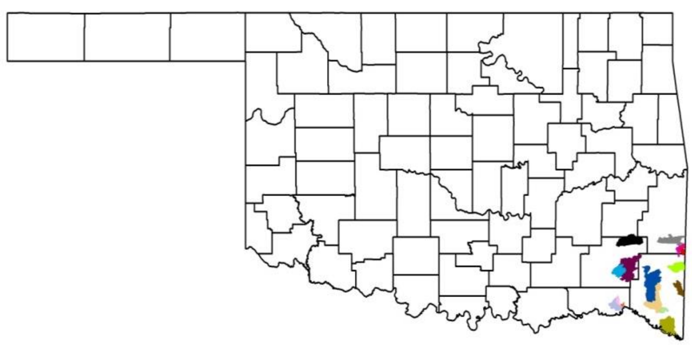
FINAL

2014 BACTERIAL AND TURBIDITY TOTAL MAXIMUM DAILY LOADS FOR THE OKLAHOMA LOWER RED RIVER-LITTLE RIVER BASIN STUDY AREA (OK410100, OK410200, OK410210, OK410300, OK410310)

OKLAHOMA WATERBODY ID NUMBERS:

OK410100010010_10, OK410200010200_00, OK410200010200_10, OK410200030010_00, OK410210020140_00, OK410210020300_00, OK410210060020_00, OK410210060320_00, OK410210060350_00, OK410210080010_00, OK410300010010_00, OK410300010020_00, OK410300010100_00, OK410310010010_00, OK410310020010_10



OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

AUGUST 2014

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ACRONYMS AND ABBREVIATIONS

AEMS	Agricultural Environmental Management Service
AFO	Animal Feeding Operation
AgPDES	Agriculture Pollutant Discharge Elimination System
ASAE	American Society of Agricultural Engineers
BMP	Best management practices
BOD	Biochemical Oxygen Demand
BUMP	Beneficial Use Monitoring Program
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
CWAC	Cool water aquatic community
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

MSGP	Multi-Sector General Permit
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source
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
r^2	Correlation coefficient
RMSE	Root mean square error
SH	State Highway
SSO	Sanitary sewer overflow
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WWAC	warm water aquatic community
WLA	wasteload allocation
WQ	Water Quality
WQM	Water quality monitoring
WQMP	Water Quality Management Plan
WQS	Water quality standards
WWTF	wastewater treatment facility

EXECUTIVE SUMMARY

ES - 1 OVERVIEW

As promulgated by Section 402 of the Clean Water Act (CWA), the U.S. Environmental Protection Agency (EPA) has delegated authority to the Oklahoma Department of Environmental Quality (DEQ) to partially oversee the National Pollutant Discharge Elimination System (NPDES) Program in the State of Oklahoma. Exceptions are agriculture (retained by State Department of Agriculture, Food, and Forestry), and the oil & gas industry (retained by the Oklahoma Corporation Commission) for which EPA has retained permitting authority. The NPDES Program in Oklahoma, in accordance with an agreement between DEQ and EPA, is implemented via the Oklahoma Pollutant Discharge Elimination System (OPDES) Act [Title 252, Chapter 606 (http://www.deq.state.ok.us/rules/606.pdf)].

This total maximum daily load (TMDL) 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 Red-Little River Basin. 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 were 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 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 study was 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 OPDES 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.

ES - 2 PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

This TMDL report focused on waterbodies in the Red-Little River Basin, identified in **Table ES-1**, that DEQ placed in Category 5 [303(d) list] of the *Water Quality in Oklahoma, 2010 Integrated Report* (aka 2010 Integrated Report) for nonsupport of primary body contact recreation (PBCR) or Fish and Wildlife Propagation-Warm Water Aquatic Community (WWAC)/Fish and Wildlife Propagation-Cool Water Aquatic Community (CWAC).

Elevated levels of bacteria or turbidity above the WQS necessitated 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-2 summarizes water quality data collected during primary contact recreation season from the water quality monitoring (WQM) stations between 2001 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 2010 303(d) list (DEQ 2010).

ES-2.1 Chapter 45: Definition of PBCR and Bacterial WQSs

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.

(Chapter 45 continues on page ES-5)

Table ES- 1: 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 Community	Designated Use Cool Water Aquatic Community
OK410100010010_10	**Red River**	22.99	2018	3			F	X	N	
OK410200010200_00	**Little River**	8.2	2012	1			F	X		N
OK410200010200_10	**Little River**	24.14	2012	1			F	X		N
OK410200030010_00	**Rock Creek**	12.35	2021	4			I	X		N
OK410210020140_00	**Little River**	24.68	2012	1			N[1]	X		N
OK410210020300_00	**Cloudy Creek**	25.63	2012	1			I	X		N
OK410210060020_00	**Buffalo Creek**	23.38	2012	1			I	X		N
OK410210060320_00	**Beech Creek**	12.71	2012	1			I	X		N
OK410210060350_00	**Cow Creek**	11.03	2012	1			I	X		N
OK410210080010_00	**Glover River**	33.95	2012	2			F	X		N
OK410300010010_00	**Kiamichi River**	18.11	2015	2	X		N		N	
OK410300010020_00	**Gates Creek**	4.85	2015	2			I	X		N
OK410300010100_00	**Bird Creek**	8.05	2015	2			I	X	N	
OK410310010010_00	**Kiamichi River**	26.35	2015	2	X		N		N	
OK410310020010_10	**Kiamichi River**	25.18	2015	2	X		N		N	

ENT = Enterococci; EC = *E.coli*; F=Fully Supporting; N = Not attaining; X = Criterion exceeded — Source: 2010 Integrated Report, DEQ 2010

[1] A TMDL was developed for this impairment in 2007.

Table ES- 2: Summary of Indicator Bacterial Samples from Primary Body Contact Recreation Season, 2001-2008

Waterbody ID	Waterbody Name	Indicator	Number of samples	Geometric Mean Concentration (count/100 ml)	Notes
OK410100010010_10	**Red River**	EC	28	14.6	
		ENT	28	20.6	
OK410200010200_00	**Little River**	EC	20	36.3	
		ENT	20	49.4	Mixing zone data
OK410200010200_10	**Little River**	EC	12	31.5	
		ENT	12	31.5	
OK410200030010_00	**Rock Creek**	EC	6	16.7	
		ENT	6	23.3	
OK410210020140_00	**Little River**	EC	29	32.6	
		ENT	29	64.1	TMDL in 2007
OK410210020300_00	**Cloudy Creek**	EC	8	19.1	
		ENT	8	28.5	
OK410210060020_00	**Buffalo Creek**	EC	7	17.3	
		ENT	7	16.8	
OK410210060320_00	**Beech Creek**	EC	7	17.9	
		ENT	7	25.3	
OK410210060350_00	**Cow Creek**	EC	7	41.6	
		ENT	7	26.7	
OK410210080010_00	**Glover River**	EC	30	21.2	
		ENT	30	28.3	
OK410300010010_00	**Kiamichi River**	EC	23	34.8	
		ENT	23	35.8	Impaired
OK410300010020_00	**Gates Creek**	EC	8	55.7	
		ENT	8	35.5	Insufficient number of samples
OK410300010100_00	**Bird Creek**	EC	6	168.4	Insufficient number of samples
		ENT	6	68.0	Insufficient number of samples
OK410310010010_00	**Kiamichi River**	EC	27	47.9	
		ENT	27	54.3	Impaired
OK410310020010_10	**Kiamichi River**	EC	28	20.9	
		ENT	28	47.0	Impaired

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

(Text from Chapter 45 on page ES-2 continues below)

(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.

ES-2.2 Chapter 46: Implementation of OWQS for PBCR

To implement Oklahoma's WQS for PBCR, OWRB promulgated Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2013a). The excerpt below from Chapter 46: 785:46-15-6, stipulates how water quality data was assessed to determine support of the PBCR use as well as how the water quality target for TMDLs was 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 2013).

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 were 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 2010 303(d) list. Bacterial TMDLs will be developed only for *E. coli* and/or Enterococci impaired streams.

ES-2.3 Chapter 45: Criteria for Turbidity

The beneficial use of WWAC or CWAC 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.

ES-2.4 Chapter 46: Implementation of OWQS for Fish and Wildlife Propagation

Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2013a) describes Oklahoma's WQS for Fish and Wildlife Propagation. The excerpt below from Chapter 46: 785:46-15-5, stipulates how water quality data was assessed to determine support of fish and wildlife propagation as well as how the water quality target for TMDLs was defined for turbidity.

785:46-15-5 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.

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) were 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 25th flow exceedance percentile (i.e., the lower 75% of flows). Water quality samples collected under flow conditions greater than the 25th flow exceedance percentile (highest flows) were therefore excluded from the data set used for TMDL analysis.

TMDLs for turbidity in streams designated as WWAC or CWAC must take into account that no more than 10% of the samples may exceed the numeric criterion of turbidity, 50 or 10 nephelometric turbidity units (NTU), respectively. 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.

After re-evaluating bacterial and turbidity/TSS data for the streams listed in **Table ES-1**, it was discovered that the samples for the Little River (OK410200010200_00) were collected in a mixing zone. According to *Implementation of Oklahoma's Water Quality Standards* [Title 785, Chapter 46-15-3(b)(5)], "Samples and other data shall not be taken within any regulatory mixing zone." As a result, the Little River (OK410200010200_00) was recommended for delisting of turbidity impairment from the 303(d) list.

Table ES-5 shows the bacterial and turbidity TMDLs that were developed in this Report.

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

Point sources are permitted through the OPDES program. OPDES-permitted facilities that discharge treated sanitary wastewater and are required to monitor fecal coliform under the current permits will be required to monitor *E. coli* when their permits come up for renewal. 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 OPDES 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 are 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.

(Text continues on Page ES-13)

Table ES- 3: Summary of Turbidity and TSS Samples Collected During Base Flow Conditions, 1998-2012

Waterbody ID	Waterbody Name	WQM Stations	Number of turbidity samples	Number of samples greater than WQS	% samples exceeding criterion	Average Turbidity (NTU)	Assessment Results
OK410100010010_10	Red River	410100010010-001AT	29	7	24.1%	40	Impaired
OK410200010200_00	Little River	410200010200-001AT	35	24	68.6%	16	Delist: Mixing zone data
OK410200010200_10	Little River	410200010200-002AT	30	18	60.0%	14	Impaired
OK410200030010_00	Rock Creek	OK410200-03-0010G	20	4	20.0%	17	Impaired
OK410210020140_00	Little River	410210020140-001AT	40	14	35.0%	10	Impaired
OK410210020300_00	Cloudy Creek	OK410210-02-0300C	20	6	30.0%	46	Impaired
OK410210060020_00	Buffalo Creek	OK410210-06-0020G	18	5	27.8%	8	Impaired
OK410210060320_00	Beech Creek	OK410210-06-0320G	21	7	33.3%	16	Impaired
OK410210060350_00	Cow Creek	OK410210-06-0350G	21	7	33.3%	22	Impaired
OK410210080010_00	Glover River	410210080010-001AT	40	9	22.5%	9	Impaired
OK410300010010_00	Kiamichi River	410300010010-002AT	32	2	6.3%	31	
OK410300010020_00	Gates Creek	OK410300-01-0020F	19	16	84.2%	20	Impaired
OK410300010100_00	Bird Creek	OK410300-01-0100C	19	4	21.1%	32	Impaired
OK410310010010_00	Kiamichi River	410310010010-001AT	31	1	3.2%	13	
OK410310020010_10	Kiamichi River	410310020010-001AT	37	0	0%	6	

TMDLs will be developed for waterbodies highlighted in green.

Table ES- 4: Regression Statistics and TSS Goals

Waterbody ID	Waterbody Name	R-square	NRMSE	TSS Goal (mg/L)[a]	MOS[b]
OK410100010010_10	Red River	0.79	10.7%	85.4	15%
OK410200010200_10	Little River	0.74	12.0%	6.9	15%
OK410200030010_00	Rock Creek	0.61	28.0%	6.9	30%
OK410210020140_00	Little River	0.74	12.0%	6.9	15%
OK410210020300_00	Cloudy Creek	0.74	12.0%	6.9	15%
OK410210060020_00	Buffalo Creek	0.61	28.0%	6.9	30%
OK410210060320_00	Beech Creek	0.61	28.0%	6.9	30%
OK410210060350_00	Cow Creek	0.61	28.0%	6.9	30%
OK410210080010_00	Glover River	0.74	12.0%	6.9	15%
OK410300010020_00	Gates Creek	0.53	17.7%	7.4	20%
OK410300010100_00	Bird Creek	0.49	35.0%	23.6	35%

[a] Calculated using the regression equation and the turbidity standard (50 NTU for WWAC and 10 NTU for CWAC)

Table ES- 5: Stream Segments and Pollutants for TMDL Development

Waterbody ID	HUC 8	Waterbody Name	Stream Miles	TMDL Date	Priority	ENT	Turbidity
OK410100010010_10	11140106	Red River	22.99	2018	3		X
OK410200010200_00	11140107	Little River	8.2	2012	1		Delist
OK410200010200_10	11140107	Little River	24.14	2012	1		X
OK410200030010_00	11140109	Rock Creek	12.35	2021	4		X
OK410210020140_00	11140107	Little River	24.68	2012	1	Done 2007	X
OK410210020300_00	11140107	Cloudy Creek	25.63	2012	1		X
OK410210060020_00	11140108	Buffalo Creek	23.38	2012	1		X
OK410210060320_00	11140108	Beech Creek	12.71	2012	1		X
OK410210060350_00	11140108	Cow Creek	11.03	2012	1		X
OK410210080010_00	11140107	Glover River	33.95	2012	2		X
OK410300010010_00	11140105	Kiamichi River	18.11	2015	2	X	
OK410300010020_00	11140105	Gates Creek	4.85	2015	2		X
OK410300010100_00	11140105	Bird Creek	8.05	2015	2		X
OK410310010010_00	11140105	Kiamichi River	26.35	2015	2	X	
OK410310020010_10	11140105	Kiamichi River	25.18	2015	2	X	

Table ES- 6: Summary of Potential Pollutant Sources by Category

Waterbody ID	Waterbody Name	Municipal OPDES Facility	Industrial OPDES Facility	MS4	OPDES No Discharge Facility	PFO	Mines	Construction Stormwater Permit	Multi-Sector General Permit	Nonpoint Source
OK410100010010_10	**Red River**									Turbidity
OK410200010200_00	**Little River**									Not impaired
OK410200010200_10	**Little River**									Turbidity
OK410200030010_00	**Rock Creek**									Turbidity
OK410210020140_00	**Little River**									Turbidity
OK410210020300_00	**Cloudy Creek**									Turbidity
OK410210060020_00	**Buffalo Creek**									Turbidity
OK410210060320_00	**Beech Creek**									Turbidity
OK410210060350_00	**Cow Creek**									Turbidity
OK410210080010_00	**Glover River**									Turbidity
OK410300010010_00	**Kiamichi River**									Bacteria
OK410300010020_00	**Gates Creek**									Turbidity
OK410300010100_00	**Bird Creek**									Turbidity
OK410310010010_00	**Kiamichi River**									Bacteria
OK410310020010_10	**Kiamichi River**									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

ES - 4 USING LOAD DURATION CURVES TO DEVELOP TMDLS

The TMDL calculations presented in this report were 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 segment. Plotting future monitoring information on the LDC will show trends of improvement to sources that will identify areas for revision to the segment restoration plan. The low cost of the LDC method allows the development of TMDL plans on more segments and the evaluation of the implementation of WLAs and BMPs on more segments. The technical approach for using LDCs for TMDL development includes the following steps:

1. Prepare flow duration curves for gaged and ungaged WQM stations.

2. Estimate existing loading in the waterbody using ambient bacterial water quality data.

3. Estimate loading in the waterbody using measured TSS water quality data and turbidity-converted data.

4. Use 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 facility (WWTF) 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 following are the basic steps in developing an LDC:

1. Obtain daily flow data for the site of interest from the U.S. Geological Survey (USGS), or if unavailable, projected from a nearby USGS site.

2. Sort the flow data and calculating flow exceedance percentiles.

3. Obtain the water quality data from the primary contact recreation season (May 1 through September 30).

4. For turbidity, obtain available turbidity and TSS water quality data.

5. Match the water quality observations with the flow data from the same date.

6. Display 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.

7. Display a curve on a plot that represents the allowable load determined by multiplying the actual or estimated flow by the WQ_{goal} for TSS.

8. For bacterial TMDLs, display and differentiate 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.

9. For turbidity TMDLs, match the water quality observations with the flow data from the same date and determining the corresponding exceedance percentile. Plot the flow exceedance percentiles and daily load observations in a load duration plot (See Section 5).

ES-4.1 Bacterial LDC

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

ES-4.2 TSS LDC

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) = $\boldsymbol{WQ_{goal}}$ **** flow (cfs) * unit conversion factor***

Where:

***WQ_{goal} = waterbody specific TSS concentration derived from regression analysis results presented in* Table 5-2**

Unit conversion factor = 5.39377

ES-4.3 LDC Summary

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 were paired with flow data and were 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 were not plotted on the LDCs.

ES - 5 TMDL CALCULATIONS

A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS, which attempts to account for the lack of knowledge concerning the relationship between pollutant loading and water quality.

This definition can be expressed by the following equation:

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

ES-5.1 Bacterial PRG

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 was 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 target (TMDL target = TMDL - MOS).

Table ES-7 presents the percent reductions necessary for each bacterial indicator that caused nonsupport of the PBCR use in each waterbody of the Study Area. The PRGs for the waterbodies requiring bacterial TMDLs range from 17% to 45.3% for Enterococci.

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

Waterbody ID	Waterbody Name	Geometric mean		Required Reduction Rate	
		EC	ENT	EC	ENT
OK410300010010_00	**Kiamichi River**	34.8	35.8	-	17.0%
OK410310010010_00	**Kiamichi River**	47.9	54.3	-	45.3%
OK410310020010_10	**Kiamichi River**	20.9	47.0	-	36.9%

ES-5.2 TSS PRG

Similarly, PRGs for TSS are calculated as the required overall reduction so that no more than 10% of the samples exceed the TMDL target for TSS. The PRGs for the waterbodies requiring turbidity TMDLs in this report are summarized in **Table ES-8** and range from 46.5% to 82.6%.

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

Waterbody ID	Waterbody Name	TSS Required Reduction Rate
OK410100010010_10	**Red River**	57.8%
OK410200010200_10	**Little River**	65.7%
OK410200030010_00	**Rock Creek**	51.6%
OK410210020140_00	**Little River**	67.3%
OK410210020300_00	**Cloudy Creek**	46.5%
OK410210060020_00	**Buffalo Creek**	56.0%
OK410210060320_00	**Beech Creek**	78.0%
OK410210060350_00	**Cow Creek**	78.0%
OK410210080010_00	**Glover River**	64.3%
OK410300010020_00	**Gates Creek**	73.1%
OK410300010100_00	**Bird Creek**	82.6%

ES-5.3 MOS

The TMDL, WLA, LA, and MOS vary with flow condition, and were calculated at every 5^{th} flow interval percentile. The WLA component of each TMDL is the sum of all WLAs within each contributing watershed. The LA was then 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**).

ES-5.4 PBCR Season

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.

ES - 6 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 source (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.

ES - 7 Public Participation

A public notice was sent to local newspapers, to stakeholders in the Study Area affected by these draft TMDLs, and to stakeholders who have requested copies of all TMDL public notices. The public notice, draft TMDL report, and draft 208 Factsheet were posted at the following DEQ website: www.deq.state.ok.us/wqdnew/index.htm. The public had 45 days (February 3, 2014 to March 21, 2014) to review the draft TMDL report and make written comments.

One written comment was received during the public notice period. This comment, along with DEQ's response (**Appendix G**), is now part of the record of this TMDL report. As a result of that comment, changes were made to this final TMDL report and its 208 Factsheet. Some additional staff-identified revisions were also made to this TMDL report.

There were no requests for a public meeting.

This TMDL report was then finalized and submitted to EPA for final approval.

SECTION 1 INTRODUCTION

1.1 TMDL PROGRAM BACKGROUND

As promulgated by Section 402 of the Clean Water Act (CWA), the U.S. Environmental Protection Agency (EPA) has delegated authority to the Oklahoma Department of Environmental Quality (DEQ) to partially oversee the National Pollutant Discharge Elimination System (NPDES) Program in the State of Oklahoma. Exceptions are agriculture (retained by State Department of Agriculture, Food, and Forestry), and the oil & gas industry (retained by the Oklahoma Corporation Commission) for which EPA has retained permitting authority. The NPDES Program in Oklahoma, in accordance with an agreement between DEQ and EPA, is implemented via the Oklahoma Pollutant Discharge Elimination System (OPDES) Act [Title 252, Chapter 606 (http://www.deq.state.ok.us/rules/606.pdf)].

Section 303(d) of the CWA and 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. Segments and pollutants identified on the approved 303(d) list as not meeting designated uses where technology-based controls are in place will be given a higher priority for development of TMDLs. TMDLs establish the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and 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][1] and turbidity for selected waterbodies in the Red-Little 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 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 received notification of the approval or disapproval action. Once the EPA approves a TMDL, then the waterbody

[1] All future references to bacteria in this document imply these two fecal pathogen indicator bacterial groups unless specifically stated otherwise.

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 study was 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 OPDES. 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 focused on waterbodies that DEQ placed in Category 5 [303(d) list] of the *Water Quality in Oklahoma, 2010 Integrated Report* (aka 2010 Integrated Report) for nonsupport of primary body contact recreation (PBCR) or Fish and Wildlife Propagation-Warm Water Aquatic Community (WWAC)/Fish and Wildlife Propagation-Cool Water Aquatic Community (CWAC) beneficial uses. The waterbodies considered for TMDL development in this report, which are presented upstream to downstream, are in **Table 1-1**.

Table 1-1 Lower Red River/Little River Waterbodies and Waterbody IDs

Waterbody Name	Oklahoma Waterbody Identification Number (OK WBID)
Red River	OK410100010010_10
Little River	OK410200010200_00
Little River	OK410200010200_10
Rock Creek	OK410200030010_00
Little River	OK410210020140_00
Cloudy Creek	OK410210020300_00
Buffalo Creek	OK410210060020_00
Beech Creek	OK410210060320_00

Waterbody Name	Oklahoma Waterbody Identification Number (OK WBID)
Cow Creek	OK410210060350_00
Glover River	OK410210080010_00
Kiamichi River	OK410300010010_00
Gates Creek	OK410300010020_00
Bird Creek	OK410300010100_00
Kiamichi River	OK410310010010_00
Kiamichi River	OK410310020010_10

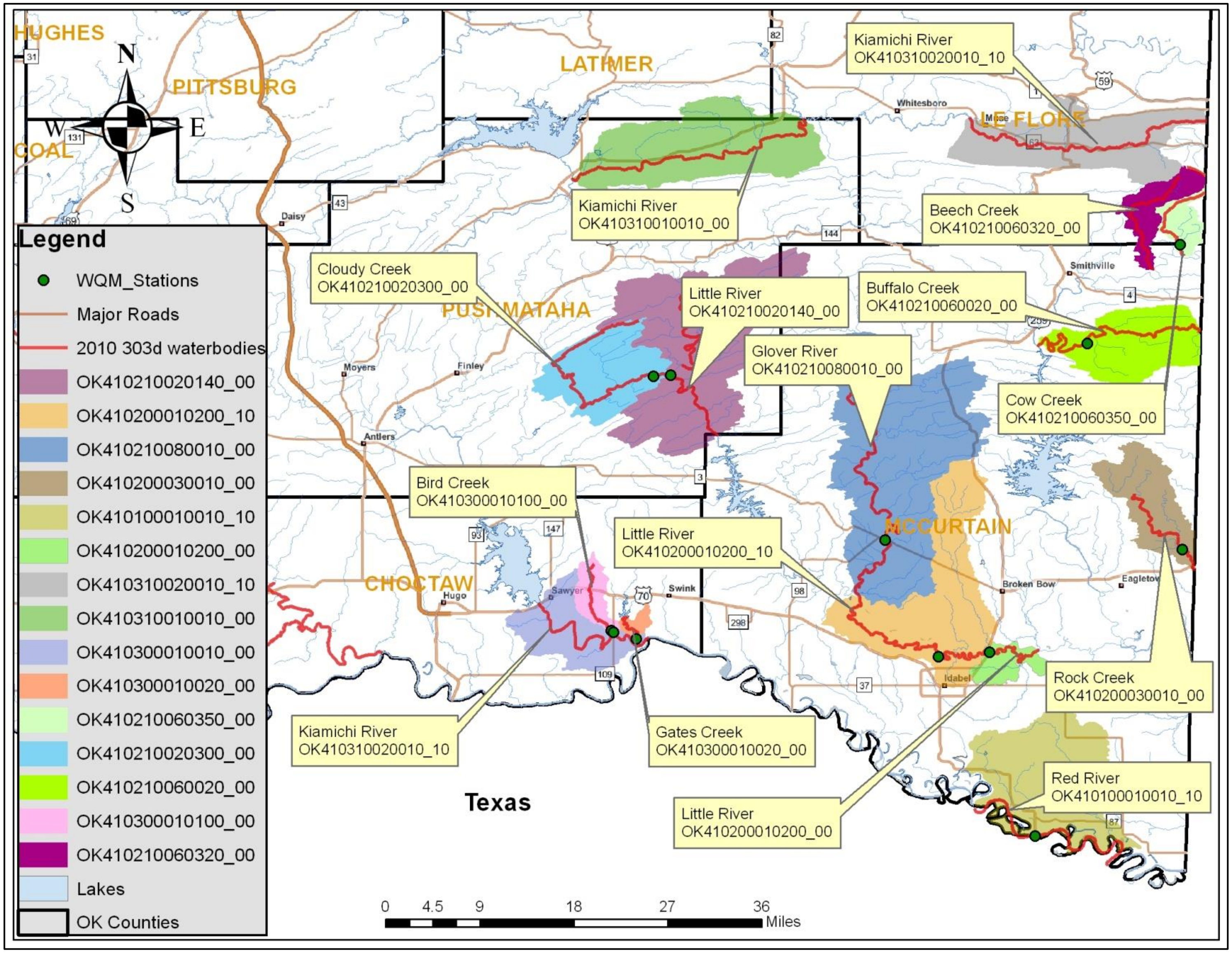
Figure 1-1 shows these Oklahoma waterbodies and their contributing watersheds. These maps also display locations of the water quality monitoring (WQM) stations used as the basis for placement of these waterbodies on the Oklahoma 303(d) list. These waterbodies and their surrounding watersheds are hereinafter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

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 1-2** provides a description of the locations of WQM stations on the 303(d)-listed waterbodies.

Table 1-2 Water Quality Monitoring Stations used for Assessment of Streams

Station ID	Waterbody Name	WBID
410100010010-001AT	**Red River**	OK410100010010_10
410200010200-001AT	**Little River**	OK410200010200_00
410200010200-002AT	**Little River**	OK410200010200_10
OK410200-03-0010G	**Rock Creek**	OK410200030010_00
410210020140-001AT	**Little River**	OK410210020140_00
OK410210-02-0300C	**Cloudy Creek**	OK410210020300_00
OK410210-06-0020G	**Buffalo Creek**	OK410210060020_00
OK410210-06-0320G	**Beech Creek**	OK410210060320_00
OK410210-06-0350G	**Cow Creek**	OK410210060350_00
410210080010-001AT	**Glover River**	OK410210080010_00
410300010010-002AT	**Kiamichi River**	OK410300010010_00
OK410300-01-0020F	**Gates Creek**	OK410300010020_00
OK410300-01-0100C	**Bird Creek**	OK410300010100_00
410310010010-001AT	**Kiamichi River**	OK410310010010_00
410310020010-001AT	Kiamichi River	OK410310020010_10

Figure 1-1 Watersheds Not Supporting Primary Body Contact Recreation or Fish and Wildlife Propagation Use in the Lower Red River-Little River Basin Study Area



1.2 Watershed Description

1.2.1 General

The Red-Little River Basin is located in the southeastern section of Oklahoma, bordered on the east by the State of Arkansas and the south by the State of Texas. The majority of the waterbodies addressed in this report are located in Choctaw, Latimer, Le Flore, McCurtain, and Pushmataha Counties. These counties are part of the South Central Plains and Ouachita Mountains Level III ecoregions (Woods, A.J, Omerik, J.M., et al 2005). The watersheds in the Study Area are located in the Ouachita Mountain Uplift geological province. **Table 1-3**, derived from the 2010 U.S. Census, demonstrates that the counties in which these watersheds are located are mostly sparsely populated. **Table 1-4** lists the towns and cities located in each watershed.

Table 1-3 County Population and Density

County Name	Population (2010 Census)	Population Density (per square mile)
Choctaw	11,188	14
Latimer	11,150	15
Le Flore	50,520	31
McCurtain	33,167	17
Pushmataha	11,579	8

Table 1-4 Towns and Cities by Watershed

Waterbody Name	Waterbody ID	Municipalities
Red River	OK410100010010_10	Haworth, Bokhoma, Tom, De Kalb, Oak Grove
Little River	OK410200010200_00	Shults
Little River	OK410200010200_10	Garvin, Broken Bow, Steel Junction
Rock Creek	OK410200030010_00	Toblerville, De Queen, Eagletown, Chapel Hill
Little River	OK410210020140_00	Clebit, Nashoba, Signal Mountain, Caney Mountain, Alikchi, Sobol
Cloudy Creek	OK410210020300_00	Cloudy, Spencerville
Buffalo Creek	OK410210060020_00	Bog Springs, Big Hudson Creek, Hee Creek,
Beech Creek	OK410210060320_00	Zafra, Watson
Cow Creek	OK410210060350_00	Cove
Glover River	OK410210080010_00	Bethel, Old Glory Mountain, Bear Mountain, Golden
Kiamichi River	OK410300010010_00	Frogville, Shoals, Woodland
Gates Creek	OK410300010020_00	Kiomatia
Bird Creek	OK410300010100_00	Fort Towson
Kiamichi River	OK410310010010_00	Albion, Kiamichi, Honobia, Clayton,
Kiamichi River	OK410310020010_10	Sawyer, Mountain Fork, Page, Big Cedar, Lynn Mountain, Octavia, Ludlow

1.2.2 Climate

Table 1-5 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 49 and 64 inches (Oklahoma Climatological Survey 2005).

Table 1-5 Average Annual Precipitation by Watershed

Waterbody Name	Waterbody ID	Average Annual Precipitation (inches)
Red River	OK410100010010_10	52.0
Little River	OK410200010200_00	52.0
Little River	OK410200010200_10	52.2
Rock Creek	OK410200030010_00	54.9
Little River	OK410210020140_00	52.9
Cloudy Creek	OK410210020300_00	52.1
Buffalo Creek	OK410210060020_00	56.5
Beech Creek	OK410210060320_00	60.6
Cow Creek	OK410210060350_00	57.1
Glover River	OK410210080010_00	53.6
Kiamichi River	OK410300010010_00	49.2
Gates Creek	OK410300010020_00	50.4
Bird Creek	OK410300010100_00	49.8
Kiamichi River	OK410310010010_00	51.8
Kiamichi River	OK410310020010_10	57.1

1.2.3 Land Use

Tables 1-6 and **1-7** 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 1-6** and **1-7** are rounded so in some cases may not total exactly 100%. The land use categories are displayed in **Figure 1-2**. The most dominant land use category throughout the Study Area is deciduous forest. The Red River (OK410100010010_10) watershed in the Study Area has a significant percentage of land use classified as row crops (approximately 19%). In remaining 14 watersheds of the Study Area row crop land accounts for less than 10% of the land use. Seven of the 15 watersheds have sizeable areas covered in pasture/hay land ranging from 20% to 59% of the respective watersheds. The aggregated total of developed land accounts for less than 2% of land use in the Study Area. The watersheds targeted for TMDL development in this Study Area range in size from 3,136 acres (Gates Creek, OK410300010020_00) to 118,404 acres (Glover River, OK410210080010_00).

Table 1-6 Land Use Summaries by Watershed

Landuse Category	Watershed						
	Red River	Little River	Little River	Rock Creek	Cloudy Creek	Buffalo Creek	Beech Creek
Waterbody ID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060020_00
Percent of Open Water	4.25%	1.00%	0.62%	0.19%	0.01%	0.08%	0.02%
Percent of Developed, Open Space	0.06%	0.01%	0.40%	0.00%	0.00%	0.00%	0.00%
Percent of Developed, Low Intensity	0.01%	0.00%	0.08%	0.00%	0.00%	0.00%	0.00%
Percent of Developed, Medium Intensity	0.21%	0.43%	0.25%	0.01%	0.00%	0.00%	0.00%
Percent of Barren Land (Rock/Sand/Clay)	0.12%	0.11%	0.03%	0.01%	0.00%	0.00%	0.00%
Percent of Quarries/strip Mines, Gravel pits	0.00%	0.41%	0.12%	0.00%	0.00%	0.00%	0.00%
Percent of Transitional	0.42%	0.00%	1.67%	6.52%	6.91%	9.26%	0.16%
Percent of Deciduous Forest	8.75%	28.88%	33.37%	19.31%	29.88%	37.85%	70.16%
Percent of Evergreen Forest	14.71%	0.84%	5.76%	21.67%	26.56%	14.63%	3.64%
Percent of Mixed Forest	6.41%	4.97%	16.05%	49.34%	34.35%	34.47%	24.76%
Percent of Grassland/Herbaceous	0.00%	5.63%	2.01%	0.00%	0.15%	0.00%	0.00%
Percent of Pasture/Hay	34.21%	44.69%	33.26%	2.89%	2.13%	3.70%	1.27%
Percent of Row Crops	19.08%	0.31%	0.07%	0.00%	0.00%	0.00%	0.00%
Percent of Urban/Recreational Grass	0.00%	0.01%	0.04%	0.00%	0.00%	0.00%	0.00%
Percent of Woody Wetlands	9.56%	11.54%	5.57%	0.05%	0.00%	0.00%	0.00%
Percent of Emergent Herbaceous Wetlands	2.20%	1.16%	0.70%	0.02%	0.00%	0.00%	0.00%
Acres Open Water	3,075.3	103.2	467.7	58.9	4.1	33.6	2.5
Acres Developed, Open Space	45.6	0.9	304.3	0.0	0.0	0.0	0.0
Acres Developed, Low Intensity	6.0	0.0	63.9	0.0	0.0	0.0	0.0
Acres Developed, Medium Intensity	151.1	44.1	189.1	2.1	0.0	0.0	0.0
Acres Barren Land (Rock/Sand/Clay)	84.9	11.2	20.8	2.5	0.0	1.5	0.0

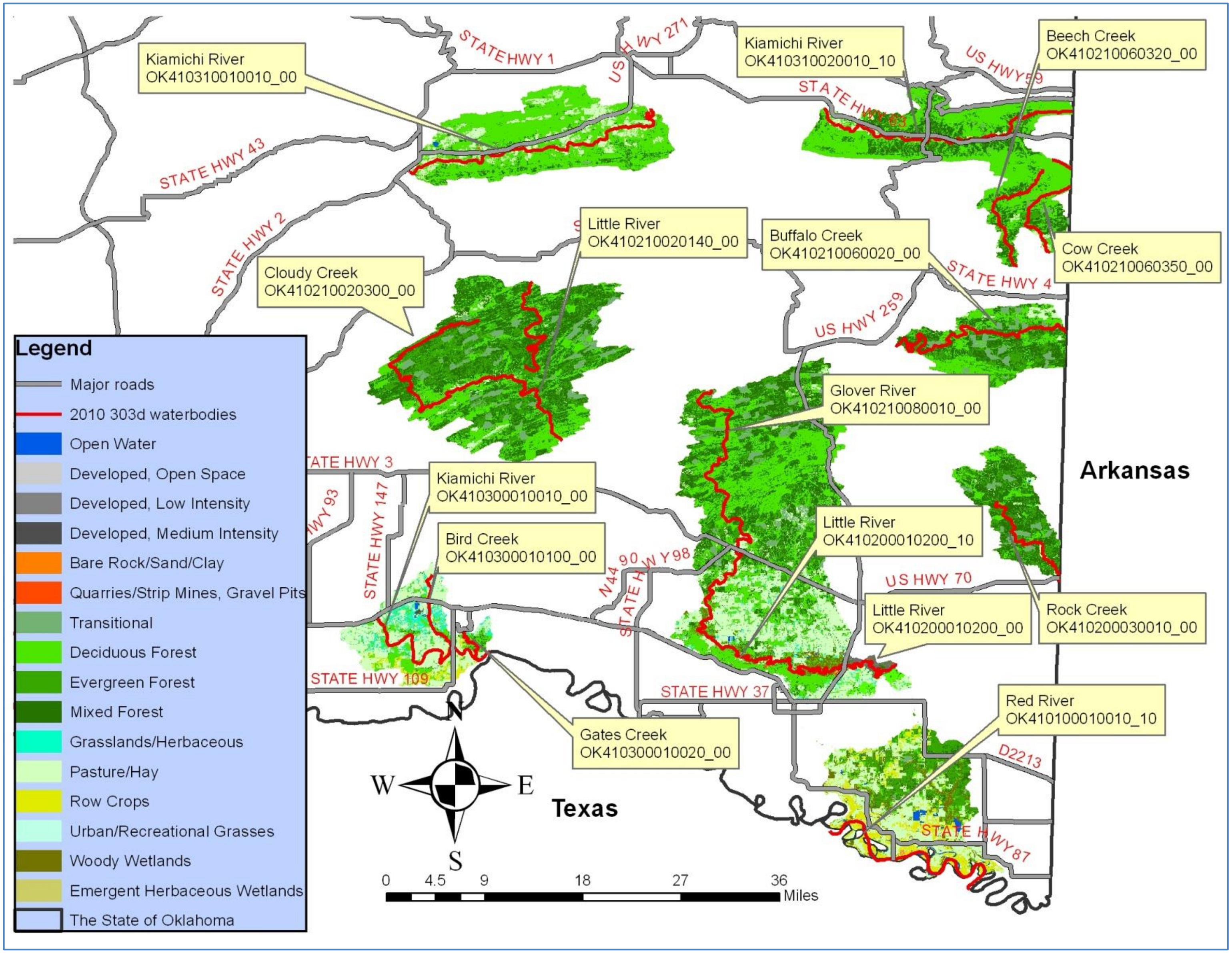
Landuse Category	Watershed						
	Red River	Little River	Little River	Rock Creek	Cloudy Creek	Buffalo Creek	Beech Creek
Waterbody ID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060020_00
Acres Quarries/strip Mines, Gravel pits	0.0	42.6	88.0	0.0	0.0	0.0	0.0
Acres Transitional	305.4	0.0	1,258.1	2,009.8	2,783.4	3,808.2	25.0
Acres Deciduous Forest	6,332.3	2,982.9	25,130.2	5,954.1	12,031.3	15,562.6	11,054.7
Acres Evergreen Forest	10,642.2	86.9	4,339.2	6,682.2	10,696.2	6,016.9	573.2
Acres Mixed Forest	4,633.4	513.1	12,084.2	15,214.5	13,831.6	14,174.7	3,901.3
Acres Grassland/Herbaceous	0.0	581.9	1,510.1	0.0	60.7	0.0	0.0
Acres Pasture/Hay	24,746.7	4,615.4	25,052.7	891.3	858.0	1,519.9	199.7
Acres Row Crops	13,801.0	32.4	52.6	0.6	1.5	0.8	0.0
Acres Urban/Recreational Grass	0.0	0.9	30.0	0.0	0.0	0.0	0.0
Acres Woody Wetlands	6,918.6	1,192.3	4,196.3	15.5	0.0	0.0	0.0
Acres Emergent Herbaceous Wetlands	1,589.6	120.0	525.7	4.9	0.0	0.0	0.0
Total (Acres)	72,332.1	10,328.0	75,312.7	30,836.3	40,266.9	41,118.3	15,756.4

Table 1-7 Land Use Summaries by Watershed

Landuse Category	Watershed							
	Cow Creek	Kiamichi River	Gates Creek	Bird Creek	Kiamichi River	Kiamichi River	Glover River	Little River
Waterbody ID	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
Percent of Open Water	0.02%	1.81%	0.07%	1.83%	0.23%	0.03%	0.32%	0.45%
Percent of Developed, Open Space	0.00%	0.08%	0.00%	0.00%	0.07%	0.00%	0.00%	0.00%
Percent of Developed, Low Intensity	0.00%	0.01%	0.00%	0.04%	0.01%	0.00%	0.00%	0.00%
Percent of Developed, Medium Intensity	0.00%	0.39%	0.00%	1.47%	0.19%	0.18%	0.18%	0.00%
Percent of Barren Land (Rock/Sand/Clay)	0.00%	0.02%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Percent of Quarries/strip Mines, Gravel pits	0.00%	0.00%	0.00%	0.00%	0.03%	0.00%	0.00%	0.00%
Percent of Transitional	4.05%	0.00%	0.00%	0.00%	0.11%	0.45%	5.51%	7.06%
Percent of Deciduous Forest	52.45%	19.85%	45.55%	16.28%	71.46%	67.64%	42.37%	32.41%
Percent of Evergreen Forest	8.30%	0.16%	0.22%	0.04%	0.90%	3.02%	11.68%	16.35%
Percent of Mixed Forest	29.11%	1.39%	13.71%	1.60%	7.18%	24.55%	29.40%	41.89%
Percent of Grassland/Herbaceous	0.00%	8.55%	9.69%	20.39%	0.00%	0.00%	0.45%	0.07%
Percent of Pasture/Hay	6.08%	59.25%	26.28%	56.99%	19.53%	4.10%	9.88%	1.77%
Percent of Row Crops	0.00%	8.42%	4.47%	1.37%	0.18%	0.03%	0.05%	0.00%
Percent of Urban/Recreational Grass	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Percent of Woody Wetlands	0.00%	0.04%	0.00%	0.00%	0.10%	0.00%	0.15%	0.00%
Percent of Emergent Herbaceous Wetlands	0.00%	0.02%	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%
Acres Open Water	1.6	552.8	2.2	172.2	166.5	15.1	382.6	394.8
Acres Developed, Open Space	0.0	24.9	0.0	0.0	49.2	0.0	0.2	0.0
Acres Developed, Low Intensity	0.0	3.7	0.0	3.6	3.7	0.0	0.0	0.0
Acres Developed, Medium Intensity	0.0	118.5	0.0	138.2	140.4	109.5	214.4	0.0
Acres Barren Land (Rock/Sand/Clay)	0.0	5.6	0.0	0.2	0.0	0.0	2.4	0.0

Landuse Category	Watershed							
	Cow Creek	Kiamichi River	Gates Creek	Bird Creek	Kiamichi River	Kiamichi River	Glover River	Little River
Waterbody ID	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
Acres Quarries/strip Mines, Gravel pits	0.0	0.0	0.0	0.0	24.0	0.0	4.7	0.0
Acres Transitional	382.4	0.0	0.0	0.0	78.6	267.0	6,527.9	6,251.3
Acres Deciduous Forest	4,958.3	6,067.5	1,428.6	1,534.2	52,134.7	40,064.2	50,173.4	28,699.4
Acres Evergreen Forest	784.2	49.8	6.8	3.9	653.7	1,790.8	13,828.4	14,481.6
Acres Mixed Forest	2,751.9	426.0	430.1	150.7	5,234.8	14,542.0	34,806.5	37,089.6
Acres Grassland/Herbaceous	0.0	2,612.8	304.0	1,921.6	0.0	0.0	528.0	65.1
Acres Pasture/Hay	574.9	18,110.7	824.4	5,371.1	14,251.8	2,425.6	11,696.2	1,568.0
Acres Row Crops	0.2	2,572.9	140.2	129.5	130.6	16.6	61.9	0.9
Acres Urban/Recreational Grass	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Acres Woody Wetlands	0.0	11.9	0.0	0.0	73.2	0.0	173.9	0.0
Acres Emergent Herbaceous Wetlands	0.0	7.1	0.0	0.0	16.7	0.0	4.0	0.0
Total (Acres)	9,453.5	30,564.8	3,136.4	9,425.2	72,957.9	59,230.8	118,404.2	88,550.7

Figure 1-2 Land Use Map



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 the *Oklahoma Water Quality Standards – Chapter 45 (OWQS)* and *Implementation of the Water Quality Standards - Chapter 46* (OWRB 2013). 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 2013). 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 2010 Integrated Report (DEQ 2010), lists beneficial uses designated for each bacteria 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 – Cool Water Aquatic Community
- FISH – Fish Consumption
- PBCR – Primary Body Contact Recreation
- PPWS – Public & Private Water Supply
- SWS – Sensitive Water Supply

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

Waterbody ID	Waterbody Name	AES	AG	WWAC	CWAC	FISH	PBCR	PPWS	SWS
OK410100010010_10	Red River	I	F	N		N	F	I	
OK410200010200_00	Little River	I	F		N	I	F	F	
OK410200010200_10	Little River	I	F		N	F	F	F	
OK410200030010_00	Rock Creek	F	F		N	X	I	X	
OK410210020140_00	Little River	F	F		N	N	N	F	
OK410210020300_00	Cloudy Creek	F	F		N	X	I	X	
OK410210060020_00	Buffalo Creek	F	F		N	X	I	X	
OK410210060320_00	Beech Creek	F	F		N	X	I	X	

Waterbody ID	Waterbody Name	AES	AG	WWAC	CWAC	FISH	PBCR	PPWS	SWS
OK410210060350_00	**Cow Creek**	F	F		N	X	I	X	
OK410210080010_00	**Glover River**	F	F		N	N	F	F	
OK410300010010_00	**Kiamichi River**	I	F	N		N	N	N	
OK410300010020_00	**Gates Creek**	I	F		N	X	I	X	
OK410300010100_00	**Bird Creek**	F	F	N		X	I	I	
OK410310010010_00	**Kiamichi River**	I	F	N		N	N	F	
OK410310020010_10	**Kiamichi River**	N	F	N		F	N	F	
F – Fully supporting information		**N** – Not supporting		**I** – Insufficient	**X** – Not assessed	Source: **DEQ 2010 Integrated Report**			

Table 2-2 summarizes the PBCR and Fish and Wildlife Propagation 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 Fish and Wildlife Propagation beneficial uses.

2.1.1 Chapter 45: Definition of PBCR and Bacterial WQSs

The definition of PBCR and the bacterial WQSs for PBCR are summarized by the following excerpt from Chapter 45-5-16 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.

2.1.2 Chapter 46: Implementation of OWQS for PBCR

To implement Oklahoma's WQS for PBCR, OWRB promulgated Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2013). The excerpt below from Chapter 46: 785:46-15-6, stipulates how water quality data was assessed to determine support of the PBCR use as well as how the water quality target for TMDLs was 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).

2.1.3 Chapter 45: Criteria for Turbidity

The beneficial use of WWAC or CWAC 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.

2.1.4 Chapter 46: Implementation of OWQS for Fish and Wildlife Propagation

To implement Oklahoma's WQS for Fish and Wildlife Propagation, OWRB promulgated Chapter 46, *Implementation of Oklahoma's Water Quality Standards* (OWRB 2013). The excerpt below from Chapter 46: 785:46-15-5, stipulates how water quality data was assessed to determine support of fish and wildlife propagation as well as how the water quality target for TMDLs was defined for turbidity.

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

Waterbody ID	HUC 8	Waterbody Name	Stream Miles	TMDL Date	Priority	ENT	*E. coli*	Designated Use Primary Body Contact Recreation	Turbidity	Designated Use Warm Water Aquatic Community	Designated Use Cool Water Aquatic Community
OK410100010010_10	11140106	**Red River**	22.99	2018	3				X	N	
OK410200010200_00	11140107	**Little River**	8.20	2012	1				X		N
OK410200010200_10	11140107	**Little River**	24.14	2012	1				X		N
OK410200030010_00	11140109	**Rock Creek**	12.35	2021	4				X		N
OK410210020140_00	11140107	**Little River**	24.68	2012	1			N[1]	X		N
OK410210020300_00	11140107	**Cloudy Creek**	25.63	2012	1				X		N
OK410210060020_00	11140108	**Buffalo Creek**	23.38	2012	1				X		N
OK410210060320_00	11140108	**Beech Creek**	12.71	2012	1				X		N
OK410210060350_00	11140108	**Cow Creek**	11.03	2012	1				X		N
OK410210080010_00	11140107	**Glover River**	33.95	2012	2				X		N
OK410300010010_00	11140105	**Kiamichi River**	18.11	2015	2	X		N		N	
OK410300010020_00	11140105	**Gates Creek**	4.85	2015	2				X		N
OK410300010100_00	11140105	**Bird Creek**	8.05	2015	2				X	N	
OK410310010010_00	11140105	**Kiamichi River**	26.35	2015	2	X		N		N	
OK410310020010_10	11140105	**Kiamichi River**	25.18	2015	2	X		N		N	

ENT = Enterococci; **N** = Not attaining; **X** = Criterion exceeded — **Source: 2010 Integrated Report, DEQ 2010**

[1] A TMDL was developed for this impairment in 2007.

785:46-15-5 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.

2.1.5 Prioritization of TMDL Development

After the draft 303(d) List is compiled, DEQ assigns a four-level rank to each of the Category 5a waterbodies. This rank helps in determining the priority for TMDL development. The rank is based on criteria developed using the procedure outlined in the 2012 Continuing Planning Process (pp. 139-140). The TMDL prioritization point totals calculated for each watershed were broken down into the following four priority levels in Appendix C of the 2010 Integrated Report:

Priority 1 watersheds - above the 90th percentile (32 watersheds)

Priority 2 watersheds - 70th to 90th percentile (59 watersheds)

Priority 3 watersheds - 40th to 70th percentile (99 watersheds)

Priority 4 watersheds - below the 40th percentile (139 watersheds)

Each waterbody on the 2010 303(d) list has been assigned a potential date of TMDL development based on the priority level for the corresponding HUC 11 watershed. Priority 1 watersheds are targeted for TMDL development within the next two years.

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 2013).

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 2010 303(d) list. Bacterial TMDLs will be developed only for *E. coli* and/or Enterococci impaired streams.

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 2001 and 2008 for both 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 2001 and 2008, evidence of nonsupport of the PBCR use - based on elevated Enterococci concentrations - was observed in the Little River (OK410210020140_00) and Kiamichi River (OK410300010010_00, OK410310010010_00, and OK410310020010_10). In this study, bacterial TMDLs were developed for three segments of Kiamichi River (OK410300010010_00, OK410310010010_00, and OK410310020010_10). The bacterial TMDL for

Enterococci on the Little River (OK410210020140_00) was not done in this study because it was already developed previously in 2007 (*Bacterial Total Maximum Daily Loads for OK410210, OK410300, OK410310 in the Little River Area, Oklahoma*).

Detailed review of the data collected between 2001 and 2008 indicated an insufficient number of samples were available for Gates (OK410300010020_00) and Bird (OK410300010100_00) Creeks, therefore no TMDLs are required for these waterbodies since there aren't enough data to show they are impaired. Samples on the Little River (OK410200010200_00) were collected in a mixing zone. According to *Implementation of Oklahoma's Water Quality Standards* [Title 785, Chapter 46-15-3(b)(5)], "Samples and other data shall not be taken within any regulatory mixing zone." Therefore, the Little River (OK410200010200_00) was not assessed as impaired. Rows highlighted in green in **Table 2-3** require TMDLs. Of the 15 waterbodies for which water quality data was assessed, 3 had TMDLs developed for bacteria.

Table 2-3 Summary of Assessment of Indicator Bacterial Samples from Primary Body Contact Recreation Subcategory Season May 1 to September 30, 2001-2008

Waterbody ID	Waterbody Name	Indicator	Number of samples	Geometric Mean Concentration (count/100 ml) *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	Notes
OK410100010010_10	Red River	EC	28	14.6	
		ENT	28	20.6	
OK410200010200_00	Little River	EC	20	36.3	Mixing zone data
		ENT	20	49.4	Mixing zone data
OK410200010200_10	Little River	EC	12	31.5	
		ENT	12	31.5	
OK410200030010_00	Rock Creek	EC	6	16.7	
		ENT	6	23.3	
OK410210020140_00	Little River	EC	29	32.6	
		ENT	29	64.1	TMDL in 2007
OK410210020300_00	Cloudy Creek	EC	8	19.1	
		ENT	8	28.5	
OK410210060020_00	Buffalo Creek	EC	7	17.3	
		ENT	7	16.8	
OK410210060320_00	Beech Creek	EC	7	17.9	
		ENT	7	25.3	
OK410210060350_00	Cow Creek	EC	7	41.6	
		ENT	7	26.7	
OK410210080010_00	Glover River	EC	30	21.2	
		ENT	30	28.3	

Waterbody ID	Waterbody Name	Indicator	Number of samples	Geometric Mean Concentration (count/100 ml) *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	Notes
OK410300010010_00	Kiamichi River	EC	23	34.8	
		ENT	23	35.8	TMDL Required
OK410300010020_00	Gates Creek	EC	8	55.7	
		ENT	8	35.5	Insufficient number of samples
OK410300010100_00	Bird Creek	EC	6	168.4	Insufficient number of samples
		ENT	6	68	Insufficient number of samples
OK410310010010_00	Kiamichi River	EC	27	47.9	
		ENT	27	54.3	TMDL Required
OK410310020010_10	Kiamichi River	EC	28	20.9	
		ENT	28	47.0	TMDL Required

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 are used as a surrogate in this TMDL. Therefore, both turbidity and TSS data are presented in this subsection.

For the 15 waterbodies assessed in this report for turbidity, **Table 2-4** summarizes water quality data collected from the WQM stations between 1998 and 2012. 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 Oklahoma WQS, DEQ considers base flow conditions to be all flows less than the 25th flow exceedance percentile (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 for samples collected during base flow conditions. Water quality samples collected under flow conditions greater than the 25th flow exceedance percentile (highest flows) were therefore excluded from the data set used for TMDL analysis. Using this qualified data set, 11 of the 15 waterbodies identified in **Table 2-5** indicate nonsupport of the Fish and Wildlife Propagation use based on turbidity levels observed in the waterbody so TMDLs were developed for them. **Table 2-6** summarizes water quality data collected from the WQM stations between 1998 and 2007 for TSS. **Table 2-7** presents a subset of these data for samples collected during base flow conditions. In using TSS as a surrogate to support TMDL development, at least 10 TSS samples are required to conduct the regression analysis between turbidity and TSS. The water quality data analyzed for turbidity and TSS are provided in **Appendix A**.

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, with MOS.

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 or CWAC beneficial use is 50 or 10 NTUs, respectively (OWRB 2013). The turbidity numerical criteria apply 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 or CWAC must take into account that no more than 10% of the samples may exceed the numeric criteria for turbidity. 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 waterbody 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.

Table 2-4 Summary of All Turbidity Samples, 1998-2012

Waterbody ID	Waterbody Name	WQM Stations	Number of turbidity samples	Number of samples greater than WQS	% samples exceeding criterion	Average Turbidity (NTU)	Sampling period
OK410100010010_10	Red River	410100010010-001AT	35	13	37%	58	2007 - 2012
OK410200010200_00	Little River	410200010200-001AT	49	38	78%	25	1998 - 2003
OK410200010200_10	Little River	410200010200-002AT	37	25	68%	17	2007 - 2012
OK410200030010_00	Rock Creek	OK410200-03-0010G	20	4	20%	17	2005 - 2007
OK410210020140_00	Little River	410210020140-001AT	42	16	38%	10	2007 - 2012
OK410210020300_00	Cloudy Creek	OK410210-02-0300C	21	7	33%	45	2005 - 2007
OK410210060020_00	Buffalo Creek	OK410210-06-0020G	21	5	24%	8	2005 - 2007
OK410210060320_00	Beech Creek	OK410210-06-0320G	21	7	33%	16	2005 - 2007
OK410210060350_00	Cow Creek	OK410210-06-0350G	21	7	33%	22	2005 - 2007
OK410210080010_00	Glover River	410210080010-001AT	41	10	24%	9	2007 - 2012
OK410300010010_00	Kiamichi River	410300010010-002AT	34	3	9%	31	2007 - 2012
OK410300010020_00	Gates Creek	OK410300-01-0020F	20	17	85%	20	2005 - 2007
OK410300010100_00	Bird Creek	OK410300-01-0100C	19	4	21%	32	2005 - 2007
OK410310010010_00	Kiamichi River	410310010010-001AT	34	2	6%	17	2007 - 2012
OK410310020010_10	Kiamichi River	410310020010-001AT	40	0	0%	7	2007 - 2012

Table 2-5 Summary of Turbidity Samples Collected During Base Flow Conditions, 1998-2012

Waterbody ID	Waterbody Name	WQM Stations	Number of turbidity samples	Number of samples greater than WQS	% samples exceeding criterion	Average Turbidity (NTU)	Assessment Results
OK410100010010_10	Red River	410100010010-001AT	29	7	24.1%	40	TMDL Required
OK410200010200_00	Little River	410200010200-001AT	35	24	68.6%	16	Delist: Mixing zone data
OK410200010200_10	Little River	410200010200-002AT	30	18	60.0%	14	TMDL Required
OK410200030010_00	Rock Creek	OK410200-03-0010G	20	4	20.0%	17	TMDL Required
OK410210020140_00	Little River	410210020140-001AT	40	14	35.0%	10	TMDL Required
OK410210020300_00	Cloudy Creek	OK410210-02-0300C	20	6	30.0%	46	TMDL Required
OK410210060020_00	Buffalo Creek	OK410210-06-0020G	18	5	27.8%	8	TMDL Required
OK410210060320_00	Beech Creek	OK410210-06-0320G	21	7	33.3%	16	TMDL Required
OK410210060350_00	Cow Creek	OK410210-06-0350G	21	7	33.3%	22	TMDL Required
OK410210080010_00	Glover River	410210080010-001AT	40	9	22.5%	9	TMDL Required
OK410300010010_00	Kiamichi River	410300010010-002AT	32	2	6.3%	31	
OK410300010020_00	Gates Creek	OK410300-01-0020F	19	16	84.2%	20	TMDL Required
OK410300010100_00	Bird Creek	OK410300-01-0100C	19	4	21.1%	32	TMDL Required
OK410310010010_00	Kiamichi River	410310010010-001AT	31	1	3.2%	13	
OK410310020010_10	Kiamichi River	410310020010-001AT	37	0	0.0%	6	

TMDLs will be developed for waterbodies highlighted in tan.

Table 2-6 Summary of All TSS Samples, 1998-2007

Waterbody ID	Waterbody Name	WQM Stations	Number of TSS samples	Average TSS (mg/L)	Sampling period
OK410100010010_10	Red River	410100010010-001AT	24	104.0	1998 - 2000
OK410200010200_00	Little River	410200010200-001AT	24	31.3	1998 - 2000
OK410200010200_10	Little River	410200010200-002AT	0	-	
OK410200030010_00	Rock Creek	OK410200-03-0010G	19	10.6	2005 - 2007
OK410210020140_00	Little River	410210020140-001AT	23	7.1	1998 - 2000
OK410210020300_00	Cloudy Creek	OK410210-02-0300C	20	13.1	2005 - 2007
OK410210060020_00	Buffalo Creek	OK410210-06-0020G	20	10.9	2005 - 2007
OK410210060320_00	Beech Creek	OK410210-06-0320G	20	12.3	2005 - 2007
OK410210060350_00	Cow Creek	OK410210-06-0350G	20	15.5	2005 - 2007
OK410210080010_00	Glover River	410210080010-001AT	23	11.5	1998 - 2000
OK410300010020_00	Gates Creek	OK410300-01-0020F	19	14.2	2005 - 2007
OK410300010100_00	Bird Creek	OK410300-01-0100C	18	27.3	2005 - 2007

Table 2-7 Summary of TSS Samples During Base Flow Conditions 1998-2007

Waterbody ID	Waterbody Name	WQM Stations	Number of TSS samples	Average TSS (mg/L)
OK410100010010_10	Red River	410100010010-001AT	15	86.0
OK410200010200_00	Little River	410200010200-001AT	15	9.8
OK410200010200_10	Little River	410200010200-002AT	0	-
OK410200030010_00	Rock Creek	OK410200-03-0010G	19	10.6
OK410210020140_00	Little River	410210020140-001AT	18	6.9
OK410210020300_00	Cloudy Creek	OK410210-02-0300C	19	13.2
OK410210060020_00	Buffalo Creek	OK410210-06-0020G	17	11.0
OK410210060320_00	Beech Creek	OK410210-06-0320G	20	12.3
OK410210060350_00	Cow Creek	OK410210-06-0350G	20	15.5
OK410210080010_00	Glover River	410210080010-001AT	17	8.3
OK410300010020_00	Gates Creek	OK410300-01-0020F	18	14.4
OK410300010100_00	Bird Creek	OK410300-01-0100C	18	27.3

SECTION 3 POLLUTANT SOURCE ASSESSMENT

3.1 OVERVIEW

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 OPDES-permitted facilities, fields, construction sites, quarries, stormwater runoff and eroding stream banks.

Point sources are permitted through the OPDES program. OPDES-permitted facilities that discharge treated wastewater are currently required to monitor for fecal coliform and TSS in accordance with their permits. Currently facilities with bacterial limits monitor for fecal coliform. When their permits are renewed, they will be required to monitor for *E. coli*.

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 OPDES 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. The limits of *E. coli* that will be in permits originated in human health studies (EPA 2012).

The following nonpoint sources of bacteria were considered in this report:

- Wildlife (deer)
- Non-Permitted Agricultural Activities and Farm animals
- Failing Onsite Wastewater Disposal (OSWD) Systems and Illicit Discharges
- Domesticated Dogs and Cats

The 2010 Integrated Water Quality Assessment Report (DEQ 2010) listed potential sources of turbidity as grazing in riparian corridors of streams and creeks, highway/road/bridge runoff (non-construction related), impacts from abandoned mine lands, non-irrigated crop production, rangeland grazing, silviculture harvesting, as well as other unknown sources. The following discussion describes what is known regarding point and nonpoint sources of bacteria and TSS in the Study Area.

3.2 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. OPDES-permitted facilities classified as point sources that may contribute bacteria or TSS loading includes:

- Continuous Point Source Dischargers
  - OPDES municipal wastewater treatment facilities (WWTF)
  - OPDES Industrial WWTF Discharges
- OPDES-regulated stormwater discharges
  - Municipal separate storm sewer system (MS4) discharges
    - Phase 1 MS4
    - Phase 2 MS4 – OKR04
  - Multi-sector general permits (OKR05)
  - Construction stormwater discharges (OKR10)
- No-discharge WWTF
- Sanitary sewer overflow (SSO)
- NPDES Animal Feeding Operations (AFO)
  - Concentrated Animal Feeding Operations (CAFO)
  - Swine Feeding Operation (SFO)
  - Poultry Feeding Operation (PFO)

Continuous point source dischargers such as WWTFs 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 dischargers including municipal and industrial WWTFs 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 WWTFs 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 WWTFs 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 WWTF 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. AFOs 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 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 OPDES 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, TSS WLAs for OPDES-regulated stormwater discharges was essentially considered unnecessary in this TMDL report and were not included in the TMDL calculations.

3.2.1 Continuous Point Source Dischargers

The locations of the OPDES-permitted facilities that discharge wastewater to surface waters addressed in these TMDLs are listed in **Table 3-1** and displayed in **Figure 3-1** and **3-2**. There are two OPDES-permitted facilities in the Study Area: Tyson Foods – Broken Bow in the Little River (OK410200010200_00) watershed, and Western Farmers Electric Cooperative-Hugo plant in the Bird Creek (OK410300010100_00) watershed. In the remaining 13 watersheds of the Study Area, there are no OPDES-permitted facilities.

Tyson Foods – Broken Bow discharges into the Little River (OK410200010200_00) watershed. But since those samples were collected in a mixing zone, that data is no longer being assessed. Since there isn't any data to support bacterial or turbidity impairment in the Little River (OK410200010200_00), Tyson Foods – Broken Bow will not receive a WLA. The Western Farmers Electric Cooperative (WFEC)-Hugo plant discharges strormwater into the Bird Creek (OK410300010100_00) watershed. It also discharges wastewater to the Red River (OK410100010010_50) which is not impaired for turbidity. The turbidity impairment status is limited to base flow conditions and stormwater discharges from the facilities do not contribute to the violation of Oklahoma's turbidity standard. Therefore, WFEC_Hugo plant did not receive a WLA for TSS.

3.2.2 OPDES-regulated stormwater discharges

Stormwater runoff from OPDES-permitted facilities [MS4s, facilities with multi-sector general permits (MSGP), and construction sites] can contain impairments. EPA regulations [40 C.F.R. §130.2(h)] require that OPDES-regulated stormwater discharges must be addressed by the WLA component of a TMDL.

3.2.2.1 OPDES Municipal Separate Storm Sewer System

3.2.2.1.1 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 facilities in the Study Area.

3.2.2.1.2 Phase II MS4

Phase II of the rule extends coverage of the OPDES 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 OPDES Stormwater Program. Phase II requires operators of regulated small MS4s to obtain OPDES 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
- Pollution Prevention/Good Housekeeping

There are no permitted MS4s in the Study area.

3.2.2.2 Multi-Sector General Permit

A DEQ multi-sector industrial general permit (OKR05) is required by DEQ for stormwater discharges from industrial facilities (DEQ 2011) whose Standard Industrial Classification (SIC) code is listed on Table 1-2 of the MSGP. The determination of whether or not an industrial facility must obtain stormwater discharge permit coverage is based both on the facility's Standard Industrial Classification (SIC) code and whether or not the facility has the potential to contaminate stormwater. The OKR05 permits are valid for five years. Since stormwater discharges from industrial facilities occur when the turbidity criteria do not apply (i.e. during or immediately following periods of rainfall and elevated flow conditions), industrial facilities are not considered to be sources of turbidity impairment.

Mine dewatering discharges at crushed stone, construction sand and gravel, or industrial sand mining facilities can happen at any time and have the following specific number 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 needed, additional TSS limitations and monitoring requirements will be implemented under the multi-sector general permit. There is one facility in the Little River (OK410200010200_10) watershed with a multi-sector general permit and one facility in the Little River (OK410200010200_00) watershed. They are listed in **Table 3-2** and displayed in **Figure 3-1**. Tyson Foods Inc (OKR050522) in the Little River (OK410200010200_00) watershed did not require a wasteload allocation for TSS since the receiving stream is not impaired for TSS. Meridian Aggregates Co (OKR050878) is a mining operation with dewatering discharges into a tributary of the Little River (OK410200010200_10) watershed. It received a wasteload allocation as part of the Little River (OK410200010200_10) turbidity TMDL. More details about that WLA is in Section 5.4.2.

3.2.2.3 Construction Activities

A general stormwater permit (OKR10) is required by 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 2012). 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 3-2**.

Table 3-1 Point Source Dischargers in the Study Area

OPDES Permit No.	Name	Receiving Water	Receiving Waterbody Name	Facility Type	SIC Code	County	Design Flow (mgd)	Facility ID	Expiration Date	Avg./Max. FC cfu/100mL	Avg./Max. TSS mg/L	Outfall
OK0000795	Tyson Foods, Inc.- Broken Bow	OK410200010200_00	Little River	Poultry Slaughtering and Processing	2015	McCurtain	1.5464[a]	48000020	10/31/2011	200/400	20/30	001
OK0035327	Western Farmers Electric Cooperative-Hugo plant	OK410300010100_00	Bird Creek	Electric Services	4911	Choctaw	Stormwater	12000630	5/31/2013	NA	30/100	001

[a] Maximum 30-day flow ($Q_{e(30)}$).
N/A = not available.

Table 3-2 Permits Summary

Company Name		County	Permit ID	Date Issued	Waterbody ID	Watershed	Estimated Acres
Construction General Permits (OKR10)							
	ODOT JP #18849(04)	Choctaw	OKR107548	N/A	OK410300010010_00	Kiamichi River	2
	ODOT JP #18851(04)	Choctaw	OKR106906	5/23/2008	OK410300010100_00	Bird Creek	34
	THE WOODLANDS	McCurtain	OKR107418	N/A	OK410200010200_10	Little River	5.5
Multi-Sector General Permits (OKR05)							
	Meridian Aggregates Co	McCurtain	OKR050878	8/18/2006	OK410200010200_10	Little River	N/A
	Tyson Foods Inc	McCurtain	OKR050522	7/5/2006	OK410200010200_00	Little River	N/A

Figure 3-1 Locations of OPDES-Permitted Facilities for Discharges and Constructions in the Study Area

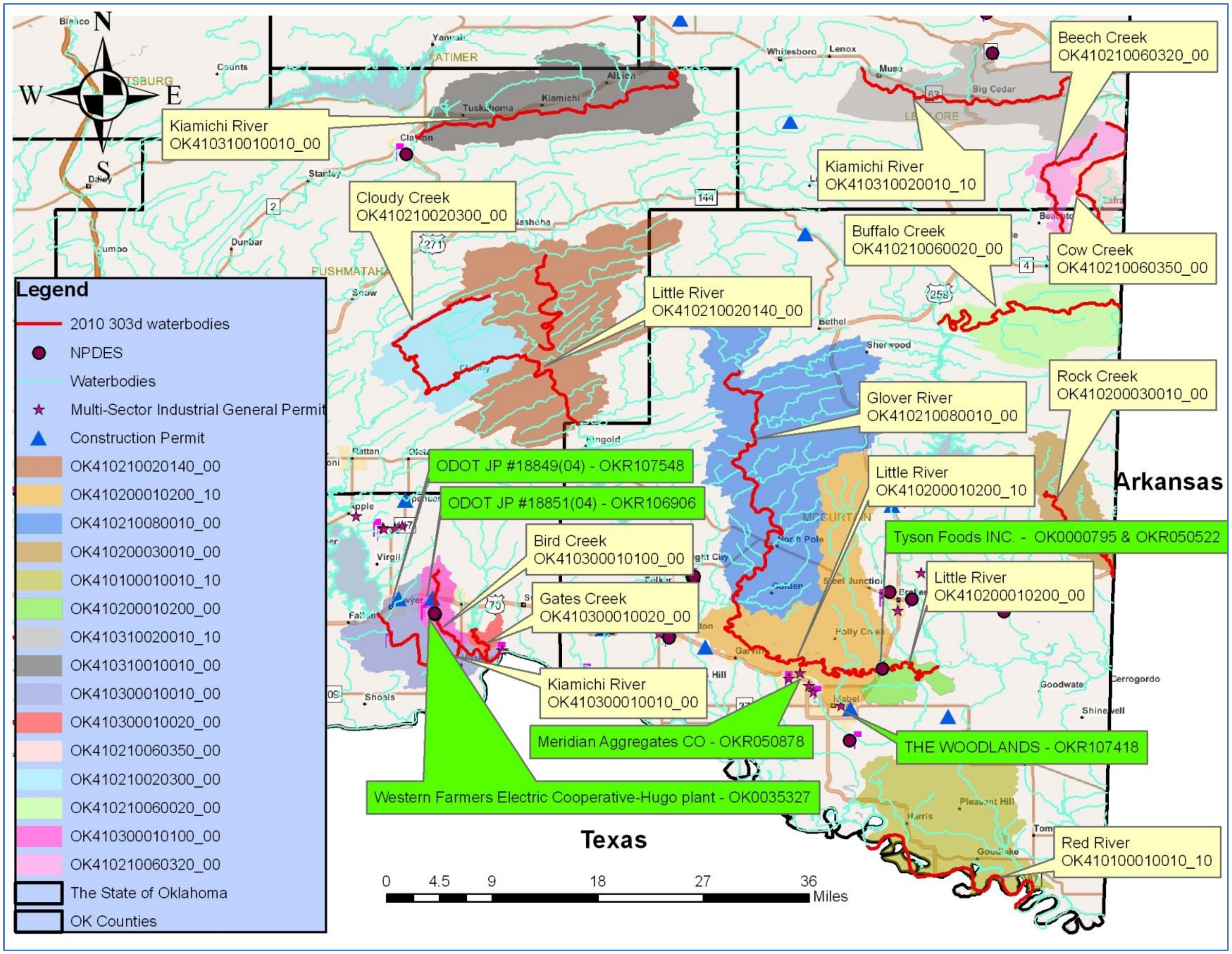
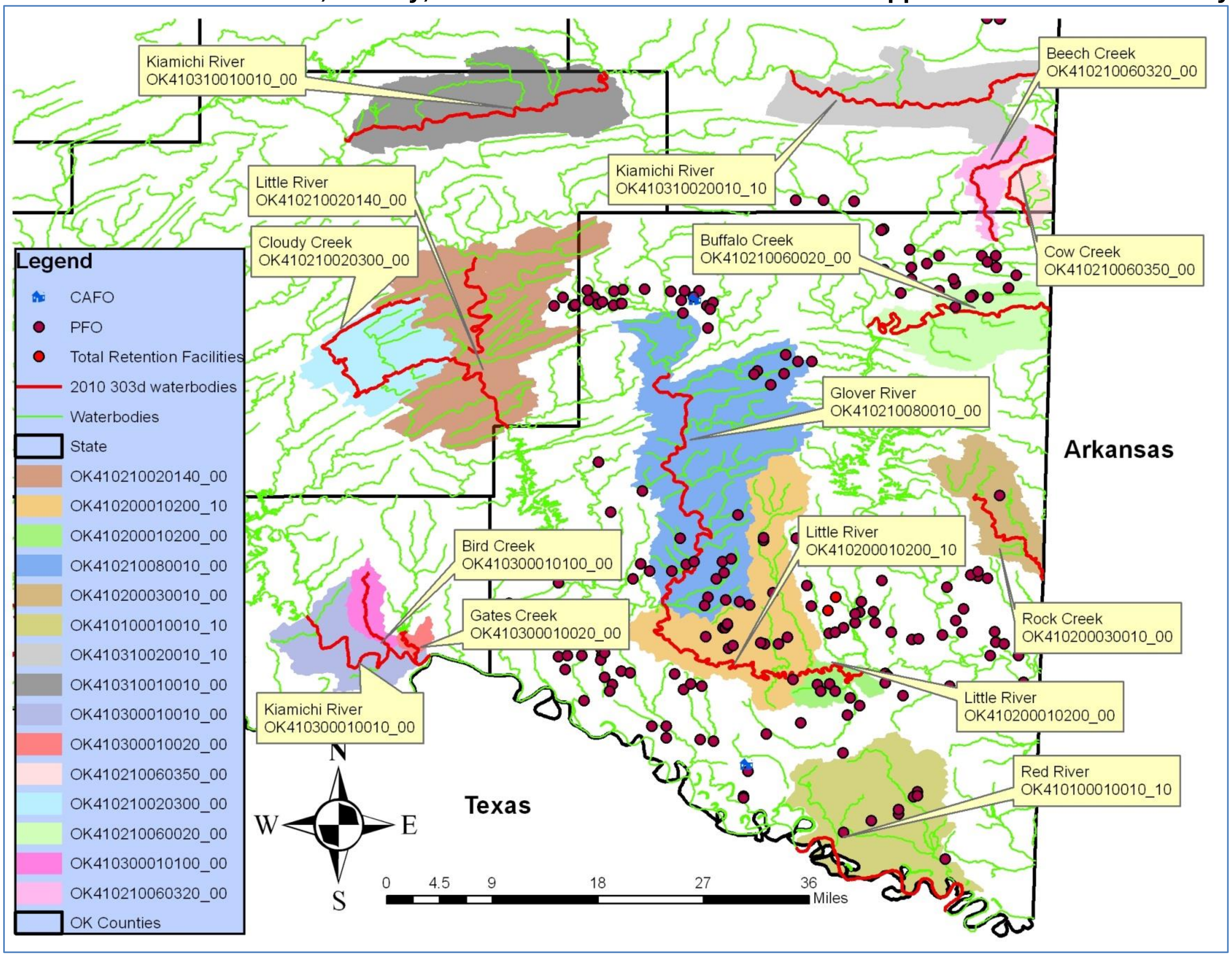


Figure 3-2 Locations of CAFOs, Poultry, Total Retention Facilities and Land Application Sites in the Study Area



3.2.2.4 Rock, Sand and Gravel Quarries

Operators of rock, sand and gravel quarries in Oklahoma are regulated with a general permit (OKG950000) issued by DEQ. The general permit does not allow discharge of wastewater to turbidity-impaired waterbodies on Oklahoma's 303(d) list. The discharge of wastewater is also not allowed into turbidity-impaired waterbodies for which a TMDL has not been performed or the result of a turbidity TMDL indicates that discharge limits more stringent than 45 mg/l for TSS are required (DEQ 2008). There are no quarries in this Study Area.

3.2.3 No-Discharge Facilities

For the purposes of these TMDLs, it was 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. In the Study Area, there are no no-discharge facilities.

3.2.4 Sanitary Sewer Overflows

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 OPDES 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. In this Study Area, there weren't any SSOs.

3.2.5 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. ODAFF is the NPDES-permitting authority for CAFOs and SFOs in Oklahoma under what ODAFF calls the Agriculture Pollutant Discharge Elimination System (AgPDES). Through regulations (rules) established by the Oklahoma Concentrated Animal Feeding Operation (CAFO) Act (Title 2, Chapter 1, Article 20 – 40 to Article 20 – 64 of the State Statutes), Swine Feeding Operation (SFO) Act (Title 2, Chapter 1, Article 20 – 1 to Article 20 – 29 of the State Statutes), and Poultry Feeding Operation (PFO) Registration Act (Title 2, Chapter 10-9.1 to 10-9.25 of the State Statutes), AEMS works with producers and concerned citizens to ensure that animal waste does not impact the waters of the State. All of these animal feeding operations (AFO) require an Animal Waste Management Plan (AWMP) to prevent animal waste from entering any Oklahoma waterbody. These plans outline how the animal feeding operator will prevent direct discharges of animal waste into waterbodies as well as any runoff of waste into waterbodies. The rules for all of these AFOs recommend using the USDA NRCS' Agricultural Waste Management Field Handbook to develop their Plan. NRCS has developed Animal Waste Management Software to develop this Plan.

3.2.5.1 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 2007). Animal Waste Management Plans (Section 35:17-4-12) specified in Oklahoma's CAFO regulations are designed to protect water quality through the use of structures such as dikes, berms, terraces, ditches, to isolate animal waste from outside surface drainage, except for a 25-year, 24–hour rainfall event.[1] AWMPs may include, but are not limited to, a Comprehensive Nutrient Management Plan per NRCS guidance or Nutrient Management Plan per EPA guidance.

CAFOs are considered no-discharge facilities for the purpose of the TMDL calculations in this report, and runoff of animal waste into surface waterbodies or groundwater is prohibited.

CAFOs are designated by EPA as significant sources of pollution (ODAFF 2009) and may have the potential to cause serious impacts to water quality if not managed properly. 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 locations of the CAFOs are shown in **Figure 3-2**. However, they are not in the Study area.

3.2.5.2 SFO

The purpose of the SFO Act is to provide for environmentally responsible construction and expansion of swine feeding operations and to protect the safety, welfare and quality of life of persons who live in the vicinity of a swine feeding operation[2]. According to the SFO Act, a "Concentrated swine feeding operation" is a lot or facility where swine kept for at least ninety (90) consecutive days or more in any twelve-month period and where crops, vegetation, forage growth or post-harvest residues are not grown during the normal growing season on any part of the lot.

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1 CAFO Animal Waste Management Plan Requirements [Title 35 (ODAFF), Chapter 17 (Water Quality), Subchapter 4 (Concentrated Animal Feeding Operations)] can be found in 35:17-4-12.

2 A concentrated swine feeding operation has at least 750 swine that each weighs over 25 kilograms (about 55 pounds), 3,000 weaned swine weighing under 25 kilograms, or 300 swine animal units. A swine animal unit is a unit of measurement for any swine feeding operation calculated by adding the following numbers: The number of swine weighing over twenty-five (25) kilograms, multiplied by four-tenths (0.4), plus the number of weaned swine weighing under twenty-five (25) kilograms multiplied by one-tenth (0.1)

A "concentrated swine feeding operation" has a certain number of swine and either discharges its pollutants into nearby waterbodies through a ditch, flushing system or other constructed device, or the pollutants flow directly into waterbodies that flow through or come into direct contact with swine at the facility.

SFOs are required to develop a Swine Waste Management Plan[3], to prevent swine waste from being discharged into surface or groundwaters. This Plan includes the BMPs being used to prevent runoff & erosion. The Swine Waste Management Plan may include, but is not limited to, a Comprehensive Nutrient Management Plan (CNMP) per NRCS guidance or Nutrient Management Plan (NMP) per EPA guidance. SFOs are not allowed to discharge to State waterbodies.

There are no SFOs in this Study Area.

3.2.5.3 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 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. A PFO AWMP must address both nitrogen and phosphorus.

According to the PFO rules, runoff of poultry waste from the application site is prohibited. BMPs and practices must be used to minimize movement of poultry waste to waterbodies. Grassed strips at the edge of the field must be used to prevent runoff from carrying eroded soil and poultry waste into the waterbodies. Poultry waste is not allowed to be applied to land when the ground is saturated or while it is raining; and poultry waste application is prohibited on land with excessive erosion.[4]

PFOs located in nutrient limited watersheds should have a nutrient sample analysis from that year to make available.[5] PFOs in non-nutrient limited watersheds need to have available the most recent nutrient sample analysis.

Per data provided by ODAFF in May 2011, there are 44 PFOs located in the watershed as shown in **Table 3-3**. These PFOs are small animal feeding operations 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.

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3 Swine Animal Waste Management Plan Requirements [Title 35 (ODAFF), Chapter 17 (Water Quality), Subchapter 3 (Swine Feeding Operations)] can be found in 35:17-3-14.

4 PFO Animal Waste Management Plan Requirements [Title 35 (ODAFF), Chapter 17 (Water Quality), Subchapter 5 (Registered Poultry Feeding Operations)] can be found in 35:17-5-5.

5 Nutrient limited watersheds are defined in the Oklahoma Water Quality Standards (Title 785, Chapter 45). Nutrient limited watersheds can be found in Appendix A of the OWQS. They are the ones designated "NLW" in the "Remarks" column.

Table 3-3 Registered PFOs in Study Area

Waterbody Name	Waterbody ID	Company Name	Poultry ID	County	Type	Total Birds
Red River	OK410100010010_10	Tyson Foods	210	McCurtain	Broilers	64,000
		Tyson Foods	798		Broilers	60,000
		Tyson Foods	933		Broilers	54,000
		Tyson Foods	1363		Broilers	128,800
		Tyson Foods	1679		Broilers	288,000
		Tyson Foods	1681		Broilers	240,000
Little River	OK410200010200_00	Tyson Foods	357	McCurtain	Broilers	108,000
		Tyson Foods	358		Broilers	103,000
Little River	OK410200010200_10	Tyson Foods	122	McCurtain	Broilers	90,000
		Tyson Foods	198		Broilers	30,000
		Tyson Foods	418		Broilers	36,000
		Tyson Foods	419		Broilers	36,000
		Tyson Foods	495		Broilers	72,000
		Tyson Foods	792		Broilers	60,000
		Tyson Foods	793		Broilers	60,000
		Tyson Foods	1105		Broilers	36,000
		Tyson Foods	1227		Broilers	48,000
		Tyson Foods	1401		Broilers	49,000
		Tyson Foods	1553		Broilers	87,000
		Tyson Foods	1624		Broilers	256,000
		Tyson Foods	1636		Broilers	36,000
		Tyson Foods	1639		Broilers	70,000
		Tyson Foods	1648		Broilers	184,000
Rock Creek	OK410200030010_00	Tyson Foods	466	McCurtain	Broilers	97,000
Buffalo Creek	OK410210060020_00	Tyson Foods	216	McCurtain	Pullets	26,000
		Tyson Foods	770		Layers	23,400
		Tyson Foods	858		Layers	34,500
		Tyson Foods	1605		Layers	23,000
Glover River	OK410210080010_00	Tyson Foods	5	McCurtain	Broilers	36,000

Waterbody Name	Waterbody ID	Company Name	Poultry ID	County	Type	Total Birds
Glover River	OK410210080010_00	Tyson Foods	68	McCurtain	Layers	15,000
		Tyson Foods	98		Layers	20,000
		Tyson Foods	181		Broilers	32,000
		Tyson Foods	267		Broilers	102,000
		Tyson Foods	429		Broilers	126,000
		Tyson Foods	443		Layers	10,500
		Tyson Foods	444		Layers	22,000
		Pilgrims Pride	475		Layers	25,100
		Tyson Foods	794		Broilers	50,000
		Tyson Foods	820		Pullets	20,000
		Tyson Foods	935		Broilers	32,000
		Tyson Foods	1232		Broilers	64,400
		Tyson Foods	1414		Pullets	22,000
		Tyson Foods	1579		Layers	10,000
		Tyson Foods	1589		Broilers	60,000

3.2.6 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 comply with Oklahoma WQS.

3.3 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 farm animals, land application fields, urban runoff, failing OSWD systems, and domesticated dogs & cats. 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 2010 Integrated Report include sediments originating from grazing in riparian corridors of streams and creeks, highway/road/bridge runoff, impacts from abandoned mine lands, non-irrigated crop production, rangeland grazing, silviculture harvesting and other sources of sediment loading (DEQ 2010). 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 bacterial or TSS loading within the Study Area.

3.3.1 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. By using the Oklahoma Department of Wildlife and Conservation (ODWC) county data (ODWC 2009), 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 5×10^8 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 3-4** in cfu/day provides a relative magnitude of loading in each watershed.

Table 3-4 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
OK410100010010_10	Red River	72,332.1	247	0.0034	124
OK410200010200_00	Little River	10,328.0	36	0.0035	18
OK410200010200_10	Little River	75,312.7	267	0.0035	133
OK410200030010_00	Rock Creek	30,836.3	104	0.0034	52
OK410210020140_00	Little River	88,550.7	634	0.0072	317
OK410210020300_00	Cloudy Creek	40,266.9	292	0.0073	146
OK410210060020_00	Buffalo Creek	41,118.3	110	0.0027	55
OK410210060320_00	Beech Creek	15,756.4	64	0.0040	32
OK410210060350_00	Cow Creek	9,453.5	38	0.0040	19
OK410210080010_00	Glover River	118,404.2	417	0.0035	209
OK410300010010_00	Kiamichi River	30,564.8	243	0.0079	121
OK410300010020_00	Gates Creek	3,136.4	25	0.0080	13
OK410300010100_00	Bird Creek	9,425.2	75	0.0079	37
OK410310010010_00	Kiamichi River	72,957.9	540	0.0074	270
OK410310020010_10	Kiamichi River	59,230.8	246	0.0042	123

3.3.2 Non-Permitted Agricultural Activities and Farm 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.

- Farm animals grazing in pastures deposit manure containing fecal bacteria onto land surfaces. These bacteria may be washed into waterbodies by runoff.
- Farm 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 3-5 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 3-5** 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. Poultry are clearly the most abundant species of commercially raised farm animals and cattle are the second in the Study Area. However, cattle 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 3-5**. 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

(Section 3.3.2 text continues on page 3-19)

Table 3-5 Commercially Raised Farm Animals and Manure Application Area Estimates by Watershed

Waterbody ID	Waterbody Name	Cattle & Calves	Dairy Cows	Hogs & Pigs	Chickens & Turkeys	Sheep & Lambs	Horses & Ponies	Goats	Ducks & Geese	Acres of Manure Application
OK410100010010_10	Red River	4,839	46	479	505,638	16	173	0	13	951
OK410200010200_00	Little River	668	5	81	84,164	2	28	0	2	136
OK410200010200_10	Little River	4,848	39	586	610,726	17	205	0	15	990
OK410200030010_00	Rock Creek	2,038	16	292	270,939	7	80	0	6	405
OK410210020140_00	Little River	3,551	7	101	20,844	21	172	0	43	126
OK410210020300_00	Cloudy Creek	1,583	2	38	26	10	77	0	20	55
OK410210060020_00	Buffalo Creek	2,702	16	382	343,486	13	89	0	7	541
OK410210060320_00	Beech Creek	1,168	3	201	173,265	11	44	0	5	471
OK410210060350_00	Cow Creek	708	2	124	105,291	7	26	0	3	317
OK410210080010_00	Glover River	7,588	61	918	955,905	27	321	1	23	1,557
OK410300010010_00	Kiamichi River	4,088	10	20	129	18	137	0	11	132
OK410300010020_00	Gates Creek	420	1	2	8	2	14	0	1	14
OK410300010100_00	Bird Creek	1,251	3	6	23	5	42	0	3	41
OK410310010010_00	Kiamichi River	3,038	5	137	1,039	19	146	0	35	136
OK410310020010_10	Kiamichi River	4,486	9	798	675,059	45	166	0	19	1,909

Table 3-6 Fecal Coliform Production Estimates for Commercially Raised Farm Animals (x10^9 number/day)

Waterbody ID	Waterbody Name	Cattle & Calves	Dairy Cows	Hogs & Pigs	Chickens & Turkeys	Sheep & Lambs	Horses & Ponies	Goats	Ducks & Geese	Total
OK410100010010_10	Red River	503,220	4,694	5,176	68,767	191	73	0	31	582,152
OK410200010200_00	Little River	69,472	505	33	11,446	24	302	0	5	81,787
OK410200010200_10	Little River	504,163	3,906	6,332	83,059	205	86	0	36	597,786
OK410200030010_00	Rock Creek	211,959	1,624	3,157	36,848	80	34	0	14	253,716
OK410210020140_00	Little River	369,285	670	1,095	2,835	258	72	0	106	374,321
OK410210020300_00	Cloudy Creek	164,60	251	411	4	117	32	0	49	165,485
OK410210060020_00	Buffalo Creek	281,036	1,614	4,126	46,714	151	37	0	16	333,693
OK410210060320_00	Beech Creek	121,496	316	2,173	23,564	131	18	0	12	147,710
OK410210060350_00	Cow Creek	73,603	174	1,335	14,320	81	11	0	7	89,530
OK410210080010_00	Glover River	789,112	6,114	9,910	130,003	320	135	9	57	935,660
OK410300010010_00	Kiamichi River	425,168	1,022	215	18	214	57	0	28	426,721
OK410300010020_00	Gates Creek	43,631	104	22	1	22	6	0	3	43,788
OK410300010100_00	Bird Creek	130,058	309	66	3	66	18	0	8	130,528
OK410310010010_00	Kiamichi River	315,937	456	1,479	141	225	61	0	86	318,384
OK410310020010_10	Kiamichi River	466,492	923	8,619	91,808	540	70	0	47	568,499

(Section 3.3.2 text continues from page 3-16)

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 3-6**. As stated in the introduction to this chapter, even though 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. 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 and coliform production, cattle appear to represent the most likely commercially raised farm animal source of fecal bacteria.

3.3.3 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 2012). 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 1985). **Table 3-7** summarizes estimates of sewered and unsewered households and the average number of septic tanks per square mile for each watershed in the Study Area.

Table 3-7 Estimates of Sewered and Unsewered Households

Waterbody ID	Waterbody Name	Public Sewer	Septic Tank	Other Means	Housing Units	# of Septic Tanks / Mile^2
OK410100010010_10	Red River	204	419	44	667	3.7
OK410200010200_00	Little River	229	130	6	365	8.1
OK410200010200_10	Little River	498	738	34	1270	6.3
OK410200030010_00	Rock Creek	15	176	12	203	3.7
OK410210020140_00	Little River	12	226	37	275	1.6
OK410210020300_00	Cloudy Creek	1	95	17	113	1.5
OK410210060020_00	Buffalo Creek	4	150	13	166	2.3
OK410210060320_00	Beech Creek	23	57	4	83	2.3
OK410210060350_00	Cow Creek	14	38	2	54	2.6
OK410210080010_00	Glover River	100	536	52	688	2.9
OK410300010010_00	Kiamichi River	37	218	10	265	4.6
OK410300010020_00	Gates Creek	4	22	1	28	4.6
OK410300010100_00	Bird Creek	13	67	3	83	4.5
OK410310010010_00	Kiamichi River	63	222	22	307	1.9
OK410310020010_10	Kiamichi River	97	220	9	326	2.4

For the purpose of estimating fecal coliform loading in watersheds, an OSWD failure rate of 12% 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):

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

The average of number of people per household was calculated to be 2.5 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 in **Table 3-8**.

Table 3-8 Estimated Fecal Coliform Load from OSWD Systems

Waterbody ID	Waterbody Name	Acres	Septic Tanks	# of Failing Septic Tanks	Estimated Loads from Septic Tanks (x 10^9 counts/day)
OK410100010010_10	Red River	72,332.1	419	50	333
OK410200010200_00	Little River	10,328.0	130	16	103
OK410200010200_10	Little River	75,312.7	738	89	587
OK410200030010_00	Rock Creek	30,836.3	176	21	140
OK410210020140_00	Little River	88,550.7	226	27	179
OK410210020300_00	Cloudy Creek	40,266.9	95	11	76
OK410210060020_00	Buffalo Creek	41,118.3	150	18	119
OK410210060320_00	Beech Creek	15,756.4	57	7	45
OK410210060350_00	Cow Creek	9,453.5	38	5	30
OK410210080010_00	Glover River	118,404.2	536	64	426
OK410300010010_00	Kiamichi River	30,564.8	218	26	173
OK410300010020_00	Gates Creek	3,136.4	22	3	18
OK410300010100_00	Bird Creek	9,425.2	67	8	53
OK410310010010_00	Kiamichi River	72,957.9	222	27	177
OK410310020010_10	Kiamichi River	59,230.8	220	26	175

3.3.4 Domesticated Dogs and Cats

Fecal matter from domesticated 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. In these households, the average number per household is 1.7 dogs and 2.2 cats (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 3-9** summarizes the estimated number of dogs and cats for the watersheds of the Study Area.

Table 3-9 Estimated Numbers of Domesticated Dogs and Cats

Waterbody ID	Waterbody Name	Dogs	Cats
OK410100010010_10	**Red River**	422	475
OK410200010200_00	**Little River**	231	260
OK410200010200_10	**Little River**	803	905
OK410200030010_00	**Rock Creek**	128	145
OK410210020140_00	**Little River**	174	196
OK410210020300_00	**Cloudy Creek**	71	81
OK410210060020_00	**Buffalo Creek**	105	118
OK410210060320_00	**Beech Creek**	53	59
OK410210060350_00	**Cow Creek**	34	39

Waterbody ID	Waterbody Name	Dogs	Cats
OK410210080010_00	**Glover River**	435	490
OK410300010010_00	**Kiamichi River**	168	189
OK410300010020_00	**Gates Creek**	18	20
OK410300010100_00	**Bird Creek**	52	59
OK410310010010_00	**Kiamichi River**	194	219
OK410310020010_10	**Kiamichi River**	206	233

Table 3-10 provides an estimate of the fecal coliform production from domesticated dogs and cats. These estimates are based on estimated fecal coliform production rates of 5.4×10^8 per day for cats and 3.3×10^9 per day for dogs (Schueler 2000).

Table 3-10 Estimated Fecal Coliform Daily Production by Domesticated Dogs and Cats ($\times 10^9$ counts/day)

Waterbody ID	Waterbody Name	Dogs	Cats	Total
OK410100010010_10	Red River	1,392	257	1,649
OK410200010200_00	Little River	762	140	902
OK410200010200_10	Little River	2,650	489	3,138
OK410200030010_00	Rock Creek	423	78	501
OK410210020140_00	Little River	573	106	679
OK410210020300_00	Cloudy Creek	236	43	279
OK410210060020_00	Buffalo Creek	347	64	411
OK410210060320_00	Beech Creek	174	32	206
OK410210060350_00	Cow Creek	113	21	134
OK410210080010_00	Glover River	1,436	265	1,701
OK410300010010_00	Kiamichi River	553	102	655
OK410300010020_00	Gates Creek	58	11	69
OK410300010100_00	Bird Creek	173	32	205
OK410310010010_00	Kiamichi River	641	118	759
OK410310020010_10	Kiamichi River	681	126	807

3.4 Summary of Sources of Impairments

3.4.1 Bacteria

There are no continuous, permitted point sources of bacteria, CAFOs or PFOs in the Kiamichi River (OK410300010010_00, OK410310010010_00, and OK410310020010_10) watersheds which require bacterial TMDLs. Therefore, the conclusion is that nonsupport of PBCR use in these watersheds is caused by nonpoint sources of bacteria.

Table 3-11 below provides a summary of the estimated fecal coliform loads in percentage for the four major nonpoint source categories (commercially raised farm animals, domesticated dogs & cats, 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.

The magnitude of loading to land surfaces may not reflect the magnitude of loading to a stream. 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.

If poultry litter is applied to areas in the watershed in a pulverized form, it could be a larger source during storm runoff events. The Shoal Creek report by the Missouri Department of Natural Resources showed that poultry litter was about 71% of the high flow load and cow pats contributed only about 28% of it (MDNR, 2003). The Shoal Creek report also showed that poultry litter was insignificant under low flow conditions up to 50% frequency. 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.

Table 3-11 Percentage Contribution of Fecal Coliform Load Estimates from Nonpoint Sources to Land Surfaces

Waterbody ID	Waterbody Name	All Livestock	Domesticated Dogs and Cats	Deer	Estimated Loads from Septic Tanks
OK410100010010_10	**Red River**	99.63%	0.28%	0.02%	0.07%
OK410200010200_00	**Little River**	98.76%	1.09%	0.02%	0.12%
OK410200010200_10	**Little River**	99.34%	0.52%	0.02%	0.12%
OK410200030010_00	**Rock Creek**	99.72%	0.20%	0.02%	0.07%
OK410210020140_00	**Little River**	99.68%	0.18%	0.08%	0.06%
OK410210020300_00	**Cloudy Creek**	99.69%	0.17%	0.09%	0.05%
OK410210060020_00	**Buffalo Creek**	99.82%	0.12%	0.02%	0.04%
OK410210060320_00	**Beech Creek**	99.80%	0.14%	0.02%	0.04%
OK410210060350_00	**Cow Creek**	99.79%	0.15%	0.02%	0.04%

Waterbody ID	Waterbody Name	All Livestock	Domesticated Dogs and Cats	Deer	Estimated Loads from Septic Tanks
OK410210080010_00	**Glover River**	99.74%	0.18%	0.02%	0.05%
OK410300010010_00	**Kiamichi River**	99.77%	0.15%	0.03%	0.05%
OK410300010020_00	**Gates Creek**	99.77%	0.16%	0.03%	0.05%
OK410300010100_00	**Bird Creek**	99.77%	0.16%	0.03%	0.05%
OK410310010010_00	**Kiamichi River**	99.61%	0.24%	0.08%	0.07%
OK410310020010_10	**Kiamichi River**	99.80%	0.14%	0.02%	0.04%

3.4.2 Turbidity

Of the eleven watersheds in the Study Area that require turbidity TMDLs, one of them - Little River (OK410200010200_10) - has dewatering discharges from Meridian Aggregates Co (OKR050878) for which they were given a WLA. There was also a permitted construction project in the Little River (OK410200010200_10) from 2008 – 2009 and another permitted construction project in Bird Creek (OK410300010100_00) in 2008 that could have resulted in some TSS getting into those waterbodies. Stormwater runoff was not considered as the cause of turbidity impairment because the turbidity standard does not apply. In addition, stormwater dischargers have a TSS limit in their permit and must use BMPs to prevent sediment from leaving their site and entering a waterbody. Therefore, nonpoint sources were thought to be most responsible for the turbidity impairments in these watersheds.

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

4.1 POLLUTANT LOADS AND TMDLS

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:

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

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.

4.2 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 TSS 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 2007 at stations within the Study Area.

4.2.1 Steps Prior to Regression

Prior to developing the regression the following steps were taken to refine the dataset:

- Remove data collected under high flow conditions exceeding the base-flow criterion. This means that measurements corresponding to flow exceedance percentiles lower than 25th 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.

- Check the non-detect rate. Non-detects (aka “censored data”) are TSS sample observations less than detection limit (10 mg/L). If the percent of non-detects is ≤ 15%, follow the steps outlined in Section 4.2.2. If the percent of non-detects is > 15%, follow the steps outlined in Section 4.2.3.

4.2.2 Non-Detect Rate Less Than or Equal to (≤) 15%

For observed data where the non-detect rate is less than or equal to (≤) 15%, EPA (2006) recommends using substitution. 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 in-stream turbidity values. For this purpose, an alternate regression fitting procedure known as the line of organic correlation (LOC) was applied. To apply LOC, TSS samples of less than 10 were replaced with 9.99 and then both turbidity and TSS data were log-transformed to minimize effects of their non-linear data distribution. 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
- 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:

$$m1 = \sqrt{m \cdot m'} = \sin(r) \cdot \frac{s_y}{s_x}$$

$m1$ 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

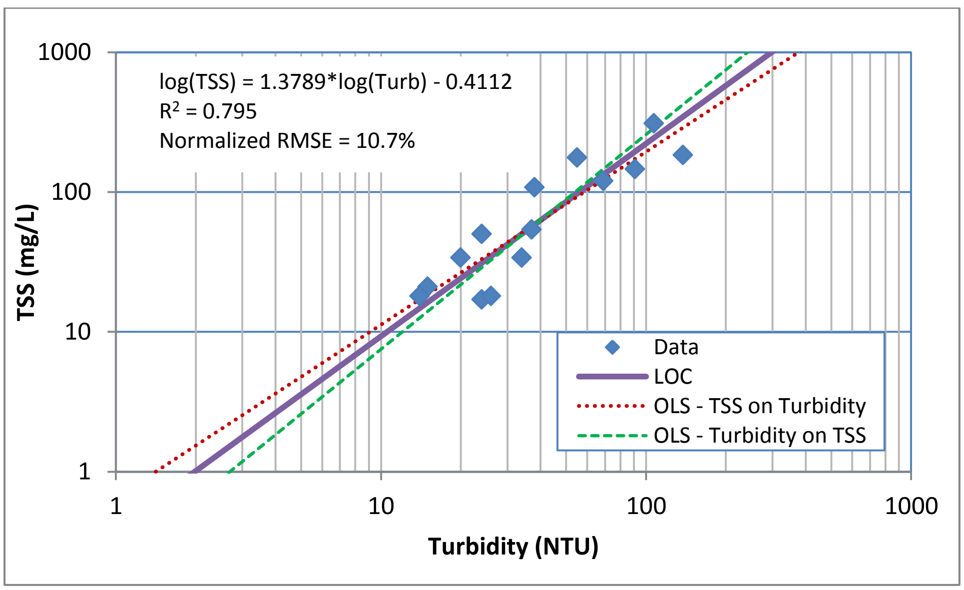
s_x is the standard deviation of the turbidity measurements

The *r* can range from -1 to 1 with 0 indicating no correlation, and negative *r* indicating an inverse correlation. Correlation values of 0 to 0.5 indicate a weaker correlation whereas values greater than 0.5 indicate a strong correlation. As a result, correlations of approximately 0.5 or greater are commonly used in TMDL studies (Christensen, Jian, and Ziegler; 2000). This Study considered an R-square (r^2 or coefficient of determination) value of approximately 0.5 to represent a satisfactory relationship between turbidity and TSS, if based on at least 10 observations.

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^2 were used as the primary measures of goodness-of-fit. As shown in **Figure 4-1**, the LOC yields a NRMSE value of 10.7 which means the root mean square error (RMSE) is 10.7% of the average of the observed log-transformed TSS values. The R-square 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 or 10 NTUs to TSS goals.

Figure 4-1 Linear Regression for TSS-Turbidity for the Red River (OK410100010010_10)



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 regressions presented in Section 5 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.

4.2.3 Non-Detect Rate is Greater Than 15%

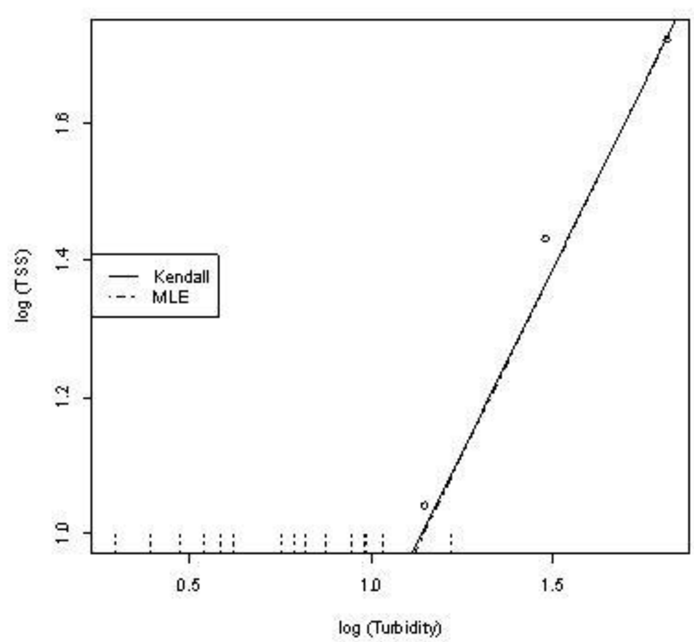
For observed data where the non-detect rate is greater than 15%, follow these steps:

- If the number of samples is less than 25 (Helsel, 2002; p. 360), combine sample data based on their ecoregion, geological area, and beneficial use.
- Log-transform both turbidity and TSS data to minimize effects of their non-linear data distributions.
- Use methods for estimating summary statistics of data which include non-detects: simple substitution, distributional, and robust methods (Helsel and Hirsch, 2002).
- Compare results for the mean and the variance for desirable methods. Extrapolated values are not considered as estimates for specific samples, but only used collectively to estimate summary statistics.
- Choose regression methods for data-sets containing non-detects depend on distribution of data. If the data are linear and normally distributed without outliers, parametric methods may be used. Non-parametric methods may be used regardless of whether or not they are linear (Huston and Juarez-Colunga, 2009).
- Use statistical software (such as Excel, JMP, R, Minitab, or SAS) to calculate the turbidity-TSS relationship. Then, the TSS goal is computed based on regression coefficients.
- Replace Less-thans with their detection limits for percentage reduction goal (PRG) calculation. Detection limit substitution may not be the best estimation method, but it is the best conservative method for calculating PRG.

If a small proportion of the observations are not detected, these may be substituted with a value (EPA 2006), the detection limit (dl) in this study. However, substituting for non-detects may incorrectly alter the mean and the variance (**Appendix D**). Therefore, censored data regression was issued for the data set of censoring greater than 15%. Before determine the relationship between turbidity and TSS, censored data were set as a range from one (TSS=1[1] mg/L) to detection limit (TSS=10 mg/L). Then, turbidity and TSS data were log-transformed and statistical software R determined regression relationships.

With statistical software R, maximum likelihood estimation (MLE) or non-parametric approaches can estimate correlation and regression coefficients as shown in **Figure 4-2**. If extreme outliers were not present in the sample data and the distributions of points were close to trend line (**Appendix E**), parametric method (MLE) performed similar or slightly better than non-parametric method (Kendall's tau).

Figure 4-2 Regression estimates by parametric and non-parametric method



After computing TSS goal with estimated regression, censored data were replaced with their detection limit (dl). This simple substitution is the most conservative to calculate PRG among estimation methods for censored data (**Appendix D**). Then, NRMSE and R-square (r^2) were computed as:

$$RMSE = (Standard\ Error\ of\ Slope) \cdot \sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

$$NRMSE = \frac{RMSE}{\bar{y}}$$

[1] Having a TSS of "0" would be almost impossible because there is always some sediment in the background. Consequently, "1" is used as the lowest amount of TSS.

$$R^2 = 1 - \left[\frac{exp\left(loglik_{intercept}\right)}{exp\left(loglik_{model}\right)}\right]^{\frac{2}{n}}$$

Where x_i = log(turbidity)$_i$, y_i = log(TSS)$_i$, i = 1…n, $\bar{x}$ = average of x_i, $\bar{y}$ = average of y_i, and n = number of observes.

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

4.3 Steps to Calculating 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 4.3.1 through 4.3.3 below:

1. Prepare flow duration curves for gaged and ungaged WQM stations
2. Estimate existing loading in the waterbody using ambient bacterial water quality data; and estimate loading in the waterbody using measured TSS water quality data and turbidity-converted data
3. Use 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 WWTF 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.

4.3.1 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. Eight of the fourteen waterbodies that require TMDL 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**.

To estimate flows at an ungaged site:

- Identify an upstream or downstream flow gage
- Calculate the contributing drainage areas of the ungaged sites and the flow gage
- Calculate 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.

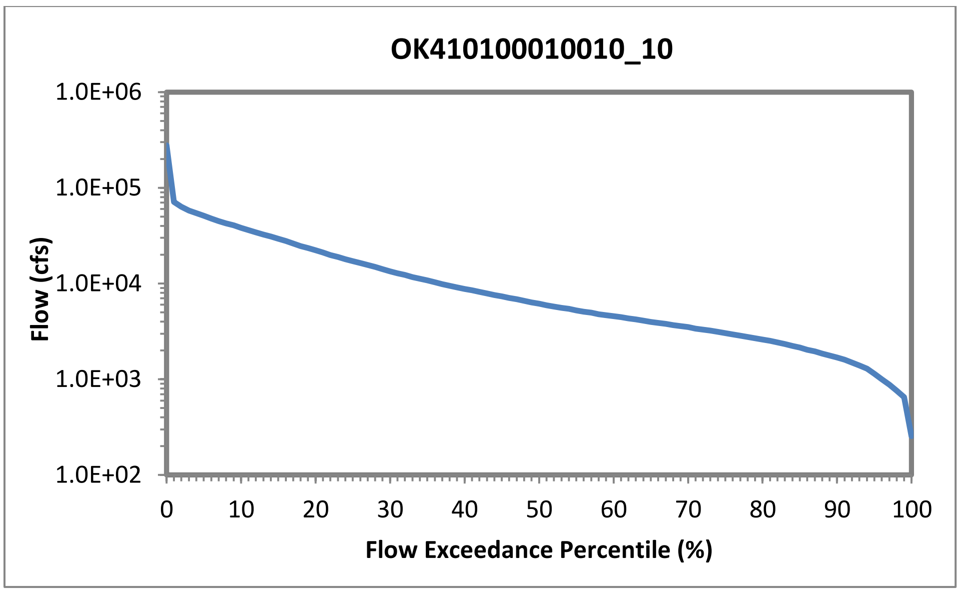
The USGS National Water Information System serves as the primary source of flow measurements for the Oklahoma TMDL Toolbox. All available daily average flow values for all gages in Oklahoma, as well as the nearest upstream and downstream gages in adjacent states, were retrieved for use in the Oklahoma 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 with 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 4-3**.

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

Figure 4-3 Flow Duration Curve for the Red River (OK410100010010_10)



4.3.2 Estimating Existing Loading

4.3.2.1 Bacterial FDC

Existing instream loads can be estimated using FDCs. For bacteria:

- Calculate the geometric mean of all water quality observations from the period of record selected for the waterbody.
- Convert 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.

4.3.2.2 TSS FDC

- Match the water quality observations with the flow data from the same date.
- Convert 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).

4.3.3 Using Load Duration Curves to Develop TMDLs

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).

4.3.3.1 Step 1 - Generate LDCs

LDCs are similar in appearance to flow duration curves.

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 equation in Section 4.3.3.1.1 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 TSS, the ordinate is expressed in terms of a load in lbs/day. The curve represents the water quality target for TSS from **Table 5-2** expressed in terms of a load obtained through multiplication of the TSS goal by the continuum of flows historically observed at the site.

The following are the basic steps in developing an LDC:

1. Obtain daily flow data for the site of interest from the USGS
2. Sort the flow data and calculate flow exceedance percentiles
3. For bacteria, obtain water quality data for the primary contact recreation season (May 1 through September 30).
4. Obtain available turbidity and TSS water quality data.

5. Display 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)

6. For bacterial TMDLs, display 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)

7. For turbidity TMDLs, match the water quality observations with the flow data from the same date and determine the corresponding exceedance percentile (See Section 5).

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.

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).

4.3.3.1.1 Bacterial LDC

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

Historical observations of bacteria were plotted as a separate LDC based on the geometric mean of all samples. 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.

4.3.3.1.2 Turbidity LDC

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 5-2**

Unit conversion factor = 5.39377

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.

4.3.3.2 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.

4.3.3.3 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 OPDES-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 WWTF

For watersheds with permitted point sources discharging the pollutant of concern, OPDES 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 WWTF, then the average of monthly flow rates derived from DMRs can be used. WLA values for each OPDES 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.

4.3.3.3.1 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

4.3.3.3.2 WLA for TSS

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

Where:

WQ goal= Waterbody specific water quality goal provided in* Table 5-2*, or monthly TSS limit in the current permit, whichever is smaller

Flow (mgd) = permitted flow or average monthly flow

Unit conversion factor = 8.3445

4.3.3.4 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 OPDES 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_WWTF - WLA_MS4 – MOS

4.3.3.4.1 Bacterial 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.

4.3.3.4.2 Turbidity WLA for MS4s

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.

4.3.3.5 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 (PRG) 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:

1. If the geometric mean of the reduced values of all samples is less than the geometric mean standards (for bacteria) or

2. If no more than 10% of the reduced values of the samples under flow-base conditions exceed the TMDL (for turbidity).

4.3.3.5.1 WLA Load Reduction

The WLA load reduction for bacteria was not calculated as it was assumed that continuous dischargers (OPDES-permitted WWTFs) 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.

4.3.3.5.2 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

Regression methods used in this report depend on the percentage of censored data. When censored data are less than or equal to 15%, the line of organic correlation (LOC) is applied with simple substitution of detection limit for censored data. When censored data are greater than 15%, maximum likelihood estimation (MLE) is applied for the data set without extreme outliers. Therefore, MLE was used for all waterbodies in **Table 5-1**.

Table 5-1 Censored TSS data in base flow

Waterbody ID	Waterbody Name	Total number of TSS data	Number of censored data (# of samples falling below the 10 mg/L detection limit)	Percent of censored data (% of samples falling below the 10 mg/L detection limit)
OK410200030010_00	**Rock Creek**	18	16	84.2
OK410210020300_00	**Cloudy Creek**	18	15	78.9
OK410210060020_00	**Buffalo Creek**	17	15	88.2
OK410210060320_00	**Beech Creek**	20	16	80.0
OK410210060350_00	**Cow Creek**	20	15	75.0
OK410300010020_00	**Gates Creek**	18	8	44.4
OK410300010100_00	**Bird Creek**	18	9	50.0

Using the line of organic correlation (LOC) and maximum likelihood estimation (MLE) methods described in Section 4.1, correlations between TSS and turbidity were developed for establishing the statistics of the regressions and the resulting TSS goals provided in **Table 5-2**. The regression analysis for each impaired waterbody in the Study Area using the LOC or MLE method is displayed in **Figures 5-1** through **5-5**. No concurrent turbidity and TSS data were available for Little River (OK410200010200_10) and an acceptable regression relationship (R^2 value of approximately 0.5) could not be developed for Rock Creek (OK410200030010_00), Buffalo Creek (OK410210060020_00), Beech Creek (OK410210060320_00), Little River (OK410210020140_00), and Glover River (OK410210080010_00). Therefore, the regression statistics for these six waterbodies were derived from the data based on nearby waterbodies with similar watershed characteristics including land use and geophysical features. It was superior to one based on a larger geographic area, which presumably would have more diverse hydrologic conditions and watershed characteristics.

Table 5-2 Regression Statistics and TSS Goals

Waterbody ID	Waterbody Name	R-square	NRMSE	TSS Goal (mg/L)[a]	MOS
OK410100010010_10	**Red River**	0.79	10.7%	85.4	15%
OK410200010200_10	**Little River**	0.74	12.0%	6.9	15%
OK410200030010_00	**Rock Creek**	0.61	28.0%	6.9	30%
OK410210020140_00	**Little River**	0.74	12.0%	6.9	15%
OK410210020300_00	**Cloudy Creek**	0.74	12.0%	6.9	15%
OK410210060020_00	**Buffalo Creek**	0.61	28.0%	6.9	30%
OK410210060320_00	**Beech Creek**	0.61	28.0%	6.9	30%
OK410210060350_00	**Cow Creek**	0.61	28.0%	6.9	30%
OK410210080010_00	**Glover River**	0.74	12.0%	6.9	15%
OK410300010020_00	**Gates Creek**	0.54	17.7%	7.4	20%
OK410300010100_00	**Bird Creek**	0.49	35.0%	23.6	35%

[a] Calculated using the regression equation and the turbidity standard (50 NTU for WWAC and 10 NTU for CWAC)

Figure 5-1 Linear Regression for TSS-Turbidity for the Red River (OK410100010010_10)

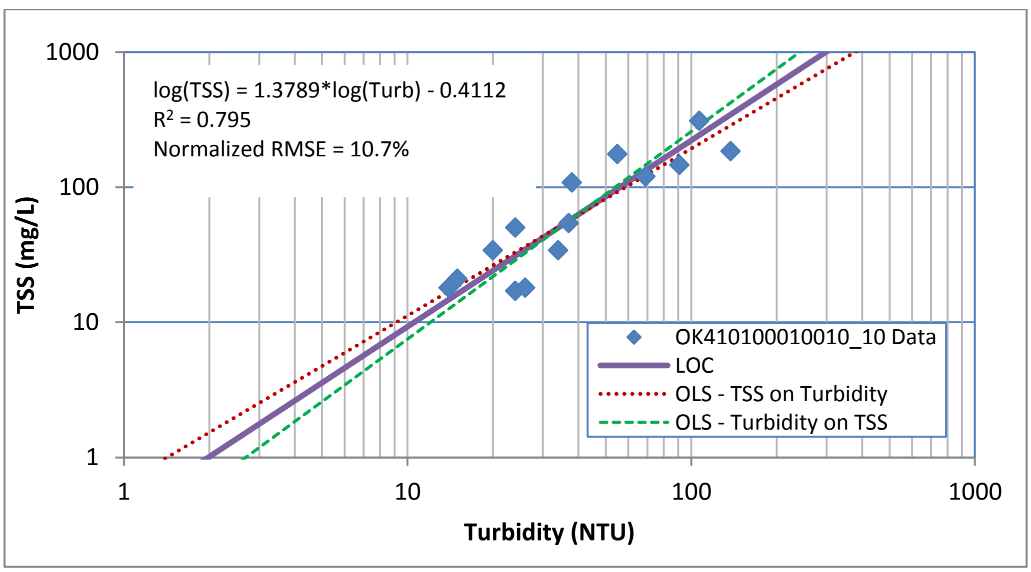


Figure 5-2 Regression Estimation for TSS-Turbidity for Cloudy Creek[1] (OK410210020300_00)

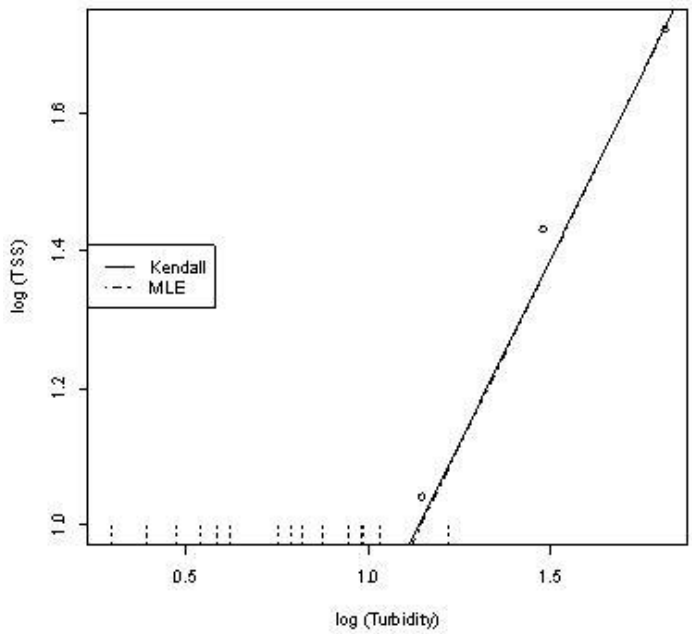
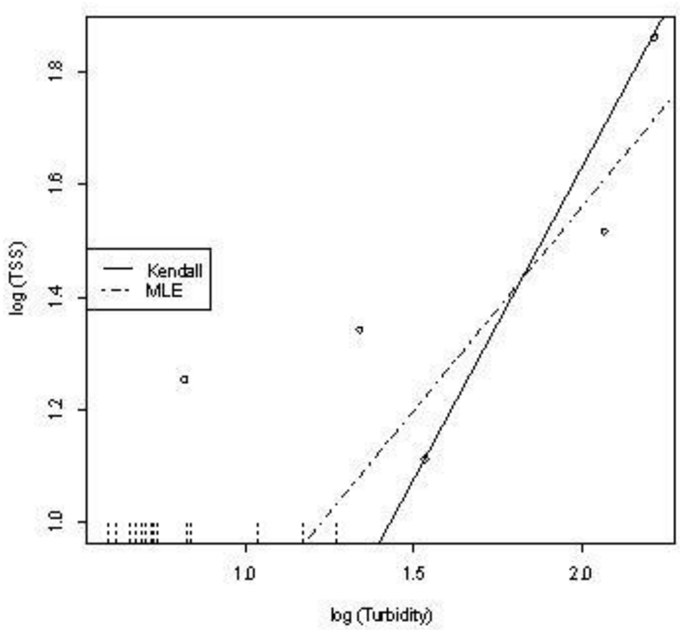


Figure 5-3 Regression Estimation for TSS-Turbidity for Cow Creek (OK410210060350_00)



[1] The correlation coefficient for Cloudy Creek is > than 0.5. The correlation coefficient for the Little (OK410200010200_10, and OK410210020140_00), and Glover (OK410210080010_00) Rivers was < than 0.5. Since these waterbodies are in the same geographical area and have similar land uses as Cloudy Creek, that is why the regression for Cloudy Creek was used for them.

Note: The regression for Rock Creek (OK410200030010_00), Beech Creek (OK410210060320_00), and Buffalo Creek (OK410210060020_00) were developed using data from since they are also in a similar geographic area and have similar land uses as Cow Creek (OK410210060350_00).

Figure 5-4 Regression Estimation for TSS-Turbidity for Gates Creek (OK410300010020_00)

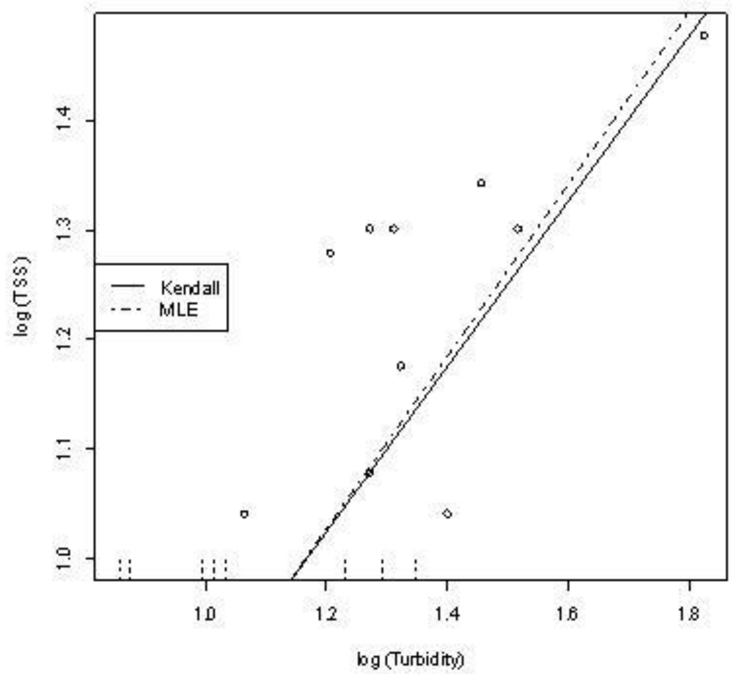
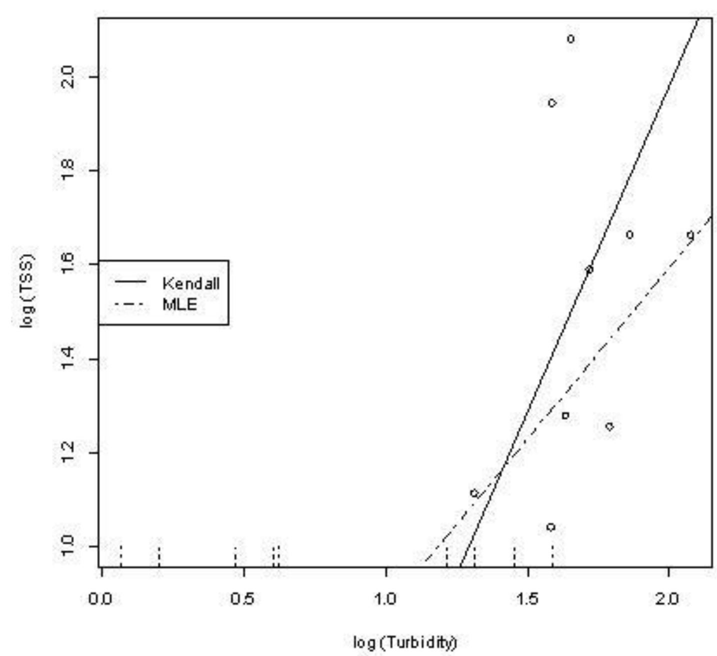


Figure 5-5 Regression Estimation for TSS-Turbidity for Bird Creek (OK410300010100_00)



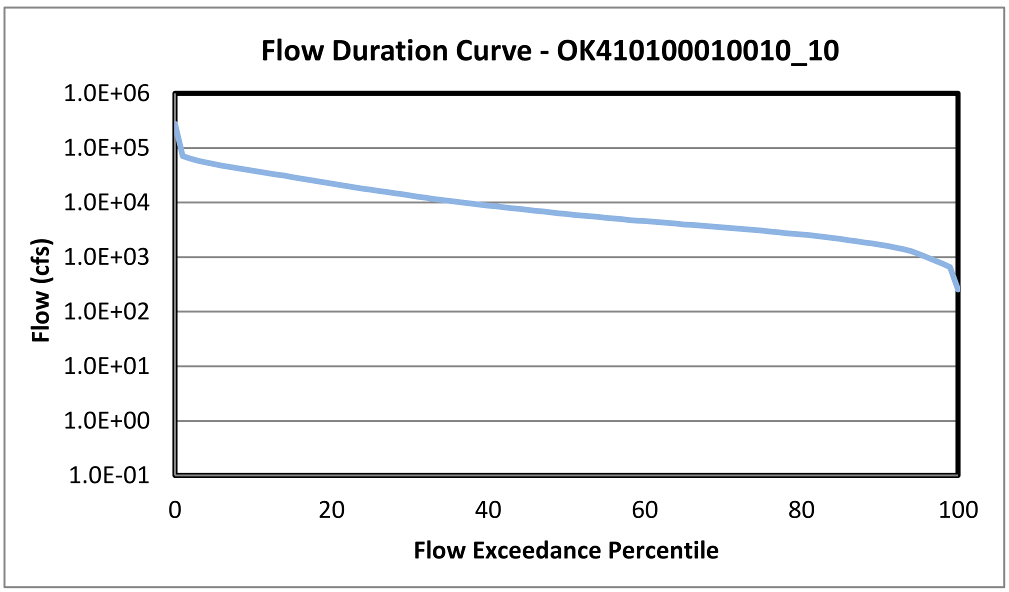
Regression method is not truly approparIate for the data set which has a very high rate of censoring (greather than 50%). However, regression with MLE method were used in this study because there are no alternatives to find relationship between TSS and turbidity. Even though regression method was inappropriate for highly censored data, PRGs from regression method were not much different from those computed by direct calculation with turbidity (**Appendix F**).

5.2 Flow Duration Curve

Following the same procedures described in Section 4.3.1, a flow duration curve for each stream segment in this study was developed. These are shown in **Figures 5-6** through **Figure 5-19**.

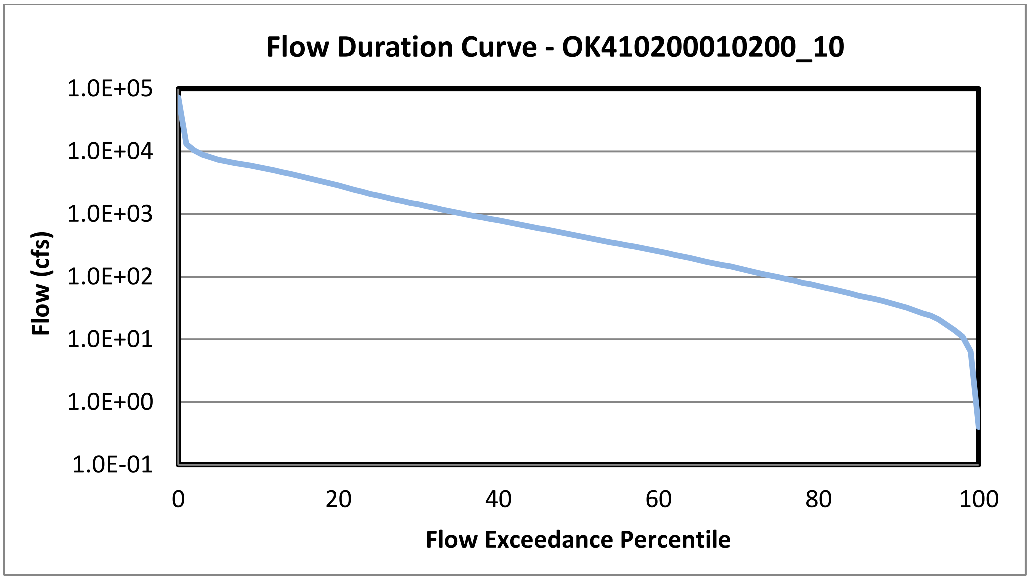
The flow duration curve for the Red River (OK410100010010_10) was estimated based on measured flows at USGS gage station 07336820 on the Red River near De Kalb, Texas. USGS flow data used to develop the flow duration curve range from 1968 to 2013.

Figure 5-6 Flow Duration Curve for the Red River (OK410100010010_10)



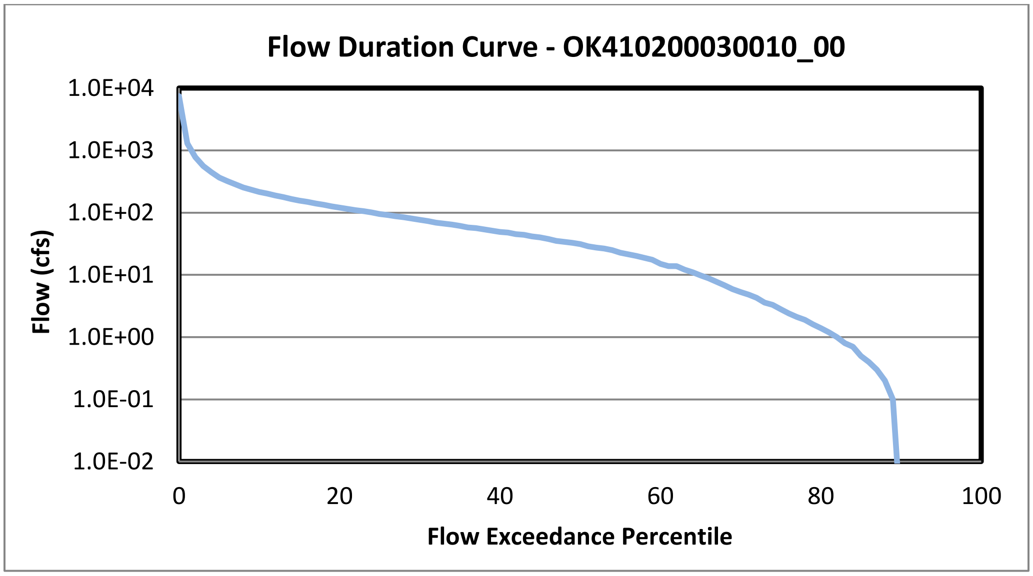
The flow duration curve for Little River (OK410200010200_10) was estimated based on measured flows at USGS gage station 07338500 on Little River below Lufaka Creek, near Idabel, Oklahoma. USGS flow data used to develop the flow duration curve range from 1946 to 2013.

Figure 5-7 Flow Duration Curve for the Little River (OK410200010200_10)



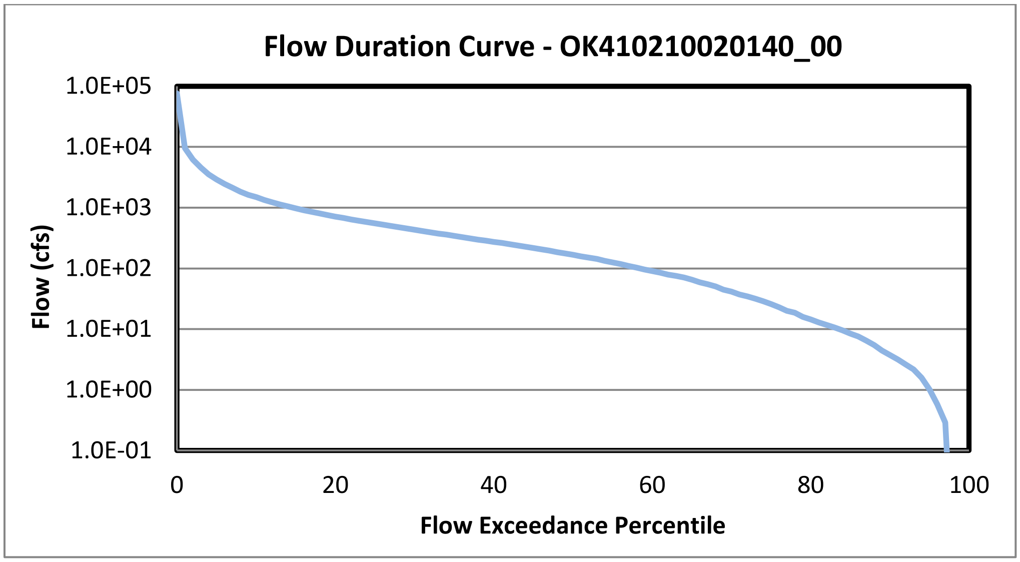
No flow gage exists on Rock Creek, segment OK410200030010_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07335700 located in an adjacent watershed (Kiamichi River near Big Cedar, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1965 to 2013.

Figure 5-8 Flow Duration Curve for Rock Creek (OK410200030010_00)



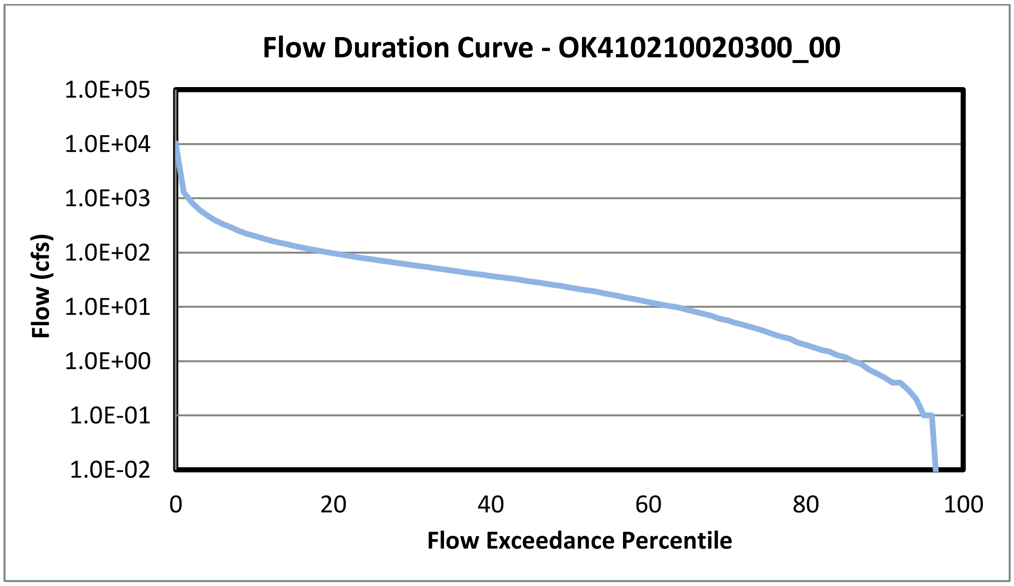
No flow gage exists on Little River, segment OK410210020140_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07337900 (Glover River, near Glover, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1961 to 2013.

Figure 5-9 Flow Duration Curve for the Little River (OK410210020140_00)



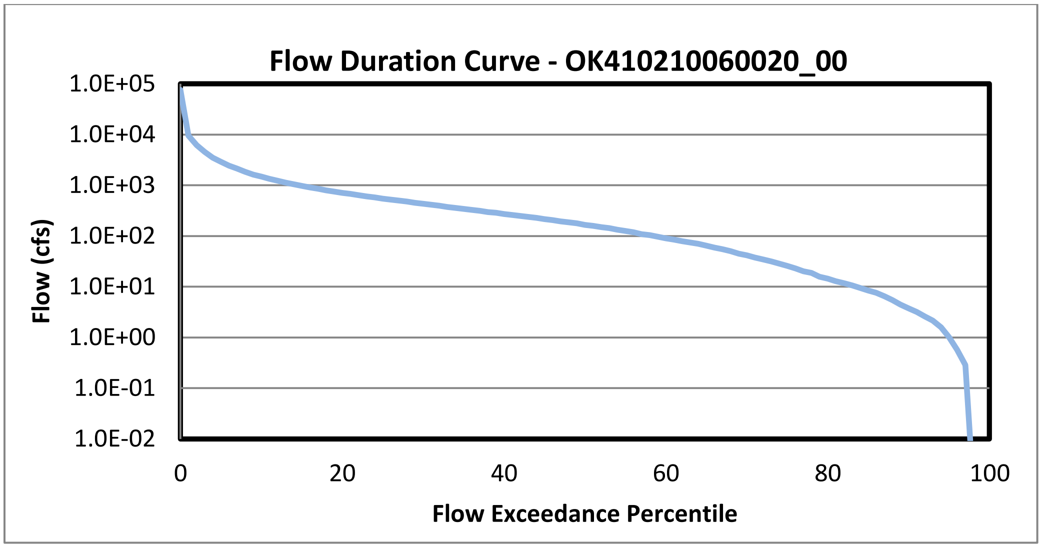
No flow gage exists on Cloudy Creek, segment OK410210020300_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07337900 (Glover River, near Glover, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1961 to 2013.

Figure 5-10 Flow Duration Curve for Cloudy Creek (OK410210020300_00)



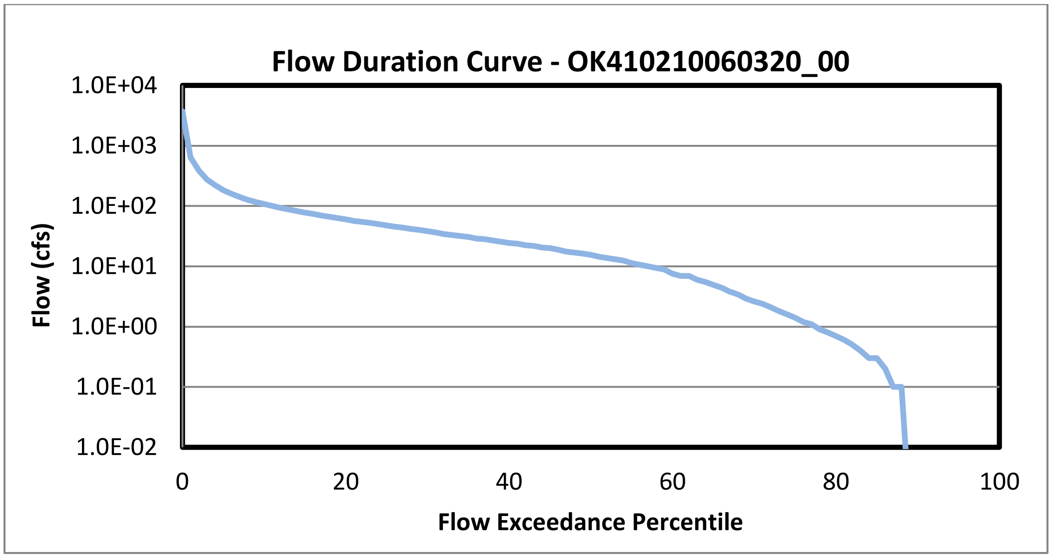
No flow gage exists on Buffalo Creek, segment OK410210060020_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07338750 located in an adjacent watershed (Mountain Fork at Smithville, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1991 to 2013.

Figure 5-11 Flow Duration Curve for Buffalo Creek (OK410210060020_00)



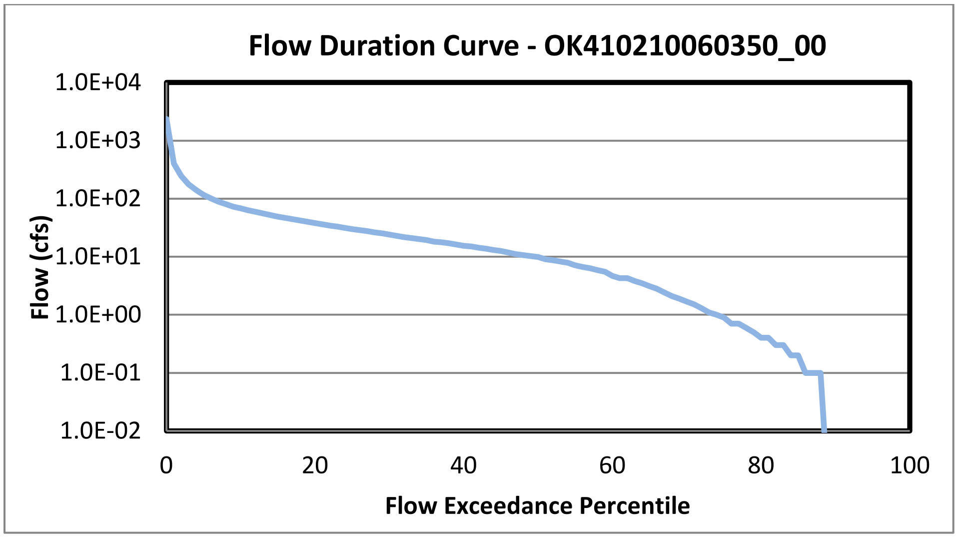
No flow gage exists on Beech Creek, segment OK410210060320_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07335700 located in an adjacent watershed (Kiamichi River near Big Cedar, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1965 to 2013.

Figure 5-12 Flow Duration Curve for Beech Creek (OK410210060320_00)



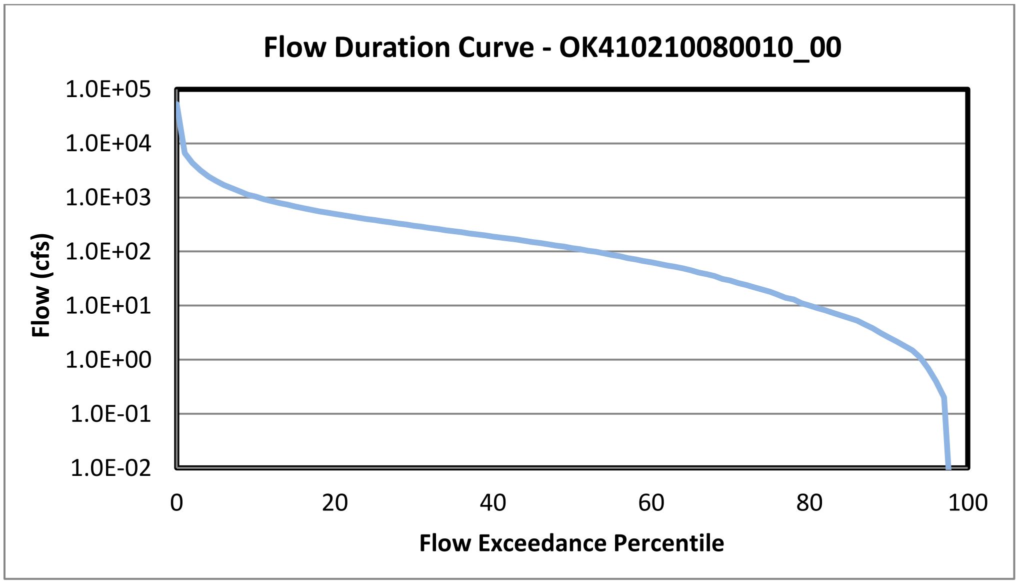
No flow gage exists on Cow Creek, segment OK410210060350_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07335700 located in an adjacent watershed (Kiamichi River near Big Cedar, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1965 to 2013.

Figure 5-13 Flow Duration Curve for Cow Creek (OK410210060350_00)



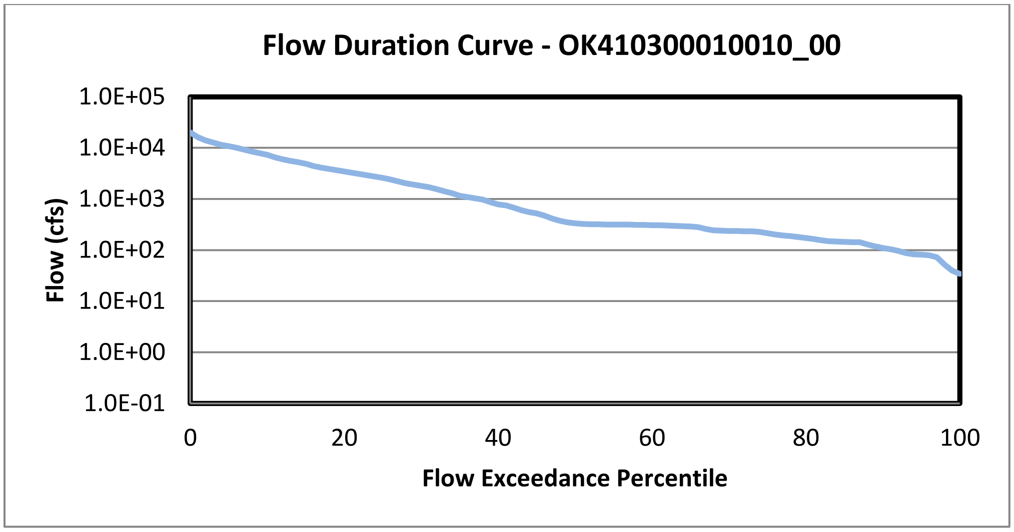
The flow duration curve for Glover River (OK410210080010_00) was estimated based on measured flows at USGS gage station 07337900 on Glover River, near Glover, Oklahoma. USGS flow data used to develop the flow duration curve range from 1961 to 2013.

Figure 5-14 Flow Duration Curve for the Glover River (OK410210080010_00)



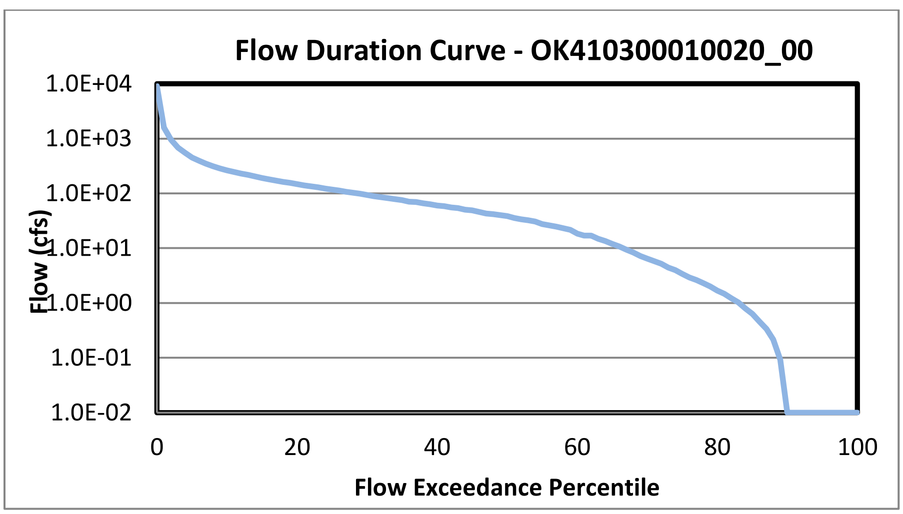
The flow duration curve for Kiamichi River (OK410300010010_00) was estimated based on Lake Release from Hugo Lake near Hugo, Oklahoma (U.S. Army Corps of Engineers Water Control Data System HGLO2: Hugo Lake) and measured flows at USGS gage station 07335700 located in Kiamichi River near Big Cedar, Oklahoma. Lake Release and measured flow data used to develop the flow duration curve range from 1994 to 2012.

Figure 5-15 Flow Duration Curve for the Kiamichi River (OK410300010010_00)



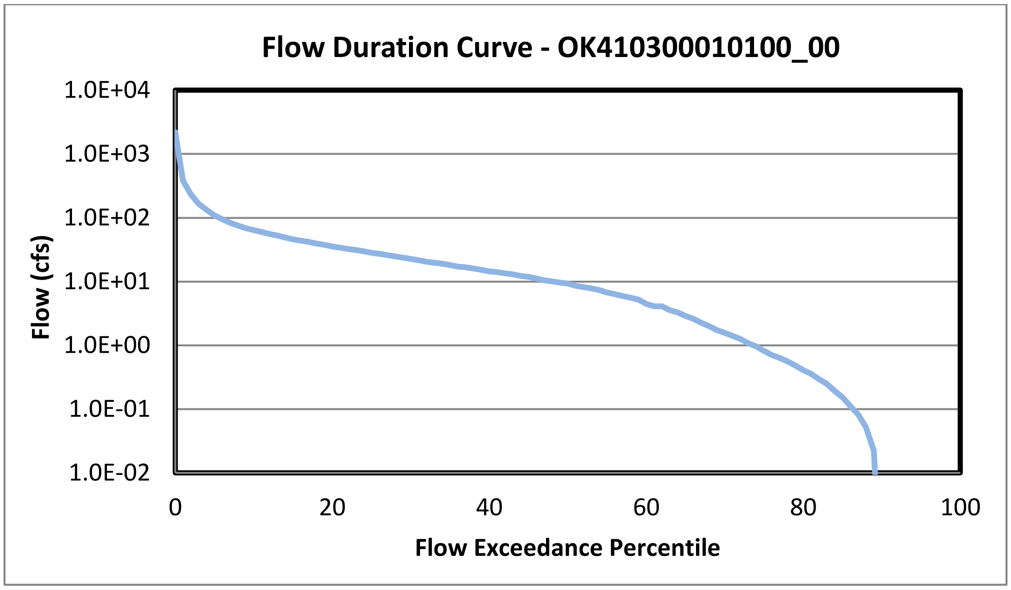
No flow gage exists on Gates Creek, segment OK410300010020_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07335700 located in an adjacent watershed (Kiamichi River near Big Cedar, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1965 to 2013.

Figure 5-16 Flow Duration Curve for Gates Creek (OK410300010020_00)



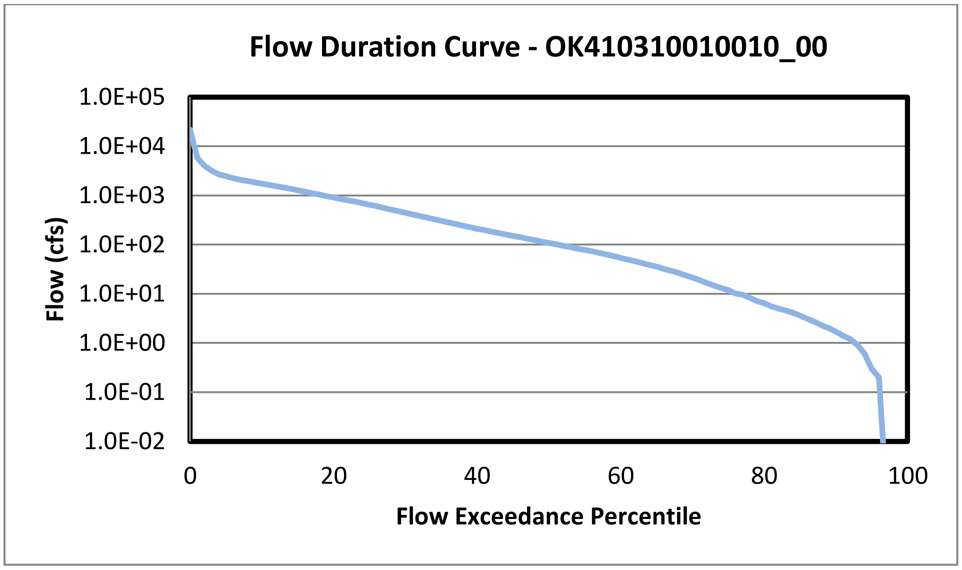
No flow gage exists on Bird Creek, segment OK410300010100_00. Therefore, flows for this waterbody were estimated using the watershed area ratio method based on measured flows at USGS gage station 07335700 located in an adjacent watershed (Kiamichi River near Big Cedar, Oklahoma) since they are geographically close and have similar land uses. The flow duration curve was based on measured flows from 1965 to 2013.

Figure 5-17 Flow Duration Curve for Bird Creek (OK410300010100_00)



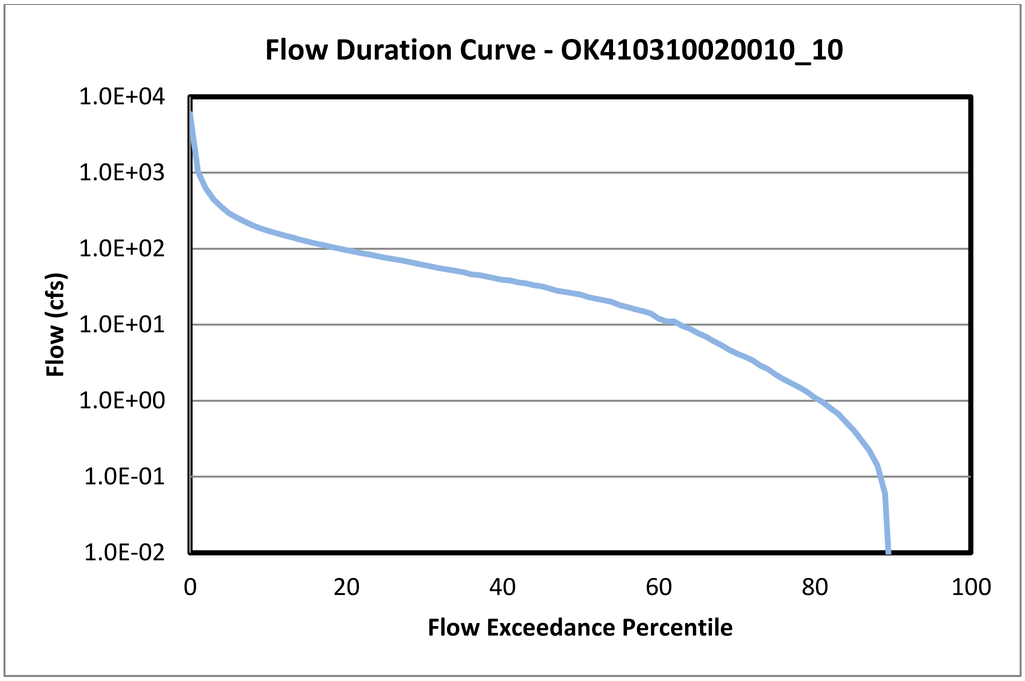
The flow duration curve for Kiamichi River (OK410310010010_00) was estimated based on measured flows at USGS gage station 07335790 on Kiamichi River near Clayton, Oklahoma. USGS flow data used to develop the flow duration curve range from 1980 to 2013.

Figure 5-18 Flow Duration Curve for the Kiamichi River (OK410310010010_00)



The flow duration curve for Kiamichi River (OK410310020010_10) was estimated based on measured flows at USGS gage station 0 07335700 on Kiamichi River near Big Cedar, Oklahoma. USGS flow data used to develop the flow duration curve range from 1965 to 2013.

Figure 5-19 Flow Duration Curve for the Kiamichi River (OK410310020010_10)



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

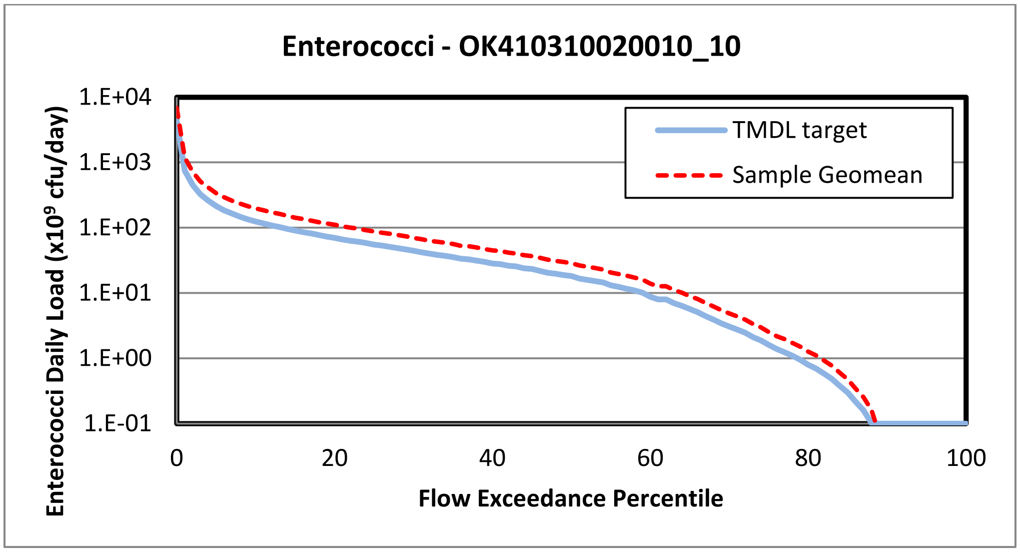
To calculate the allowable bacterial load, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (*24,465,525*) and the geometric mean water quality criterion for each bacterial indicator. This calculation produces the maximum bacterial load in the stream over the 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 2001 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 (representing the primary contact recreation season from 2001 through 2008) are shown in **Figures 5-20** through **5-22**. Each waterbody had an LDC for Enterococci.

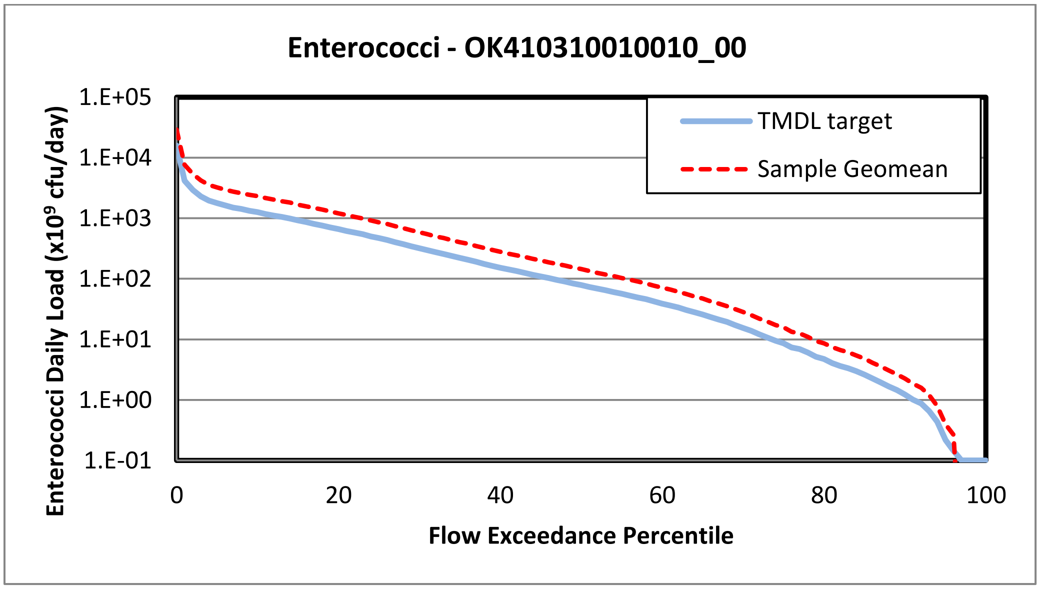
The LDC for the Kiamichi River (**Figure 5-20**) was based on Enterococci bacterial measurements collected during primary contact recreation season at WQM station 410310020010-001AT.

Figure 5-20 Load Duration Curve for Enterococci in the Kiamichi River (OK410310020010_10)



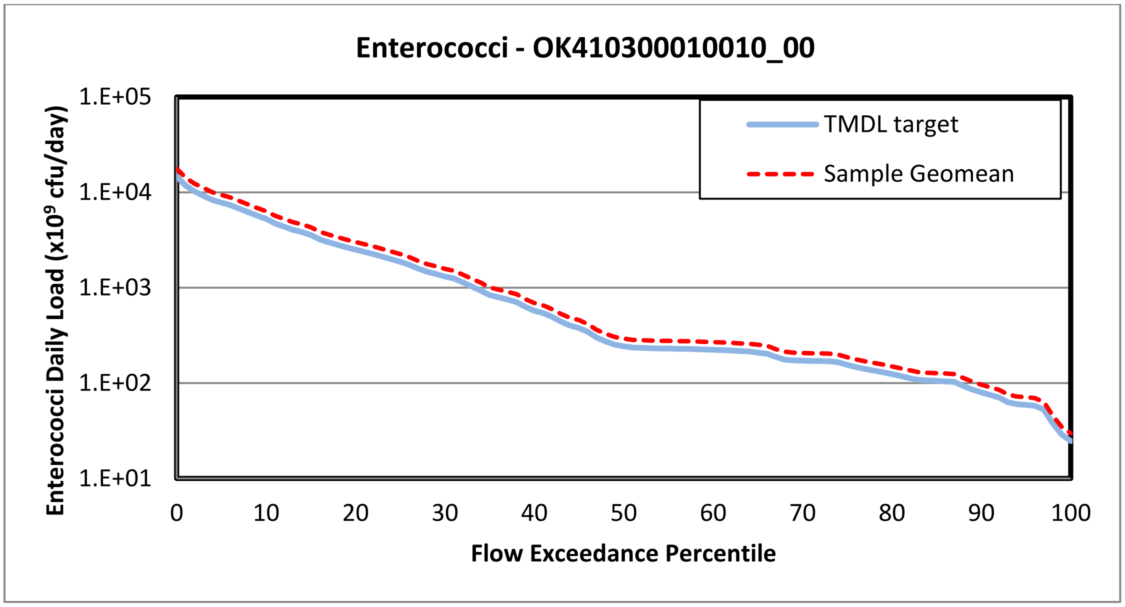
The LDC for the Kiamichi River (**Figure 5-21**) is based on Enterococci measurements during primary contact recreation season at WQM station 410310010010-001AT.

Figure 5-21 Load Duration Curve for Enterococci in the Kiamichi River (OK410310010010_00)



The LDC for Kiamichi River (**Figure 5-22**) is based on Enterococci measurements during primary contact recreation season at WQM station 410300010010-002AT.

Figure 5-22 Load Duration Curve for Enterococci in the Kiamichi River (OK410300010010_00)



5.3.2 TSS LDC

To calculate the TSS load at the WQ target, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (*5.39377*) and the TSS goal for each waterbody. This calculation produces the maximum TSS load in the waterbody that will result in attainment of the WQ target (50 NTU for WWAC and 10 NTU for CWAC) 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 2012 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 and estimated 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/estimated 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 5-23 through **Figure 5-33** 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 5-23 Load Duration Curve for TSS in the Red River (OK410100010010_10)

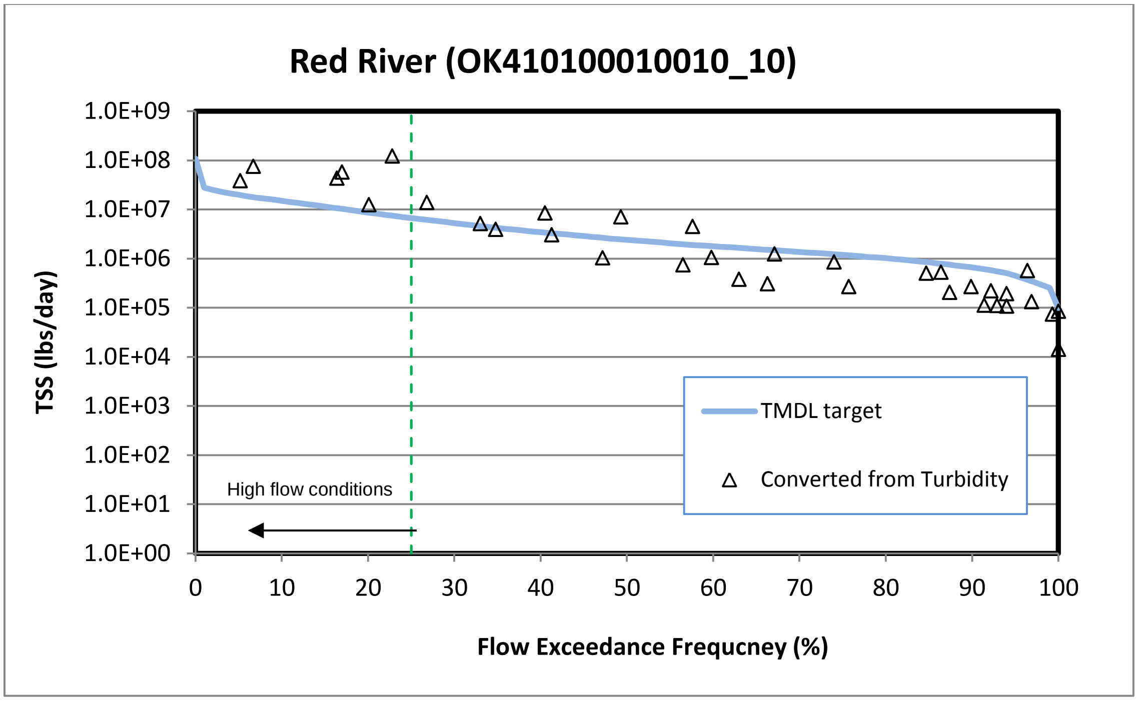


Figure 5-24 Load Duration Curve for TSS in the Little River (OK410200010200_10)

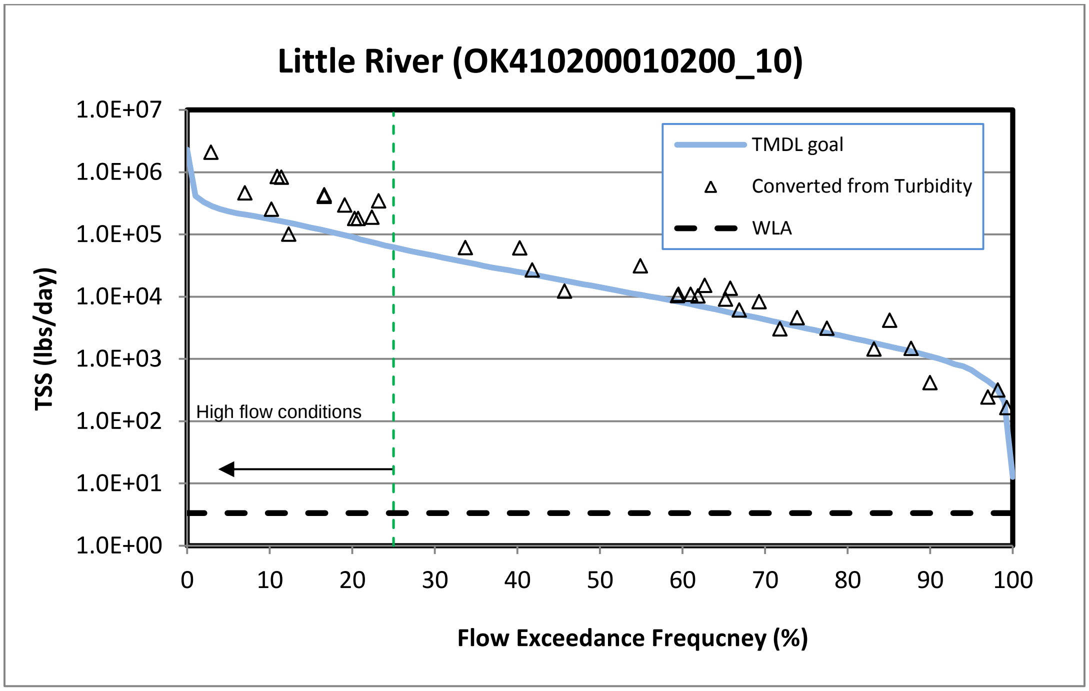


Figure 5-25 Load Duration Curve for TSS in Rock Creek (OK410200030010_00)

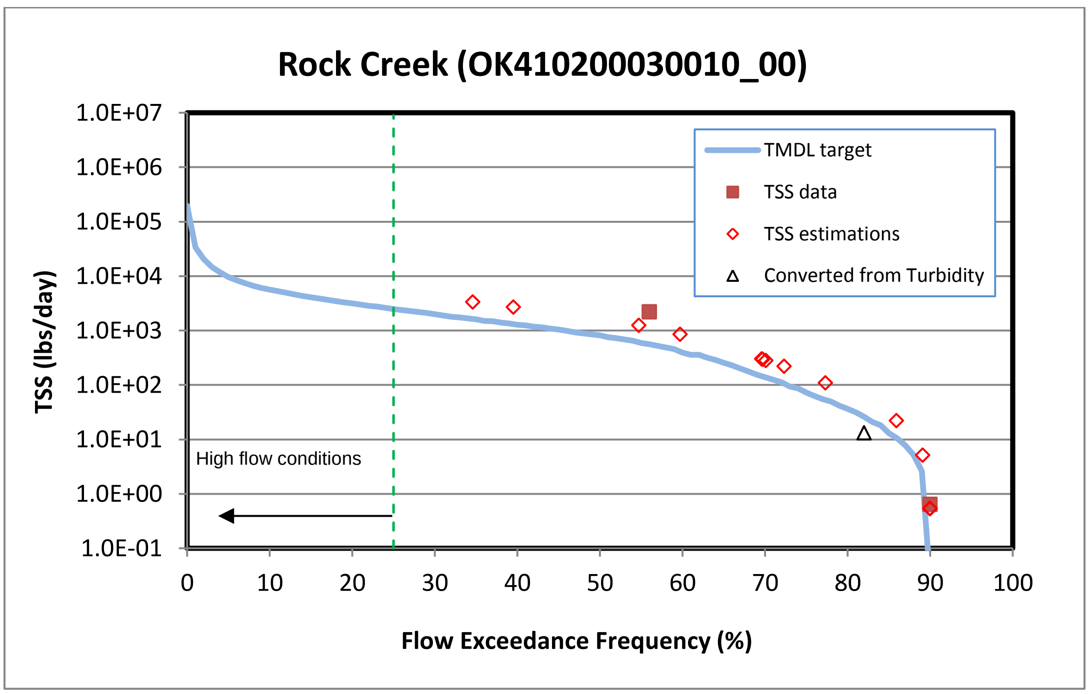


Figure 5-26 Load Duration Curve for TSS in the Little River (OK410210020140_00)

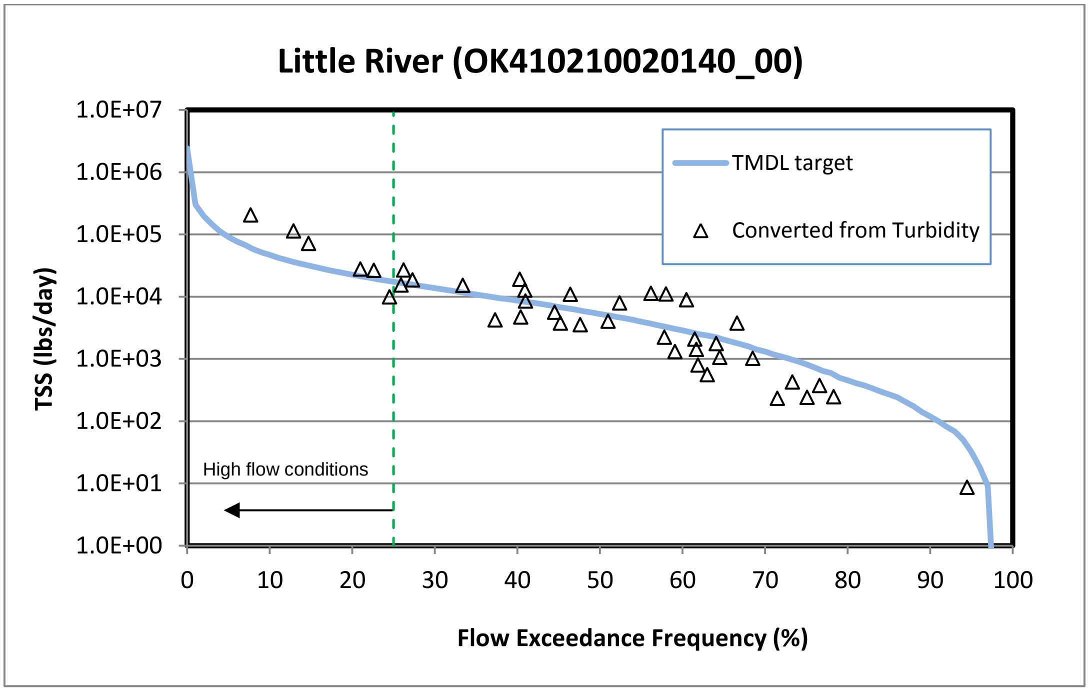


Figure 5-27 Load Duration Curve for TSS in Cloudy Creek (OK410210020300_00)

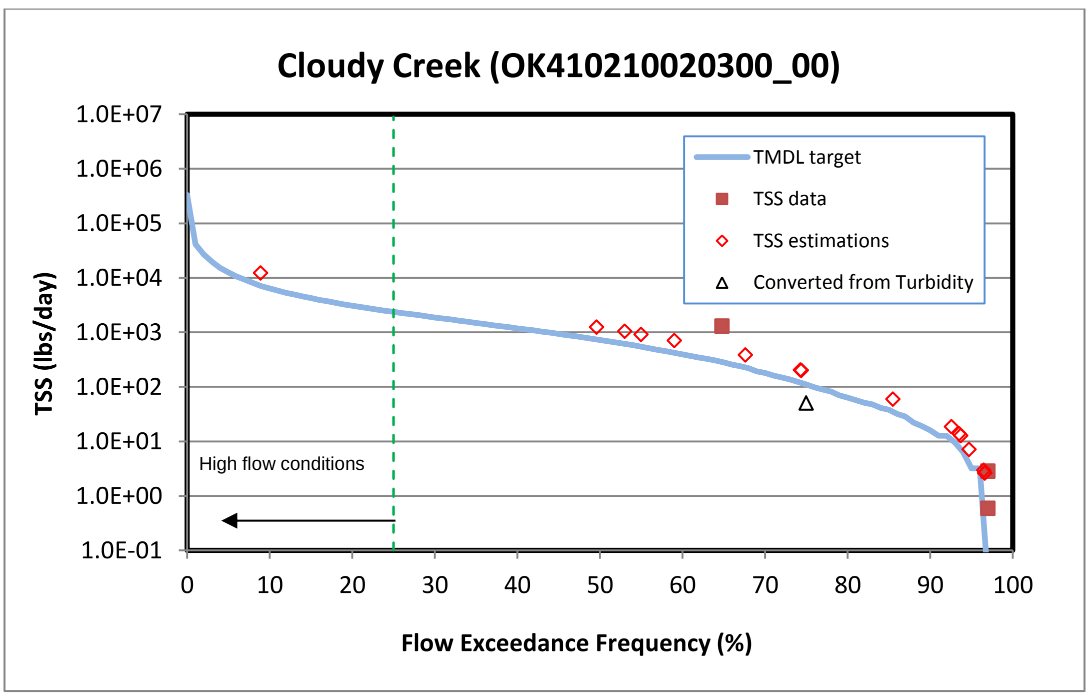


Figure 5-28 Load Duration Curve for TSS in Buffalo Creek (OK410210060020_00)

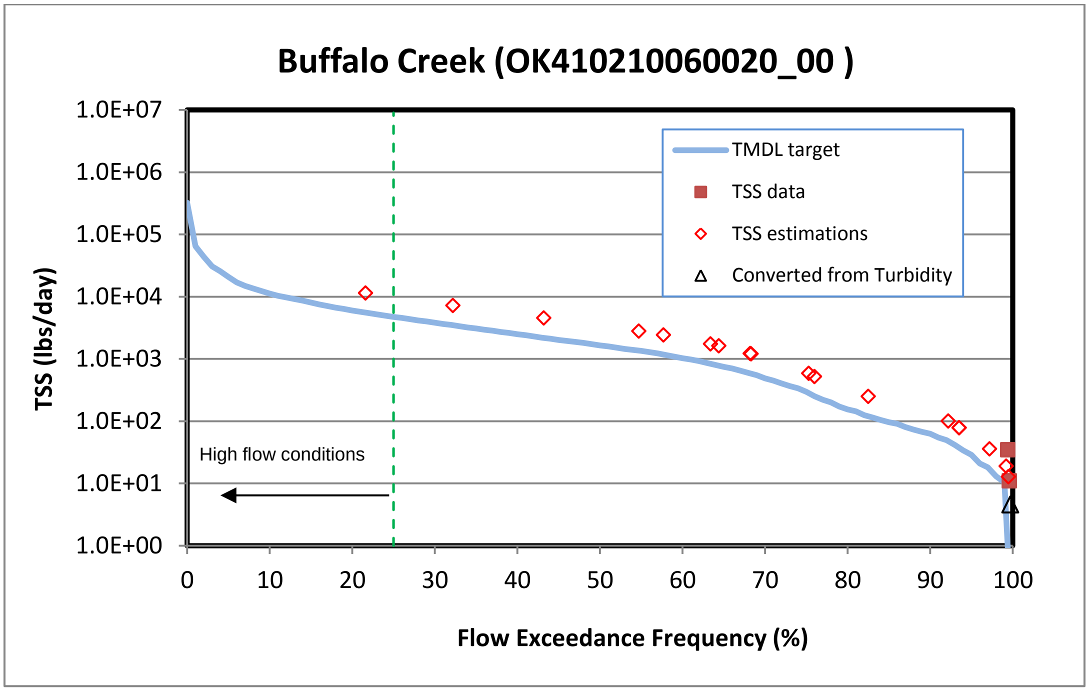


Figure 5-29 Load Duration Curve for TSS in Beech Creek (OK410210060320_00)

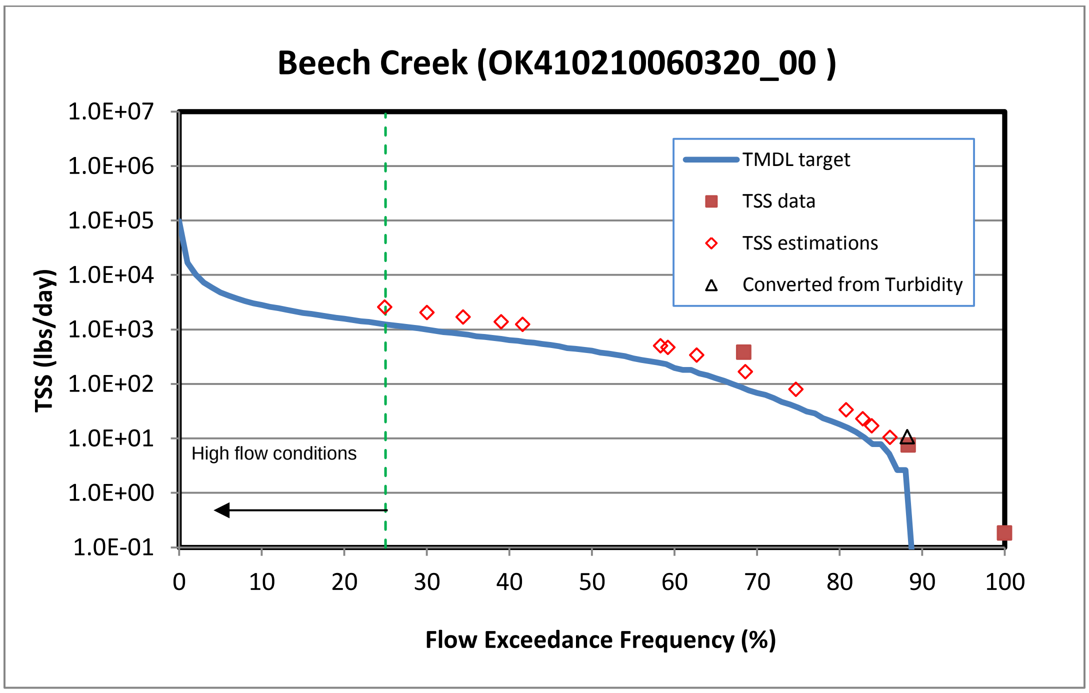


Figure 5-30 Load Duration Curve for TSS in Cow Creek (OK410210060350_00)

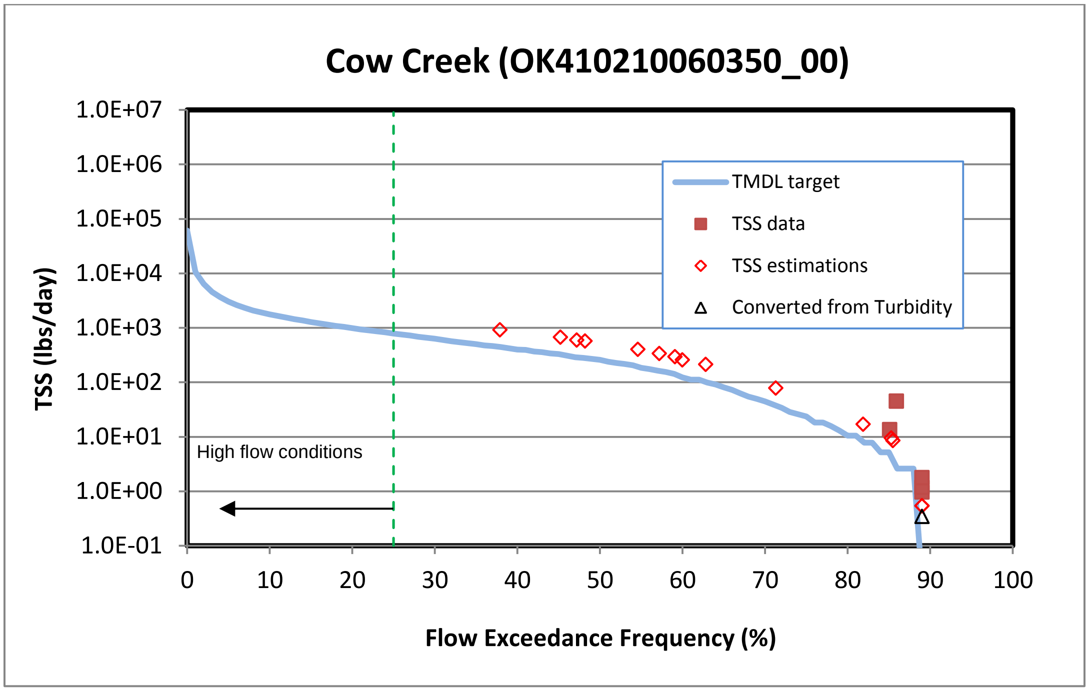


Figure 5-31 Load Duration Curve for TSS in the Glover River (OK410210080010_00)

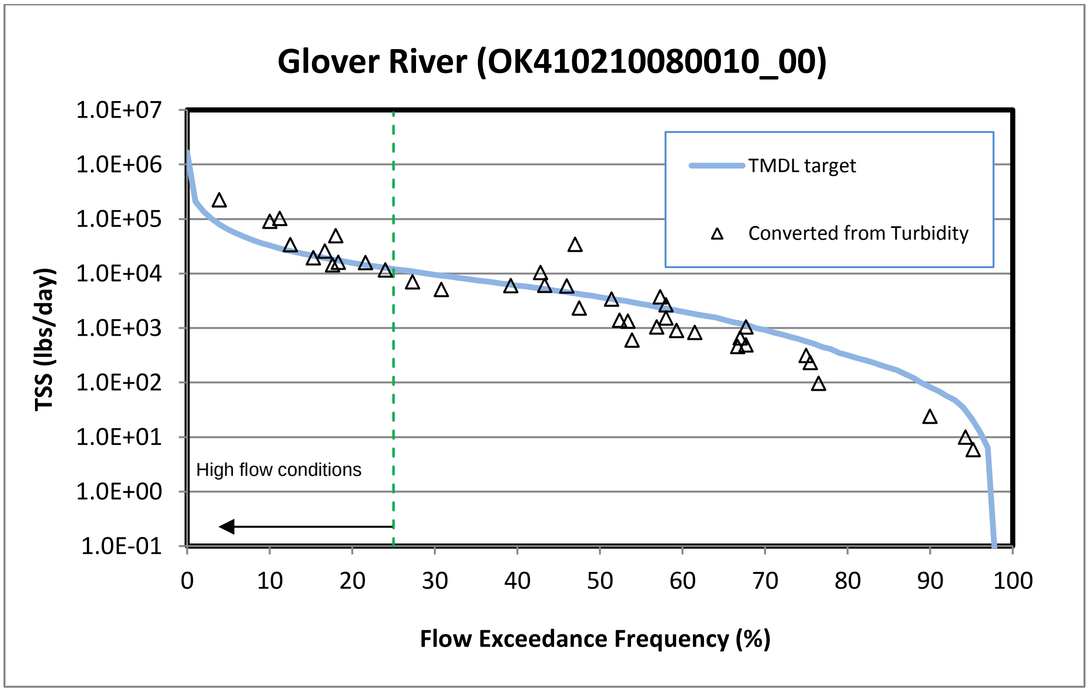


Figure 5-32 Load Duration Curve for TSS in Gates Creek (OK410300010020_00)

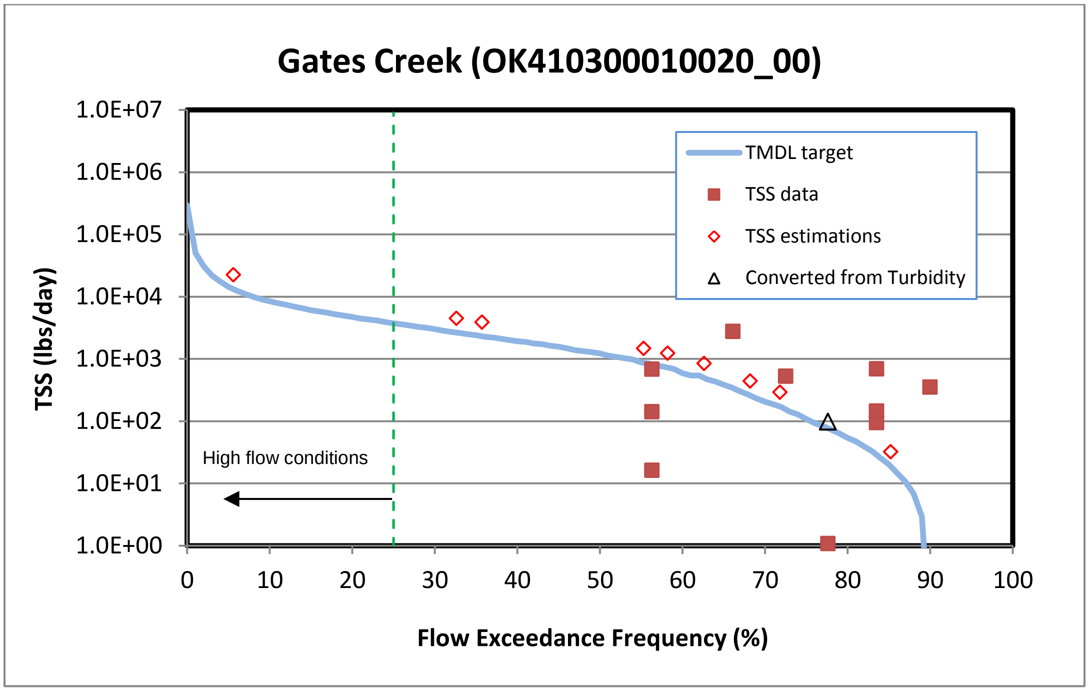
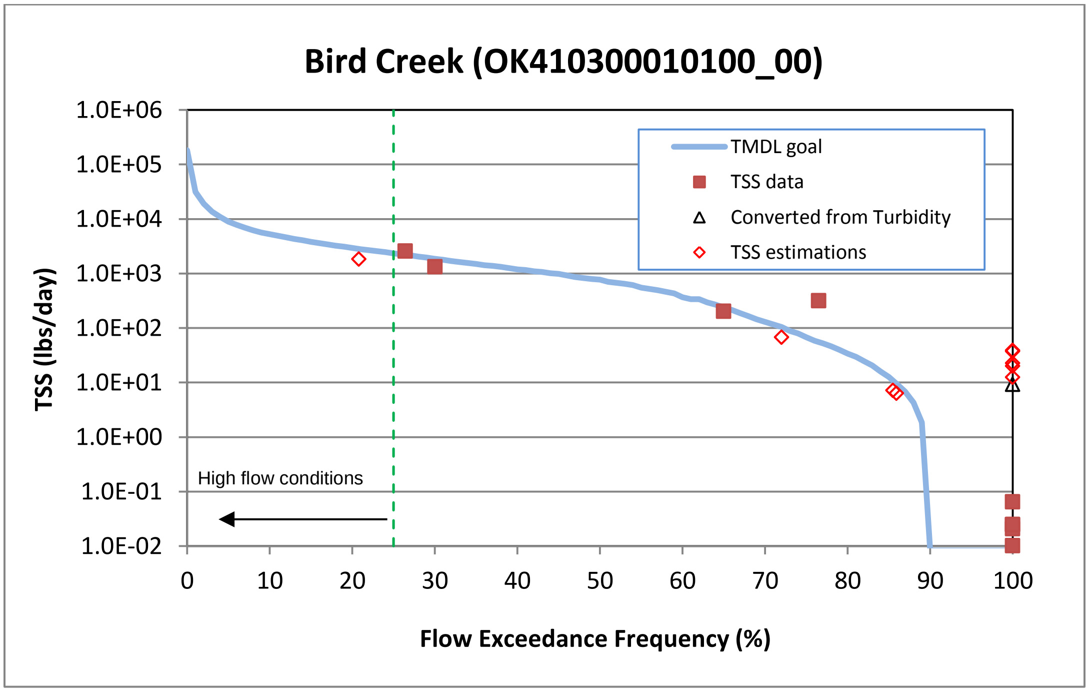


Figure 5-33 Load Duration Curve for TSS in Bird Creek (OK410300010100_00)



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 target 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 5-3** 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 17% to 45.3%.

Table 5-3 TMDL Percent Reductions Required to Meet Water Quality Standards for Indicator Bacteria

Waterbody ID	Waterbody Name	Required Reduction Rate	
		EC	ENT
OK410300010010_00	**Kiamichi River**	-	17.0%
OK410310010010_00	**Kiamichi River**	-	45.3%
OK410310020010_10	**Kiamichi River**	-	36.9%

PRGs for TSS are calculated as the required overall reduction so that no more than 10% of the samples exceed the TMDL target for TSS. The PRGs for the 11 waterbodies included in this TMDL report are summarized in **Table 5-4** and range from 46.5% to 82.6%.

Table 5-4 TMDL Percent Reductions Required to Meet Water Quality Targets for Total Suspended Solids

Waterbody ID	Waterbody Name	Required Reduction Rate
OK410100010010_10	**Red River**	57.8%
OK410200010200_10	**Little River**	65.7%
OK410200030010_00	**Rock Creek**	51.6%
OK410210020140_00	**Little River**	67.3%
OK410210020300_00	**Cloudy Creek**	46.5%
OK410210060020_00	**Buffalo Creek**	56.0%
OK410210060320_00	**Beech Creek**	78.0%
OK410210060350_00	**Cow Creek**	78.0%
OK410210080010_00	**Glover River**	64.3%
OK410300010020_00	**Gates Creek**	73.1%
OK410300010100_00	**Bird Creek**	82.6%

5.4 WASTELOAD ALLOCATION

5.4.1 Indicator Bacteria

For bacterial TMDLs, OPDES-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. 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)

<u>Where:</u>

WQS = 33 cfu/100 mL for **Enterococci**

Flow (mgd) = permitted flow

Unit conversion factor = 37,854,120

When multiple OPDES 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 OPDES WWTFs 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 OPDES permits. Currently, facilities that discharge treated wastewater are 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.

There are no OPDES WWTFs receiving bacterial WLAs in the Study Area.

Permitted stormwater discharges are considered point sources. However, there are no areas designed as MS4s within the watershed of the waterbodies impaired for contact recreation, so the WLA for MS4 is zero.

5.4.2 Total Suspended Solids

OPDES-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 OPDES-permitted facilities within the Red-Little River Basin Study Area. The WLA for that facility is derived as follows:

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

<u>Where:</u>

WQ goal = waterbody-specific water quality goal as summarized in* Table 5-2, *or monthlyTSS 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 OPDES-Permitted Facilities

Waterbody ID & Waterbody Name	OPDES Permit No.	Name	Average Monthly Flow (mgd)	Effluent TSS Target (mg/L)	Monthly Average TSS limit (mg/L)	Wasteload Allocation (lb/day)
Unnamed tributary to Little River (OK410200010200_10)	OKR050878	Meridian Aggregates Co	0.01 [a]	40.0	**25.0**	2.1

[a] Flow was assumed equal to 0.01 MGD for allocation purposes.

Based on regression relationship between turbidity and TSS, effluent WQ TSS goals were determined. Then, smaller effluent TSS limit in either waterbody specific water quality goal from regression or monthly TSS limit in the current permit is given to the facility. For Meridian Aggregates Co, current monthly average and daily maximum TSS permit limits are 25 mg/L and 45 mg/L, respectively. Based on the turbidity/TSS regression, 50 NTUs (WQSs for turbidity of a warm water aquatic community) is equal to 40 mg/L. The effluent WQ TSS goal is greater than current monthly average permit limit. Therefore, WLA is calculated with current monthly average permit limit. If the effluent TSS concentration is greater than 40 mg/L, turbidity concentration is likely to exceed its standard in 50 NTUs.

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 that proposed discharges under Section 404 Permits comply with Oklahoma WQS. The proposed discharge must also comply with the 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 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:

$$\mathbf{LA = TMDL - WLA_{WWTF} - WLA_{MS4} - MOS}$$

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:

$$\mathbf{LA = TMDL - WLA_{WWTF} - WLA_{MS4} - WLA_{growth} - MOS}$$

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 adheres 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. When conservative assumptions are used in development of the TMDL, or conservative factors are used in the calculations, the MOS is implicit. When a specific percentage of the TMDL is set aside to account for the lack of knowledge, then the MOS is considered explicit.

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 ranges from 15% to 35%. **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
OK410100010010_10	Red River	10.7%	15%
OK410200010200_10	Little River	12.0%	15%
OK410200030010_00	Rock Creek	28.0%	30%
OK410210020140_00	Little River	12.0%	15%
OK410210020300_00	Cloudy Creek	12.0%	15%
OK410210060020_00	Buffalo Creek	28.0%	30%
OK410210060320_00	Beech Creek	28.0%	30%
OK410210060350_00	Cow Creek	28.0%	30%
OK410210080010_00	Glover River	12.0%	15%
OK410300010020_00	Gates Creek	17.7%	20%
OK410300010100_00	Bird Creek	35.0%	35%

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 OPDES 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** through **5-9** 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 5-10** to **5-20** present the allocations for total suspended solids.

Table 5-7 Enterococci TMDL Calculations for the Kiamichi River (OK410310020010_10)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTF} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	5,960.0	4.81E+12	0	0	4.33E+12	4.81E+11
5	293.0	2.37E+11	0	0	2.13E+11	2.37E+10
10	172.0	1.39E+11	0	0	1.25E+11	1.39E+10
15	124.0	1.00E+11	0	0	9.01E+10	1.00E+10
20	96.0	7.75E+10	0	0	6.98E+10	7.75E+09
25	76.0	6.14E+10	0	0	5.52E+10	6.14E+09
30	61.0	4.92E+10	0	0	4.43E+10	4.92E+09
35	49.0	3.96E+10	0	0	3.56E+10	3.96E+09
40	39.0	3.15E+10	0	0	2.83E+10	3.15E+09
45	32.0	2.58E+10	0	0	2.33E+10	2.58E+09
50	25.0	2.02E+10	0	0	1.82E+10	2.02E+09
55	18.0	1.45E+10	0	0	1.31E+10	1.45E+09
60	12.0	9.69E+09	0	0	8.72E+09	9.69E+08
65	7.8	6.30E+09	0	0	5.67E+09	6.30E+08
70	4.2	3.39E+09	0	0	3.05E+09	3.39E+08
75	2.2	1.78E+09	0	0	1.60E+09	1.78E+08
80	1.1	8.88E+08	0	0	7.99E+08	8.88E+07
85	0.4	3.31E+08	0	0	2.98E+08	3.31E+07
90	0	0	0	0	0	0
95	0	0	0	0	0	0
100	0	0	0	0	0	0

Table 5-8 Enterococci TMDL Calculations for the Kiamichi River (OK410310010010_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTF} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	21,807.8	1.76E+13	0	0	1.58E+13	1.76E+12
5	2,433.8	1.96E+12	0	0	1.77E+12	1.96E+11
10	1,736.3	1.40E+12	0	0	1.26E+12	1.40E+11
15	1,262.2	1.02E+12	0	0	9.17E+11	1.02E+11
20	906.7	7.32E+11	0	0	6.59E+11	7.32E+10
25	645.9	5.21E+11	0	0	4.69E+11	5.21E+10
30	441.6	3.57E+11	0	0	3.21E+11	3.57E+10
35	303.4	2.45E+11	0	0	2.20E+11	2.45E+10
40	209.8	1.69E+11	0	0	1.52E+11	1.69E+10
45	150.7	1.22E+11	0	0	1.10E+11	1.22E+10
50	108.4	8.75E+10	0	0	7.88E+10	8.75E+09
55	78.0	6.30E+10	0	0	5.67E+10	6.30E+09
60	53.9	4.35E+10	0	0	3.92E+10	4.35E+09
65	35.6	2.87E+10	0	0	2.59E+10	2.87E+09
70	21.3	1.72E+10	0	0	1.55E+10	1.72E+09
75	11.9	9.61E+09	0	0	8.65E+09	9.61E+08
80	6.5	5.25E+09	0	0	4.72E+09	5.25E+08
85	3.6	2.91E+09	0	0	2.62E+09	2.91E+08
90	1.7	1.37E+09	0	0	1.24E+09	1.37E+08
95	0.3	2.42E+08	0	0	2.18E+08	2.42E+07
100	0.0	0	0	0	0	0

Table 5-9 Enterococci TMDL Calculations for the Kiamichi River (OK410300010010_00)

Percentile	Flow (cfs)	TMDL (cfu/day)	WLA_{WWTF} (cfu/day)	WLA_{MS4} (cfu/day)	LA (cfu/day)	MOS (cfu/day)
0	20,200.6	1.63E+13	0	0	1.47E+13	1.63E+12
5	10,757.2	8.68E+12	0	0	7.82E+12	8.68E+11
10	7,263.0	5.86E+12	0	0	5.28E+12	5.86E+11
15	4,908.5	3.96E+12	0	0	3.57E+12	3.96E+11
20	3,440.7	2.78E+12	0	0	2.50E+12	2.78E+11
25	2,572.7	2.08E+12	0	0	1.87E+12	2.08E+11
30	1,801.7	1.45E+12	0	0	1.31E+12	1.45E+11
35	1,154.0	9.32E+11	0	0	8.39E+11	9.32E+10
40	786.7	6.35E+11	0	0	5.72E+11	6.35E+10
45	522.1	4.22E+11	0	0	3.79E+11	4.22E+10
50	336.2	2.71E+11	0	0	2.44E+11	2.71E+10
55	316.4	2.55E+11	0	0	2.30E+11	2.55E+10
60	308.4	2.49E+11	0	0	2.24E+11	2.49E+10
65	288.1	2.33E+11	0	0	2.09E+11	2.33E+10
70	237.0	1.91E+11	0	0	1.72E+11	1.91E+10
75	214.2	1.73E+11	0	0	1.56E+11	1.73E+10
80	171.5	1.38E+11	0	0	1.25E+11	1.38E+10
85	145.4	1.17E+11	0	0	1.06E+11	1.17E+10
90	109.8	8.87E+10	0	0	7.98E+10	8.87E+09
95	81.5	6.58E+10	0	0	5.92E+10	6.58E+09
100	34.1	2.75E+10	0	0	2.48E+10	2.75E+09

Table 5-10 TSS TMDL Calculations for the Red River (OK410100010010_10)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	278,000	N/A	N/A	N/A	N/A	N/A
5	51,000	N/A	N/A	N/A	N/A	N/A
10	38,250	N/A	N/A	N/A	N/A	N/A
15	29,300	N/A	N/A	N/A	N/A	N/A
20	22,200	N/A	N/A	N/A	N/A	N/A
25	17,200	7,916,388	0	79,164	6,649,766	1,187,458
30	13,450	6,190,432	0	61,904	5,199,963	928,565
35	10,800	4,970,756	0	49,708	4,175,435	745,613
40	8,790	4,045,643	0	40,456	3,398,340	606,846
45	7,360	3,387,478	0	33,875	2,845,481	508,122
50	6,155	2,832,870	0	28,329	2,379,611	424,931
55	5,260	2,420,942	0	24,209	2,033,591	363,141
60	4,570	2,103,366	0	21,034	1,766,827	315,505
65	3,970	1,827,213	0	18,272	1,534,859	274,082
70	3,500	1,610,893	0	16,109	1,353,150	241,634
75	3,040	1,399,176	0	13,992	1,175,308	209,876
80	2,610	1,201,266	0	12,013	1,009,063	180,190
85	2,140	984,946	0	9,849	827,355	147,742
90	1,690	777,831	0	7,778	653,378	116,675
95	1,140	524,691	0	5,247	440,740	78,704
100	254	116,905	0	1,169	104,045	11,690

Table 5-11 TSS TMDL Calculations for the Little River (OK410200010200_10)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	72,600	N/A	N/A	N/A	N/A	N/A
5	7,373	N/A	N/A	N/A	N/A	N/A
10	5,600	N/A	N/A	N/A	N/A	N/A
15	4,070	N/A	N/A	N/A	N/A	N/A
20	2,860	N/A	N/A	N/A	N/A	N/A
25	1,970	73,553	2.1	736	61,782	11,033
30	1,430	53,391	2.1	534	44,846	8,009
35	1,050	39,203	2.1	392	32,929	5,880
40	794	29,645	2.1	296	24,900	4,447
45	597	22,290	2.1	223	18,721	3,343
50	449	16,745	2.1	167	14,064	2,512
55	337	12,582	2.1	126	10,567	1,887
60	254	9,483	2.1	95	7,964	1,423
65	185	6,907	2.1	69	5,800	1,036
70	136	5,078	2.1	51	4,263	762
75	98	3,659	2.1	37	3,071	549
80	71	2,651	2.1	27	2,225	398
85	50	1,867	2.1	19	1,566	280
90	35	1,307	2.1	13	1,096	196
95	20.8	777	2.1	7.8	650	116
100	0.4	15	2.1	0.1	10	2.2

Table 5-12 TSS TMDL Calculations for Rock Creek (OK410200030010_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	7,488	N/A	N/A	N/A	N/A	N/A
5	368	N/A	N/A	N/A	N/A	N/A
10	216	N/A	N/A	N/A	N/A	N/A
15	156	N/A	N/A	N/A	N/A	N/A
20	121	N/A	N/A	N/A	N/A	N/A
25	96	3,560	0	36	2,457	1,068
30	77	2,856	0	29	1,971	857
35	62	2,297	0	23	1,585	689
40	49	1,827	0	18	1,261	548
45	40	1,499	0	15	1,034	450
50	31	1,171	0	12	808	351
55	23	843	0	8.4	581	253
60	15	563	0	5.6	388	169
65	9.8	365	0	3.7	252	110
70	5.3	198	0	2.0	136	59
75	2.8	104	0	1.0	72	31
80	1.4	52	0	0.5	36	16
85	0.5	19	0	0.2	13	5.6
90	0	0	0	0	0	0
95	0	0	0	0	0	0
100	0	0	0	0	0	0

Table 5-13 TSS TMDL Calculations for the Little River (OK410210020140_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	76,362	N/A	N/A	N/A	N/A	N/A
5	2,891	N/A	N/A	N/A	N/A	N/A
10	1,481	N/A	N/A	N/A	N/A	N/A
15	978	N/A	N/A	N/A	N/A	N/A
20	709	N/A	N/A	N/A	N/A	N/A
25	548	20,457	0	205	17,184	3,069
30	431	16,108	0	161	13,531	2,416
35	342	12,779	0	128	10,734	1,917
40	272	10,148	0	101	8,524	1,522
45	216	8,054	0	81	6,765	1,208
50	167	6,228	0	62	5,232	934
55	125	4,671	0	47	3,924	701
60	91	3,383	0	34	2,841	507
65	65	2,416	0	24	2,030	362
70	42	1,557	0	16	1,308	234
75	26	966	0	9.7	812	145
80	14	537	0	5.4	451	81
85	8.5	317	0	3.2	266	48
90	3.7	140	0	1.4	117	21
95	1.0	38	0	0.4	32	5.6
100	0	0	0	0	0	0

Table 5-14 TSS TMDL Calculations for Cloudy Creek (OK410210020300_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	10,440	N/A	N/A	N/A	N/A	N/A
5	395	N/A	N/A	N/A	N/A	N/A
10	203	N/A	N/A	N/A	N/A	N/A
15	134	N/A	N/A	N/A	N/A	N/A
20	97	N/A	N/A	N/A	N/A	N/A
25	75	2,796	0	28	2,349	419
30	59	2,203	0	22	1,850	330
35	47	1,747	0	17	1,468	262
40	37	1,389	0	14	1,167	208
45	30	1,101	0	11	925	165
50	23	851	0	8.5	715	128
55	17	638	0	6.4	536	96
60	12	463	0	4.6	389	69
65	8.8	329	0	3.3	276	49
70	5.7	213	0	2.1	179	32
75	3.5	131	0	1.3	110	20
80	2.0	75	0	0.7	63	11
85	1.2	45	0	0.4	38	6.7
90	0.5	19	0	0.2	16	2.8
95	0.1	3.7	0	0	3.1	0.6
100	0	0	0	0	0	0

Table 5-15 TSS TMDL Calculations for Buffalo Creek (OK410210060020_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	12,405	N/A	N/A	N/A	N/A	N/A
5	795	N/A	N/A	N/A	N/A	N/A
10	431	N/A	N/A	N/A	N/A	N/A
15	307	N/A	N/A	N/A	N/A	N/A
20	231	N/A	N/A	N/A	N/A	N/A
25	182	6,797	0	68	4,690	2,039
30	146	5,440	0	54	3,753	1,632
35	118	4,392	0	44	3,030	1,318
40	96	3,583	0	36	2,472	1,075
45	77	2,882	0	29	1,989	865
50	63	2,360	0	24	1,628	708
55	52	1,920	0	19	1,325	576
60	39	1,469	0	15	1,014	441
65	29	1,070	0	11	738	321
70	19	701	0	7.0	484	210
75	11	425	0	4.3	293	128
80	5.9	220	0	2.2	152	66
85	3.7	138	0	1.4	95	41
90	2.4	89	0	0.9	62	27
95	1.1	41	0	0.4	28	12
100	0	0	0	0	0	0

Table 5-16 TSS TMDL Calculations for Beech Creek (OK410210060320_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	3,725	N/A	N/A	N/A	N/A	N/A
5	183	N/A	N/A	N/A	N/A	N/A
10	108	N/A	N/A	N/A	N/A	N/A
15	78	N/A	N/A	N/A	N/A	N/A
20	60	N/A	N/A	N/A	N/A	N/A
25	48	1,771	0	18	1,222	531
30	38	1,420	0	14	980	426
35	31	1,141	0	11	787	342
40	24	910	0	9.1	628	273
45	20	746	0	7.5	514	224
50	16	582	0	5.8	401	174
55	11	421	0	4.2	291	126
60	7.5	280	0	2.8	193	84
65	4.9	183	0	1.8	126	55
70	2.6	97	0	1.0	67	29
75	1.4	52	0	0.5	36	16
80	0.7	26	0	0.3	18	7.8
85	0.3	11	0	0.1	7.7	3.4
90	0	0	0	0	0	0
95	0	0	0	0	0	0
100	0	0	0	0	0	0

Table 5-17 TSS TMDL Calculations for Cow Creek (OK410210060350_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	2,352	N/A	N/A	N/A	N/A	N/A
5	116	N/A	N/A	N/A	N/A	N/A
10	68	N/A	N/A	N/A	N/A	N/A
15	49	N/A	N/A	N/A	N/A	N/A
20	38	N/A	N/A	N/A	N/A	N/A
25	30	1,118	0	11	772	336
30	24	899	0	9.0	620	270
35	19	720	0	7.2	496	216
40	15	574	0	5.7	396	172
45	13	470	0	4.7	324	141
50	9.9	369	0	3.7	255	111
55	7.1	265	0	2.6	183	79
60	4.7	175	0	1.8	121	53
65	3.1	116	0	1.2	80	35
70	1.7	63	0	0.6	44	19
75	0.9	34	0	0.3	23	10
80	0.4	15	0	0.1	10	4.5
85	0.2	7.5	0	0.1	5.1	2.2
90	0	0	0	0	0	0
95	0	0	0	0	0	0
100	0	0	0	0	0	0

Table 5-18 TSS TMDL Calculations for the Glover River (OK410210080010_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	53,100	N/A	N/A	N/A	N/A	N/A
5	2,010	N/A	N/A	N/A	N/A	N/A
10	1,030	N/A	N/A	N/A	N/A	N/A
15	680	N/A	N/A	N/A	N/A	N/A
20	493	N/A	N/A	N/A	N/A	N/A
25	381	14,225	0	142	11,949	2,134
30	300	11,201	0	112	9,409	1,680
35	238	8,886	0	89	7,464	1,333
40	189	7,057	0	71	5,928	1,058
45	150	5,600	0	56	4,704	840
50	116	4,331	0	43	3,638	650
55	87	3,248	0	32	2,729	487
60	63	2,352	0	24	1,976	353
65	45	1,680	0	17	1,411	252
70	29	1,083	0	11	910	162
75	18	672	0	6.7	565	101
80	10	373	0	3.7	314	56
85	5.9	220	0	2.2	185	33
90	2.6	97	0	1.0	82	15
95	0.7	26	0	0.3	22	3.9
100	0	0	0	0	0	0

Table 5-19 TSS TMDL Calculations for Gates Creek (OK410300010020_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	9,166	N/A	N/A	N/A	N/A	N/A
5	451	N/A	N/A	N/A	N/A	N/A
10	265	N/A	N/A	N/A	N/A	N/A
15	191	N/A	N/A	N/A	N/A	N/A
20	148	N/A	N/A	N/A	N/A	N/A
25	117	4,679	0	47	3,696	936
30	94	3,755	0	38	2,967	751
35	75	3,017	0	30	2,383	603
40	60	2,401	0	24	1,897	480
45	49	1,970	0	20	1,556	394
50	38	1,539	0	15	1,216	308
55	28	1,108	0	11	875	222
60	19	739	0	7.4	584	148
65	12	480	0	4.8	379	96
70	6.5	259	0	2.6	204	52
75	3.4	135	0	1.4	107	27
80	1.7	68	0	0.7	53	14
85	0.6	25	0	0.3	20	5
90	0	0	0	0	0	0
95	0	0	0	0	0	0
100	0	0	0	0	0	0

Table 5-20 TSS TMDL Calculations for Bird Creek (OK410300010100_00)

Percentile	Flow (cfs)	TMDL (lb/day)	WLA (lb/day)		LA (lb/day)	MOS (lb/day)
			WWTF	Future growth		
0	2,216	N/A	N/A	N/A	N/A	N/A
5	109	N/A	N/A	N/A	N/A	N/A
10	64	N/A	N/A	N/A	N/A	N/A
15	46	N/A	N/A	N/A	N/A	N/A
20	36	N/A	N/A	N/A	N/A	N/A
25	28	3,588	0	36	2,296	1,256
30	23	2,880	0	29	1,843	1,008
35	18	2,313	0	23	1,480	810
40	15	1,841	0	18	1,178	644
45	12	1,511	0	15	967	529
50	9	1,180	0	12	755	413
55	7	850	0	8	544	297
60	4	566	0	6	363	198
65	3	368	0	4	236	129
70	2	198	0	2	127	69
75	0.8	104	0	1	66	36
80	0.4	52	0	0.5	33	18
85	0.2	19	0	0.2	12	7
90	0	0	0	0	0	0
95	0	0	0	0	0	0
100	0	0	0	0	0	0

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. The CPP, required by the CWA §303(e)(3)(A)-(H) and 40 CFR 130.5, summarizes Oklahoma's commitments and programs aimed at restoring and protecting water quality throughout the State (DEQ 2012). The CPP can be viewed from DEQ's website at http://www.deq.state.ok.us/wqdnew/305b_303d/Final%20CPP.pdf.

Table 5-21 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 5-21 Partial Lists 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

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 other agencies that collect water monitoring information and/or address water quality problems associated with nonpoint source pollution. These agencies at the State level are DEQ, OWRB, Corporation Commission (for oil & gas activities), and ODAFF [they are the NPDES-permitting authority for CAFOs and SFOs in Oklahoma under what ODAFF calls the Agriculture Pollutant Discharge Elimination System (AgPDES)]. The agencies at the Federal level are EPA, USGS, U.S. Army Corps of Engineers (USACE) & the National Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA). 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.

The reduction rates called for in this TMDL report are as high as 82.6%. 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 Health and Environment 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 that may apply to such revisions.

- Remove 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.
- Modify 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.
- Revise the existing numeric criteria: Oklahoma's current pathogen criteria, revised in 2011, are based on EPA guidelines (See the *2012 Recreational Water Quality Criteria*, December 2012; *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 to 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

The draft TMDL report was preliminarily reviewed by EPA before being sent out for public notice. The public notice and draft 208 Factsheet was sent to local newspapers, to stakeholders in the Study Area affected by these draft TMDLs, and to stakeholders who have requested copies of all TMDL public notices. The public notice, draft 208 Factsheet, and draft TMDL report was also posted at the following DEQ website: http://www.deq.state.ok.us/wqdnew/index.htm.

The public comment period lasted 45 days and was open from February 3, 2014 to March 21, 2014. During that time, the public had the opportunity to review the draft TMDL report and make written comments. One comment was received. The response to that comment is in **Appendix G**. The comment and response are part of the record of this TMDL report. As a result of the public comment, changes were made to the final TMDL report and 208 Factsheet. There were no requests for a public meeting.

After EPA's final approval, the 208 Factsheet and each TMDL was adopted into Oklahoma's 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 in-stream criterion is predicted to be met.

SECTION 7 REFERENCES

American Veterinary Medical Association 2007. *U.S. Pet Ownership and Demographics Sourcebook*. Schaumberg, IL.

Arnold and Meister; 1999. Stephen D. Arnold and Edward A. Meister; *Dairy Feedlot Contributions to Groundwater Contamination: A Preliminary Study in New Mexico*. Sept 1999.

ASAE (American Society of Agricultural Engineers) 1999. *ASAE standards, 46th edition*: standards, engineering practices, data. St. Joseph, MI.

Canter, LW and RC Knox 1985. *Septic tank system effects on ground water quality*. Lewis Publishers, Boca Raton, FL.

Christensen, V.G., Jian, X., Ziegler, A.C., 2000. *Regression Analysis and Real-Time Water-Quality Monitoring to Estimate Constituent Concentrations, Loads, and Yields in the Little Arkansas River, South-Central Kansas, 1995-99*. U.S. Geological Survey Water-Resources Investigations Report 00-4126, 36p. http://ks.water.usgs.gov/pubs/reports/wrir.00-4126.html

Cogger, CG and BL Carlile 1984. *Field performance of conventional and alternative septic systems in wet soils*. J. Environ. Qual. 13 (1).

DEQ; 2013. General Permit No OKG950000: *General Wastewater Permit For Rock, Sand and Gravel Quarries (Excluding Dredging Operations) and Stone Cuting Facilities; To Construct Or Operate Industrial Wastewater Impoundments; and/or To Land Apply Industrial Wastewater For Dust Suppression; and/or To Recycle Wastewater As Wash Water or Cooling Water.* http://www.deq.state.ok.us/wqdnew/opdes/industrial/general_permits/RSG_Pmt_13.pdf

DEQ; 2013. OKG950000 Fact Sheet: *General Wastewater Permit For Rock, Sand and Gravel Quarries (Excluding Dredging Operations) and Stone Cuting Facilities; To Construct Or Operate Industrial Wastewater Impoundments; and/or To Land Apply Industrial Wastewater For Dust Suppression; and/or To Recycle Wastewater As Wash Water or Cooling Water*. http://www.deq.state.ok.us/wqdnew/opdes/industrial/general_permits/RSG_Pmt_13.pdf

DEQ; 2011. *General Permit OKR05 for Storm Water Discharges from Industrial Activities Under the Multi-Sector Industrial General Permit*. Fact Sheet. September 5, 2011. http://www.deq.state.ok.us/WQDnew/stormwater/msgp/msgp_okr05_permit_2011-09-05.pdf

DEQ; 2012. *Individual and Small Public On-Site Sewage Treatment Systems (Chapter 641).* July 1, 2012. http://www.deq.state.ok.us/rules/641.pdf

DEQ; 2013. *Oklahoma Pollutant Discharge Elimination System (OPDES) Standards (Chapter 606).* July 1, 2013. http://www.deq.state.ok.us/rules/606.pdf

DEQ; 2012. The State of Oklahoma 2012 *Continuing Planning Process*. http://www.deq.state.ok.us/wqdnew/305b_303d/Final%20CPP.pdf

DEQ; 2012. *Issuance of General Permit OKR10 for Stormwater Discharges from Construction Activities Within the State of Oklahoma*. Fact Sheet. August, 2012. www.deq.state.ok.us/wqdnew/stormwater/OKR10FactSheet_Publicreview_August2012.pdf

DEQ; 2010. *Water Quality in Oklahoma, 2010 Integrated Report*. http://www.deq.state.ok.us/wqdnew/305b_303d/2010/2010%20Oklahoma%20Integrated%20Report_complete.pdf

Drapcho, C.M. and A.K.B. Hubbs; 2002. *Fecal Coliform Concentration in Runoff from Fields with Applied Dairy Manure*. http://www.lwrri.lsu.edu/downloads/Drapcho_annual%20report01-02.pdf

DEQ; 2012. DEQ ArcGIS Flexviewer. http://gis.deq.ok.gov/flexviewer/.

EPA; 1983. *Final Report of the Nationwide Urban Runoff Program*. U.S. Environmental Protection Agency, Water Planning Division.

EPA; 1991. *Guidance for Water Quality-Based Decisions: The TMDL Process*. Office of Water, EPA 440/4-91-001.

EPA; 1997. *Compendium of Tools for Watershed Assessment and TMDL Development*. EPA 841-B-97-006. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/comptool.cfm.

EPA; 2001. *2001 Protocol for Developing Pathogen TMDLs*. First Edition. Office of Water, EPA 841-R-00-002.

EPA; 2003. *Guidance for 2004 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d) and 305(b) of the Clean Water Act*, TMDL -01-03 - Diane Regas-- July 21, 2003.

EPA; 2005. U.S. Environmental Protection Agency, Office of Water. *Stormwater Phase II Final Rule*. EPA833-F-00-002 Fact Sheet 2.0. December 2005.

EPA; 2006. *Guidance for Data Quality Assessment: Statistical Tools for Practitioners*, EPA QA/G-9S; EPA/240/B-06/003; Section 4.7.1, p 131: http://www.epa.gov/quality/qs-docs/g9s-final.pdf

EPA; 2007. *An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006*. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2007_08_23_tmdl_duration_curve_guide_aug2007.pdf.

EPA; 2008. *Handbook for Developing Watershed TMDLs: Draft*. http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/upload/2009_01_09_tmdl_draft_handbook.pdf.

EPA; 2012. *Recreational Water Quality Criteria document*. http://water.epa.gov/scitech/swguidance/standards/criteria/health/recreation/index.cfm

EPA; 2012. *STORET data warehouse*. http://www.epa.gov/storet/dbtop.html.

EPA; 2012. *Discharge Monitoring Report Pollutant Loading Tool*. http://cfpub.epa.gov/dmr/ez_search.cfm.

Hall, S.; 2002. Washington State Department of Health, Wastewater Management Program Rule Development Committee, *Issue Research Report - Failing Systems*, June 2002.

Horizon Systems Corporation; 2012. *NHDPlus Version 2*. http://www.horizon-systems.com/nhdplus/.

Institute for Statistics and Mathematics; 2013. *The R Project for Statistical Computing*. http://www.r-project.org/

Lee-Ing, Tong and Wang Chung-Ho; 2002. *STATISTICA V5.5 and Basic Statistic Analysis*. TasngHai Publisher, Taiwan, R.O.C.

Metcalf and Eddy; 1991. *Wastewater Engineering: Treatment, Disposal, Reuse*: 2nd Edition.

Missouri Department of Natural Resources; 2003. *Total Maximum daily Loads (TMDLs) for Shoal Creek Newton and Barry Counties, Missouri*.

National Cooperative Soil Survey; 2012. *National Cooperative Soil Characterization Database*. http://ncsslabdatamart.sc.egov.usda.gov/.

National Water Quality Monitoring Council; 2012. *Water Quality Portal of the USGS, EPA, and National Water Quality Monitoring Council*. http://www.waterqualitydata.us.

ODAFF; 2014. Agricultural Environmental Management Services, http://www.oda.state.ok.us/aems/.

ODAFF; 2014. *Oklahoma Concentrated Animal Feeding Operations Act*. www.oda.state.ok.us/aems/CAFO-ActOklahomaConcentratedAnimalFeedingOperations.pdf

ODAFF; 2014. *Oklahoma Swine Feeding Operations Act*. http://www.oda.state.ok.us/aems/Swine-FeedingOperations_Act.pdf

ODAFF; 2014. *Oklahoma Registered Poultry Feeding Operations Act*. http://www.oda.state.ok.us/aems/RPFO-Title2-OKRegisteredPoultryFeedingOps_Act.pdf

ODAFF; 2014. *Oklahoma Concentrated Animal Feeding Operations Rules*. www.oda.state.ok.us/aems/CAFO-RulesOKConcentratedAnimalFeedingOperations_Permanent.pdf

ODAFF; 2014. *Oklahoma Swine Feeding Operations Rules*. http://www.oda.state.ok.us/aems/Swine-FeedingOperations_Rules.pdf

ODAFF; 2014. *Oklahoma Registered Poultry Feeding Operations Rules*. http://www.oda.state.ok.us/aems/RPFO-RegisteredPoultryFeedingOps_Rules.pdf

ODWC 2009. Oklahoma Department of Wildlife Conservation, *Deer Harvest Totals*. http://www.wildlifedepartment.com/hunting/deerharvesttotals.htm

Oklahoma Climate Survey. 2005. Viewed August 29, 2005 in http://climate.ocs.ou.edu/county_climate/Products/County_Climatologies/

Oklahoma Conservation Commission; 2012. http://www.ok.gov/conservation/Agency_Divisions/Water_Quality_Division/WQ_Monitoring/WQ_Assessment_Rotating_Basin_Monitoring_Program.html.

Oklahoma Department of Commerce, 2010. Policy, Research, and Economic Analysis Division: http://okcommerce.gov/data-and-research/demographics-and-population-data/

Oklahoma Mesonet; 2012. *Oklahoma Mesonet Meteorological Data*. http://www.mesonet.org/.

OWRB; 2012. *Oklahoma Water Resources Board Water Quality Monitoring Sites*. www.owrb.ok.gov/maps/pmg/owrbdata_SW.html.

OWRB; 2013. Oklahoma Water Resources Board. *2013 Water Quality Standards (Chapter 45)*. http://www.owrb.ok.gov/util/rules/pdf_rul/current/Ch45.pdf

OWRB; 2013. *Oklahoma Water Resources Board. Implementation of Oklahoma's Water Quality Standards (Chapter 46)*. http://www.owrb.ok.gov/util/rules/pdf_rul/current/Ch46.pdf

Pitt, R.; Maestre, A.; and Morquecho, R. 2004. *The National Stormwater Quality Database*, version 1.1. http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html.

PRISM Climate Group; 2014. *PRISM Climate Data*: http://prism.oregonstate.edu/

Reed, Stowe &Yanke, LLC 2001. *Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in Texas*. September 2001.

Schueler, TR 2000. *Microbes and Urban Watersheds: Concentrations, Sources, and Pathways. In The Practice of Watershed Protection,* TR Schueler and HK Holland, eds. Center for Watershed Protection, Ellicott City, MD.

Tukey, J.W. 1977. *Exploratory Data Analysis*. Addison-Wesely.

University of Florida 1987. *Institute of Food and Agricultural Sciences*, University Of Florida, Florida Cooperative Extension Service, No. 31, December, 1987.

University of Oklahoma Center for Spatial Analysis; 2007. *Roads of Oklahoma*. http://geo.ou.edu/oeb/Statewide/R2000.txt.

USACE; 2012. U.S. Army Corps of Engineers Water Control Data System (Tulsa District). http://www.swt-wc.usace.army.mil/stations.htm.

U.S. Bureau of Reclamation; 2012. U.S. Bureau of Reclamation Oklahoma Lakes and Reservoir Operations. http://www.usbr.gov/gp/lakes_reservoirs/oklahoma_lakes.htm.

U.S. Census Bureau ; 2000. http://www.census.gov/main/www/cen2000.html

U.S. Census Bureau; 2010. http://www.census.gov/2010census/popmap/ipmtext.php?fl=40.

USDA; 2007. Census of Agriculture, National Agricultural Statistics Service, United States Department of Agriculture. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Census_by_State/Oklahoma/index.asp

USDA-NRCS (U.S. Department of Agriculture - Natural Resources Conservation Service); 1986. Technical Release 55 – *Urban Hydrology for Small Watersheds*. Second Edition. 210-VI-TR-55. Washington, DC. June 1986.

USDA NRCS; 2009. *Agricultural Waste Management Field Handbook*, Part 651. www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/technical/ecoscience/mnm/?&cid=stelprdb1045935

USDA NRCS; 2010. *Animal Waste Management Software*. www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/ecoscience/mnm/?cid=stelprdb1045812

USDA NRCS; 2009. *Comprehensive Nutrient Management Plans* (NCMP). http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/plantsanimals/livestock/afo/

USDA NRCS; 2014. *Manure Management Planner* (MMP). ftp://ftp.wcc.nrcs.usda.gov/wntsc/nutrientMgt/MMP.pdf and http://www.purdue.edu/agsoftware/mmp/

U.S. Department of Commerce, Bureau of the Census 1990. *1990 Census of Housing, Detailed Housing Characteristics Oklahoma*. http://www.census.gov/prod/cen1990/ch2/ch-2-38.pdf

USGS; 2002. *Statistical Methods in Water Resources; Techniques of Water Resources Investigations*; Book 4, Chapter A3, 522 p. by Helsel, D.R. and R.M. Hirsch http://pubs.usgs.gov/twri/twri4a3/

USGS; 2012. *Multi-Resolution Land Characteristics Consortium. USGS National Land Cover Dataset.* http://www.mrlc.gov/index.asp.

USGS, 2013. *National Hydrography Dataset* : http://nhd.usgs.gov/data.html.

USGS; 2012. *USGS Daily Streamflow Data*. http://waterdata.usgs.gov/ok/nwis/rt.

USGS. 2012. *USGS National Elevation Dataset*. http://ned.usgs.gov/

USGS; 2012. *USGS National Water Information Syste*m. http://waterdata.usgs.gov/ok/nwis/nwis.

USGS; 2012. *The National Map Viewer*, version 2.0: http://viewer.nationalmap.gov/viewer/.

Woods, A.J., Omernik, J.M., Butler, D.R., Ford, J.G., Henley, J.E., Hoagland, B.W., Arndt, D.S., and Moran, B.C., 2005. *Ecoregions of Oklahoma* (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,250,000).

APPENDIX A: Ambient Water Quality Data

Table Appendix A-1: Bacterial Data: 2001 to 2008

Waterbody ID	WQM Station	Date*	*E. coli* Units = counts/100 mL STORET Code: 31609	Enterococci Units = counts/100 mL STORET Code: 31649
OK410100010010_10	410100010010-001AT	6/19/2001	10	10
OK410100010010_10	410100010010-001AT	8/20/2001	10	30
OK410100010010_10	410100010010-001AT	9/17/2001	10	30
OK410100010010_10	410100010010-001AT	9/19/2001	10	10
OK410100010010_10	410100010010-001AT	5/13/2002	72	60
OK410100010010_10	410100010010-001AT	6/10/2002	63	10
OK410100010010_10	410100010010-001AT	7/15/2002	10	80
OK410100010010_10	410100010010-001AT	9/9/2002	20	50
OK410100010010_10	410100010010-001AT	5/10/2004	10	50
OK410100010010_10	410100010010-001AT	5/25/2004	20	10
OK410100010010_10	410100010010-001AT	6/8/2004	31	10
OK410100010010_10	410100010010-001AT	6/15/2004	134	300
OK410100010010_10	410100010010-001AT	6/29/2004	52	600
OK410100010010_10	410100010010-001AT	7/20/2004	10	10
OK410100010010_10	410100010010-001AT	8/3/2004	10	10
OK410100010010_10	410100010010-001AT	8/24/2004	10	10
OK410100010010_10	410100010010-001AT	9/8/2004	10	10
OK410100010010_10	410100010010-001AT	9/22/2004	10	10
OK410100010010_10	410100010010-001AT	5/24/2006	10	10
OK410100010010_10	410100010010-001AT	6/7/2006	10	10
OK410100010010_10	410100010010-001AT	6/7/2006	10	41
OK410100010010_10	410100010010-001AT	6/27/2006	10	41
OK410100010010_10	410100010010-001AT	7/12/2006	10	10
OK410100010010_10	410100010010-001AT	7/26/2006	10	10
OK410100010010_10	410100010010-001AT	8/2/2006	10	10
OK410100010010_10	410100010010-001AT	8/15/2006	10	10
OK410100010010_10	410100010010-001AT	9/6/2006	10	10
OK410100010010_10	410100010010-001AT	9/20/2006	10	20
OK410100010010_10	410100010010-001AT	10/4/2006	74	275
OK410200010200_00	410200010200-001AT	6/20/2001	10	20
OK410200010200_00	410200010200-001AT	8/21/2001	30	30
OK410200010200_00	410200010200-001AT	9/18/2001	10	20
OK410200010200_00	410200010200-001AT	5/22/2002	63	90
OK410200010200_00	410200010200-001AT	6/18/2002	10	4000
OK410200010200_00	410200010200-001AT	7/23/2002	10	170

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	*E. coli* Units = counts/100 mL STORET Code: 31609	Enterococci Units = counts/100 mL STORET Code: 31649
OK410200010200_00	410200010200-001AT	9/11/2002	216	10
OK410200010200_00	410200010200-001AT	5/20/2003	98	700
OK410200010200_00	410200010200-001AT	5/10/2004	41	20
OK410200010200_00	410200010200-001AT	5/26/2004	10	80
OK410200010200_00	410200010200-001AT	6/8/2004	20	30
OK410200010200_00	410200010200-001AT	6/15/2004	63	700
OK410200010200_00	410200010200-001AT	7/20/2004	41	10
OK410200010200_00	410200010200-001AT	8/24/2004	10	10
OK410200010200_00	410200010200-001AT	9/22/2004	31	20
OK410200010200_00	410200010200-001AT	5/21/2008	52	10
OK410200010200_00	410200010200-001AT	6/11/2008	175	41
OK410200010200_00	410200010200-001AT	7/2/2008	175	31
OK410200010200_00	410200010200-001AT	7/23/2008	10	10
OK410200010200_00	410200010200-001AT	8/13/2008	384	169
OK410200010200_10	410200010200-002AT	6/29/2004	1296	2200
OK410200010200_10	410200010200-002AT	8/2/2004	10	70
OK410200010200_10	410200010200-002AT	9/7/2004	20	31
OK410200010200_10	410200010200-002AT	5/24/2006	20	10
OK410200010200_10	410200010200-002AT	6/27/2006	10	20
OK410200010200_10	410200010200-002AT	7/12/2006	52	20
OK410200010200_10	410200010200-002AT	7/26/2006	10	31
OK410200010200_10	410200010200-002AT	8/2/2006	41	10
OK410200010200_10	410200010200-002AT	8/15/2006	10	10
OK410200010200_10	410200010200-002AT	9/6/2006	52	20
OK410200010200_10	410200010200-002AT	9/20/2006	10	20
OK410200010200_10	410200010200-002AT	6/11/2008	169	41
OK410200010200_10	410200010200-002AT	10/4/2006	41	41
OK410200030010_00	OK410200-03-0010G	6/28/2005	5	5
OK410200030010_00	OK410200-03-0010G	8/1/2005	20	10
OK410200030010_00	OK410200-03-0010G	8/29/2005	10	20
OK410200030010_00	OK410200-03-0010G	4/10/2006	20	30
OK410200030010_00	OK410200-03-0010G	5/16/2006	95	40
OK410200030010_00	OK410200-03-0010G	7/25/2006	5	35
OK410200030010_00	OK410200-03-0010G	8/29/2006	45	115
OK410200030010_00	OK410200-03-0010G	4/17/2007	105	5
OK410210020140_00	410210020140-001AT	5/23/2001	98	160

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	***E. coli*** **Units = counts/100 mL** STORET Code: 31609	**Enterococci** **Units = counts/100 mL** STORET Code: 31649
OK410210020140_00	410210020140-001AT	6/20/2001	10	10
OK410210020140_00	410210020140-001AT	7/25/2001	10	70
OK410210020140_00	410210020140-001AT	8/21/2001	10	70
OK410210020140_00	410210020140-001AT	9/18/2001	472	550
OK410210020140_00	410210020140-001AT	5/22/2002	10	25
OK410210020140_00	410210020140-001AT	6/18/2002	10	15
OK410210020140_00	410210020140-001AT	7/24/2002	10	120
OK410210020140_00	410210020140-001AT	9/11/2002	10	30
OK410210020140_00	410210020140-001AT	5/5/2003	26	135
OK410210020140_00	410210020140-001AT	5/21/2003	10	75
OK410210020140_00	410210020140-001AT	6/9/2003	84	90
OK410210020140_00	410210020140-001AT	6/25/2003	80	270
OK410210020140_00	410210020140-001AT	7/14/2003	15	450
OK410210020140_00	410210020140-001AT	8/18/2003	101	3450
OK410210020140_00	410210020140-001AT	9/3/2003	37	400
OK410210020140_00	410210020140-001AT	9/22/2003	20	25
OK410210020140_00	410210020140-001AT	6/6/2006	10	15
OK410210020140_00	410210020140-001AT	6/20/2006	10	15
OK410210020140_00	410210020140-001AT	7/5/2006	76	15
OK410210020140_00	410210020140-001AT	7/11/2006	20	37
OK410210020140_00	410210020140-001AT	7/25/2006	31	10
OK410210020140_00	410210020140-001AT	8/15/2006	10	15
OK410210020140_00	410210020140-001AT	9/19/2006	760	600
OK410210020140_00	410210020140-001AT	5/21/2008	20	10
OK410210020140_00	410210020140-001AT	6/10/2008	393	143
OK410210020140_00	410210020140-001AT	7/1/2008	31	10
OK410210020140_00	410210020140-001AT	7/22/2008	10	10
OK410210020140_00	410210020140-001AT	8/12/2008	1012	717
OK410210020300_00	OK410210-02-0300C	6/29/2005	5	20
OK410210020300_00	OK410210-02-0300C	8/2/2005	35	125
OK410210020300_00	OK410210-02-0300C	9/7/2005	20	50
OK410210020300_00	OK410210-02-0300C	10/11/2005	5	5
OK410210020300_00	OK410210-02-0300C	4/11/2006	5	15
OK410210020300_00	OK410210-02-0300C	5/16/2006	35	30
OK410210020300_00	OK410210-02-0300C	6/20/2006	10	10
OK410210020300_00	OK410210-02-0300C	7/17/2006	5	5

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	***E. coli*** Units = counts/100 mL STORET Code: 31609	**Enterococci** Units = counts/100 mL STORET Code: 31649
OK410210020300_00	OK410210-02-0300C	8/21/2006	10	10
OK410210020300_00	OK410210-02-0300C	9/5/2006	290	230
OK410210020300_00	OK410210-02-0300C	4/16/2007	40	5
OK410210060020_00	OK410210-06-0020G	6/29/2005	125	25
OK410210060020_00	OK410210-06-0020G	8/2/2005	30	120
OK410210060020_00	OK410210-06-0020G	8/29/2005	10	10
OK410210060020_00	OK410210-06-0020G	4/10/2006	5	5
OK410210060020_00	OK410210-06-0020G	5/15/2006	20	10
OK410210060020_00	OK410210-06-0020G	6/12/2006	5	10
OK410210060020_00	OK410210-06-0020G	7/24/2006	5	5
OK410210060020_00	OK410210-06-0020G	8/28/2006	25	25
OK410210060020_00	OK410210-06-0020G	4/16/2007	15	5
OK410210060320_00	OK410210-06-0320G	6/29/2005	30	35
OK410210060320_00	OK410210-06-0320G	8/1/2005	50	10
OK410210060320_00	OK410210-06-0320G	8/29/2005	10	30
OK410210060320_00	OK410210-06-0320G	4/10/2006	5	5
OK410210060320_00	OK410210-06-0320G	5/15/2006	5	10
OK410210060320_00	OK410210-06-0320G	6/12/2006	20	140
OK410210060320_00	OK410210-06-0320G	7/24/2006	10	10
OK410210060320_00	OK410210-06-0320G	8/28/2006	40	45
OK410210060320_00	OK410210-06-0320G	4/16/2007	5	5
OK410210060350_00	OK410210-06-0350G	6/29/2005	80	10
OK410210060350_00	OK410210-06-0350G	8/2/2005	30	190
OK410210060350_00	OK410210-06-0350G	8/29/2005	10	20
OK410210060350_00	OK410210-06-0350G	4/10/2006	15	5
OK410210060350_00	OK410210-06-0350G	5/15/2006	10	15
OK410210060350_00	OK410210-06-0350G	6/12/2006	15	5
OK410210060350_00	OK410210-06-0350G	7/24/2006	60	5
OK410210060350_00	OK410210-06-0350G	8/28/2006	1000	680
OK410210060350_00	OK410210-06-0350G	4/16/2007	5	20
OK410210080010_00	410210080010-001AT	6/20/2001	10	30
OK410210080010_00	410210080010-001AT	8/21/2001	10	10
OK410210080010_00	410210080010-001AT	9/18/2001	41	50
OK410210080010_00	410210080010-001AT	5/22/2002	30	10
OK410210080010_00	410210080010-001AT	6/18/2002	10	10
OK410210080010_00	410210080010-001AT	7/23/2002	10	110

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	*E. coli* Units = counts/100 mL STORET Code: 31609	Enterococci Units = counts/100 mL STORET Code: 31649
OK410210080010_00	410210080010-001AT	9/11/2002	74	20
OK410210080010_00	410210080010-001AT	5/21/2003	20	70
OK410210080010_00	410210080010-001AT	5/10/2004	21	25
OK410210080010_00	410210080010-001AT	5/26/2004	10	10
OK410210080010_00	410210080010-001AT	6/8/2004	36	30
OK410210080010_00	410210080010-001AT	6/15/2004	31	300
OK410210080010_00	410210080010-001AT	6/30/2004	25	140
OK410210080010_00	410210080010-001AT	7/20/2004	63	250
OK410210080010_00	410210080010-001AT	8/3/2004	10	115
OK410210080010_00	410210080010-001AT	8/24/2004	15	10
OK410210080010_00	410210080010-001AT	9/8/2004	10	10
OK410210080010_00	410210080010-001AT	9/22/2004	10	15
OK410210080010_00	410210080010-001AT	6/6/2006	10	10
OK410210080010_00	410210080010-001AT	6/20/2006	20	10
OK410210080010_00	410210080010-001AT	7/11/2006	20	63
OK410210080010_00	410210080010-001AT	7/25/2006	10	10
OK410210080010_00	410210080010-001AT	8/2/2006	10	41
OK410210080010_00	410210080010-001AT	8/15/2006	10	10
OK410210080010_00	410210080010-001AT	9/19/2006	10	50
OK410210080010_00	410210080010-001AT	5/21/2008	20	10
OK410210080010_00	410210080010-001AT	6/11/2008	190	52
OK410210080010_00	410210080010-001AT	7/2/2008	122	20
OK410210080010_00	410210080010-001AT	7/23/2008	10	10
OK410210080010_00	410210080010-001AT	8/13/2008	354	86
OK410210080010_00	410210080010-001AT	10/3/2006	31	10
OK410300010010_00	410300010010-002AT	5/13/2002	63	400
OK410300010010_00	410300010010-002AT	6/10/2002	52	50
OK410300010010_00	410300010010-002AT	7/15/2002	85	130
OK410300010010_00	410300010010-002AT	9/9/2002	20	70
OK410300010010_00	410300010010-002AT	5/10/2004	30	130
OK410300010010_00	410300010010-002AT	5/25/2004	97	30
OK410300010010_00	410300010010-002AT	6/8/2004	63	50
OK410300010010_00	410300010010-002AT	6/15/2004	20	6700
OK410300010010_00	410300010010-002AT	6/29/2004	789	2750
OK410300010010_00	410300010010-002AT	7/20/2004	10	10
OK410300010010_00	410300010010-002AT	8/3/2004	10	10

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	*E. coli* Units = counts/100 mL STORET Code: 31609	Enterococci Units = counts/100 mL STORET Code: 31649
OK410300010010_00	410300010010-002AT	8/24/2004	85	10
OK410300010010_00	410300010010-002AT	9/8/2004	108	10
OK410300010010_00	410300010010-002AT	9/22/2004	20	10
OK410300010010_00	410300010010-002AT	5/24/2006	31	10
OK410300010010_00	410300010010-002AT	6/7/2006	10	20
OK410300010010_00	410300010010-002AT	6/27/2006	52	10
OK410300010010_00	410300010010-002AT	7/12/2006	41	10
OK410300010010_00	410300010010-002AT	7/26/2006	10	10
OK410300010010_00	410300010010-002AT	8/2/2006	20	10
OK410300010010_00	410300010010-002AT	8/15/2006	10	10
OK410300010010_00	410300010010-002AT	9/6/2006	10	10
OK410300010010_00	410300010010-002AT	9/20/2006	74	41
OK410300010010_00	410300010010-002AT	10/4/2006	10	10
OK410300010020_00	OK410300-01-0020F	6/21/2005	20	10
OK410300010020_00	OK410300-01-0020F	7/26/2005	80	10
OK410300010020_00	OK410300-01-0020F	8/30/2005	30	10
OK410300010020_00	OK410300-01-0020F	10/4/2005	10	20
OK410300010020_00	OK410300-01-0020F	4/4/2006	20	65
OK410300010020_00	OK410300-01-0020F	5/9/2006	100	140
OK410300010020_00	OK410300-01-0020F	6/13/2006	30	60
OK410300010020_00	OK410300-01-0020F	7/18/2006	10	5
OK410300010020_00	OK410300-01-0020F	8/22/2006	460	350
OK410300010020_00	OK410300-01-0020F	9/26/2006	140	170
OK410300010020_00	OK410300-01-0020F	4/17/2007	180	50
OK410300010100_00	OK410300-01-0100C	6/21/2005	100	60
OK410300010100_00	OK410300-01-0100C	7/26/2005	50	20
OK410300010100_00	OK410300-01-0100C	8/30/2005	30	10
OK410300010100_00	OK410300-01-0100C	10/4/2005	5	5
OK410300010100_00	OK410300-01-0100C	4/4/2006	5	40
OK410300010100_00	OK410300-01-0100C	5/9/2006	660	330
OK410300010100_00	OK410300-01-0100C	6/13/2006	590	100
OK410300010100_00	OK410300-01-0100C	7/18/2006	390	250
OK410300010100_00	OK410300-01-0100C	4/17/2007	35	45
OK410310010010_00	410310010010-001AT	8/20/2001	10	10
OK410310010010_00	410310010010-001AT	9/17/2001	4611	35000
OK410310010010_00	410310010010-001AT	5/22/2002	35.5	15

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	*E. coli* Units = counts/100 mL STORET Code: 31609	Enterococci Units = counts/100 mL STORET Code: 31649
OK410310010010_00	410310010010-001AT	6/18/2002	15	2350
OK410310010010_00	410310010010-001AT	9/11/2002	10	10
OK410310010010_00	410310010010-001AT	5/5/2003	52	80
OK410310010010_00	410310010010-001AT	6/9/2003	41	70
OK410310010010_00	410310010010-001AT	6/24/2003	25.5	65
OK410310010010_00	410310010010-001AT	7/14/2003	52	100
OK410310010010_00	410310010010-001AT	7/28/2003	10	100
OK410310010010_00	410310010010-001AT	7/28/2003	10	40
OK410310010010_00	410310010010-001AT	8/18/2003	120	70
OK410310010010_00	410310010010-001AT	9/3/2003	15	115
OK410310010010_00	410310010010-001AT	9/22/2003	86	50
OK410310010010_00	410310010010-001AT	5/25/2004	41	60
OK410310010010_00	410310010010-001AT	6/6/2006	41	10
OK410310010010_00	410310010010-001AT	6/20/2006	110	84
OK410310010010_00	410310010010-001AT	7/5/2006	20	10
OK410310010010_00	410310010010-001AT	7/11/2006	20	20
OK410310010010_00	410310010010-001AT	7/25/2006	10	10
OK410310010010_00	410310010010-001AT	8/23/2006	63	10
OK410310010010_00	410310010010-001AT	9/19/2006	132	20
OK410310010010_00	410310010010-001AT	5/20/2008	41	10
OK410310010010_00	410310010010-001AT	6/9/2008	63	51
OK410310010010_00	410310010010-001AT	6/30/2008	697	41
OK410310010010_00	410310010010-001AT	7/21/2008	10	10
OK410310010010_00	410310010010-001AT	8/11/2008	1935	2282
OK410310020010_10	410310020010-001AT	8/20/2001	10	30
OK410310020010_10	410310020010-001AT	9/17/2001	1317	24000
OK410310020010_10	410310020010-001AT	5/22/2002	10	10
OK410310020010_10	410310020010-001AT	6/18/2002	10	1900
OK410310020010_10	410310020010-001AT	9/11/2002	10	200
OK410310020010_10	410310020010-001AT	5/10/2004	52	70
OK410310020010_10	410310020010-001AT	5/26/2004	10	50
OK410310020010_10	410310020010-001AT	6/8/2004	10	20
OK410310020010_10	410310020010-001AT	6/15/2004	10	60
OK410310020010_10	410310020010-001AT	6/30/2004	1281	3100
OK410310020010_10	410310020010-001AT	7/20/2004	10	90
OK410310020010_10	410310020010-001AT	8/3/2004	10	60

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Waterbody ID	WQM Station	Date*	*E. coli* Units = counts/100 mL STORET Code: 31609	Enterococci Units = counts/100 mL STORET Code: 31649
OK410310020010_10	410310020010-001AT	8/24/2004	31	10
OK410310020010_10	410310020010-001AT	9/8/2004	10	10
OK410310020010_10	410310020010-001AT	9/21/2004	20	10
OK410310020010_10	410310020010-001AT	5/23/2006	10	10
OK410310020010_10	410310020010-001AT	6/6/2006	10	30
OK410310020010_10	410310020010-001AT	6/20/2006	10	10
OK410310020010_10	410310020010-001AT	7/11/2006	10	10
OK410310020010_10	410310020010-001AT	7/25/2006	10	10
OK410310020010_10	410310020010-001AT	8/23/2006	62	86
OK410310020010_10	410310020010-001AT	9/6/2006	10	20
OK410310020010_10	410310020010-001AT	9/19/2006	62	132
OK410310020010_10	410310020010-001AT	5/21/2008	30	10
OK410310020010_10	410310020010-001AT	6/11/2008	10	20
OK410310020010_10	410310020010-001AT	7/2/2008	10	10
OK410310020010_10	410310020010-001AT	7/23/2008	10	63
OK410310020010_10	410310020010-001AT	8/13/2008	156	41

* Samples collected during secondary contact recreation season (October 1st and April 30th) are included in Appendix A but were not used in TMDL calculations.

Table Appendix A-2: Turbidity and Total Suspended Solids Data – 1998-2012

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410100010010_10	410100010010-001AT	11/4/1998	91	146	3
OK410100010010_10	410100010010-001AT	12/8/1998	316	0	3
OK410100010010_10	410100010010-001AT	1/5/1999	50	52	4
OK410100010010_10	410100010010-001AT	2/2/1999	288	392	4
OK410100010010_10	410100010010-001AT	3/3/1999	21	21	4
OK410100010010_10	410100010010-001AT	4/19/1999		112	N/A
OK410100010010_10	410100010010-001AT	5/5/1999	112	100	4
OK410100010010_10	410100010010-001AT	6/9/1999	96	117	4
OK410100010010_10	410100010010-001AT	7/11/1999	63	88	4
OK410100010010_10	410100010010-001AT	8/4/1999	44	37	4
OK410100010010_10	410100010010-001AT	9/8/1999	34	34	3
OK410100010010_10	410100010010-001AT	10/5/1999	20	34	N/A
OK410100010010_10	410100010010-001AT	11/3/1999	24	17	N/A
OK410100010010_10	410100010010-001AT	12/1/1999	15	21	3
OK410100010010_10	410100010010-001AT	1/12/2000	14	18	N/A
OK410100010010_10	410100010010-001AT	2/15/2000	24	50	N/A
OK410100010010_10	410100010010-001AT	3/6/2000	138	184	N/A
OK410100010010_10	410100010010-001AT	5/2/2000	38	108	N/A
OK410100010010_10	410100010010-001AT	6/6/2000	69	120	N/A
OK410100010010_10	410100010010-001AT	7/11/2000	107	310	3
OK410100010010_10	410100010010-001AT	8/8/2000	55	176	3
OK410100010010_10	410100010010-001AT	9/5/2000	37	54	2
OK410100010010_10	410100010010-001AT	10/3/2000	26	18	2
OK410100010010_10	410100010010-001AT	11/7/2000	258	288	4
OK410100010010_10	410100010010-001AT	2/13/2007	34		2
OK410100010010_10	410100010010-001AT	3/20/2007	22		2
OK410100010010_10	410100010010-001AT	4/17/2007	42		3
OK410100010010_10	410100010010-001AT	5/22/2007	60		3
OK410100010010_10	410100010010-001AT	6/26/2007	134		5
OK410100010010_10	410100010010-001AT	7/31/2007	72		4
OK410100010010_10	410100010010-001AT	10/9/2007	30		2
OK410100010010_10	410100010010-001AT	11/14/2007	22		2
OK410100010010_10	410100010010-001AT	2/5/2008	39		3
OK410100010010_10	410100010010-001AT	3/11/2008	122		4

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410100010010_10	410100010010-001AT	4/8/2008	155		3
OK410100010010_10	410100010010-001AT	5/13/2008	42		2
OK410100010010_10	410100010010-001AT	8/19/2008	83		3
OK410100010010_10	410100010010-001AT	9/30/2008	95		2
OK410100010010_10	410100010010-001AT	12/9/2008	22		2
OK410100010010_10	410100010010-001AT	2/11/2009	23		2
OK410100010010_10	410100010010-001AT	3/10/2009	14.5		1
OK410100010010_10	410100010010-001AT	3/31/2009	33.25		2
OK410100010010_10	410100010010-001AT	5/20/2009	126		4
OK410100010010_10	410100010010-001AT	7/21/2009	15.25		2
OK410100010010_10	410100010010-001AT	9/15/2009	14		2
OK410100010010_10	410100010010-001AT	12/14/2009	22.3		3
OK410100010010_10	410100010010-001AT	2/23/2010	57.5		3
OK410100010010_10	410100010010-001AT	3/30/2010	80		3
OK410100010010_10	410100010010-001AT	6/15/2010	22		2
OK410100010010_10	410100010010-001AT	10/5/2010	15.3		2
OK410100010010_10	410100010010-001AT	12/14/2010	13		2
OK410100010010_10	410100010010-001AT	2/28/2011	60.3		3
OK410100010010_10	410100010010-001AT	3/29/2011	13.8		3
OK410100010010_10	410100010010-001AT	5/24/2011	333.8		4
OK410100010010_10	410100010010-001AT	8/16/2011	17.3		2
OK410100010010_10	410100010010-001AT	10/25/2011	20.5		3
OK410100010010_10	410100010010-001AT	11/29/2011	86.3		4
OK410100010010_10	410100010010-001AT	1/4/2012	30.5		1
OK410100010010_10	410100010010-001AT	4/17/2012	48.3		3
OK410200010200_00	410200010200-001AT	11/04/1998	23	42.0	High Flow
OK410200010200_00	410200010200-001AT	12/08/1998	31	32.0	High Flow
OK410200010200_00	410200010200-001AT	01/05/1999	13	11.0	
OK410200010200_00	410200010200-001AT	02/01/1999	42	24.0	High Flow
OK410200010200_00	410200010200-001AT	03/02/1999	13	16.0	
OK410200010200_00	410200010200-001AT	04/07/1999	40	35.0	High Flow
OK410200010200_00	410200010200-001AT	05/05/1999	113	98.0	High Flow
OK410200010200_00	410200010200-001AT	06/08/1999	19	15.0	
OK410200010200_00	410200010200-001AT	07/06/1999	39	31.0	High Flow
OK410200010200_00	410200010200-001AT	08/03/1999	16	1.0	

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410200010200_00	410200010200-001AT	09/07/1999	8	22.0	
OK410200010200_00	410200010200-001AT	10/04/1999	6	6.0	
OK410200010200_00	410200010200-001AT	11/03/1999	5	3.0	
OK410200010200_00	410200010200-001AT	11/30/1999	6	6.0	
OK410200010200_00	410200010200-001AT	01/11/2000	14	12.0	
OK410200010200_00	410200010200-001AT	02/08/2000	12	7.0	
OK410200010200_00	410200010200-001AT	03/06/2000	13	18.0	
OK410200010200_00	410200010200-001AT	05/02/2000	20	184.0	High Flow
OK410200010200_00	410200010200-001AT	06/06/2000	51	48.0	High Flow
OK410200010200_00	410200010200-001AT	07/11/2000	12	14.0	
OK410200010200_00	410200010200-001AT	08/08/2000	13	14.0	
OK410200010200_00	410200010200-001AT	09/05/2000	8	1.0	
OK410200010200_00	410200010200-001AT	10/03/2000	6	1.0	
OK410200010200_00	410200010200-001AT	11/07/2000	122	110.0	High Flow
OK410200010200_00	410200010200-001AT	02/28/2001	90		
OK410200010200_00	410200010200-001AT	03/21/2001	18		High Flow
OK410200010200_00	410200010200-001AT	04/25/2001	28		
OK410200010200_00	410200010200-001AT	05/23/2001	60		High Flow
OK410200010200_00	410200010200-001AT	06/20/2001	8		
OK410200010200_00	410200010200-001AT	07/25/2001	6		
OK410200010200_00	410200010200-001AT	08/21/2001	9		
OK410200010200_00	410200010200-001AT	9/18/2001	14		
OK410200010200_00	410200010200-001AT	10/24/2001	14		
OK410200010200_00	410200010200-001AT	11/14/2001	6		
OK410200010200_00	410200010200-001AT	2/19/2002	41		High Flow
OK410200010200_00	410200010200-001AT	3/26/2002	12		High Flow
OK410200010200_00	410200010200-001AT	04/23/2002	40		High Flow
OK410200010200_00	410200010200-001AT	05/21/2002	29		
OK410200010200_00	410200010200-001AT	06/18/2002	17		
OK410200010200_00	410200010200-001AT	07/23/2002	12		
OK410200010200_00	410200010200-001AT	09/10/2002	33		
OK410200010200_00	410200010200-001AT	10/08/2002	12		
OK410200010200_00	410200010200-001AT	11/05/2002	17		
OK410200010200_00	410200010200-001AT	12/17/2002	25		
OK410200010200_00	410200010200-001AT	03/11/2003	17		

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410200010200_00	410200010200-001AT	04/15/2003	13		
OK410200010200_00	410200010200-001AT	06/24/2003	15		
OK410200010200_00	410200010200-001AT	09/03/2003	27		
OK410200010200_00	410200010200-001AT	10/07/2003	10		
OK410200010200_10	410200010200-002AT	2/13/2007	18		2
OK410200010200_10	410200010200-002AT	3/19/2007	10		2
OK410200010200_10	410200010200-002AT	4/16/2007	7		2
OK410200010200_10	410200010200-002AT	5/21/2007	13		2
OK410200010200_10	410200010200-002AT	6/25/2007	37		4
OK410200010200_10	410200010200-002AT	7/30/2007	12		4
OK410200010200_10	410200010200-002AT	8/27/2007	10		2
OK410200010200_10	410200010200-002AT	10/8/2007	15		2
OK410200010200_10	410200010200-002AT	11/14/2007	7		2
OK410200010200_10	410200010200-002AT	2/5/2008	11		2
OK410200010200_10	410200010200-002AT	3/11/2008	29		4
OK410200010200_10	410200010200-002AT	4/8/2008	53		4
OK410200010200_10	410200010200-002AT	5/13/2008	17		3
OK410200010200_10	410200010200-002AT	8/18/2008	23		3
OK410200010200_10	410200010200-002AT	9/30/2008	12		2
OK410200010200_10	410200010200-002AT	12/9/2008	21		2
OK410200010200_10	410200010200-002AT	2/10/2009	19.6		2
OK410200010200_10	410200010200-002AT	3/10/2009	11.6		2
OK410200010200_10	410200010200-002AT	3/31/2009	24		4
OK410200010200_10	410200010200-002AT	5/19/2009	38		3
OK410200010200_10	410200010200-002AT	7/21/2009	9.5		1
OK410200010200_10	410200010200-002AT	9/16/2009	20		3
OK410200010200_10	410200010200-002AT	12/15/2009	10		2
OK410200010200_10	410200010200-002AT	2/23/2010	27.3		3
OK410200010200_10	410200010200-002AT	3/30/2010	18		4
OK410200010200_10	410200010200-002AT	6/15/2010	14		3
OK410200010200_10	410200010200-002AT	6/22/2010	9		1
OK410200010200_10	410200010200-002AT	10/5/2010	8.3		2
OK410200010200_10	410200010200-002AT	12/14/2010	3.5		2
OK410200010200_10	410200010200-002AT	2/15/2011	19.5		2
OK410200010200_10	410200010200-002AT	3/29/2011	12		2

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410200010200_10	410200010200-002AT	5/24/2011	16.5		4
OK410200010200_10	410200010200-002AT	8/16/2011	5		1
OK410200010200_10	410200010200-002AT	10/25/2011	5.8		1
OK410200010200_10	410200010200-002AT	11/29/2011	38.5		3
OK410200010200_10	410200010200-002AT	1/4/2012	6		3
OK410200010200_10	410200010200-002AT	4/17/2012	10.5		2
OK410200030010_00	OK410200-03-0010G	6/15/2005	2.36		
OK410200030010_00	OK410200-03-0010G	6/28/2005	3.22	<10	
OK410200030010_00	OK410200-03-0010G	8/1/2005	4.26	<10	
OK410200030010_00	OK410200-03-0010G	8/29/2005	11.9	<10	
OK410200030010_00	OK410200-03-0010G	10/3/2005	5.04	12	
OK410200030010_00	OK410200-03-0010G	11/14/2005	4.08	<10	
OK410200030010_00	OK410200-03-0010G	12/20/2005	2.4	<10	
OK410200030010_00	OK410200-03-0010G	1/31/2006	21.3	19	
OK410200030010_00	OK410200-03-0010G	3/6/2006	4.67	<10	
OK410200030010_00	OK410200-03-0010G	4/10/2006	3.1	<10	
OK410200030010_00	OK410200-03-0010G	5/16/2006	5.6	<10	
OK410200030010_00	OK410200-03-0010G	7/25/2006	2.91	<10	
OK410200030010_00	OK410200-03-0010G	8/29/2006	222	<10	
OK410200030010_00	OK410200-03-0010G	9/26/2006	11.7	<10	
OK410200030010_00	OK410200-03-0010G	10/31/2006	8.53	<10	
OK410200030010_00	OK410200-03-0010G	12/5/2006	7.93	<10	
OK410200030010_00	OK410200-03-0010G	1/9/2007	6.58	<10	
OK410200030010_00	OK410200-03-0010G	2/21/2007	5.9	<10	
OK410200030010_00	OK410200-03-0010G	3/27/2007	2.79	<10	
OK410200030010_00	OK410200-03-0010G	4/17/2007	4.25	<10	
OK410210020140_00	410210020140-001AT	12/8/1998	20	17	4
OK410210020140_00	410210020140-001AT	1/5/1999	4	2	3
OK410210020140_00	410210020140-001AT	2/1/1999	24	2	4
OK410210020140_00	410210020140-001AT	3/2/1999	7	2	2
OK410210020140_00	410210020140-001AT	4/7/1999	22	1	4
OK410210020140_00	410210020140-001AT	5/4/1999	21	11	3
OK410210020140_00	410210020140-001AT	6/8/1999	11	1	3
OK410210020140_00	410210020140-001AT	7/7/1999	10	8	2
OK410210020140_00	410210020140-001AT	8/3/1999	6	2	1

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410210020140_00	410210020140-001AT	9/7/1999	6	18	1
OK410210020140_00	410210020140-001AT	10/4/1999	6	10	1
OK410210020140_00	410210020140-001AT	11/2/1999	8	5	1
OK410210020140_00	410210020140-001AT	11/30/1999	8	13	1
OK410210020140_00	410210020140-001AT	1/11/2000	17	8	3
OK410210020140_00	410210020140-001AT	2/8/2000	11	3	3
OK410210020140_00	410210020140-001AT	3/6/2000	11	2	3
OK410210020140_00	410210020140-001AT	5/9/2000		13	4
OK410210020140_00	410210020140-001AT	6/6/2000	22	25	5
OK410210020140_00	410210020140-001AT	7/12/2000	5	4	2
OK410210020140_00	410210020140-001AT	8/8/2000	5	10	2
OK410210020140_00	410210020140-001AT	9/5/2000	8	1	1
OK410210020140_00	410210020140-001AT	10/3/2000	15	1	1
OK410210020140_00	410210020140-001AT	11/7/2000	21	6	4
OK410210020140_00	410210020140-001AT	2/12/2007	5		2
OK410210020140_00	410210020140-001AT	3/5/2007	5		2
OK410210020140_00	410210020140-001AT	3/19/2007	4		2
OK410210020140_00	410210020140-001AT	4/16/2007	5		2
OK410210020140_00	410210020140-001AT	5/8/2007	26		3
OK410210020140_00	410210020140-001AT	5/22/2007	7		2
OK410210020140_00	410210020140-001AT	6/4/2007	14		3
OK410210020140_00	410210020140-001AT	6/26/2007	18		2
OK410210020140_00	410210020140-001AT	7/9/2007	10		3
OK410210020140_00	410210020140-001AT	7/30/2007	3		2
OK410210020140_00	410210020140-001AT	9/4/2007	6		1
OK410210020140_00	410210020140-001AT	10/8/2007	5		2
OK410210020140_00	410210020140-001AT	10/22/2007	26		3
OK410210020140_00	410210020140-001AT	11/13/2007	5		2
OK410210020140_00	410210020140-001AT	12/3/2007	4		2
OK410210020140_00	410210020140-001AT	2/4/2008	6		3
OK410210020140_00	410210020140-001AT	4/8/2008	11		3
OK410210020140_00	410210020140-001AT	6/9/2008	24		2
OK410210020140_00	410210020140-001AT	8/18/2008	17		2
OK410210020140_00	410210020140-001AT	9/30/2008	7		2
OK410210020140_00	410210020140-001AT	12/9/2008	25		2

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410210020140_00	410210020140-001AT	2/10/2009	14		2
OK410210020140_00	410210020140-001AT	3/11/2009	7		3
OK410210020140_00	410210020140-001AT	4/1/2009	18.25		4
OK410210020140_00	410210020140-001AT	5/20/2009	11		2
OK410210020140_00	410210020140-001AT	7/21/2009	3.5		1
OK410210020140_00	410210020140-001AT	9/15/2009	4		3
OK410210020140_00	410210020140-001AT	12/16/2009	8.8		3
OK410210020140_00	410210020140-001AT	2/23/2010	24.5		3
OK410210020140_00	410210020140-001AT	3/30/2010	11.3		4
OK410210020140_00	410210020140-001AT	6/15/2010	7		2
OK410210020140_00	410210020140-001AT	6/22/2010	4		2
OK410210020140_00	410210020140-001AT	10/5/2010	2.8		2
OK410210020140_00	410210020140-001AT	12/14/2010	2		2
OK410210020140_00	410210020140-001AT	2/14/2011	12.7		3
OK410210020140_00	410210020140-001AT	3/29/2011	4.5		2
OK410210020140_00	410210020140-001AT	5/24/2011	13.5		3
OK410210020140_00	410210020140-001AT	10/25/2011	2		1
OK410210020140_00	410210020140-001AT	11/29/2011	8		3
OK410210020140_00	410210020140-001AT	1/4/2012	5.3		2
OK410210020140_00	410210020140-001AT	4/17/2012	2.3		2
OK410210020300_00	OK410210-02-0300C	6/29/2005	3.86	<10	
OK410210020300_00	OK410210-02-0300C	7/13/2005	4.16		
OK410210020300_00	OK410210-02-0300C	8/2/2005	5.66	<10	
OK410210020300_00	OK410210-02-0300C	9/7/2005	14.1	11	
OK410210020300_00	OK410210-02-0300C	10/11/2005	9.64	<10	
OK410210020300_00	OK410210-02-0300C	11/15/2005	1.98	<10	
OK410210020300_00	OK410210-02-0300C	12/21/2005	2.48	<10	
OK410210020300_00	OK410210-02-0300C	1/31/2006	30.2	27	
OK410210020300_00	OK410210-02-0300C	3/7/2006	6.12	<10	
OK410210020300_00	OK410210-02-0300C	4/11/2006	4.2	<10	
OK410210020300_00	OK410210-02-0300C	5/16/2006	10.8	<10	
OK410210020300_00	OK410210-02-0300C	6/20/2006	3.49	<10	
OK410210020300_00	OK410210-02-0300C	7/17/2006	16.6	<10	
OK410210020300_00	OK410210-02-0300C	8/21/2006	64.8	53	
OK410210020300_00	OK410210-02-0300C	9/25/2006	716	<10	

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410210020300_00	OK410210-02-0300C	10/30/2006	9.69	<10	
OK410210020300_00	OK410210-02-0300C	12/12/2006	7.51	<10	
OK410210020300_00	OK410210-02-0300C	1/22/2007	11.3	<10	High Flow
OK410210020300_00	OK410210-02-0300C	2/12/2007	6.63	<10	
OK410210020300_00	OK410210-02-0300C	3/19/2007	2.98	<10	
OK410210020300_00	OK410210-02-0300C	4/16/2007	8.88	<10	
OK410210060020_00	OK410210-06-0020G	6/29/2005	4.13	<10	
OK410210060020_00	OK410210-06-0020G	8/2/2005	5.64	<10	
OK410210060020_00	OK410210-06-0020G	8/11/2005	7.46		
OK410210060020_00	OK410210-06-0020G	8/29/2005	12.3	<10	
OK410210060020_00	OK410210-06-0020G	10/3/2005	14.5	26	
OK410210060020_00	OK410210-06-0020G	11/14/2005	10.3	11	
OK410210060020_00	OK410210-06-0020G	12/20/2005	1.44	<10	
OK410210060020_00	OK410210-06-0020G	1/30/2006	28.7	<10	
OK410210060020_00	OK410210-06-0020G	3/6/2006	3.75	<10	
OK410210060020_00	OK410210-06-0020G	4/10/2006	2.6	<10	
OK410210060020_00	OK410210-06-0020G	5/15/2006	6.31	<10	
OK410210060020_00	OK410210-06-0020G	6/12/2006	3.25	<10	
OK410210060020_00	OK410210-06-0020G	7/24/2006	4.4	<10	
OK410210060020_00	OK410210-06-0020G	8/28/2006	6.62	<10	
OK410210060020_00	OK410210-06-0020G	9/25/2006	14.8	<10	
OK410210060020_00	OK410210-06-0020G	10/30/2006	8.89	<10	
OK410210060020_00	OK410210-06-0020G	12/4/2006	8.34	<10	High Flow
OK410210060020_00	OK410210-06-0020G	1/8/2007	6.77	<10	High Flow
OK410210060020_00	OK410210-06-0020G	2/20/2007	6.77	<10	High Flow
OK410210060020_00	OK410210-06-0020G	3/26/2007	2.5	<10	
OK410210060020_00	OK410210-06-0020G	4/16/2007	7.34	<10	
OK410210060320_00	OK410210-06-0320G	6/29/2005	5.2	<10	
OK410210060320_00	OK410210-06-0320G	8/1/2005	11.4	11	
OK410210060320_00	OK410210-06-0320G	8/9/2005	56.7		
OK410210060320_00	OK410210-06-0320G	8/29/2005	6.27	<10	
OK410210060320_00	OK410210-06-0320G	10/3/2005	11	34	
OK410210060320_00	OK410210-06-0320G	11/14/2005	35.4	22	
OK410210060320_00	OK410210-06-0320G	12/20/2005	2.76	<10	
OK410210060320_00	OK410210-06-0320G	1/30/2006	19.6	<10	

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410210060320_00	OK410210-06-0320G	3/6/2006	3.88	<10	
OK410210060320_00	OK410210-06-0320G	4/10/2006	2.87	<10	
OK410210060320_00	OK410210-06-0320G	5/15/2006	4.33	<10	
OK410210060320_00	OK410210-06-0320G	6/12/2006	3.21	<10	
OK410210060320_00	OK410210-06-0320G	7/24/2006	6.18	<10	
OK410210060320_00	OK410210-06-0320G	8/28/2006	7.94	<10	
OK410210060320_00	OK410210-06-0320G	9/25/2006	118	19	
OK410210060320_00	OK410210-06-0320G	10/30/2006	11	<10	
OK410210060320_00	OK410210-06-0320G	12/4/2006	4.53	<10	
OK410210060320_00	OK410210-06-0320G	1/8/2007	4.62	<10	
OK410210060320_00	OK410210-06-0320G	2/20/2007	5.17	<10	
OK410210060320_00	OK410210-06-0320G	3/26/2007	3.45	<10	
OK410210060320_00	OK410210-06-0320G	4/16/2007	4.78	<10	
OK410210060350_00	OK410210-06-0350G	6/29/2005	5.45	<10	
OK410210060350_00	OK410210-06-0350G	8/2/2005	5.2	<10	
OK410210060350_00	OK410210-06-0350G	8/9/2005	8.96		
OK410210060350_00	OK410210-06-0350G	8/29/2005	6.51	18	
OK410210060350_00	OK410210-06-0350G	10/3/2005	21.8	22	
OK410210060350_00	OK410210-06-0350G	11/14/2005	34	13	
OK410210060350_00	OK410210-06-0350G	12/20/2005	4.5	<10	
OK410210060350_00	OK410210-06-0350G	1/30/2006	18.6	<10	
OK410210060350_00	OK410210-06-0350G	3/6/2006	5.28	<10	
OK410210060350_00	OK410210-06-0350G	4/10/2006	3.88	<10	
OK410210060350_00	OK410210-06-0350G	5/15/2006	6.77	<10	
OK410210060350_00	OK410210-06-0350G	6/12/2006	4.85	<10	
OK410210060350_00	OK410210-06-0350G	7/24/2006	14.8	<10	
OK410210060350_00	OK410210-06-0350G	8/28/2006	164	73	
OK410210060350_00	OK410210-06-0350G	9/25/2006	117	33	
OK410210060350_00	OK410210-06-0350G	10/30/2006	10.7	<10	
OK410210060350_00	OK410210-06-0350G	12/4/2006	6.65	<10	
OK410210060350_00	OK410210-06-0350G	1/8/2007	4.09	<10	
OK410210060350_00	OK410210-06-0350G	2/20/2007	4.69	<10	
OK410210060350_00	OK410210-06-0350G	3/26/2007	4.5	<10	
OK410210060350_00	OK410210-06-0350G	4/16/2007	4.99	<10	
OK410210080010_00	410210080010-001AT	11/4/1998	9	2	2

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410210080010_00	410210080010-001AT	12/8/1998	10	10	4
OK410210080010_00	410210080010-001AT	1/5/1999	8	4	3
OK410210080010_00	410210080010-001AT	2/1/1999	20	4	4
OK410210080010_00	410210080010-001AT	3/2/1999	5	2	2
OK410210080010_00	410210080010-001AT	4/7/1999	16	3	4
OK410210080010_00	410210080010-001AT	5/5/1999	89	44	5
OK410210080010_00	410210080010-001AT	6/8/1999	8	3	2
OK410210080010_00	410210080010-001AT	7/6/1999	11	3	3
OK410210080010_00	410210080010-001AT	8/3/1999	5	1	2
OK410210080010_00	410210080010-001AT	9/7/1999	4	11	1
OK410210080010_00	410210080010-001AT	11/2/1999	10	9	1
OK410210080010_00	410210080010-001AT	11/30/1999	7	15	1
OK410210080010_00	410210080010-001AT	1/11/2000	11	6	3
OK410210080010_00	410210080010-001AT	2/8/2000	9	3	3
OK410210080010_00	410210080010-001AT	3/6/2000	8	3	3
OK410210080010_00	410210080010-001AT	5/3/2000	26	36	4
OK410210080010_00	410210080010-001AT	6/6/2000	18	18	3
OK410210080010_00	410210080010-001AT	7/11/2000	5	6	2
OK410210080010_00	410210080010-001AT	8/8/2000	6	12	2
OK410210080010_00	410210080010-001AT	9/5/2000	5	42	1
OK410210080010_00	410210080010-001AT	10/3/2000	5	1	1
OK410210080010_00	410210080010-001AT	11/7/2000	21	26	4
OK410210080010_00	410210080010-001AT	2/12/2007	4		2
OK410210080010_00	410210080010-001AT	3/5/2007	5		2
OK410210080010_00	410210080010-001AT	3/19/2007	4		2
OK410210080010_00	410210080010-001AT	4/17/2007	6		2
OK410210080010_00	410210080010-001AT	5/8/2007	22		3
OK410210080010_00	410210080010-001AT	5/21/2007	4		2
OK410210080010_00	410210080010-001AT	6/4/2007	8		3
OK410210080010_00	410210080010-001AT	6/26/2007	22		3
OK410210080010_00	410210080010-001AT	7/9/2007	8		3
OK410210080010_00	410210080010-001AT	7/30/2007	4		2
OK410210080010_00	410210080010-001AT	9/4/2007	10		2
OK410210080010_00	410210080010-001AT	10/8/2007	13		2
OK410210080010_00	410210080010-001AT	10/22/2007	16		1

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410210080010_00	410210080010-001AT	11/13/2007	5		2
OK410210080010_00	410210080010-001AT	12/3/2007	4		2
OK410210080010_00	410210080010-001AT	4/8/2008	11		3
OK410210080010_00	410210080010-001AT	5/12/2008	5		3
OK410210080010_00	410210080010-001AT	8/18/2008	10		2
OK410210080010_00	410210080010-001AT	9/30/2008	5		1
OK410210080010_00	410210080010-001AT	12/9/2008	8		2
OK410210080010_00	410210080010-001AT	2/10/2009	8.6		2
OK410210080010_00	410210080010-001AT	3/10/2009	4.25		2
OK410210080010_00	410210080010-001AT	4/1/2009	22.25		3
OK410210080010_00	410210080010-001AT	5/19/2009	8		2
OK410210080010_00	410210080010-001AT	9/15/2009	7		3
OK410210080010_00	410210080010-001AT	12/15/2009	8.3		2
OK410210080010_00	410210080010-001AT	2/23/2010	27.5		3
OK410210080010_00	410210080010-001AT	3/30/2010	9.5		2
OK410210080010_00	410210080010-001AT	6/15/2010	4		1
OK410210080010_00	410210080010-001AT	6/22/2010	3		1
OK410210080010_00	410210080010-001AT	10/5/2010	2.8		2
OK410210080010_00	410210080010-001AT	12/14/2010	2		2
OK410210080010_00	410210080010-001AT	2/16/2011	11		2
OK410210080010_00	410210080010-001AT	3/29/2011	3.5		2
OK410210080010_00	410210080010-001AT	5/24/2011	11.3		4
OK410210080010_00	410210080010-001AT	8/16/2011	2		1
OK410210080010_00	410210080010-001AT	10/25/2011	1.8		1
OK410210080010_00	410210080010-001AT	11/29/2011	5.8		2
OK410210080010_00	410210080010-001AT	1/3/2012	57.8		2
OK410210080010_00	410210080010-001AT	4/17/2012	2		2
OK410300010020_00	OK410300-01-0020F	6/21/2005	18.7	20	
OK410300010020_00	OK410300-01-0020F	7/21/2005	10.1		
OK410300010020_00	OK410300-01-0020F	7/26/2005	7.46	<10	
OK410300010020_00	OK410300-01-0020F	8/30/2005	16.1	19	
OK410300010020_00	OK410300-01-0020F	10/4/2005	25.1	11	
OK410300010020_00	OK410300-01-0020F	11/8/2005	10.8	<10	
OK410300010020_00	OK410300-01-0020F	12/13/2005	10.3	<10	
OK410300010020_00	OK410300-01-0020F	1/24/2006	18.7	12	

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

Waterbody ID	WQM Station	Date	Turbidity (NTU)	TSS (mg/L)	Flow Condition*
OK410300010020_00	OK410300-01-0020F	2/28/2006	32.9	20	
OK410300010020_00	OK410300-01-0020F	4/4/2006	17	<10	
OK410300010020_00	OK410300-01-0020F	5/9/2006	20.5	20	
OK410300010020_00	OK410300-01-0020F	6/13/2006	21	15	
OK410300010020_00	OK410300-01-0020F	7/18/2006	11.6	11	
OK410300010020_00	OK410300-01-0020F	8/22/2006	66.8	30	
OK410300010020_00	OK410300-01-0020F	9/26/2006	28.6	22	
OK410300010020_00	OK410300-01-0020F	10/31/2006	9.87	<10	
OK410300010020_00	OK410300-01-0020F	12/5/2006	7.18	<10	
OK410300010020_00	OK410300-01-0020F	1/9/2007	22.4	<10	
OK410300010020_00	OK410300-01-0020F	2/13/2007	16.3	<10	High Flow
OK410300010020_00	OK410300-01-0020F	4/17/2007	19.6	<10	
OK410300010100_00	OK410300-01-0100C	6/3/2005	5.01		
OK410300010100_00	OK410300-01-0100C	6/21/2005	38.6	88	
OK410300010100_00	OK410300-01-0100C	7/26/2005	44.9	121	
OK410300010100_00	OK410300-01-0100C	8/30/2005	119	46	
OK410300010100_00	OK410300-01-0100C	10/4/2005	52.7	39	
OK410300010100_00	OK410300-01-0100C	11/8/2005	72.6	46	
OK410300010100_00	OK410300-01-0100C	12/13/2005	28.4	<10	
OK410300010100_00	OK410300-01-0100C	1/24/2006	20.6	13	
OK410300010100_00	OK410300-01-0100C	2/28/2006	16.5	<10	
OK410300010100_00	OK410300-01-0100C	4/4/2006	20.6	<10	
OK410300010100_00	OK410300-01-0100C	5/9/2006	61.7	18	
OK410300010100_00	OK410300-01-0100C	6/13/2006	38.7	<10	
OK410300010100_00	OK410300-01-0100C	7/18/2006	43.1	19	
OK410300010100_00	OK410300-01-0100C	10/31/2006	1.17	<10	
OK410300010100_00	OK410300-01-0100C	12/5/2006	4.04	<10	
OK410300010100_00	OK410300-01-0100C	1/9/2007	38.5	11	
OK410300010100_00	OK410300-01-0100C	2/13/2007	1.6	<10	
OK410300010100_00	OK410300-01-0100C	3/20/2007	2.96	<10	
OK410300010100_00	OK410300-01-0100C	4/17/2007	4.19	<10	

* Stream flow conditions (1=none, 2=light, 3=moderate, 4=heavy, 5=stormwater). If flow conditions are not available, they are assumed as low flow conditions. Cells in red are best estimates based on other information

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:

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

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

   a. 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.

   b. 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.

   c. 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.

3. 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 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 Appendix B-1**. 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 Appendix 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

4. 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).

   a. <u>Furness Method</u>

      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.

   b. <u>Wurbs Modified NRCS Method</u>

      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, is 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.

c. 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.

5. In the rare case where no coincident flow data are available for a WQM station and 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 Appendix B-2: Estimated Flow Exceedance Percentiles

WBID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060320_00	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
USGS Gage Reference	7336820 (instream)	7338500 (upstream)	7338500 (instream)	7335700 (adjacent)	7337900 (adjacent)	7338750 (adjacent)	7335700 (adjacent)	7335700 (adjacent)	HGLO2 (upstream)	7335700 (adjacent)	7335700 (adjacent)	7335790 (downstream)	7335700 (instream)	7337900 (instream)	7337900 (adjacent)
Drainage Area (sq. mile)	47,401.2	1,284.1	1,228.0	49.8	62.9	118.5	24.8	15.6	1756.8	60.9	14.7	414.2	92.7	364.7	460.2
NRCS Curve Number	75.4	74.3	72.6	70.3	70.2	67.7	64.9	66.9	72.6	73.1	74.5	69.0	67.9	70.7	69.1
Ave. Annual Rainfall (inch)	52.0	52.0	52.2	54.9	52.1	56.5	60.6	57.1	49.2	50.4	49.8	51.8	57.1	53.6	52.9
Flow Exceedance Frequency	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)	Q (cfs)
0	278000.0	75917.5	72600.0	7487.7	10440.3	12404.9	3725.2	2352.2	20200.6	9165.8	2216.5	21807.8	5960.0	53100.0	76362.2
1	71075.0	13643.1	13045.0	1292.1	1304.0	2489.9	642.8	405.9	16220.2	1581.7	382.5	5727.9	1028.5	6632.4	9537.9
2	63650.0	10866.8	10390.0	780.3	846.4	1687.7	388.2	245.1	14016.9	955.2	231.0	4037.3	621.1	4304.8	6190.7
3	58000.0	9333.4	8923.5	559.1	620.8	1183.2	278.1	175.6	12668.6	684.4	165.5	3158.6	445.0	3157.2	4540.3
4	54400.0	8430.4	8060.0	447.8	481.7	982.8	222.8	140.7	11399.3	548.1	132.5	2684.5	356.4	2450.0	3523.3
5	51000.0	7711.5	7372.5	368.1	395.2	795.3	183.1	115.6	10757.2	450.6	109.0	2433.8	293.0	2010.0	2890.5
6	47600.0	7227.9	6910.0	320.4	334.2	651.5	159.4	100.6	10090.1	392.2	94.8	2233.2	255.0	1700.0	2444.7
7	44800.0	6872.4	6570.0	283.9	291.0	570.6	141.3	89.2	9254.4	347.6	84.0	2068.2	226.0	1480.0	2128.4
8	42600.0	6537.8	6250.0	255.0	251.7	519.0	126.9	80.1	8502.4	312.2	75.5	1955.6	203.0	1280.0	1840.7
9	40500.0	6213.6	5940.0	232.4	222.2	472.2	115.6	73.0	7817.8	284.5	68.8	1831.1	185.0	1130.0	1625.0
10	38250.0	5858.1	5600.0	216.1	202.5	430.7	107.5	67.9	7263.0	264.5	64.0	1736.3	172.0	1030.0	1481.2
11	36300.0	5513.0	5270.0	201.5	183.0	397.5	100.2	63.3	6509.0	246.6	59.6	1623.7	160.4	930.6	1338.3
12	34400.0	5199.3	4970.0	188.4	167.1	375.5	93.8	59.2	5993.6	230.7	55.8	1528.9	150.0	850.0	1222.4
13	32500.0	4863.2	4648.5	177.1	155.0	353.4	88.1	55.6	5555.6	216.8	52.4	1440.0	141.0	788.1	1133.4
14	31000.0	4561.5	4360.0	165.8	143.9	331.8	82.5	52.1	5275.3	203.0	49.1	1362.8	132.0	732.0	1052.7
15	29300.0	4258.2	4070.0	155.8	133.7	307.4	77.5	48.9	4908.5	190.7	46.1	1262.2	124.0	680.0	977.9
16	27800.0	3986.4	3810.0	148.2	124.3	289.3	73.8	46.6	4407.9	181.5	43.9	1185.2	118.0	632.0	908.9

WBID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060320_00	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
USGS Gage Reference	**7336820 (instream)**	**7338500 (upstream)**	**7338500 (instream)**	**7335700 (adjacent)**	**7337900 (adjacent)**	**7338750 (adjacent)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**HGLO2 (upstream)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**7335790 (downstream)**	**7335700 (instream)**	**7337900 (instream)**	**7337900 (adjacent)**
Drainage Area (sq. mile)	**47,401.2**	**1,284.1**	**1,228.0**	**49.8**	**62.9**	**118.5**	**24.8**	**15.6**	**1756.8**	**60.9**	**14.7**	**414.2**	**92.7**	**364.7**	**460.2**
NRCS Curve Number	**75.4**	**74.3**	**72.6**	**70.3**	**70.2**	**67.7**	**64.9**	**66.9**	**72.6**	**73.1**	**74.5**	**69.0**	**67.9**	**70.7**	**69.1**
Ave. Annual Rainfall (inch)	**52.0**	**52.0**	**52.2**	**54.9**	**52.1**	**56.5**	**60.6**	**57.1**	**49.2**	**50.4**	**49.8**	**51.8**	**57.1**	**53.6**	**52.9**
Flow Exceedance Frequency	**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)**	**Q (cfs)**
17	26200.0	3704.0	3540.0	140.7	116.8	271.7	70.0	44.2	4118.7	172.2	41.7	1114.1	112.0	594.0	854.2
18	24700.0	3453.1	3300.0	133.2	109.3	256.9	66.3	41.8	3873.6	163.0	39.4	1048.9	106.0	556.0	799.6
19	23500.0	3223.0	3080.0	126.9	103.0	242.9	63.1	39.9	3644.2	155.3	37.6	971.9	101.0	524.0	753.6
20	22200.0	2993.0	2860.0	120.6	96.9	230.8	60.0	37.9	3440.7	147.6	35.7	906.7	96.0	493.0	709.0
21	21100.0	2752.5	2630.0	114.3	92.0	218.7	56.9	35.9	3259.9	139.9	33.8	847.4	91.0	468.0	673.0
22	19900.0	2563.2	2449.0	109.3	87.1	208.3	54.4	34.3	3093.1	133.8	32.4	794.1	87.0	443.0	637.1
23	19000.0	2365.6	2260.0	105.5	82.8	200.6	52.5	33.2	2913.3	129.2	31.2	746.7	84.0	421.0	605.4
24	17900.0	2198.3	2100.0	100.5	78.6	190.1	50.0	31.6	2745.8	123.0	29.8	693.3	80.0	400.0	575.2
25	17200.0	2062.3	1970.0	95.5	74.9	182.3	47.5	30.0	2572.7	116.9	28.3	645.9	76.0	381.0	547.9
26	16400.0	1926.4	1840.0	91.7	71.4	174.1	45.6	28.8	2404.1	112.3	27.1	604.5	73.0	363.0	522.0
27	15600.0	1790.5	1710.0	87.9	68.6	166.4	43.8	27.6	2194.8	107.7	26.0	556.9	70.0	349.0	501.9
28	14900.0	1681.7	1606.0	84.2	65.1	160.1	41.9	26.4	2027.1	103.0	24.9	514.9	67.0	331.0	476.0
29	14200.0	1581.3	1510.0	80.4	62.1	153.1	40.0	25.3	1919.3	98.4	23.8	475.3	64.0	316.0	454.4
30	13450.0	1497.7	1430.0	76.6	59.0	145.9	38.1	24.1	1801.7	93.8	22.7	441.6	61.0	300.0	431.4
31	12825.0	1403.6	1340.0	72.9	56.5	139.9	36.3	22.9	1716.5	89.2	21.6	409.7	58.0	287.4	413.4
32	12300.0	1319.9	1260.0	69.1	53.9	134.4	34.4	21.7	1563.8	84.6	20.5	379.3	55.0	274.0	394.0
33	11700.0	1236.3	1180.0	66.6	51.3	128.5	33.1	20.9	1422.3	81.5	19.7	353.0	53.0	261.0	375.3
34	11200.0	1163.1	1110.0	64.1	49.0	123.1	31.9	20.1	1288.6	78.4	19.0	327.6	51.0	249.0	358.1

WBID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060320_00	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
USGS Gage Reference	**7336820 (instream)**	**7338500 (upstream)**	**7338500 (instream)**	**7335700 (adjacent)**	**7337900 (adjacent)**	**7338750 (adjacent)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**HGLO2 (upstream)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**7335790 (downstream)**	**7335700 (instream)**	**7337900 (instream)**	**7337900 (adjacent)**
Drainage Area (sq. mile)	**47,401.2**	**1,284.1**	**1,228.0**	**49.8**	**62.9**	**118.5**	**24.8**	**15.6**	**1756.8**	**60.9**	**14.7**	**414.2**	**92.7**	**364.7**	**460.2**
NRCS Curve Number	**75.4**	**74.3**	**72.6**	**70.3**	**70.2**	**67.7**	**64.9**	**66.9**	**72.6**	**73.1**	**74.5**	**69.0**	**67.9**	**70.7**	**69.1**
Ave. Annual Rainfall (inch)	**52.0**	**52.0**	**52.2**	**54.9**	**52.1**	**56.5**	**60.6**	**57.1**	**49.2**	**50.4**	**49.8**	**51.8**	**57.1**	**53.6**	**52.9**
Flow Exceedance Frequency	**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)**	**Q (cfs)**
35	10800.0	1100.3	1050.0	61.6	46.8	117.8	30.6	19.3	1154.0	75.4	18.2	303.4	49.0	238.0	342.3
36	10300.0	1031.3	984.0	57.8	44.6	113.4	28.8	18.2	1089.4	70.7	17.1	284.5	46.0	227.0	326.4
37	9880.0	971.7	927.0	56.5	42.7	109.0	28.1	17.8	1035.9	69.2	16.7	262.5	45.0	217.0	312.1
38	9480.0	926.8	884.0	54.0	40.7	104.5	26.9	17.0	976.2	66.1	16.0	243.6	43.0	207.0	297.7
39	9142.5	877.6	837.0	51.5	39.1	100.5	25.6	16.2	864.8	63.1	15.2	226.4	41.0	199.0	286.2
40	8790.0	832.7	794.0	49.0	37.2	96.1	24.4	15.4	786.7	60.0	14.5	209.8	39.0	189.0	271.8
41	8490.0	791.3	754.5	47.7	35.8	92.8	23.8	15.0	746.4	58.4	14.1	196.2	38.0	182.0	261.7
42	8175.0	745.9	711.0	45.2	34.2	88.3	22.5	14.2	679.8	55.4	13.4	184.3	36.0	174.0	250.2
43	7890.0	700.9	668.0	44.0	32.6	84.3	21.9	13.8	605.9	53.8	13.0	173.0	35.0	166.0	238.7
44	7610.0	663.3	632.0	41.5	31.1	80.8	20.6	13.0	553.8	50.8	12.3	160.1	33.0	158.0	227.2
45	7360.0	626.7	597.0	40.2	29.5	77.3	20.0	12.6	522.1	49.2	11.9	150.7	32.0	150.0	215.7
46	7085.0	592.1	564.0	37.7	28.1	74.4	18.8	11.8	473.4	46.1	11.2	141.0	30.0	143.0	205.6
47	6840.0	558.7	532.0	35.2	26.7	72.1	17.5	11.1	413.9	43.1	10.4	132.2	28.0	136.0	195.6
48	6580.0	526.9	501.6	33.9	25.4	69.2	16.9	10.7	376.2	41.5	10.0	124.4	27.0	129.0	185.5
49	6360.0	498.1	474.1	32.7	24.2	66.5	16.3	10.3	349.1	40.0	9.7	115.6	26.0	123.0	176.9
50	6155.0	471.4	448.5	31.4	22.8	63.3	15.6	9.9	336.2	38.4	9.3	108.4	25.0	116.0	166.8
51	5932.5	444.7	423.0	28.9	21.6	61.1	14.4	9.1	325.5	35.4	8.6	101.3	23.0	110.0	158.2
52	5770.0	418.6	398.0	27.6	20.4	58.2	13.8	8.7	321.5	33.8	8.2	94.8	22.0	104.0	149.6

WBID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060320_00	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
USGS Gage Reference	**7336820 (instream)**	**7338500 (upstream)**	**7338500 (instream)**	**7335700 (adjacent)**	**7337900 (adjacent)**	**7338750 (adjacent)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**HGLO2 (upstream)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**7335790 (downstream)**	**7335700 (instream)**	**7337900 (instream)**	**7337900 (adjacent)**
Drainage Area (sq. mile)	**47,401.2**	**1,284.1**	**1,228.0**	**49.8**	**62.9**	**118.5**	**24.8**	**15.6**	**1756.8**	**60.9**	**14.7**	**414.2**	**92.7**	**364.7**	**460.2**
NRCS Curve Number	**75.4**	**74.3**	**72.6**	**70.3**	**70.2**	**67.7**	**64.9**	**66.9**	**72.6**	**73.1**	**74.5**	**69.0**	**67.9**	**70.7**	**69.1**
Ave. Annual Rainfall (inch)	**52.0**	**52.0**	**52.2**	**54.9**	**52.1**	**56.5**	**60.6**	**57.1**	**49.2**	**50.4**	**49.8**	**51.8**	**57.1**	**53.6**	**52.9**
Flow Exceedance Frequency	**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)**	**Q (cfs)**
53	5587.5	396.6	377.0	26.4	19.5	55.6	13.1	8.3	319.4	32.3	7.8	88.9	21.0	99.0	142.4
54	5430.0	374.6	356.0	25.0	18.3	53.4	12.4	7.9	317.5	30.6	7.4	83.0	19.9	93.0	133.7
55	5260.0	354.8	337.0	22.6	17.1	51.5	11.3	7.1	316.4	27.7	6.7	78.0	18.0	87.0	125.1
56	5100.0	336.0	319.0	21.4	16.1	49.3	10.6	6.7	314.7	26.1	6.3	72.9	17.0	82.0	117.9
57	4950.0	320.3	304.0	20.1	14.9	46.8	10.0	6.3	314.4	24.6	6.0	67.6	16.0	76.0	109.3
58	4795.0	301.5	286.0	18.8	14.2	44.2	9.4	5.9	312.7	23.1	5.6	63.4	15.0	72.0	103.5
59	4670.0	285.8	271.0	17.6	13.2	41.6	8.8	5.5	310.4	21.5	5.2	58.1	14.0	67.0	96.4
60	4570.0	268.0	254.0	15.1	12.4	39.4	7.5	4.7	308.4	18.5	4.5	53.9	12.0	63.0	90.6
61	4457.5	253.4	240.0	13.8	11.6	37.5	6.9	4.3	305.7	16.9	4.1	49.8	11.0	59.0	84.8
62	4330.0	236.6	224.0	13.8	10.8	35.3	6.9	4.3	302.4	16.9	4.1	46.2	11.0	55.0	79.1
63	4210.0	223.0	211.0	12.1	10.2	33.1	6.0	3.8	298.8	14.8	3.6	42.1	9.6	52.0	74.8
64	4110.0	209.4	198.0	11.1	9.6	30.9	5.5	3.5	295.3	13.5	3.3	38.5	8.8	49.0	70.5
65	3970.0	195.8	185.0	9.8	8.8	28.7	4.9	3.1	288.1	12.0	2.9	35.6	7.8	45.0	64.7
66	3880.0	183.3	173.0	8.8	8.1	26.9	4.4	2.8	281.5	10.8	2.6	32.0	7.0	41.0	59.0
67	3790.0	172.8	163.0	7.7	7.5	24.7	3.8	2.4	259.4	9.4	2.3	29.3	6.1	38.0	54.6
68	3680.0	163.4	154.0	6.8	6.9	22.8	3.4	2.1	243.1	8.3	2.0	26.7	5.4	35.0	50.3
69	3590.0	155.1	146.0	5.9	6.1	21.0	2.9	1.9	238.4	7.2	1.7	23.7	4.7	31.0	44.6
70	3500.0	144.6	136.0	5.3	5.7	18.8	2.6	1.7	237.0	6.5	1.6	21.3	4.2	29.0	41.7

WBID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060320_00	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
USGS Gage Reference	**7336820 (instream)**	**7338500 (upstream)**	**7338500 (instream)**	**7335700 (adjacent)**	**7337900 (adjacent)**	**7338750 (adjacent)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**HGLO2 (upstream)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**7335790 (downstream)**	**7335700 (instream)**	**7337900 (instream)**	**7337900 (adjacent)**
Drainage Area (sq. mile)	**47,401.2**	**1,284.1**	**1,228.0**	**49.8**	**62.9**	**118.5**	**24.8**	**15.6**	**1756.8**	**60.9**	**14.7**	**414.2**	**92.7**	**364.7**	**460.2**
NRCS Curve Number	**75.4**	**74.3**	**72.6**	**70.3**	**70.2**	**67.7**	**64.9**	**66.9**	**72.6**	**73.1**	**74.5**	**69.0**	**67.9**	**70.7**	**69.1**
Ave. Annual Rainfall (inch)	**52.0**	**52.0**	**52.2**	**54.9**	**52.1**	**56.5**	**60.6**	**57.1**	**49.2**	**50.4**	**49.8**	**51.8**	**57.1**	**53.6**	**52.9**
Flow Exceedance Frequency	**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)**	**Q (cfs)**
71	3390.0	135.2	127.0	4.8	5.1	17.3	2.4	1.5	235.4	5.8	1.4	19.0	3.8	26.0	37.4
72	3310.0	126.8	119.0	4.3	4.7	15.5	2.1	1.3	234.4	5.2	1.3	16.6	3.4	24.0	34.5
73	3220.0	118.5	111.0	3.6	4.3	14.0	1.8	1.1	232.4	4.5	1.1	14.8	2.9	22.0	31.6
74	3135.0	111.1	104.0	3.3	3.9	12.9	1.6	1.0	227.6	4.0	1.0	13.0	2.6	20.0	28.8
75	3040.0	104.9	98.0	2.8	3.5	11.4	1.4	0.9	214.2	3.4	0.8	11.9	2.2	18.0	25.9
76	2940.0	98.6	92.0	2.4	3.1	9.6	1.2	0.7	203.0	2.9	0.7	10.1	1.9	16.0	23.0
77	2850.0	92.3	86.0	2.1	2.8	8.5	1.1	0.7	194.1	2.6	0.6	9.5	1.7	14.0	20.1
78	2760.0	86.0	80.0	1.9	2.6	7.7	0.9	0.6	186.6	2.3	0.6	8.3	1.5	13.0	18.7
79	2680.0	81.9	76.0	1.6	2.2	6.6	0.8	0.5	179.2	2.0	0.5	7.1	1.3	11.0	15.8
80	2610.0	76.6	71.0	1.4	2.0	5.9	0.7	0.4	171.5	1.7	0.4	6.5	1.1	10.0	14.4
81	2517.5	71.4	66.0	1.2	1.8	5.5	0.6	0.4	163.9	1.5	0.4	5.6	1.0	9.0	12.9
82	2430.0	67.2	62.0	1.0	1.6	4.8	0.5	0.3	155.4	1.2	0.3	5.0	0.8	8.2	11.8
83	2330.0	63.0	58.0	0.8	1.5	4.4	0.4	0.3	148.4	1.0	0.3	4.6	0.7	7.4	10.6
84	2230.0	58.9	54.0	0.7	1.3	4.0	0.3	0.2	146.6	0.8	0.2	4.1	0.5	6.6	9.5
85	2140.0	54.7	50.0	0.5	1.2	3.7	0.3	0.2	145.4	0.6	0.2	3.6	0.4	5.9	8.5
86	2040.0	51.5	47.0	0.4	1.0	3.5	0.2	0.1	143.9	0.5	0.1	3.1	0.3	5.3	7.6
87	1960.0	48.4	44.0	0.3	0.9	3.1	0.1	0.1	142.4	0.3	0.1	2.7	0.2	4.5	6.5
88	1860.0	45.3	41.0	0.2	0.7	2.8	0.1	0.1	129.1	0.2	0.05	2.3	0.1	3.8	5.5

WBID	OK410100010010_10	OK410200010200_00	OK410200010200_10	OK410200030010_00	OK410210020300_00	OK410210060020_00	OK410210060320_00	OK410210060350_00	OK410300010010_00	OK410300010020_00	OK410300010100_00	OK410310010010_00	OK410310020010_10	OK410210080010_00	OK410210020140_00
USGS Gage Reference	**7336820 (instream)**	**7338500 (upstream)**	**7338500 (instream)**	**7335700 (adjacent)**	**7337900 (adjacent)**	**7338750 (adjacent)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**HGLO2 (upstream)**	**7335700 (adjacent)**	**7335700 (adjacent)**	**7335790 (downstream)**	**7335700 (instream)**	**7337900 (instream)**	**7337900 (adjacent)**
Drainage Area (sq. mile)	**47,401.2**	**1,284.1**	**1,228.0**	**49.8**	**62.9**	**118.5**	**24.8**	**15.6**	**1756.8**	**60.9**	**14.7**	**414.2**	**92.7**	**364.7**	**460.2**
NRCS Curve Number	**75.4**	**74.3**	**72.6**	**70.3**	**70.2**	**67.7**	**64.9**	**66.9**	**72.6**	**73.1**	**74.5**	**69.0**	**67.9**	**70.7**	**69.1**
Ave. Annual Rainfall (inch)	**52.0**	**52.0**	**52.2**	**54.9**	**52.1**	**56.5**	**60.6**	**57.1**	**49.2**	**50.4**	**49.8**	**51.8**	**57.1**	**53.6**	**52.9**
Flow Exceedance Frequency	**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)**	**Q (cfs)**
89	1777.5	42.1	38.0	0.1	0.6	2.6	0.0	0.0	118.6	0.1	0.02	2.0	0.1	3.1	4.5
90	1690.0	39.0	35.0	0.0	0.5	2.4	0.0	0.0	109.8	0.0	0	1.7	0.0	2.6	3.7
91	1600.0	35.9	32.0	0.0	0.4	2.1	0.0	0.0	103.3	0.0	0	1.4	0.0	2.2	3.2
92	1500.0	32.7	29.0	0.0	0.4	1.9	0.0	0.0	97.2	0.0	0	1.2	0.0	1.8	2.6
93	1400.0	29.6	26.0	0.0	0.3	1.6	0.0	0.0	86.9	0.0	0	0.9	0.0	1.5	2.2
94	1290.0	27.5	24.0	0.0	0.2	1.3	0.0	0.0	82.8	0.0	0	0.6	0.0	1.1	1.6
95	1140.0	24.1	20.8	0.0	0.1	1.1	0.0	0.0	81.5	0.0	0	0.3	0.0	0.7	1.0
96	1000.0	20.2	17.0	0.0	0.1	0.8	0.0	0.0	79.4	0.0	0	0.2	0.0	0.4	0.6
97	877.5	17.0	14.0	0.0	0.0	0.7	0.0	0.0	72.6	0.0	0	0.0	0.0	0.2	0.3
98	759.5	13.9	11.0	0.0	0.0	0.5	0.0	0.0	52.0	0.0	0	0.0	0.0	0.0	0.0
99	653.3	9.1	6.4	0.0	0.0	0.4	0.0	0.0	39.7	0.0	0	0.0	0.0	0.0	0.0
100	254.0	2.8	0.4	0.0	0.0	0.0	0.0	0.0	34.1	0.0	0	0.0	0.0	0.0	0.0

APPENDIX C: State of Oklahoma Antidegradation Policy

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) **LMFOs**. 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: Censored Data Estimation for the Lower Red River-Little River Basin

Censored Data Estimation for the Lower Red River-Little River Basin

1. Background

Sample size is an important feature of any empirical study. In this Study, 7 out of 15 waterbodies in the Study area have 10 or less countable TSS data, as small as 2 in Rock Creek and Buffalo Creek. Beneficial use of these waterbodies is CWAC, except for Bird Creek (WWAC). The small sample size (less than 25) has been shown to produce estimates with large bias and poor statistical representation. To lessen these problems, all sample data listed in **Table Appendix D-1** were combined under assumption of similar distribution and uniform characteristics. It is assumed as log-normal distribution with equivalent mean (μ) and standard deviation (σ). This assumption can hold because sampling locations are geologically closed and sampling areas are located in same geological province as the Ouachita Mountain Uplift. They are also part of the South Central Plains and Ouachita Mountains Level III ecoregions.

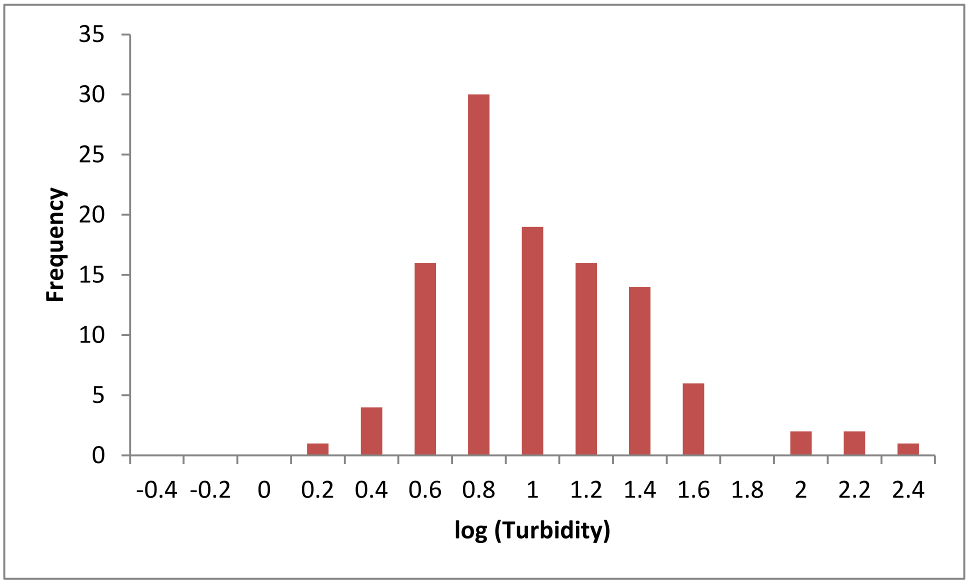
Table Appendix D-1: Censored TSS Data in Base Flow for CWAC waterbodies

WBID	Waterbody name	Total number of TSS data	Number of censored data	% of censored data
OK410210020300_00	Cloudy Creek	18	15	78.9%
OK410200030010_00	Rock Creek	18	16	84.2%
OK410210060020_00	Buffalo Creek	17	15	88.2%
OK410210060350_00	Cow Creek	20	15	75.0%
OK410210060320_00	Beech Creek	20	16	80.0%
OK410300010020_00	Gates Creek	18	8	44.4%
Total		**111**	**85**	**76.6%**

In addition to this, turbidity data can be combined with above assumption, then so does TSS (TSS is common surrogate for turbidity). All combined turbidity data of waterbodies in **Table Appendix D-1** are illustrated in **Figure Appendix D-1**. It demonstrated log-normal distribution and difference in log-mean between combined data and each stream data ranged approximately 4% to 35%.

Among combined data for TSS, about 77% of TSS data are censored-data, recorded as 10 mg/L of detection limits (dl). Methods for estimating these non-detects (censored data) can be divided into the three classes: simple substitution, distributional, and robust methods.

Figure Appendix D-1: Histogram of Combined Turbidity Data

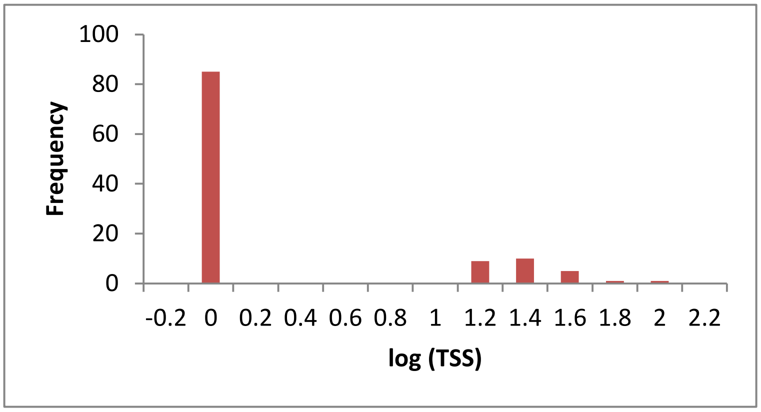


2. Simple Substitution Methods

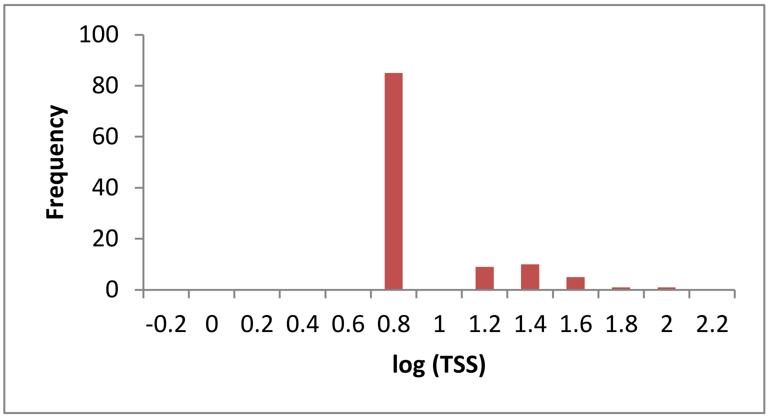
Simple substitution methods substitute a single value such as one-half the reporting limit for each less-than values (censored data). Summary statistics are calculated and shown in **Table Appendix D-2** and **Figure Appendix D-2**.

The distribution resulting from simple substitution methods have large gaps and do not appear realistic. Substitution of one produced estimates of mean and median which were biased low, while substituting the reporting limit resulted in estimates above the true value. Results for the standard deviation and interquartile range (IQR), and for substituting one-half the reporting limit, were also far less desirable than alternative methods discussed below.

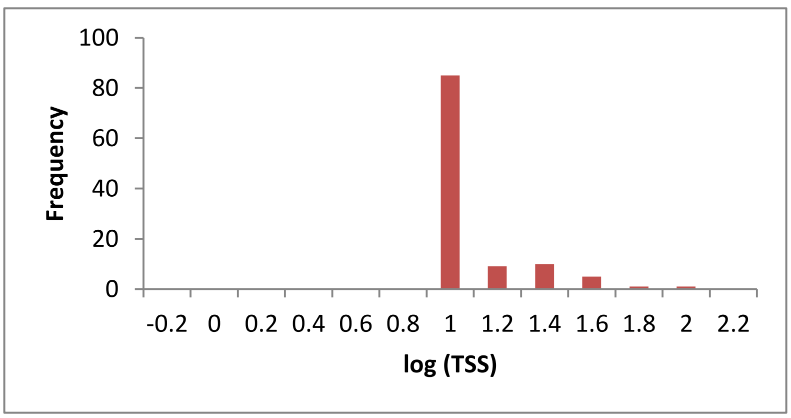
Figure Appendix D-2: Histograms for Simple Substitution Methods



(a) Substitute one [(log(TSS) = 0] for all less-thans



(b) Substitute one-half the reporting limit for all less-thans



(c) Substitute the reporting limit for all less-thans

3. Distributional Methods

Distributional methods use the characteristics of an assumed distribution to estimate summary statistics. Data both below (non-detects) and above (detects) the reporting limit are assumed follow a log-normal distribution. Given a distribution, estimates of summary statistics are computed which best match the observed concentrations above the reporting limit and the percentage of data below the limit. Maximum-likelihood estimation (MLE) is used to estimate summary statistics in this study.

Cohen's procedure can be used for left-censored lognormal distribution (Gilbert, 1987). This hand calculated estimation is compared with estimation results from EXCEL and R (**Table Appendix D-2**). Cohen's procedure is followed below:

$$h = \frac{(n-k)}{n}$$

$$\bar{y}_u = \frac{\sum_{i=1}^{k} y_i}{k}$$

$${s_u}^2 = \frac{\sum_{i=1}^{k}(y_i - \bar{y}_u)^2}{k}$$

$$\hat{\gamma} = \frac{{s_u}^2}{(\bar{y}_u - y_0)^2}$$

$$\hat{\mu}_y = \bar{y}_u - \hat{\lambda}(\bar{y}_u - y_0)$$

$${\hat{\sigma}_y}^2 = {s_u}^2 + \hat{\lambda}(\bar{y}_u - y_0)^2$$

$$\hat{\mu} = exp\left(\hat{\mu}_y + \frac{{\hat{\sigma}_y}^2}{2}\right)$$

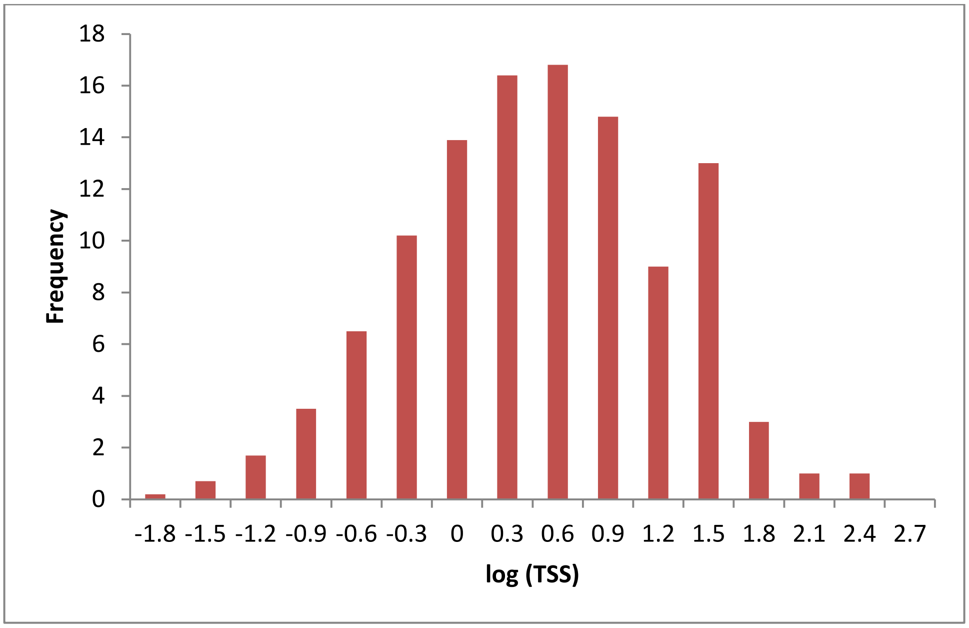
$$\hat{\sigma}^2 = \hat{\mu}^2\left[exp\left({\hat{\sigma}_y}^2\right) - 1\right]$$

Where n = total number of observed TSS, k = number out of n that are above dl, y_i = ln (TSS)$_i$, y_0 = ln (dl), $\hat{\lambda}$ = 2.2 based on h and $\hat{\gamma}$ from Table A15 (Gilbert, 1987), $\hat{\mu}$ = the mean of the lognormal distribution, and $\hat{\sigma}^2$ = the variance of the lognormal distribution.

For EXCEL, calculation includes following steps that are described below:

- Build normal distribution curve for log-transformed TSS data with guessed μ and σ.
- Draw probability density function (pdf) for detects.
- Minimize area difference under the curve for above two distribution curves in the same range of x-axis with solver in EXCEL by changing μ and σ.

Figure Appendix D-3: EXCEL Histograms for Distributional Methods (MLE)



For R, the R code shown below can be used.

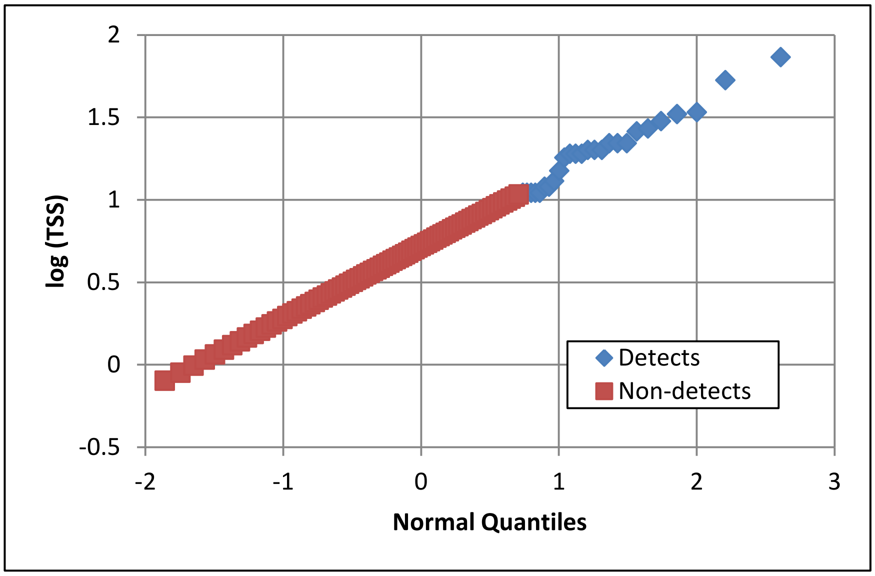
```
read.csv("d:/CWAC.csv", header=T)
data=read.csv("d:/CWAC.csv", header=T)
data_mle=with(data,cenmle(TSS,TSSCen), dis='lognormal')
data_mle
```

4. Robust Methods

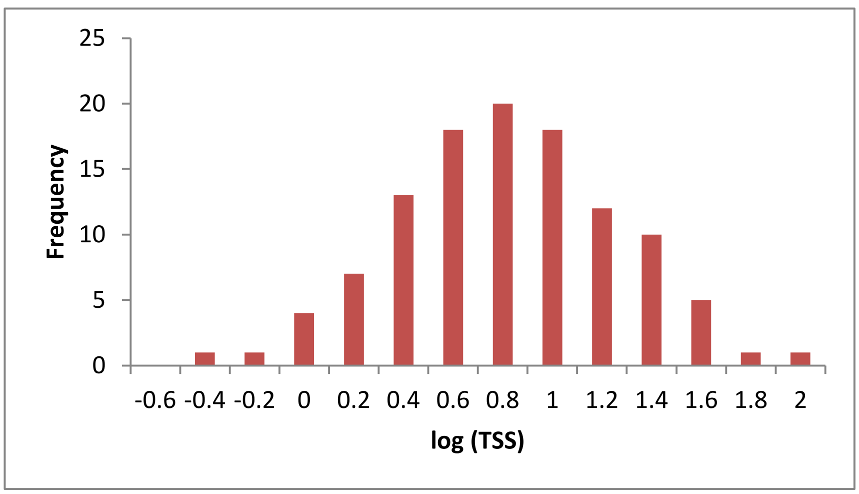
Robust methods combine observed data above the reporting limit with below-limit values extrapolated assuming a distributional shape, in order to compute estimates of summary statistics. A distribution is fit to the data above the reporting limit by either MLE or probability plot procedures, but the fitted distribution is used only to extrapolate a collection of values below the reporting limit.

First, Regression of log of concentration (TSS) verse normal score is used to extrapolate “fill-in” values below the reporting limit. Then, these “fill-ins” are retransformed back to original units, and combined with data above the reporting limit to compute estimates of summary statistics.

Figure Appendix D-4: Robust Method of Estimating Summary Statistics



(a) Normal Quantiles



(b) Histogram for Robust Regression on Order Statistics (ROS)

5. Results

Either Robust ROS or MLE has shown to perform well for estimating the median and IQR in this Study when comparing to turbidity distribution. In addition to this, estimations can be compared for their 75^{th} percentile. For Robust ROS, upper one-sided 95% confidence limit (10 mg/L) of the mean is less than 75^{th} percentile of the estimations whereas that (10.5 mg/L) of the mean for MLE is greater than 75^{th} percentile. This tells that Robust ROS will estimate 95% of estimated mean intervals will not contain 75^{th} percentile and mean estimation is more centered at sample mean than that of MLE.

Use of these methods rather than simple substitution methods for censored data should substantially lower estimation errors for summary statistics. However, extrapolating censored data obtained using one of the estimation methods listed in **Table Appendix D-2** may produce coefficients strongly dependent on the values extrapolated in the regression analysis. Therefore, alternative methods capable of incorporating censored observations are described in **Appendix E**. In this study, dl substitution was used for conservative PRG calculation because dl is believed to be greater than actual concentration of censored data.

Table Appendix D-2: Summary Statistics

Category	Censored data estimation		Mean	Standard deviation	25^{th} percentile	Median	75^{th} percentile	IQR
Turbidity	All detects		13.9	22.9	4.4	6.6	14.3	9.9
TSS	dl subbed		12.9	8.5	10.0	10.0	10.0	0
	dl/2 subbed		9.1	10.0	5.0	5.0	5.0	0
	One [log(TSS)=0]subbed		6.0	11.3	1.0	1.0	1.0	0
	MLE	Cohen's procedure	8.3	13.0	n/a	n/a	n/a	n/a
		EXCEL	8.4	10.6	2.1	4.0	10.0	7.9
		R	8.4	13.0	n/a	4.5	n/a	n/a
	Robust ROS	EXCEL	8.7	10.5	2.7	5.2	10.3	7.6
		R	8.3	10.6	n/a	4.7	n/a	n/a

n/a = not available

References

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Wiley.

APPENDIX E: Censored Data Regression for the Lower Red River-Little River Basin

Censored Data Regression for the Lower Red River-Little River Basin

1. Background

With censored data the use of ordinary least squares (OLS) for regression is prohibited (See **Table Appendix D-1**; Helsel and Hirsch, 2002). Coefficients for slopes and intercept cannot be computed without values for the censored observations, and substituting fabricated values may produce coefficients strongly dependent on the values substituted. Two alternative methods capable of incorporating censored observations are described below. All data were log-tranformed and censored data were set as a range from one (TSS=1 mg/L; log (TSS) = 0) to detection limit (TSS=10 mg/L; log (TSS) = 1).

2. Maximum Likelihood Estimation (MLE)

Maximum likelihood estimation (MLE) in the presence of censored data is very similar to the estimation that occurs when conducting a standard linear regression. The difference is that the likelihood that is computed when censored values are present explicitly accounts for the values below the detection limit (dl).

Assumptions for correlation and regression type maximum likelihood estimators include:

- The presence of a linear trend in the data;
- Observations are approximately normally distributed about the estimated trend line;
- Variances are approximately equal in magnitude at all points along the trend line; and
- Independent observations.

The relationship between two variables is presented with the correlation coefficient (logLik-r) and p-value in **Table Appendix E-1**.

3. Non-Parametric Approaches

Non-parametric measures of association tend to evaluate the monotonic association between two variables. This means that such methods are evaluating whether values of the response tend to increase as values of the explanatory variable increase (or vice versa). These non-parametric measures do not quantify how big the increase or decrease is, merely whether there is an increase or decrease. This means that non-parametric methods should be useful at evaluating whether there is an increasing or decreasing trend in the data, regardless of whether or not it is linear.

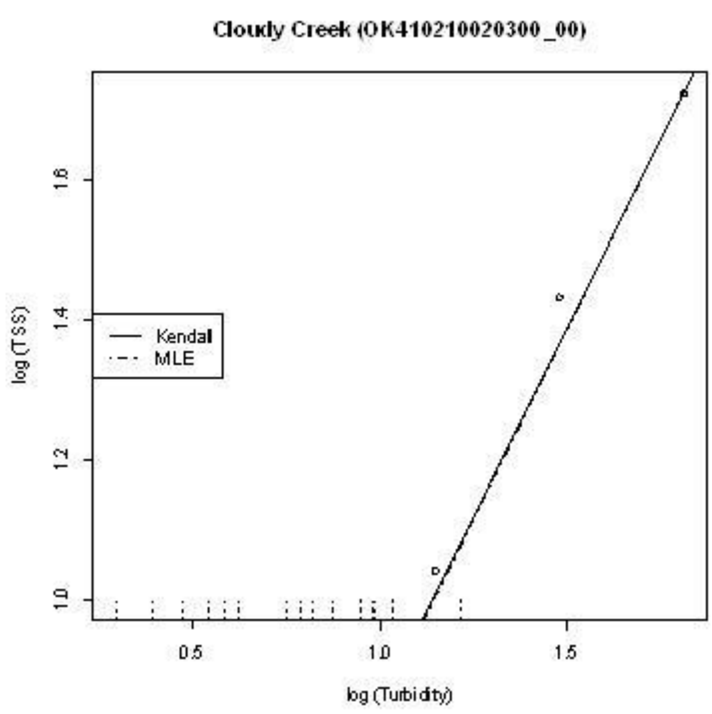
One of the most popular non-parametric measures of association between variables in water quality is Kendall's tau (Huston & Juarez-Colunga, 2009). Like other measures of correlation, Kendall's tau falls between -1 and 1, where values close to 1 indicate a strong positive association and values close to -1 indicate a strong negative association. Values of tau near 0 indicate little or no association. Kendall’s tau was used in this study because of the high number of non-detects (censored data). Because tau depends only on the ranks of the data and not the values themselves, it can be used in cases where some of the data are censored (Helsel and Hirsch, 2002).

To estimate regression coefficient and correlation when censored observations are present, the following R[11] code shown as an example for Cloudy Creek:

```
read.csv("d:/Cloudylog.csv", header=T)
data=read.csv("d:/Cloudylog.csv", header=T)
with(data,cenxyplot(x=Turbidity,xcen=0,y=TSS,ycen=TSSCen,log="",
main="Cloudy Creek (OK410210020300_00)",
xlab="log (Turbidity)",
ylab="log (TSS)",
)
)
mle.reg=cenreg(Cen(obs=data$TSS,censored=data$TSSCen)~data$Turbidity,dist="gaussian")
data.Kendall=cenken(y=data$TSS, ycen=data$TSSCen,x=data$Turbidity,xcen=data$TurCen)
abline(mle.reg,lty=4,lwd=2)
lines(data.Kendall,lwd=2)
legend(x="left",legend=c("Kendall","MLE"),lty=c(1,4),lwd=2)
```

4. Results

Figure Appendix E-1: Trend lines estimated for Cloudy Creek by MLE and non-parametric methods



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11 R is a computer language and environment for statistical computing and graphics. http://www.r-project.org/

Figure Appendix E-2: Trend lines estimated for Rock Creek by MLE and non-parametric methods

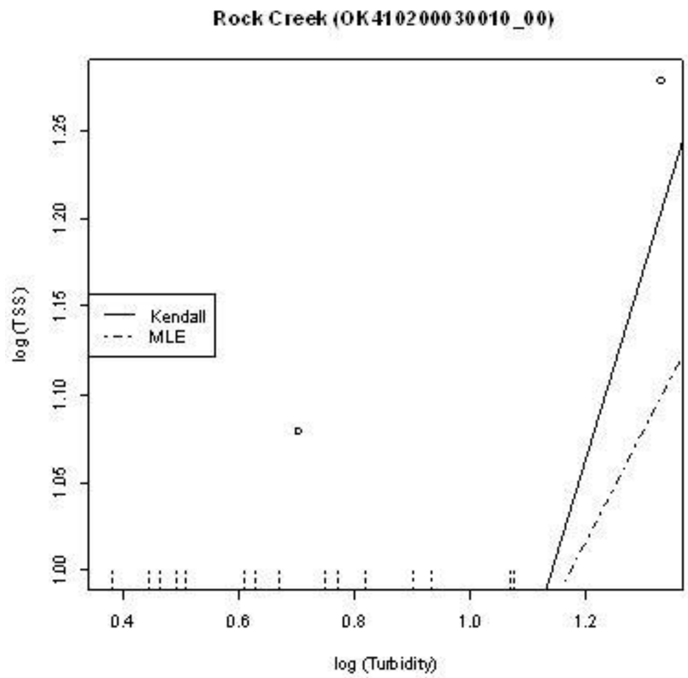


Figure Appendix E-3: Trend lines estimated for Buffalo Creek by MLE and non-parametric methods

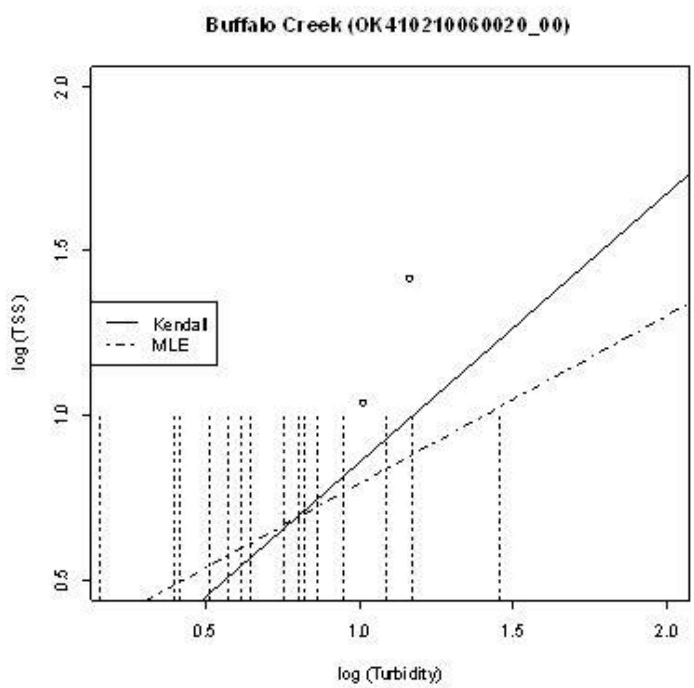


Figure Appendix E-4: Trend lines estimated for Cow Creek by MLE and non-parametric methods

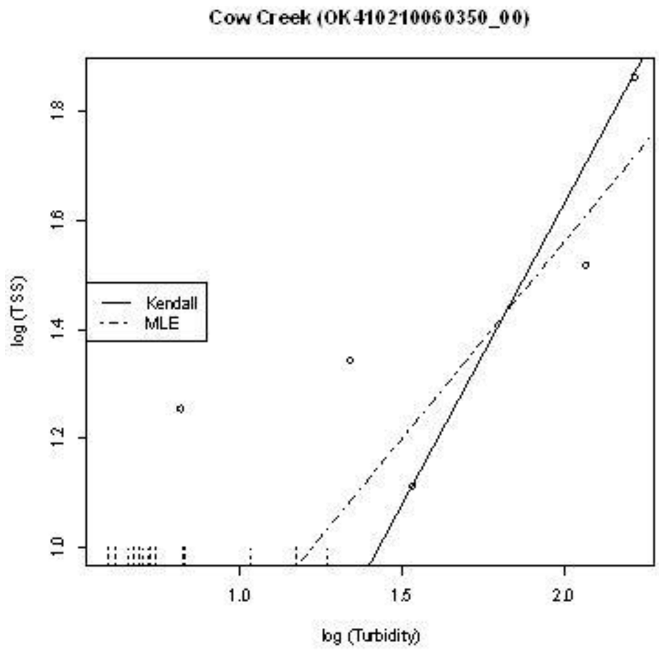


Figure Appendix E-5: Trend lines estimated for Beech Creek by MLE and non-parametric methods

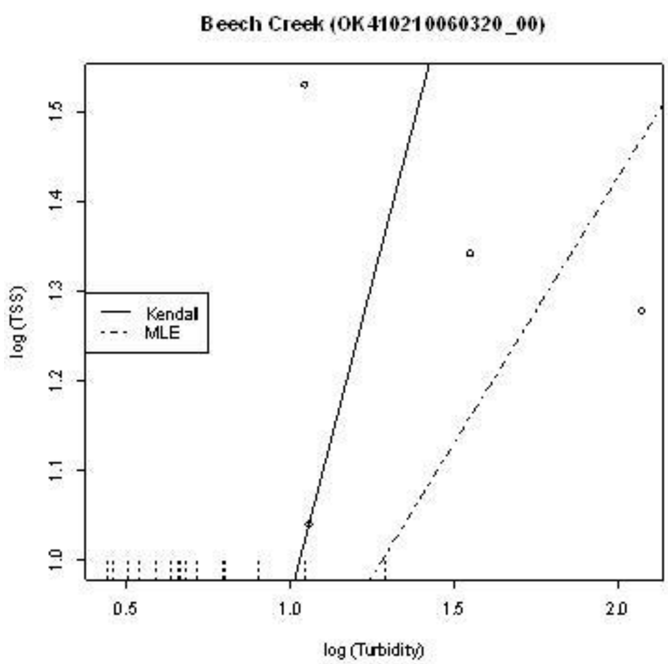


Figure Appendix E-6: Trend lines estimated for Gates Creek by MLE and non-parametric methods

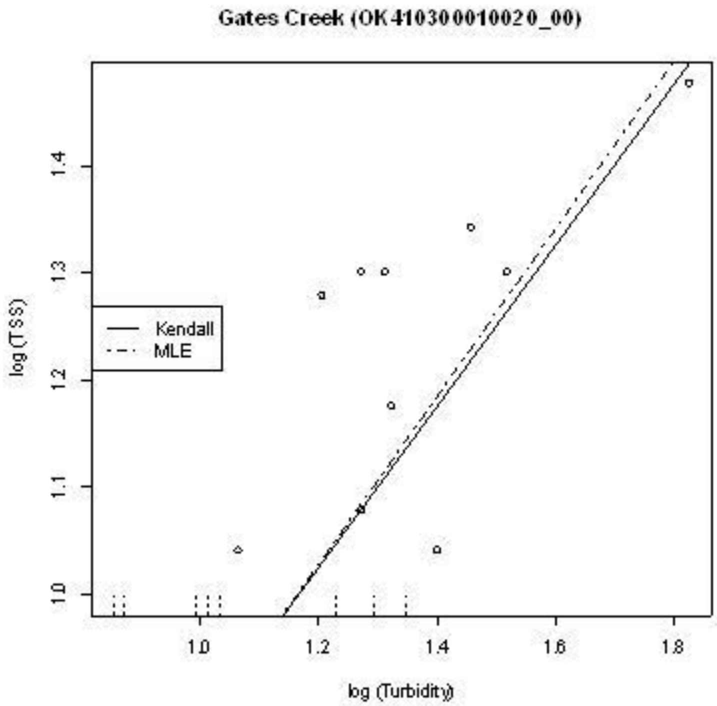
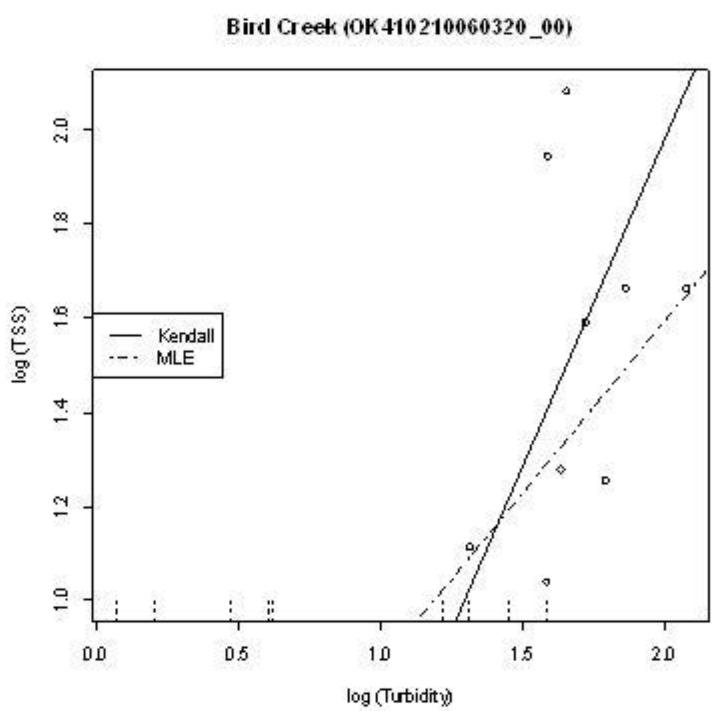


Figure Appendix E-7: Trend lines estimated for Bird Creek by MLE and non-parametric methods



Non-parametric methods have been described as robust compared to parametric ones. This means that when extreme outliers are present, or the distribution of points is highly unusual, non-parametric methods are recommended. In less extreme situations, non-parametric methods performed similarly or slightly worse than MLE methods (Huston & Juarez-Colunga, 2009). In this Study, the MLE method estimated correlation better than Kendall's tau. However, only four out of seven waterbodies had acceptable R-square values (0.49 – 0.74; see **Table Appendix E-1**).

Table Appendix E-1: Regression Statistics with Censored Data

WBID	Waterbody name	MLE Method					Non-parametric method				
		TSS target (mg/L)	Slope	Intercept	Loglik-r (R^2)	p-value	TSS target (mg/L)	Slope	Intercept	tau	p-value
OK410210020300_00	**Cloudy Creek**	6.93	1.09	-0.25	0.86 (**0.74**)	7.3E-07	7.04	1.08	-0.23	0.30	0.0014
OK410200030010_00	**Rock Creek**	7.80	0.63	0.26	0.45 (0.21)	0.042	7.03	1.08	-0.23	0.30	0.0014
OK410210060020_00	**Buffalo Creek**	6.21	0.51	0.28	0.37 (0.14)	0.11	7.04	1.08	-0.23	0.30	0.0014
OK410210060350_00	**Cow Creek**	6.92	0.72	0.12	0.78 (**0.61**)	1.5E-05	3.37	1.10	-0.58	0.37	9.6E-04
OK410210060320_00	**Beech Creek**	6.82	0.59	0.24	0.61 (0.38)	0.0021	9.16	1.40	-0.44	0.30	0.0028
OK410300010020_00	**Gates Creek**	7.43	0.78	0.09	0.73 (**0.54**)	2.1E-04	7.51	0.75	0.13	0.50	0.0023
OK410300010100_00	**Bird Creek**	23.56	0.73	0.13	0.70 (**0.49**)	4.7E-04	36.25	1.39	-0.80	0.54	6.3E-04

References

Helsel, D.R., and Hirsch R.M., 2002. Statistical Methods in Water Resources. Techniques of Water-Resources Investigations, Book 4, Chapter. A3, U.S. Geological Survey, 522 p., http://pubs.usgs.gov/twri/twri4a3/

Huston, C and E Juarez-Colunga 2009. Guidelines for computing summary statistics for data-sets containing non-detects. Department of Statistics and Actuarial Science, Simon Fraser University.

APPENDIX F: Direct Calculation of Percent Reduction Goals from Turbidity Data

Direct Calculation of Percent Reduction Goals from Turbidity Data

1. Background

Regression of censoring greater than 50% is not truly appropriate. However, there is no alternative to find relationship between TSS and turbidity for this study.

Percent reduction goals (PRGs) were computed directly from turbidity data and compared with regression method. PRG agreement between methods can be used as verification of regression method. For this purpose, 10% explicit MOS was applied in direct calculation to meet no more than 10% of the samples exceed the standards. Then, these PRGs were compared with PRGs from regression in this study.

2. Regression Methods

Except for the Red River (LOC regression), censored data MLE regression was applied to all turbidity impaired waterbodies in this study. Censored data were about 44 to 88% of base flow TSS data. Regression methods were explained in Section 4.1 and results from this method were summarized in **Table Appendix F-1**. MOS for MLE regression ranged from 15 to 35% because they were calculated based on NRMSE.

3. Results

PRG differences between MLE method and direct calculation were less than 15% except Rock, Buffalo, Cloudy and Bird Creeks. PRGs from MLE method were similar to or greater than those from direct calculation, except Cloudy Creek. PRGs were not underestimated in the regression method. Therefore, MLE method was more conservative than direct calculation. Even though MLE method was not appropriate for this data set, it did not underestimate pollutant in the most waterbodies.

Table Appendix F-1: Percent Reduction Goals

WBID	Waterbody name	MLE Method			Direct Calculation		
		TSS target (mg/L)	MOS (%)	PRG (%)	Turbidity target (NTU)	MOS (%)	PRG (%)
OK410100010010_10	**Red River**	85.4	15	57.8	50	10	45.8
OK410200010200_10	**Little River**	6.9	15	65.7	10	10	60.9
OK410200030010_00	**Rock Creek**	6.9	30	51.6	10	10	24.4
OK410210020140_00	**Little River**	6.9	15	67.3	10	10	62.6
OK410210020300_00	**Cloudy Creek**	6.9	15	46.5	10	10	70.2
OK410210060020_00	**Buffalo Creek**	6.9	30	56.0	10	10	39.2
OK410210060320_00	**Beech Creek**	6.9	30	78.0	10	10	74.6
OK410210060350_00	**Cow Creek**	6.9	30	78.0	10	10	73.6
OK410210080010_00	**Glover River**	6.9	15	64.3	10	10	59.1
OK410300010020_00	**Gates Creek**	7.4	20	73.1	10	10	72.7
OK410300010100_00	**Bird Creek**	23.6	35	82.6	50	10	38.1

APPENDIX G: Response to Public Comments

Scott A. Thompson
Executive Director

OKLAHOMA
DEPARTMENT OF ENVIRONMENTAL QUALITY

Mary Fallin
Governor

OKLAHOMA DEPARTMENT OF ENVIRONMENTAL QUALITY

Response to the Public Comment Received for the Draft Bacterial and Turbidity TMDL Report for the Lower Red River/ Little River Study Area

March 27, 2014

1. **Comment sent by via email from Monty Porter, Oklahoma Water Resource Board:**

   Little River Segment OK410200010200_00 was included in the "2014 Bacterial and Turbidity TMDL Report for the Lower Red River - Little River Basin Study Area", with TMDL's included for both turbidity and enterococci. The data used for this report, as well as data originally used to create the 303(d) listings in the early 2000's, were generated as part of the Oklahoma Water Resources Board's (OWRB) Beneficial Use Monitoring Program (BUMP). The particular site was the Little River near Idabel, station ID 410200010200-001AT. Sampling began at the station in November of 1998 but was subsequently suspended in late 2003 because the station was determined to be in the regulatory mixing zone of a permitted discharger. Oklahoma's standards implementation language (OAC 785:46-15-3) sets various data requirements for implementation programs and collected data. Specifically, subsection (b)(5) of subchapter 15-3, states "Spatial limitation for sampling sites. For purposes of this Subchapter, observations, samples, and other data shall not be taken within any regulatory mixing zone". Data were reported in OWRB agency products as well as the 2002 303(d) list, but because of this requirement, data for the "Idabel" site were excluded from all reports after 2003, including the OWRB generated 303(d) list for inclusion in the integrated report. In regards to the referenced TMDL report, data collected as part of the BUMP at the "Idabel" site should not be used to create an impaired waterbody decision and subsequent TMDL.

Response:

Since the data in Little River Segment OK410200010200_00 for bacteria and turbidity was collected in a mixing zone and cannot be used for waterbody assessment according to Implementation of Oklahoma's Water Quality Standards *[Title 785, Chapter 46-15-3(b)(5)], Little River Segment OK410200010200_00 was recommended for delisting of turbidity impairment from the 303(d) List.*

The mixing zone data in Little River Segment OK410200010200_00 showed both an Enterococci and turbidity impairment. Since this data cannot be used, these TMDLs *were deleted as was a bacterial waste load allocation in the draft TMDL report for Tyson Foods, Inc. – Broken Bow. The TMDL report was also revised to indicate Little River Segment OK410200010200_00 mixing zone data with an explanation on why that data cannot be used. Similar revisions were made to the Lower Red River/Little River TMDL 208 Factsheet.*

Thank you for your comment.

Staff Identified Changes

1. Section 3.2.2.2 (Multi-Sector General Permit) addresses mine dewatering discharges at crushed stone, construction sand and gravel, or industrial sand mining facilities. The daily maximum effluent limitation for TSS is 45 mg/L unless the TMDL shows that a TSS limit more stringent than 45 mg/L is needed. If the TMDL shows that a TSS limit more stringent than 45 mg/L is needed, additional TSS limitations and monitoring requirements will be implemented under the multi-sector general permit.

   When Section 3.2.2.2 was being revised, it was noticed that a TSS limit more stringent than 45 mg/L is needed for Meridian Aggregates Co. (OKR050878) because it has mine dewatering discharges into an unnamed tributary of the Little River (OK410200010200_10). According to the Oklahoma WQS [785:45-5-12(f)(7)(A)(iii)], turbidity in that tributary cannot exceed 50 NTUs. Since the Little River is impaired for turbidity, Meridian Aggregates Co. was given an effluent TSS wasteload allocation of 40 mg/L. Based on the turbidity/TSS correlation, 50 NTUs is equal to 40 mg/L TSS. Meridian Aggregates Co. is already required to submit Discharge Monitoring Reports according to their MSGP. They have also developed and submitted their Storm Water Pollution Prevention Plan that includes the Best Management Practices they use to prevent turbidity impairment.

2. For Section 3.2.1 (Continuous Point Source Dischargers), WFEC_Hugo plant has two discharge outfalls. It discharges stormwater to an unnamed tributary to Bird Creek (OK410300010100_00) and wastewater to the Red River (OK410100010010_50). The turbidity impairment status is limited to base flow conditions and stormwater discharges from the facilities do not contribute to the violation of Oklahoma's turbidity standard. Therefore, WFEC_Hugo plant will not receive a WLA for TSS on Bird Creek (OK410300010100_00).

3. Since ODAFF is now the NPDES-permitting authority for CAFOs and SFOs in Oklahoma under what ODAFF calls the Agriculture Pollutant Discharge Elimination System (AgPDES), language about that was added to Sections 3.2.5 and 5.9.2