	10	40
Fivemile Creek	OK121600-07-0110G	6/16/2003	20	40
Fivemile Creek	OK121600-07-0110G	7/16/2007	20	20
Fivemile Creek	OK121600-07-0110G	8/13/2001	20	65
Fivemile Creek	OK121600-07-0110G	8/7/2006	20	20
Fivemile Creek	OK121600-07-0110G	8/20/2007	30	60
Fivemile Creek	OK121600-07-0110G	6/19/2006	50	70
Fivemile Creek	OK121600-07-0110G	9/17/2001	100	210
Fivemile Creek	OK121600-07-0110G	5/7/2007	240	760
Fivemile Creek	OK121600-07-0110G	9/25/2000	393	170
Fivemile Creek	OK121600-07-0110G	9/11/2006	970	20
Fivemile Creek	OK121600-07-0110G	6/11/2007	5300	9500

EC = *E. coli*; ENT = Enterococci
[2] Units = counts/100 mL

Table A-2 Turbidity and Total Suspended Solids Data – 1998-2011

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Verdigris River	OK121510020010_00	12/2/1998	132	68	high
Verdigris River	OK121510020010_00	1/26/1999	28	25	low
Verdigris River	OK121510020010_00	2/23/1999	45	47	low
Verdigris River	OK121510020010_00	3/30/1999	15	15	low
Verdigris River	OK121510020010_00	4/27/1999	102	348	high
Verdigris River	OK121510020010_00	5/24/1999	1080	220	high
Verdigris River	OK121510020010_00	06/22/99	386	292	high
Verdigris River	OK121510020010_00	7/27/1999	57	31	low
Verdigris River	OK121510020010_00	08/24/99	25	22	low
Verdigris River	OK121510020010_00	9/28/1999	17	14	low
Verdigris River	OK121510020010_00	10/28/1999	25	14	low
Verdigris River	OK121510020010_00	11/17/1999	8	7	low
Verdigris River	OK121510020010_00	12/13/99	113	114	high
Verdigris River	OK121510020010_00	01/19/00	27.2	128	low
Verdigris River	OK121510020010_00	02/22/00	120	16	low
Verdigris River	OK121510020010_00	03/27/00	84		high
Verdigris River	OK121510020010_00	05/10/00	528	1044	high
Verdigris River	OK121510020010_00	06/28/00	706	552	high
Verdigris River	OK121510020010_00	07/22/00	47		low
Verdigris River	OK121510020010_00	07/31/00	115	76	low
Verdigris River	OK121510020010_00	08/30/00	21	22	low
Verdigris River	OK121510020010_00	09/27/00	11	0	low
Verdigris River	OK121510020010_00	10/24/00	16	20	low
Verdigris River	OK121510020010_00	11/29/00	7	9	low
Verdigris River	OK121510020010_00	2/5/2001	139		high
Verdigris River	OK121510020010_00	3/5/2001	191		high
Verdigris River	OK121510020010_00	4/1/2001	47		low
Verdigris River	OK121510020010_00	5/7/2001	41		low
Verdigris River	OK121510020010_00	6/4/2001	1000		high
Verdigris River	OK121510020010_00	7/9/2001	100		low
Verdigris River	OK121510020010_00	8/6/2001	158		low
Verdigris River	OK121510020010_00	10/1/2001	39		low
Verdigris River	OK121510020010_00	11/5/2001	21		low
Verdigris River	OK121510020010_00	2/6/2002	70		low
Verdigris River	OK121510020010_00	3/13/2002	15		low
Verdigris River	OK121510020010_00	4/9/2002	14		low
Verdigris River	OK121510020010_00	5/8/2002	1000		high
Verdigris River	OK121510020010_00	6/4/2002	125		high
Verdigris River	OK121510020010_00	7/10/2002	37		low

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Verdigris River	OK121510020010_00	9/4/2002	32		low
Verdigris River	OK121510020010_00	10/30/2002	31		low
Verdigris River	OK121510020010_00	10/30/2002	39		low
Verdigris River	OK121510020010_00	12/10/2002	6		low
Verdigris River	OK121510020010_00	1/28/2003	9		low
Verdigris River	OK121510020010_00	2/26/2003	20		low
Verdigris River	OK121510020010_00	5/12/2003	63		low
Verdigris River	OK121510020010_00	6/16/2003	81		low
Verdigris River	OK121510020010_00	8/25/2003	32		low
Verdigris River	OK121510020010_00	9/30/2003	34		low
Verdigris River	OK121510020010_00	11/4/2003	32		low
Verdigris River	OK121510020010_00	12/3/2003	38		low
Verdigris River	OK121510020010_00	1/26/2004	61		high
Verdigris River	OK121510020010_00	2/23/2004	55		high
Verdigris River	OK121510020010_00	4/5/2004	84		high
Verdigris River	OK121510020010_00	5/17/2004	177		high
Verdigris River	OK121510020010_00	6/22/2004	732		high
Verdigris River	OK121510020010_00	7/26/2004	94		high
Verdigris River	OK121510020010_00	8/31/2004	17		low
Verdigris River	OK121510020010_00	10/4/2004	19		low
Verdigris River	OK121510020010_00	11/9/2004	66		low
Verdigris River	OK121510020010_00	12/1/2004	76		high
Verdigris River	OK121510020010_00	2/1/2005	34		high
Verdigris River	OK121510020010_00	4/5/2005	61		low
Verdigris River	OK121510020010_00	5/9/2005	17		low
Verdigris River	OK121510020010_00	6/15/2005	210		high
Verdigris River	OK121510020010_00	8/3/2005	16		low
Verdigris River	OK121510020010_00	8/23/2005	325		low
Verdigris River	OK121510020010_00	9/26/2005	69		low
Verdigris River	OK121510020010_00	11/1/2005	10		low
Verdigris River	OK121510020010_00	12/13/2005	12		low
Verdigris River	OK121510020010_00	1/30/2006	30		low
Verdigris River	OK121510020010_00	3/15/2006	14		low
Verdigris River	OK121510020010_00	4/10/2006	13		low
Verdigris River	OK121510020010_00	5/16/2006	57		high
Verdigris River	OK121510020010_00	6/19/2006	36		low
Verdigris River	OK121510020010_00	7/24/2006	90		low
Verdigris River	OK121510020010_00	8/28/2006	18		low
Verdigris River	OK121510020010_00	9/25/2006	12		low
Verdigris River	OK121510020010_00	11/13/2006	8		low

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Verdigris River	OK121510020010_00	1/29/2007	29		low
Verdigris River	OK121510020010_00	3/13/2007	20		low
Verdigris River	OK121510020010_00	4/10/2007	132		high
Verdigris River	OK121510020010_00	5/7/2007	643		high
Verdigris River	OK121510020010_00	6/18/2007	84		high
Verdigris River	OK121510020010_00	7/5/2007	65		high
Verdigris River	OK121510020010_00	7/17/2007	177		high
Verdigris River	OK121510020010_00	8/14/2007	70		high
Verdigris River	OK121510020010_00	10/1/2007	29		low
Verdigris River	OK121510020010_00	11/5/2007	24		low
Verdigris River	OK121510020010_00	12/19/2007	20		low
Verdigris River	OK121510020010_00	2/20/2008	454		high
Verdigris River	OK121510020010_00	3/25/2008	107		high
Verdigris River	OK121510020010_00	4/28/2008	105		high
Verdigris River	OK121510020010_00	6/2/2008	1000		high
Verdigris River	OK121510020010_00	9/2/2008	58		low
Verdigris River	OK121510020010_00	11/10/2008	70		low
Verdigris River	OK121510020010_00	1/5/2009	48		high
Verdigris River	OK121510020010_00	3/2/2009	23		low
Verdigris River	OK121510020010_00	3/23/2009	116		high
Verdigris River	OK121510020010_00	4/20/2009	587.5		high
Verdigris River	OK121510020010_00	6/22/2009	175		high
Verdigris River	OK121510020010_00	8/17/2009	32		low
Verdigris River	OK121510020010_00	10/19/2009	54		high
Verdigris River	OK121510020010_00	2/15/2010	15		high
Verdigris River	OK121510020010_00	3/15/2010	52.3		high
Verdigris River	OK121510020010_00	5/3/2010	22.8		low
Verdigris River	OK121510020010_00	8/30/2010	22		low
Verdigris River	OK121510020010_00	9/20/2010	173.8		high
Verdigris River	OK121510020010_00	11/8/2010	9.3		low
Verdigris River	OK121510020010_00	12/27/2010	9.3		low
Verdigris River	OK121510020010_00	5/10/2011	12.5		low
Verdigris River	OK121510020010_00	7/18/2011	12.5		low
Verdigris River	OK121510020010_00	10/3/2011	13.5		low
Neosho River	OK121600040010_00	12/1/1998	108	130	high
Neosho River	OK121600040010_00	1/26/1999	38	14	low
Neosho River	OK121600040010_00	2/22/1999	32	86	high
Neosho River	OK121600040010_00	3/29/1999	20	26	low
Neosho River	OK121600040010_00	4/27/1999	221	124	high
Neosho River	OK121600040010_00	5/24/1999	0	140	high

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Neosho River	OK121600040010_00	06/29/99	560	520	high
Neosho River	OK121600040010_00	7/26/1999	19	16	low
Neosho River	OK121600040010_00	08/18/99	17	18	low
Neosho River	OK121600040010_00	9/27/1999	15	13	low
Neosho River	OK121600040010_00	10/27/1999	37	21	low
Neosho River	OK121600040010_00	12/20/1999	41	48	low
Neosho River	OK121600040010_00	02/29/00	223	182	low
Neosho River	OK121600040010_00	03/28/00	82		low
Neosho River	OK121600040010_00	04/25/00	26	22	low
Neosho River	OK121600040010_00	06/28/00	392	380	high
Neosho River	OK121600040010_00	07/31/00	29	24	low
Neosho River	OK121600040010_00	08/29/00	9	18	low
Neosho River	OK121600040010_00	09/26/00	36	0	low
Neosho River	OK121600040010_00	10/24/00	29	75	low
Neosho River	OK121600040010_00	11/28/00	10	14	low
Neosho River	OK121600040010_00	02/06/01	96		low
Neosho River	OK121600040010_00	03/06/01	257		high
Neosho River	OK121600040010_00	04/03/01	65		low
Neosho River	OK121600040010_00	6/5/2001	1000		high
Neosho River	OK121600040010_00	7/10/2001	21		low
Neosho River	OK121600040010_00	8/7/2001	42		low
Neosho River	OK121600040010_00	10/2/2001	98		low
Neosho River	OK121600040010_00	11/6/2001	99		low
Neosho River	OK121600040010_00	2/5/2002	158		low
Neosho River	OK121600040010_00	3/12/2002	61		low
Neosho River	OK121600040010_00	4/8/2002	201		low
Neosho River	OK121600040010_00	5/7/2002	55		low
Neosho River	OK121600040010_00	6/4/2002	51		low
Neosho River	OK121600040010_00	7/9/2002	15		low
Neosho River	OK121600040010_00	9/3/2002	14		low
Neosho River	OK121600040010_00	10/1/2002	9		low
Neosho River	OK121600040010_00	10/29/2002	39		low
Neosho River	OK121600040010_00	12/9/2002	5		low
Neosho River	OK121600040010_00	1/29/2003	4		low
Neosho River	OK121600040010_00	2/25/2003	18		low
Neosho River	OK121600040010_00	4/1/2003	92		low
Neosho River	OK121600040010_00	5/6/2003	233		high
Neosho River	OK121600040010_00	7/9/2003	49		low
Neosho River	OK121600040010_00	10/7/2003	71		low
Neosho River	OK121600040010_00	11/4/2003	34		low

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Neosho River	OK121600040010_00	3/1/2004	29		low
Neosho River	OK121600040010_00	4/5/2004	163		high
Neosho River	OK121600040010_00	5/5/2004	41		low
Neosho River	OK121600040010_00	7/7/2004	245		high
Neosho River	OK121600040010_00	7/20/2004	109		high
Neosho River	OK121600040010_00	8/24/2004	28		low
Neosho River	OK121600040010_00	10/13/2004	25		low
Neosho River	OK121600040010_00	10/27/2004	15		low
Neosho River	OK121600040010_00	12/1/2004	93		high
Neosho River	OK121600040010_00	1/31/2005	16		low
Neosho River	OK121600040010_00	2/23/2005	77		high
Neosho River	OK121600040010_00	8/3/2005	16		low
Neosho River	OK121600040010_00	10/5/2005	16		low
Neosho River	OK121600040010_00	11/16/2005	18		low
Neosho River	OK121600040010_00	1/11/2006	10		low
Neosho River	OK121600040010_00	2/28/2006	10		low
Neosho River	OK121600040010_00	4/11/2006	21		low
Neosho River	OK121600040010_00	6/13/2006	24		low
Neosho River	OK121600040010_00	7/17/2006	5		low
Neosho River	OK121600040010_00	9/18/2006	28		low
Neosho River	OK121600040010_00	12/18/2006	9		low
Neosho River	OK121600040010_00	2/28/2007	114		low
Neosho River	OK121600040010_00	3/27/2007	98		low
Hudson Creek	OK121600040040_00	4/27/1999	83.5	44	high
Hudson Creek	OK121600040040_00	6/22/1999	63	60	high
Hudson Creek	OK121600040040_00	7/21/1999	10	18.5	low
Hudson Creek	OK121600040040_00	8/5/1999	9.4		low
Hudson Creek	OK121600040040_00	8/24/1999	7.1	8	low
Hudson Creek	OK121600040040_00	10/5/1999	9.63	9.5	low
Hudson Creek	OK121600040040_00	11/08/99	11.1	8.5	low
Hudson Creek	OK121600040040_00	12/13/1999	94.2	50	low
Hudson Creek	OK121600040040_00	01/18/00	18.2	22	low
Hudson Creek	OK121600040040_00	2/23/2000	89.4	129	high
Hudson Creek	OK121600040040_00	3/27/2000	16.9	20	low
Hudson Creek	OK121600040040_00	5/8/2000	58.3	38	low
Hudson Creek	OK121600040040_00	06/12/00	19.5	23	low
Hudson Creek	OK121600040040_00	07/17/00	11.9	8	low
Hudson Creek	OK121600040040_00	08/21/00	18	24	low
Hudson Creek	OK121600040040_00	09/25/00	5.63	6	low
Hudson Creek	OK121600040040_00	10/30/00	4.09	1	low

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Hudson Creek	OK121600040040_00	12/06/00	14.1	12	low
Hudson Creek	OK121600040040_00	01/16/01	50.1	14	low
Hudson Creek	OK121600040040_00	02/20/01	57.5		low
Hudson Creek	OK121600040040_00	03/27/01	6.46	4	low
Cow Creek	OK121600040130_00	04/27/99	114	52	high
Cow Creek	OK121600040130_00	05/25/99	73.2	51.2	high
Cow Creek	OK121600040130_00	06/22/99	85.7	64	high
Cow Creek	OK121600040130_00	07/21/99	9.8	9.5	low
Cow Creek	OK121600040130_00	07/29/99	13.8		low
Cow Creek	OK121600040130_00	08/24/99	10.9	6.5	low
Cow Creek	OK121600040130_00	12/13/99	63.1	34	low
Cow Creek	OK121600040130_00	01/18/00	26	16	low
Cow Creek	OK121600040130_00	02/23/00	69.4	49	low
Cow Creek	OK121600040130_00	03/28/00	42.8	26	low
Cow Creek	OK121600040130_00	05/08/00	80.2	50	high
Cow Creek	OK121600040130_00	06/12/00	70.1	65	low
Cow Creek	OK121600040130_00	07/17/00	21	14	low
Cow Creek	OK121600040130_00	08/21/00	15.6	14	low
Cow Creek	OK121600040130_00	10/30/00	74	55	low
Cow Creek	OK121600040130_00	12/06/00	54.5	56	low
Cow Creek	OK121600040130_00	01/16/01	29.2	10	low
Cow Creek	OK121600040130_00	02/20/01	40.1	24	low
Cow Creek	OK121600040130_00	03/26/01	18.6	8	low
Neosho River	OK121600040220_00	10/24/2000	41	100	low
Neosho River	OK121600040220_00	11/28/2000	17	18	low
Neosho River	OK121600040220_00	2/7/2001	74		low
Neosho River	OK121600040220_00	3/7/2001	175		high
Neosho River	OK121600040220_00	4/4/2001	85		low
Neosho River	OK121600040220_00	6/6/2001	554		high
Neosho River	OK121600040220_00	07/11/01	49		low
Neosho River	OK121600040220_00	8/8/2001	37		low
Neosho River	OK121600040220_00	11/07/01	69		low
Neosho River	OK121600040220_00	2/6/2002	116		low
Neosho River	OK121600040220_00	3/13/2002	17		low
Neosho River	OK121600040220_00	4/9/2002	26		low
Neosho River	OK121600040220_00	05/08/02	1000		high
Neosho River	OK121600040220_00	06/04/02	60		low
Neosho River	OK121600040220_00	07/10/02	31		low
Neosho River	OK121600040220_00	09/04/02	30		low
Neosho River	OK121600040220_00	10/01/02	60		low

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Neosho River	OK121600040220_00	10/30/02	53		low
Neosho River	OK121600040220_00	12/10/02	5		low
Neosho River	OK121600040220_00	02/25/03	19		low
Neosho River	OK121600040220_00	04/07/03	54		low
Neosho River	OK121600040220_00	05/12/03	183		low
Neosho River	OK121600040220_00	06/17/03	64		low
Neosho River	OK121600040220_00	07/21/03	37		low
Neosho River	OK121600040220_00	8/26/2003	26		low
Neosho River	OK121600040220_00	9/30/2003	81		low
Neosho River	OK121600040220_00	11/4/2003	41		low
Neosho River	OK121600040220_00	12/3/2003	29		low
Neosho River	OK121600040220_00	1/26/2004	127		low
Neosho River	OK121600040220_00	2/23/2004	78		low
Neosho River	OK121600040220_00	4/5/2004	154		high
Neosho River	OK121600040220_00	5/17/2004	98		low
Neosho River	OK121600040220_00	6/22/2004	215		high
Neosho River	OK121600040220_00	7/26/2004	81		low
Neosho River	OK121600040220_00	10/4/2004	22		low
Neosho River	OK121600040220_00	11/8/2004	70		low
Neosho River	OK121600040220_00	11/30/2004	101		low
Neosho River	OK121600040220_00	2/1/2005	78		low
Neosho River	OK121600040220_00	3/2/2005	209		low
Neosho River	OK121600040220_00	4/5/2005	60		low
Neosho River	OK121600040220_00	5/9/2005	35		low
Neosho River	OK121600040220_00	6/15/2005	13		high
Neosho River	OK121600040220_00	8/3/2005	40		low
Neosho River	OK121600040220_00	8/23/2005	64		low
Neosho River	OK121600040220_00	9/26/2005	32		low
Neosho River	OK121600040220_00	11/1/2005	18		low
Neosho River	OK121600040220_00	12/13/2005	7		low
Neosho River	OK121600040220_00	1/30/2006	72		low
Neosho River	OK121600040220_00	3/15/2006	9		low
Neosho River	OK121600040220_00	4/10/2006	30		low
Neosho River	OK121600040220_00	5/16/2006	156		high
Neosho River	OK121600040220_00	6/19/2006	11		low
Neosho River	OK121600040220_00	7/24/2006	43		low
Neosho River	OK121600040220_00	8/28/2006	69		low
Neosho River	OK121600040220_00	9/25/2006	36		low
Neosho River	OK121600040220_00	11/14/2006	13		low
Neosho River	OK121600040220_00	12/19/2006	6		low

Waterbody Name	Waterbody ID	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition
Neosho River	OK121600040220_00	2/5/2007	11		low
Neosho River	OK121600040220_00	3/14/2007	41		low
Neosho River	OK121600040220_00	4/10/2007	116		low
Neosho River	OK121600040220_00	6/18/2007	196		high
Neosho River	OK121600040220_00	7/23/2007	97		high
Neosho River	OK121600040220_00	9/4/2007	25		low
Neosho River	OK121600040220_00	10/2/2007	40		low
Neosho River	OK121600040220_00	11/5/2007	17		low
Neosho River	OK121600040220_00	12/17/2007	25		low
Neosho River	OK121600040220_00	2/20/2008	474		high
Neosho River	OK121600040220_00	3/24/2008	257		high
Neosho River	OK121600040220_00	4/28/2008	237		high
Neosho River	OK121600040220_00	6/2/2008	547		high
Neosho River	OK121600040220_00	9/3/2008	81		low
Neosho River	OK121600040220_00	11/10/2008	79		low
Neosho River	OK121600040220_00	1/7/2009	21		low
Neosho River	OK121600040220_00	3/2/2009	11		low
Neosho River	OK121600040220_00	3/23/2009	34		low
Neosho River	OK121600040220_00	4/20/2009	451		high
Neosho River	OK121600040220_00	6/22/2009	120.25		high
Neosho River	OK121600040220_00	8/18/2009	40		low
Neosho River	OK121600040220_00	10/20/2009	25		low
Neosho River	OK121600040220_00	2/16/2010	16.3		low
Neosho River	OK121600040220_00	3/15/2010	165.3		high
Neosho River	OK121600040220_00	5/3/2010	187.3		low
Neosho River	OK121600040220_00	8/31/2010	19		low
Neosho River	OK121600040220_00	9/20/2010	44.5		low
Neosho River	OK121600040220_00	11/8/2010	8.5		low
Neosho River	OK121600040220_00	12/27/2010	6.3		low
Neosho River	OK121600040220_00	5/10/2011	29		low
Neosho River	OK121600040220_00	7/19/2011	18.8		low
Neosho River	OK121600040220_00	10/3/2011	24.8		low

APPENDIX B

GENERAL METHOD FOR ESTIMATING FLOW FOR UNGAGED STREAMS

AND

ESTIMATED FLOW EXCEEDANCE PERCENTILES

Appendix B
General Method for Estimating Flow for Ungaged Streams

Flows duration curve will be developed using existing USGS measured flow where the data exist from a gage on the stream segment of interest, or by estimating flow for stream segments with no corresponding flow record. Flow data to support flow duration curves and load duration curves will be derived for each Oklahoma stream segment in the following priority:

i) In cases where a USGS flow gage occurs on, or within one-half mile upstream or downstream of the Oklahoma stream segment.

a. If simultaneously collected flow data matching the water quality sample collection date are available, these flow measurements will be used.

b. If flow measurements at the coincident gage are missing for some dates on which water quality samples were collected, the gaps in the flow record will be filled, or the record will be extended, by estimating flow based on measured streamflows at a nearby gages. All gages within 150 km radius are identified. For each of the identified gage with a minimum of 99 flow measurements on matching dates, four different regressions are calculated including linear, log linear, logarithmic and exponential regressions. The regression with the lowest root mean square error (RMSE) is chosen for each gage. The potential filling gages are ranked by RMSE from lowest to highest. The record is filled from the first gage (lowest RMSE) for those dates that exist in both records. If dates remain unfilled in the desired timespan of the timeseries, the filling process is repeated with the next gage with the next lowest RMSE and proceeds in this fashion until all missing values in the desired timespan are filled.

c. The flow frequency for the flow duration curves will be based on measured flows only. The filled timeseries described above is used to match flows to sampling dates to calculate loads.

d. On a stream impounded by dams to form reservoirs of sufficient size to impact stream flow, only flows measured after the date of the most recent impoundment will be used to develop the flow duration curve. This also applies to reservoirs on major tributaries to the stream.

ii) In the case no coincident flow data are available for a stream segment, but flow gage(s) are present upstream and/or downstream without a major reservoir between, flows will be estimated for the stream segment from an upstream or downstream gage using a watershed area ratio method derived by delineating subwatersheds, and relying on the Natural Resources Conservation Service (NRCS) runoff curve numbers and antecedent rainfall condition. Drainage subbasins will first be delineated for all impaired 303(d)-listed WQM stations, along with all USGS flow stations located in the 8-digit HUCs with impaired streams. Parsons will then identify all the USGS gage stations upstream and downstream of the subwatersheds with 303(d) listed WQM stations.

a. Watershed delineations are performed using ESRI Arc Hydro with a 30 m resolution National Elevation Dataset digital elevation model, and National

Hydrography Dataset (NHD) streams. The area of each watershed will be calculated following watershed delineation.

b. The watershed average curve number is calculated from soil properties and land cover as described in the U.S. Department of Agriculture (USDA) Publication *TR-55: Urban Hydrology for Small Watersheds*. The soil hydrologic group is extracted from NRCS STATSGO soil data, and land use category from the 2001 National Land Cover Dataset (NLCD). Based on land use and the hydrologic soil group, SCS curve numbers are estimated at the 30-meter resolution of the NLCD grid as shown in Table 7. The average curve number is then calculated from all the grid cells within the delineated watershed.

c. The average rainfall is calculated for each watershed from gridded average annual precipitation datasets for the period 1971-2000 (Spatial Climate Analysis Service, Oregon State University, http://www.ocs.oregonstate.edu/prism/, created February 20, 2004).

Table B-1 Runoff Curve Numbers for Various Land Use Categories and Hydrologic Soil Groups

NLCD Land Use Category	Curve number for hydrologic soil group			
	A	B	C	D
0 in case of zero	100	100	100	100
11 Open Water	100	100	100	100
12 Perennial Ice/Snow	100	100	100	100
21 Developed, Open Space	39	61	74	80
22 Developed, Low Intensity	57	72	81	86
23 Developed, Medium Intensity	77	85	90	92
24 Developed, High Intensity	89	92	94	95
31 Barren Land (Rock/Sand/Clay)	77	86	91	94
32 Unconsolidated Shore	77	86	91	94
41 Deciduous Forest	37	48	57	63
42 Evergreen Forest	45	58	73	80
43 Mixed Forest	43	65	76	82
51 Dwarf Scrub	40	51	63	70
52 Shrub/Scrub	40	51	63	70
71 Grasslands/Herbaceous	40	51	63	70
72 Sedge/Herbaceous	40	51	63	70
73 Lichens	40	51	63	70
74 Moss	40	51	63	70
81 Pasture/Hay	35	56	70	77
82 Cultivated Crops	64	75	82	85
90-99 Wetlands	100	100	100	100

d. The method used to project flow from a gaged location to an ungaged location was adapted by combining aspects of two other flow projection methodologies developed by Furness (Furness 1959) and Wurbs (Wurbs 1999).

Furness Method

The Furness method has been employed in Kansas by both the USGS and Kansas Department of Health and Environment to estimate flow-duration curves. The method typically uses maps, graphs, and computations to identify six unique factors of flow duration for ungaged sites. These factors include:

- the mean streamflow and percentage duration of mean streamflow;
- the ratio of 1-percent-duration streamflow to mean streamflow;
- the ratio of 0.1-percent-duration streamflow to 1-percent-duration streamflow;
- the ratio of 50-percent-duration streamflow to mean streamflow;
- the percentage duration of appreciable (0.10 ft /s) streamflow; and
- average slope of the flow-duration curve.

Furness defined appreciable flow as 0.10 ft/s. This value of streamflow was important because, for many years, this was the smallest non-zero streamflow value reported in most Kansas streamflow records. The average slope of the duration curve is a graphical approximation of the variability index, which is the standard deviation of the logarithms of the streamflows (Furness 1959, p. 202-204, figs. 147 and 148). On a duration curve that fits the log-normal distribution exactly, the variability index is equal to the ratio of the streamflow at the 15.87-percent-duration point to the streamflow at the 50-percent-duration point. Because duration curves usually do not exactly fit the log-normal distribution, the average-slope line is drawn through an arbitrary point, and the slope is transferred to a position approximately defined by the previously estimated points.

The method provides a means of both describing shape of the flow duration curve and scaling the magnitude of the curve to another location, basically generating a new flow duration curve with a very similar shape but different magnitude at the ungaged location.

Wurbs Modified NRCS Method

As a part of the Texas water availability modeling (WAM) system developed by Texas Natural Resources Conservation Commission, now known as the Texas Commission on Environmental Quality (TCEQ), and partner agencies, various contractors developed models of all Texas rivers. As a part of developing the model code to be used, Dr. Ralph Wurbs of Texas A&M University researched methods to distribute flows from gaged locations to ungaged locations. (Wurbs 2006) His results included the development of a modified NRCS curve-number (CN) method for distributing flows from gaged locations to ungaged locations.

This modified NRCS method is based on the following relationship between rainfall depth, P in inches, and runoff depth, Q in inches (NRCS 1985; McCuen 2005):

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad (1)$$

where:

Q = runoff depth (inches)

P = rainfall (inches)

S = potential maximum retention after runoff begins (inches)

I_a = initial abstraction (inches)

If P < 0.2, Q = 0. Initial abstraction has been found to be empirically related to S by the equation

$$I_a = 0.2*S \quad (2)$$

Thus, the runoff curve number equation can be rewritten:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (3)$$

S is related to the curve number (CN) by:

$$S = \frac{1000}{CN} - 10 \quad (4)$$

P and Q in inches must be multiplied by the watershed area to obtain volumes. The potential maximum retention, S in inches, represents an upper limit on the amount of water that can be abstracted by the watershed through surface storage, infiltration, and other hydrologic abstractions. For convenience, S is expressed in terms of a curve number CN, which is a dimensionless watershed parameter ranging from 0 to 100. A CN of 100 represents a limiting condition of a perfectly impervious watershed with zero retention and thus all the rainfall becoming runoff. A CN of zero conceptually represents the other extreme with the watershed abstracting all rainfall with no runoff regardless of the rainfall amount.

First, S is calculated from the average curve number for the gaged watershed. Next, the daily historic flows at the gage are converted to depth basis (as used in equations 1 and 3) by dividing by its drainage area, then converted to inches. Equation 3 is then solved for daily precipitation depth of the gaged site, Pgaged. The daily precipitation depth for the ungaged site is then calculated as the precipitation depth of the gaged site multiplied by the ratio of the long-term average precipitation in the watersheds of the ungaged and gaged sites:

$$P_{ungaged} = P_{gaged}\left(\frac{M_{ungaged}}{M_{gaged}}\right) \quad (5)$$

where M is the mean annual precipitation of the watershed in inches. The daily precipitation depth for the ungaged watershed, along with the average curve number of the ungaged watershed, are then used to calculate the depth equivalent daily flow Q of the ungaged site. Finally, the volumetric flow rate at the ungaged site is calculated by multiplying by the area of the watershed of the ungaged site and converted to cubic feet.

In a subsequent study (Wurbs 2006), Wurbs evaluated the predictive ability of various flow distribution methods including:

- Distribution of flows in proportion to drainage area;
- Flow distribution equation with ratios for various watershed parameters;
- Modified NRCS curve-number method;
- Regression equations relating flows to watershed characteristics;
- Use of recorded data at gaging stations to develop precipitation-runoff relationships; and
- Use of watershed (precipitation-runoff) computer models such as SWAT.

As a part of the analysis, the methods were used to predict flows at one gaged station to another gage station so that fit statistics could be calculated to evaluate the efficacy of each of the methods. Based upon similar analyses performed for many gaged sites which reinforced the tests performed as part of the study, Wurbs observed that temporal variations in flows are dramatic, ranging from zero flows to major floods. Mean flows are reproduced reasonably well with the all flow distribution methods and the NRCS CN method reproduces the mean closest. Accuracy in predicting mean flows is much better than the accuracy of predicting the flow-frequency relationship. Performance in reproducing flow-frequency relationships is better than for reproducing flows for individual flows.

Wurbs concluded that the NRCS CN method, the drainage area ratio method, and drainage area – CN – mean annual precipitation depth (MP) ratio methods all yield similar levels of accuracy. If the CN and MP are the same for the gaged and ungaged watersheds, the three alternative methods yield identical results. Drainage area is the most important watershed parameter. However, the NRCS method adaptation is preferable in those situations in which differences in CN (land use and soil type) and long-term MP are significantly different between the gaged and ungaged watersheds. The CN and MP are usually similar but not identical.

Generalized Flow Projection Methodology

In the first several versions of the Oklahoma TMDL toolbox, all flows at ungaged sites that required projection from a gaged site were performed with the Modified NRCS CN method. This led a number of problems with flow projections in the early versions. As described previously, the NRCS method, in common with all others, reproduces the mean or central tendency best but the accuracy of the fit degrades towards the extremes of the frequency spectrum. Part of the degradation in accuracy is due to the quite non-linear nature of the NRCS equations. On the low flow end of the frequency spectrum, Equation 2 above constitutes a low flow limit below which the NRCS equations are not applicable at all. Given the flashy nature of most streams in locations for which the toolbox was developed, high and low flows are relatively more common and spurious results from the limits of the equations abounded.

In an effort to increase the flow prediction efficacy and remedy the failure of the NRCS CN method at the extremes of the flow spectrum, a hybrid of the NRCS CN method and the Furness method was developed. Noting the facts that all tested projection methods, and particularly the NRCS CN method, perform best near the central tendency or mean and that none of the methods predict the entire flow frequency spectrum well, an assumption that is implicit in the Furness method is applied. The Furness method implicitly assumes that the shape of the flow frequency curve at an upstream site is related to and similar to the shape of the flow frequency curve at a site downstream. As described previously, the Furness method employs several relationships derived between the mean flows and flows at differing frequencies to replicate the shape of the flow frequency curve at the projected site, while utilizing other regressed relationships to scale the magnitude of the curve. Since, as part of the toolbox calculations, the entire flow frequency curve at a 1% interval is calculated for every USGS gage utilizing very long periods of record, this vector in association with the mean flow was used to project the flow frequency curve.

In the ideal situation flows are projected from an ungaged location from a downstream gaged location. The toolbox also has the capability to project flows from and upstream gaged location if there is no useable downstream gage.

iii) In the rare case where no coincident flow data are available for a WQM station <u>and</u> no gages are present upstream or downstream, flows will be estimated for the WQM station from a gage on an adjacent watershed of similar size and properties, via the same procedure described above for upstream or downstream gages.

References

Furness, L.W., 1959, *Kansas Streamflow Characteristics- Part 1, Flow Duration*: Kansas Water Resources Board Technical Report No. 1.

Wurbs, R.A., and E.D. Sisson, *Evaluation of Methods for Distributing Naturalized Streamflows from Gaged Watersheds to Ungaged Subwatersheds*, Technical Report 179, Texas Water Resources Institute and Texas Natural Resource Conservation Commission, August 1999.

Wurbs, R.A. 2006. *Methods for Developing Naturalized Monthly Flows at Gaged and Ungaged Sites*. Journal of Hydrologic Engineering, January/February 2006, ASCE

Table B-2 Estimated Flow Exceedance Percentiles

Stream Name	Lightning Creek	Verdigris River	California Creek	Big Creek	Lost Creek	Neosho River	Hudson Creek	Cow Creek	Neosho River	Little Cabin Creek	Bull Creek	Pawpaw Creek	Spring River	Fivemile Creek
WBID Segment	OK121510010130_00	OK121510020010_00	OK121510020050_00	OK121510030010_00	OK121600030560_00	OK121600040010_00	OK121600040040_00	OK121600040130_00	OK121600040220_00	OK121600060080_00	OK121600060200_00	OK121600060240_00	OK121600070010_00	OK121600070110_00
USGS Gage	07171000	07171000	07171000	07171000	07171000	07185000	07185000	07185000	07185000	07185000	07171000	07171000	07188000	7188000
Drainage Area	47.03	365.42	10.26	70.16	283.60	114.17	25.77	30.00	221.82	160.86	15.69	51.00	234.65	33.84
Percentile	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)
0	338	168000	214	1200	2460	444787	522	380.0	251000	1693	582	601	210000	1086
1	153	26700	90	370	236	60073	93	107.6	33900	269	281	273	25608	298
2	112	19618	66	272	158	49263	69	79.0	27800	198	137	201	16600	193
3	96	16200	55	232	131	42175	59	67.6	23800	163	113	166	11900	138
4	82	13800	46	198	107	36561	50	57.6	20632	139	97	141	9580	111
5	74	12400	42	178	92	32251	45	51.7	18200	125	87	127	7794	91
6	66	11200	38	161	82	28176	41	46.7	15900	113	78	115	6730	78
7	60	10200	34	146	73	25262	37	42.5	14256	103	71	104	5990	70
8	56	9387	32	135	67	23037	34	39.1	13000	95	66	96	5406	63
9	51	8583	29	123	61	21265	31	35.8	12000	87	60	88	4880	57
10	47	7890	27	113	57	19847	29	32.9	11200	80	55	81	4450	52
11	43	7255	24	104	53	18607	26	30.3	10500	73	51	74	4090	48
12	39	6660	22	96	50	17136	24	27.8	9670	67	47	68	3810	44
13	36	6080	20	87	48	15666	22	25.4	8840	61	43	62	3560	41
14	33	5580	19	80	45	14584	20	23.3	8230	56	39	57	3321	39
15	30	5130	17	74	43	13645	19	21.4	7700	52	36	52	3140	37
16	28	4720	16	68	42	12723	17	19.7	7180	48	33	48	2970	35
17	26	4300	14	64	40	11891	16	18.5	6710	43	30	44	2810	33
18	24	3960	13	59	38	11022	15	17.1	6220	40	28	41	2680	31
19	22	3632	12	54	37	10225	14	15.7	5770	37	25	37	2560	30
20	20	3320	11	49	35	9481	12	14.3	5350	33	23	34	2460	29
21	19	3040	10	45	34	8896	11	13.1	5020	31	21	31	2340	27
22	17	2810	9	42	33	8276	11	12.1	4670	28	20	29	2240	26
23	16	2600	9	39	32	7762	10	11.2	4380	26	18	27	2150	25
24	15	2380	8	35	30	7283	9	10.3	4110	24	17	24	2060	24
25	14	2210	7	33	29	6858	8	9.5	3870	22	15	23	1980	23
26	13	2070	7	31	28	6416	8	8.9	3621	21	14	21	1900	22
27	12	1930	6	29	27	6046	7	8.3	3412	19	14	20	1830	21
28	11	1790	6	27	26	5706	7	7.7	3220	18	13	18	1760	20
29	10	1670	6	25	25	5375	6	7.2	3033	17	12	17	1710	20
30	10	1560	5	23	24	5068	6	6.7	2860	16	11	16	1650	19
31	9	1450	5	21	24	4767	5	6.3	2690	15	10	15	1590	18
32	8	1360	5	20	23	4501	5	5.9	2540	14	10	14	1530	18
33	8	1280	4	19	22	4217	5	5.5	2380	13	9	13	1480	17
34	7	1200	4	18	22	3987	4	5.2	2250	12	8	12	1430	17
35	7	1120	4	17	21	3774	4	4.8	2130	11	8	11	1380	16
36	6	1060	4	16	20	3544	4	4.6	2000	11	7	11	1330	15

Stream Name	Lightning Creek	Verdigris River	California Creek	Big Creek	Lost Creek	Neosho River	Hudson Creek	Cow Creek	Neosho River	Little Cabin Creek	Bull Creek	Pawpaw Creek	Spring River	Fivemile Creek
WBID Segment	OK121510010130_00	OK121510020010_00	OK121510020050_00	OK121510030010_00	OK121600030560_00	OK121600040010_00	OK121600040040_00	OK121600040130_00	OK121600040220_00	OK121600060080_00	OK121600060200_00	OK121600060240_00	OK121600070010_00	OK121600070110_00
USGS Gage	07171000	07171000	07171000	07171000	07171000	07185000	07185000	07185000	07185000	07185000	07171000	07171000	07188000	7188000
Drainage Area	47.03	365.42	10.26	70.16	283.60	114.17	25.77	30.00	221.82	160.86	15.69	51.00	234.65	33.84
Percentile	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)
37	6	1000	3	15	19	3348	4	4.3	1890	10	7	10	1290	15
38	6	940	3	14	18	3154	4	4.1	1780	9	7	10	1250	15
39	5	888	3	13	18	2995	3	3.8	1690	9	6	9	1210	14
40	5	834	3	12	17	2835	3	3.6	1600	8	6	9	1170	14
41	5	789	3	12	17	2676	3	3.4	1510	8	6	8	1140	13
42	5	746	3	11	16	2552	3	3.2	1440	8	5	8	1100	13
43	4	700	2	10	15	2428	3	3.0	1370	7	5	7	1070	12
44	4	659	2	10	15	2304	2	2.8	1300	7	5	7	1030	12
45	4	623	2	9	14	2180	2	2.7	1230	6	4	6	1000	12
46	4	590	2	9	14	2091	2	2.5	1180	6	4	6	971	11
47	3	555	2	8	14	1985	2	2.4	1120	6	4	6	941	11
48	3	520	2	8	13	1878	2	2.2	1060	5	4	5	913	11
49	3	488	2	7	13	1790	2	2.1	1010	5	3	5	885	10
50	3	458	2	7	12	1703	2	2.0	961	5	3	5	856	10
51	3	427	1	6	12	1613	2	1.8	910	4	3	4	828	10
52	2	402	1.4	6.0	11.0	1511.6	1.5	1.7	853	4.1	2.8	4.1	801	9
53	2	374	1.3	5.5	11.0	1419.4	1.4	1.6	801	3.8	2.6	3.8	776	9
54	2	350	1.2	5.2	11.0	1345.0	1.3	1.5	759	3.5	2.5	3.6	750	9
55	2	327	1.1	4.8	10.0	1272.3	1.2	1.4	718	3.3	2.3	3.3	723	8
56	2	303	1.0	4.5	10.0	1209.4	1.1	1.3	682	3.1	2.1	3.1	699	8
57	2	285	1.0	4.2	9.6	1148.3	1.1	1.2	648	2.9	2.0	2.9	676	8
58	2	267	0.9	4.0	9.4	1093.4	1.0	1.2	617	2.7	1.9	2.7	654	8
59	2	249	0.8	3.7	9.1	1036.7	0.9	1.1	585	2.5	1.7	2.5	635	7
60	1	232	0.8	3.4	9.0	981.7	0.9	1.0	554	2.3	1.6	2.4	613	7
61	1	216	0.7	3.2	8.8	932.1	0.8	0.9	526	2.2	1.5	2.2	593	7
62	1	201	0.7	3.0	8.6	880.7	0.8	0.9	497	2.0	1.4	2.1	574	7
63	1	188	0.6	2.8	8.3	832.9	0.7	0.8	470	1.9	1.3	1.9	556	6
64	1	175	0.6	2.6	8.1	781.5	0.7	0.8	441	1.8	1.2	1.8	538	6
65	1	163	0.5	2.4	7.9	733.6	0.6	0.7	414	1.6	1.1	1.7	519	6
66	1	150	0.5	2.2	7.6	684.5	0.6	0.6	386	1.5	1.1	1.5	501	6
67	1	140	0.5	2.1	7.5	637.9	0.5	0.6	360	1.4	1.0	1.4	484	6
68	1	132	0.4	2.0	7.3	599.0	0.5	0.6	338	1.3	0.9	1.4	469	5
69	1	123	0.4	1.8	7.2	563.5	0.5	0.5	318	1.2	0.9	1.3	453	5
70	1	113	0.4	1.7	7.0	530.9	0.4	0.5	300	1.1	0.8	1.2	438	5
71	1	105	0.4	1.6	6.8	496.2	0.4	0.5	280	1.1	0.7	1.1	425	5
72	1	97	0.3	1.4	6.6	465.6	0.4	0.4	263	1.0	0.7	1.0	412	5
73	1	90	0.3	1.3	6.3	435.9	0.3	0.4	246	0.9	0.6	0.9	400	5
74	1	83	0.3	1.2	6.1	405.7	0.3	0.4	229	0.8	0.6	0.8	388	5
75	0	77	0.3	1.1	6.0	377.4	0.3	0.3	213	0.8	0.5	0.8	375	4

Stream Name	Lightning Creek	Verdigris River	California Creek	Big Creek	Lost Creek	Neosho River	Hudson Creek	Cow Creek	Neosho River	Little Cabin Creek	Bull Creek	Pawpaw Creek	Spring River	Fivemile Creek
WBID Segment	OK121510010130_00	OK121510020010_00	OK121510020050_00	OK121510030010_00	OK121600030560_00	OK121600040010_00	OK121600040040_00	OK121600040130_00	OK121600040220_00	OK121600060080_00	OK121600060200_00	OK121600060240_00	OK121600070010_00	OK121600070110_00
USGS Gage	07171000	07171000	07171000	07171000	07171000	07185000	07185000	07185000	07185000	07185000	07171000	07171000	07188000	7188000
Drainage Area	47.03	365.42	10.26	70.16	283.60	114.17	25.77	30.00	221.82	160.86	15.69	51.00	234.65	33.84
Percentile	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)	Q (cfs)
76	0	72	0.2	1.1	5.8	352.6	0.3	0.3	199	0.7	0.5	0.7	363	4
77	0	68	0.2	1.0	5.5	329.6	0.3	0.3	186	0.7	0.5	0.7	350	4
78	0	64	0.2	0.9	5.2	304.8	0.2	0.3	172	0.6	0.4	0.7	337	4
79	0	60	0.2	0.9	5.2	281.8	0.2	0.3	159	0.6	0.4	0.6	327	4
80	0	56	0.2	0.8	5.1	256.9	0.2	0.2	145	0.6	0.4	0.6	315	4
81	0	52	0.2	0.8	4.9	233.9	0.2	0.2	132	0.5	0.4	0.5	303	4
82	0	49	0.2	0.7	4.9	212.6	0.2	0.2	120	0.5	0.3	0.5	293	3
83	0	46	0.2	0.7	4.6	194.9	0.2	0.2	110	0.5	0.3	0.5	283	3
84	0	43	0.1	0.6	4.4	177.21	0.16	0.2	100	0.4	0.30	0.44	273	3
85	0	40	0.1	0.6	4.4	161.26	0.15	0.2	91	0.4	0.28	0.41	264	3
86	0	36	0.1	0.5	4.1	148.85	0.13	0.2	84	0.4	0.25	0.37	254	3
87	0	33	0.1	0.5	3.9	138.22	0.12	0.1	78	0.3	0.23	0.34	243	3
88	0	30	0.1	0.4	3.8	127.59	0.11	0.1	72	0.3	0.21	0.31	232	3
89	0	27	0.1	0.4	3.7	116.96	0.10	0.1	66	0.3	0.19	0.28	222	3
90	0	24	0.1	0.4	3.6	106.32	0.09	0.1	60	0.2	0.17	0.25	212	2
91	0	22	0.1	0.3	3.4	93.92	0.08	0.1	53	0.2	0.15	0.23	201	2
92	0	20	0.1	0.3	3.3	81.51	0.07	0.1	46	0.2	0.14	0.20	192	2
93	0	17	0.1	0.3	3.1	70.88	0.06	0.1	40	0.2	0.12	0.17	181	2
94	0	15	0.1	0.2	2.8	58.48	0.06	0.1	33	0.2	0.11	0.15	167	2
95	0	13	0.0	0.2	2.6	47.85	0.05	0.1	27	0.1	0.09	0.13	155	1.8
96	0	10	0.0	0.1	2.2	37.21	0.04	0.0	21	0.1	0.07	0.10	142	1.7
97	0	8	0.0	0.1	1.5	28.35	0.03	0.0	16	0.1	0.05	0.08	130	1.5
98	0	6	0.0	0.1	1.2	17.72	0.02	0.0	10	0.1	0.04	0.06	114	1.3
99	0	2	0.0	0.0	0.8	3.37	0.01	0.0	2	0.0	0.01	0.02	85	1.0
100	0	0	0.0	0.0	0.3	0.0	0.0	0.0	0	0.0	0.00	0.00	6	0.1

APPENDIX C

STATE OF OKLAHOMA ANTIDEGRADATION POLICY

Appendix C
State of Oklahoma Antidegradation Policy

785:45-3-1. 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 785:45-3-2 and Subchapter 13 of OAC 785:46.

785:45-3-2. 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 785:45-5-25(c)(2)(A) and 785:46-13-6(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.

785:46-13-1. Applicability and scope

(a) The rules in this Subchapter provide a framework for implementing the antidegradation policy stated in OAC 785:45-3-2 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 or protection of High Quality Waters and Sensitive Public and Private Water Supply waters.

(3) 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 785:45. Although Appendix B areas are not mentioned in OAC 785:45-3-2, 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 and Tier 3 waterbodies or areas, and implementation rules applicable to Tier 2 waterbodies shall be applicable also to 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 or SWS limitation.

785:46-13-2. 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.

785:46-13-3. 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.

785:46-13-4. Tier 2 protection; maintenance and protection of High Quality Waters and Sensitive Water Supplies

(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 785:45 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 785:45 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" and "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 785:45.

785:46-13-5. 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 785:45 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 785:46-13-5(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 785:46-13-5(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 785:45, 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 785:45 as "ORW".

785:46-13-6. Protection for Appendix B areas

(a) General. Appendix B of OAC 785:45 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 785:45 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 785:45 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 785:45.

APPENDIX D

NPDES DISCHARGE MONITORING REPORT DATA FOR BORON PRODUCTS, LLC

Table D-1 NPDES Discharge Monitoring Report Data for Boron Products, LLC

NPDES No.	Outfall	Monitoring Date	Flow (MGD)		TSS (mg/L)	
			Monthly Ave	Daily Max	Monthly Ave	Daily Max
OK0040142	001	07/31/2009	0.015	0.015	No Discharge	No Discharge
OK0040142	001	08/31/2009	0.017	0.023	No Discharge	No Discharge
OK0040142	001	09/30/2009	0.018	0.023	No Discharge	No Discharge
OK0040142	001	10/31/2009	0.015	0.023	No Discharge	No Discharge
OK0040142	001	11/30/2009	No Discharge	No Discharge	No Discharge	No Discharge
OK0040142	001	12/31/2009	0.016	0.022	Not Received	Not Received
OK0040142	001	01/31/2010	0.009	0.011	No Discharge	No Discharge
OK0040142	001	02/28/2010	0.011	0.018	No Discharge	No Discharge
OK0040142	001	03/31/2010	0.012	0.015	No Discharge	No Discharge
OK0040142	001	04/30/2010	0.005	0.011	No Discharge	No Discharge
OK0040142	001	05/31/2010	0.007	0.011	No Discharge	No Discharge
OK0040142	001	06/30/2010	0.013	0.050	No Discharge	No Discharge
OK0040142	001	07/31/2010	0.002	0.003	No Discharge	No Discharge
OK0040142	001	08/31/2010	0.002	0.003	No Discharge	No Discharge
OK0040142	001	09/30/2010	0.004	0.008	No Discharge	No Discharge
OK0040142	001	10/31/2010	0.003	0.003	No Discharge	No Discharge
OK0040142	001	11/30/2010	0.004	0.008	No Discharge	No Discharge
OK0040142	001	12/31/2010	0.002	0.003	No Discharge	No Discharge
OK0040142	001	01/31/2011	0.002	0.002	No Discharge	No Discharge
OK0040142	001	02/28/2011	0.005	0.015	No Discharge	No Discharge
OK0040142	001	03/31/2011	0.002	0.002	No Discharge	No Discharge
OK0040142	001	04/30/2011	0.001	0.001	No Discharge	No Discharge
OK0040142	001	05/31/2011	0.002	0.002	No Discharge	No Discharge
OK0040142	001	06/30/2011	0.001	0.001	No Discharge	No Discharge
OK0040142	001	07/31/2011	0.002	0.003	No Discharge	No Discharge
OK0040142	001	08/31/2011	0.002	0.003	No Discharge	No Discharge
OK0040142	001	09/30/2011	0.004	0.008	No Discharge	No Discharge
OK0040142	001	10/31/2011	0.004	0.005	No Discharge	No Discharge
OK0040142	001	11/30/2011	0.003	0.005	No Discharge	No Discharge
OK0040142	001	12/31/2011	No Discharge	No Discharge	No Discharge	No Discharge
OK0040142	001	01/31/2012	No Discharge	No Discharge	No Discharge	No Discharge
OK0040142	001	02/29/2012	0.003	0.005	No Discharge	No Discharge
OK0040142	001	03/31/2012	0.004	0.011	No Discharge	No Discharge
OK0040142	001	04/30/2012	0.008	0.015	No Discharge	No Discharge
OK0040142	001	05/31/2012	0.005	0.008	No Discharge	No Discharge
OK0040142	001	07/31/2009	0.015	0.015	No Discharge	No Discharge

APPENDIX E

DEQ SANITARY SEWER OVERFLOW DATA – 1992-2010

Table E-1 DEQ Sanitary Sewer Overflow Data

Facility Name	Date	Facility ID	Duration (hrs)	Location	Amount (gallons)	Raw	Treated	Cause
South Coffeyville	7/13/1992	S21501	20.00	Old discharge line from the retention lagoon		x		Flood water
South Coffeyville	6/12/1995	S21501	134.00	At plant out of holding pond	6,030,000	X		Rain I/I
South Coffeyville	7/13/1992	S21501		Lagoons		X	X	Old outfall line leaking
South Coffeyville	3/31/1993	S21501	240.00	East end of storm holding basin	1,700,000	X	X	I/I problems caused plant over load
South Coffeyville	6/28/2003	S21501	77.00	2 Blk E. Of 111 Walnut St. - WWTP	>4 Million		X	Pump failure
South Coffeyville	12/25/2007	S21501	18.00	510 Walnut St.	400	X		Roots
Delaware	12/9/1992	S21502	2.00	307 E Osage	100	X		Line blockage
Delaware	11/3/1993	S21502	11.00	S Washington street	500	X		Root blockage
Delaware	1/9/1994	S21502	28.00	204 elm street	1000	X		Line blockage
Delaware	11/2/1995	S21502	2.00	201 elm street	200	X		Root stoppage
Delaware	3/3/1996	S21502	336.00	At ponds	600,000		X	Lowering pounds to replace rock filter media
Delaware	3/15/1996	S21502		Sewer lagoons	600,000		X	Construstion on new rock filter
Delaware	7/17/1996	S21502		Sewer lagoons	600		X	Construction on new rock filter
Delaware	1/5/2005	S21502	12.00	Delaware St. At Elm & Main	1,000	X		I&I
Delaware	9/10/2007	S21502	2.50	706 Elm				Storm water
Delaware	3/29/2009	S21502	20.00	Rd 17 W. of Elm	12,000	X		Storm water
Delaware	3/29/2009	S21502	20.00	Rd 17 W. of Elm	12,000	X		Storm water
Delaware	3/30/2009	S21502	0.00				X	Storm water
Delaware	5/12/2009	S21502	4.30	Washington St. & Delaware		X		Rain
Delaware	5/12/2009	S21502	4.30	Old hwy (Elm st.)		X		Rain
Delaware	10/8/2009	S21502	26.00	East of Elm	7,800	X		Rain
Delaware	6/14/2010	S21502	12.00	Delaware & Washington	18,000			Rain
Delaware	6/14/2010	S21502	18.00	Rd 17 East of Elm	162,000	X		Rain
Delaware	3/19/2012	S21502	96.00	Rd 17 1/2 blk. East of Elm	200,000	X		Rain
Delaware	4/14/2012	S21502	0.00	Rd 17 E. of Elm	50,000	X		Rain
Delaware	4/30/2012	S21502	30.30	200 ft. E. Of elm	200,000	X		Rain
Bluejacket	9/19/1991	S21677		Bluejacket School	10,000	X		Connection of school lagoon to system
Bluejacket	1/25/2008	S21677	5.00	Plant	1,000	X		Pump failure
Bluejacket	2/12/2008	S21677	1.40	Plant	200	X		Pump failure
Bluejacket	6/13/2009	S21677	0.00			X		L.s. relays went out

Facility Name	Date	Facility ID	Duration (hrs)	Location	Amount (gallons)	Raw	Treated	Cause
Bluejacket	6/30/2009	S21677	0.00	Lift station		X		Malfunction
Bluejacket	2/23/2010	S21677	2.00	House off hwy 25	1,500		X	Pump failure
Quapaw	9/14/1993	S21609	0.00	408 E. Seneca	300			Roots
Quapaw	9/14/1993	S21609	0.00	410 E. Seneca	500			Roots
Quapaw	9/14/1993	S21609	0.00					Rain
Quapaw	9/14/1993	S21609	6.00	E. 4th St on Lagoon Rd.	30	X		Conductor in control burned out due to rain
Quapaw	4/28/1996	S21609	1.00	Treatment plant	130	X		Storm
Quapaw	9/17/1999	S21609		Lagoon			X	Vandals opened gate
Quapaw	4/17/2001	S21609	5.50	4th St. at Seneca & Caugor St.				Break
Quapaw	9/16/2002	S21609	4.00	Lagoon	1,250	X		Lightning
Quapaw	7/4/2004	S21609	10.50	2 blks. E. of town on 4th	645,000	X		Rain
Quapaw	6/13/2005	S21609	9.00	Lift Station	212,000	X		Lightning
Quapaw	5/3/2007	S21609	5.00	2nd at Kentucky & Quapaw	99,360		X	Rain
Quapaw	6/8/2007	S21609	2.00	E. Side of Quapaw on 4th st.		X		Lightning
Quapaw	6/8/2007	S21609	13.00	Plant	336,000	X		Lightning strike
Quapaw	6/11/2007	S21609	8.00	Lift station	423,000	X		Lightning
Quapaw	6/11/2007	S21609	8.00	Plant	423,000	X		Transformer failed
Quapaw	12/10/2007	S21609	72.50	Lift station	398,000	X		Power loss
Quapaw	12/10/2007	S21609	72.50	N. End of Jackson st.	49,000	X		Power loss
Quapaw	12/10/2007	S21609	72.50	N. End of Cayuga st.	199,000	X		Power loss
Quapaw	12/10/2007	S21609	72.50	West side l.s. on w. 1st. & cherry	199,000	X		Power loss
Quapaw	12/10/2007	S21609	77.50	E. End of Melba St. In Beaver addition	60,000	X		Power loss
Quapaw	12/11/2007	S21609		E. 4th st.	130,000	X		Power loss
Quapaw	5/8/2009	S21609	0.00	E. 4th st. End of plant	423,000	X		Power loss
Quapaw	3/21/2010	S21609	25.50	End of 4th st at lagoon	99,000	X		Malfunction

APPENDIX F

STAFF IDENTIFIED CHANGE

Staff Identified Change

The designated beneficial use for Spring River (OK121600070010_00) is Cold Water Aquatic Community (CWAW). However, Spring River was incorrectly assessed in this TMDL Report as a Warm Water Aquatic Community (WWAC). According to the WQS [785:45-5-12(f)(7)], the turbidity criterion for streams with CWAC beneficial use is 10 NTUs instead of the 50 NTUs for WWAC (OWRB 2011). Since Spring River is designated as a CWAW, Spring River is impaired for turbidity.

EPA Region 6 is having a contractor develop TMDLs for some of the waterbodies around the Grand Lake area. Since one of these waterbodies is Spring River (OK121600070010_00), the EPA contractor will develop that TMDL for turbidity. As a result, parts of this report that were related to the turbidity assessments and calculations for Spring River (OK121600070010_00) were deleted.