Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in the Cottonwood Creek, Fish Creek, Kirby Creek, and Crockett Branch Watersheds Upstream of Mountain Creek Lake

Segments: 0841F, 0841K, 0841N, and 0841V

Assessment Units: 0841F_01, 0841K_01, 0841N_01, and 0841V_01

View of Cottonwood Creek (0841F), downstream of Robinson Street.

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Prepared for
Total Maximum Daily Load Program
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PR1503

August 2015

Acknowledgements

Financial support for this study was provided by the U.S. Environmental Protection Agency and the Texas Commission on Environmental Quality. The lead agency for this study was the Texas Commission on Environmental Quality.

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List of Acronyms and Abbreviations

AU	Assessment Unit
BMPs	Best Management Practices
cfs	Cubic Feet per Second
DAR	Drainage-Area Ratio
DFW	Dallas/Ft. Worth
DSLP	Days since last precipitation
E. coli	*Escherichia coli*
FDA_{SWP}	Fractional Drainage Area Stormwater Permit
FDC	Flow Duration Curve
FIB	Fecal Indicator Bacteria
FG	Future Growth
GIS	Geographic Information System
I&I	Inflow and infiltration
I-Plan	Implementation Plan
LA	Load Allocation
LDC	Load Duration Curve
LULC	Land Use/Land Cover
mi^2	Square Miles
mL	Milliliter
MOS	Margin of Safety
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer System
MSGP	Multi-Sector General Permit
NCTCOG	North Central Texas Council of Governments
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSFs	On-Site Sewage Facilities
RSA	Regulated Stormwater Area
SSO	Sanitary Sewer Overflow
SWMP	Stormwater Management Plan
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TMDL	Total Maximum Daily Load
TNRIS	Texas Natural Resources Information System
TPDES	Texas Pollutant Discharge Elimination System
TRA	Trinity River Authority
TSSWCB	Texas State Soil and Water Conservation Board

TWRI	Texas Water Resources Institute
USCB	United States Census Bureau
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	Waste Load Allocation
WLA_{SW}	Waste Load Allocation Stormwater
WLA_{WWTF}	Waste Load Allocation Wastewater Treatment Facilities
WWTF	Wastewater Treatment Facility

SECTION 1

INTRODUCTION

1.1 Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a Total Maximum Daily Load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The Texas Commission on Environmental Quality (TCEQ) is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. In addition to the TMDL an implementation plan (I-Plan) is developed, which is a description of the regulatory and voluntary management measures necessary to improve water quality and restore full use of the water body.

The TCEQ's TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

The TCEQ first identified the bacteria impairments within the Cottonwood Creek, Fish Creek and Kirby Creek in 2006 and for Crockett Branch in 2010, and then in each subsequent edition of the Texas *Water Quality Integrated Report for Clean Water Sections 305(b) and 303 (d) (*formerly called the *Texas Water Quality Inventory and 303(d) List)* through 2012 and also in the draft 2014 report.

This document will consider bacteria impairments in 4 water bodies (segments), each segment consisting of a single assessment unit (AU). The complete list of water bodies and their identifying AU number is shown below:

1) Cottonwood Creek 0841F_01;
2) Fish Creek 0841K_01;
3) Kirby Creek 0841N_01;
4) Crockett Branch 0841V_01

Because the 4 impaired tributary segments are each composed of only one AU that encompasses the entire segment, the AU descriptor (_01) is often unnecessarily cumbersome. From this point forward, AU and segment may be used interchangeably. For example, Cottonwood Creek may be referred to as AU 0841_01 or Segment 0841.

1.2 Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by the TCEQ. The water quality standards describe the limits for indicators which are monitored in an effort to assess the quality of available water for specific users. The TCEQ is charged with monitoring and assessing water bodies based on these water quality standards, and publishes the Texas Water Quality Integrated Report list biennially.

The *Texas Surface Water Quality Standards* (TCEQ, 2010) are rules that:

- *designate the uses, or purposes, for which the state's water bodies should be suitable;*
- *establish numerical and narrative goals for water quality throughout the state; and*
- *provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.*

Standards are established to protect designated uses assigned to water bodies of which the primary uses assigned in the *Texas Surface Water Quality Standards* to water bodies are:

- *aquatic life use*
- *contact recreation*
- *domestic water supply*
- *general use*

Fecal indicator bacteria (FIB) are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. FIBs are present in the intestinal tracts of humans and other warm-blooded animals. The presence of these bacteria in water indicates that associated pathogens from the wastes that may be reaching water bodies as a result of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006). *Escherichia coli* (*E. coli)* is a member of the fecal coliform bacteria group and is used in the State of Texas as the FIB in freshwater.

On June 30, 2010, the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ, 2010) and on June 29, 2011, the U.S. Environmental Protection Agency (USEPA) approved the categorical levels of recreational use and their associated criteria. Recreational use consists of four categories:

§ Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for *E. coli* of 126 most probable number (MPN) per 100 mL and an additional single sample criterion of 399 MPN per 100 mL;

§ Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for *E. coli* of 630 MPN per 100 mL;

§ Secondary contact recreation 2 is similar to secondary contact 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 MPN per 100 mL; and

§ Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for *E. coli* of 2,060 MPN per 100 mL (TCEQ, 2010).

Cottonwood Creek, Fish Creek, Kirby Creek and Crockett Branch are approved for primary contact recreation and have the associated *E. coli* geometric mean criterion of a 126 MPN per 100 mL and single sample of 399 MPN per 100 mL.

1.3 Report Purpose and Organization

The Cottonwood Creek, Fish Creek, Kirby Creek and Crockett Branch watersheds TMDL project was initiated through a contract between the TCEQ and Texas Institute for Applied Environmental Research (TIAER). The tasks of this project were to (1) develop, have approved, and adhere to a quality assurance project plan; (2) develop a technical support document for the impaired watersheds; and (3) assist the TCEQ with public participation. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for impaired watersheds of Cottonwood Creek, Fish Creek, Kirby Creek and Crockett Branch. This report contains:

Ø information on historical data,

Ø watershed properties and characteristics,

Ø summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to presence of indicator bacteria (*E. coli*),

Ø development of load duration curves, and

Ø application of the load duration curve approach for the pollutant load allocation process.

SECTION 2
HISTORICAL DATA REVIEW AND WATERSHED PROPERTIES

2.1 Description of Study Area

Cottonwood Creek (Segment 0841F) and Fish Creek (Segment 0841K) are adjacent waterbodies located upstream of Mountain Creek Lake. Kirby Creek (Segment 0841N) is a tributary of Fish Creek and Crockett Branch (Segment 0841V) is a tributary of Cottonwood Creek (Figure 1). All are unclassified, perennial freshwater streams that eventually feed into the classified Segment 0841 Lower West Fork of the Trinity via Mountain Creek Lake and Mountain Creek.

Cottonwood Creek (Segment 0841F) begins at the confluence with Mountain Creek Lake in Dallas County and is approximately 6.5 miles in length with portions in both Tarrant (48.5% of watershed) and Dallas (51.5%) counties (Figure 1). The entire Cottonwood Creek watershed drains an area of approximately 8,111 acres including two major tributaries, Crockett Branch (767 acres) and North Fork Cottonwood Creek (3,546 acres).

Fish Creek (Segment 0841K) begins at the confluence with Mountain Creek Lake in Dallas County and is approximately 15 miles in length with portions of the watershed in both Tarrant (75.4%) and Dallas (24.6%) counties (Figure 1). The entire Fish Creek watershed drains an area of approximately 16,634 acres including two major tributaries, Kirby Creek (1,978 acres) and North Fork Fish Creek (3,663 acres).

Kirby Creek begins at the confluence with Fish Creek and is approximately 4 miles long with 27.9% of the watershed in Tarrant County and 71.1% in Dallas County (Figure1).

Crocket Branch begins at the confluence with Cottonwood Creek and is approximately 1 mile in length with 100% of the drainage area within Dallas County (Figure 1).

The draft 2014 Texas Water Quality Integrated Report (TCEQ, 2015a) provides the following segment and AU descriptions for the water bodies considered in this document:

- Segment 0841F (AU 0841F_01; entire segment) (Cottonwood Creek) - A 6.5 mile stretch of Cottonwood Creek running upstream from approximately 0.1 miles upstream of Mountain Creek Reservoir in Dallas County, to SH 360 in Tarrant County.
- Segment 0841K (AU 0841K_01; entire segment) (Fish Creek) - A 15 mile stretch of Fish Creek running upstream from the confluence with Mountain Creek Reservoir in Grand Prairie, Dallas Co., to the upper end of the creek(NHD RC 12030102000107) in Arlington, Tarrant County.

- Segment 0841N (AU 0841N_01; entire segment) (Kirby Creek) – Four mile stretch of Kirby Creek running upstream from confluence with Fish Creek in Grand Prairie, Dallas County, to just upstream of Great Southwest Parkway in Arlington, Tarrant County.
- Segment 0841V (AU 0841_V_01; entire segment) (Crockett Branch) – A 1 mile (1.5 km) stretch of Crockett Branch extending upstream from the confluence with Cottonwood Creek to the upper end of the creek (NHD RC 12030102044745).

This study incorporates a watershed approach where the drainage area of each stream is considered.

It should be noted that North Fork Cottonwood Creek (Segment 0841P) and North Fork Fish Creek (Segment 0841Q) are also designated as unclassified water bodies within the study area shown in Figure 1 and while these water bodies are considered in this report, TMDL development will only be for the bacterial impaired segments listed below. Furthermore, while concern for *E.coli* is listed in the *Draft 2014 Texas Integrated Report* (TCEQ, 2015b) for Segments 0841P and 0841Q, both are still considered to support the primary contact recreation use.

The 4 impaired AUs listed above comprise the TMDL area addressed in this report. The phrase “TMDL watersheds” will be used when referring to only the area of the 4 impaired AUs addressed in this report. The term “TMDL study area” will be used when referring to the entire drainage area of all 4 streams (Cottonwood Creek, Crockett Branch, Fish Creek, and Kirby Creek) addressed in this report.

2.2 Watershed Climate and Hydrology

The TMDL study area is located near the center of the Dallas/Fort Worth (DFW) metroplex, which is classified as humid subtropical climate (NOAA, 2009). Typically, the DFW area encounters mild winters with the first frost occurring in late November and the last frost in mid-March; however, brief periods of extreme cold do occur (NOAA, 2009). Hot summers with high temperatures exceeding 100° F are common for the DFW area accompanied by fair skies and westerly winds (NOAA, 2009). Annual precipitation predominately occurs in the form of thunderstorms that are typically brief in nature and are recurrent in the spring (NOAA, 2009).

For the period from 1981 – 2010, average annual precipitation in the TMDL study area was 37.7 inches. (Figure 2; PRISM, 2012).

For the Arlington Municipal Airport weather station located in western Fish Creek (Segment 0841K), the average high temperatures typically peak in August (97.2 °F) with highs above 100 °F occurring June through August (Figure 3; NOAA, 2012). Average nightly lows range from 71.5 °F (June) to 74.3 °F (August) during these hot summer months. During winter, the average low temperature generally bottoms out at 35.8 °F in January (NOAA, 2012).

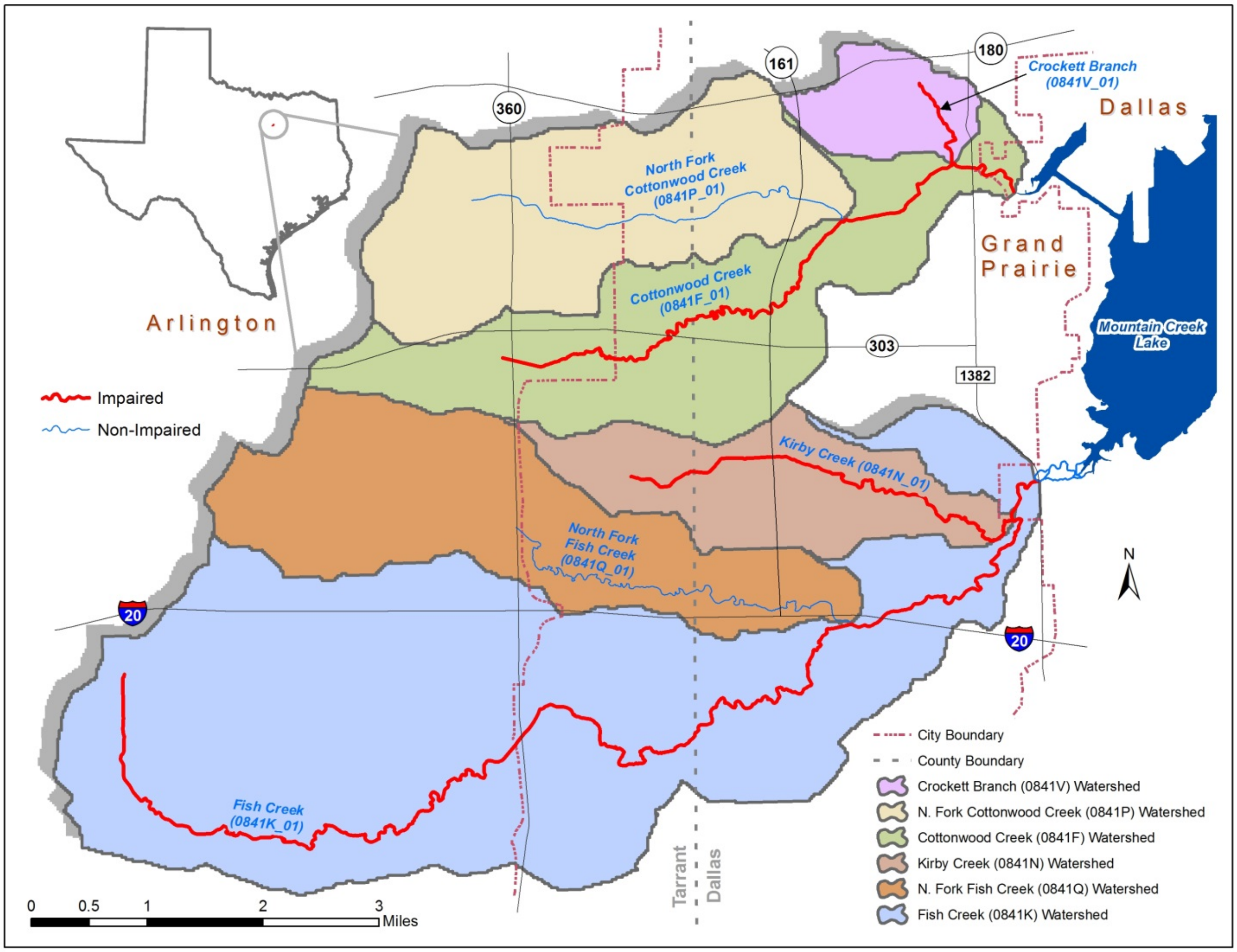

Figure 1. Overview map showing the total contributing drainage area for the study area, including AUs 0841P_01 and 0841Q_01.

Source: TCEQ (2012a)

Weather data obtained from the National Climatic Data Center for the Arlington Municipal Airport station spanning a period from 1999 through 2014 indicate the wettest month is typically October (3.7 inches) while August (1.6 inches) is the normally the driest month, with rainfall occurring throughout the year (Figure 3; NOAA, 2012).

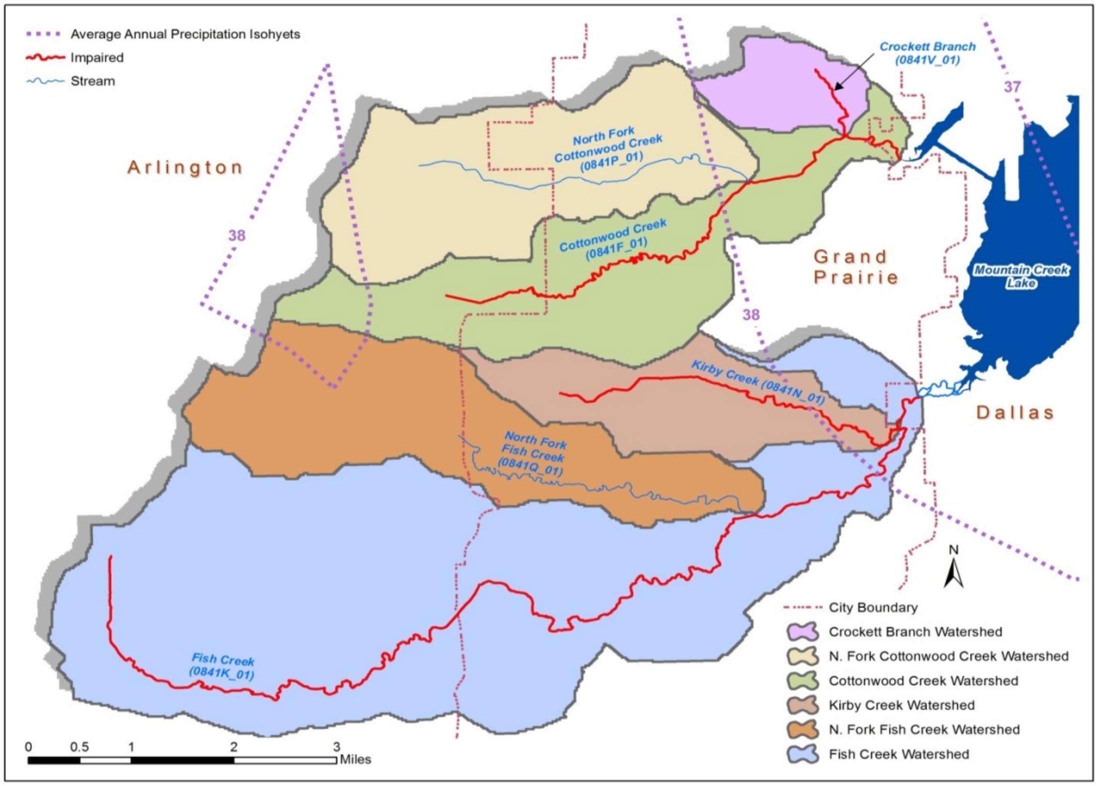

Figure 2. Annual average precipitation isohyets (in inches) in the TMDL study area.

Source: PRISM (2012)

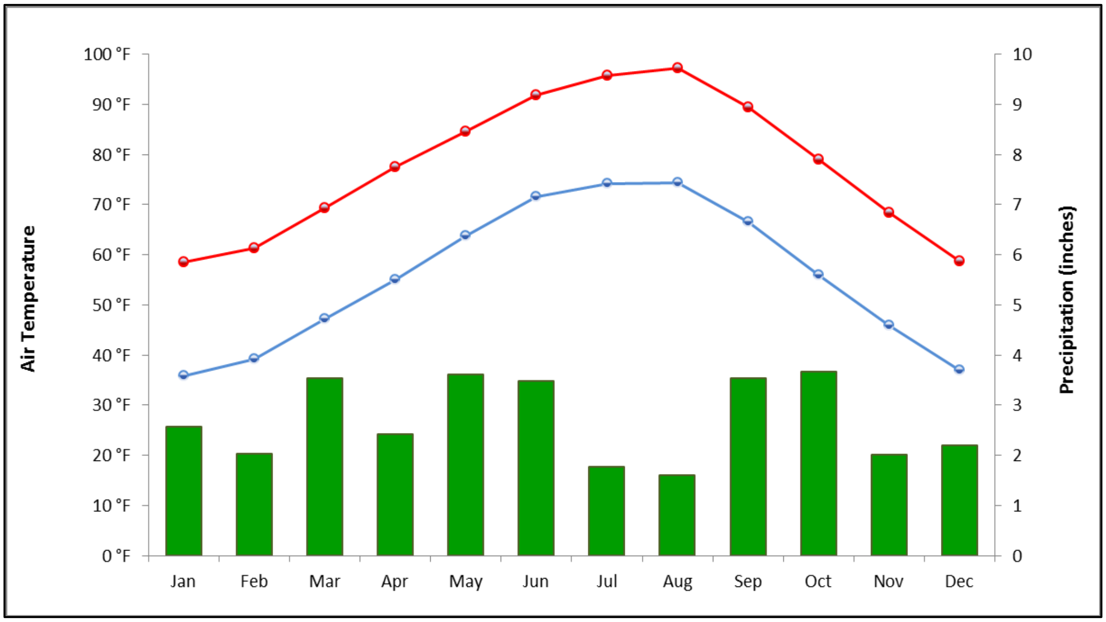

Figure 3. Average minimum and maximum air temperature and total precipitation by month from Jan 1999 –Dec 2014 for Arlington Municipals Airport.

Source: NOAA (2012)

2.3 Watershed Population and Population Projections

As depicted in Figure 1, the TMDL study area is geographically located within municipal incorporated boundaries and primarily within the jurisdictional boundaries of Arlington and Grand Prairie with a small portion located within the Dallas city limits boundary. According to the 2010 Census data (USCB, 2014a), population data indicate the TMDL study area is highly urbanized with an average population density of 4,605 people per square mile (mi^2). North Fork Cottonwood Creek (32,252 population) is the densest populated watershed with approximately 5,864 people/mi^2 with Cottonwood Creek as the least dense watershed containing 3,641 people/mi^2.

Population projections for the year 2040 were developed by the North Central Texas Council of Governments (NCTCOG) and indicate that populations will increase for each segment with the exception of Crockett Branch (-2.5% decrease; NCTCOG, 2015). Population projection increases range from a minimum of 2% to a maximum of 43% with an average increase of 24.4% for the TMDL study area. Table 1 provides a summary of the 2010 population and the 2040 population projection.

Table 1. 2010 Population and 2040 Population Projections for the TMDL study area. Source: USCB (2014a) and NCTCOG (2015)

Water Body	Segment	2010 U.S. Census Population	2040 Projected Population	Projected Population Increase/Decrease	Percent change (2010 - 2040)
Cottonwood Creek	0841F	21,480	26,979	5,499	25.6%
Fish Creek	0841K	68,511	88,086	19,575	28.6%
Kirby Creek	0841N	12,021	17,245	5,223	43.5%
Crockett Branch	0841V	5,843	5,695	-148	-2.5%
North Fork Cottonwood Creek	0841P	32,252	32,750	498	1.5%
North Fork Fish Creek	0841Q	30,749	37,588	6,839	22.2%

2.4 Review of Routine Monitoring Data

2.4.1 Data Acquisition

Ambient *E. coli* data were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on 17 October 2014. The data represent all the historical routine ambient *E. coli* and other water quality data collected in the TMDL watersheds, and include *E. coli* data collected from December 2001 through December 2013. General assessment criteria methodologies established by TCEQ were used in data evaluations.

2.4.2 Analysis of Bacteria Data

Recent environmental monitoring within the TMDL watersheds has occurred at 11 TCEQ monitoring stations (Figure 4). *E. coli* data collected at these stations over the seven-year period of 1 December 2003 through 30 November 2010 were used in assessing attainment of the primary contact recreation use as reported in the *2012 Texas Integrated Report* (TCEQ, 2013a) and as summarized in Table 2. Additionally, *E. coli* data collected at these stations over the seven-year period of 1 December 2005 through 30 November 2012 were used in assessing attainment of the primary contact recreation use as reported the *Draft 2014 Texas Integrated Report* (TCEQ, 2015b) and as summarized in Table 2. The 2012 and 2014 assessment data indicate non-support of the primary contact recreation use because geometric mean concentrations exceed the *E. coli* geometric mean criterion of 126 MPN/100 mL for the TMDL watersheds.

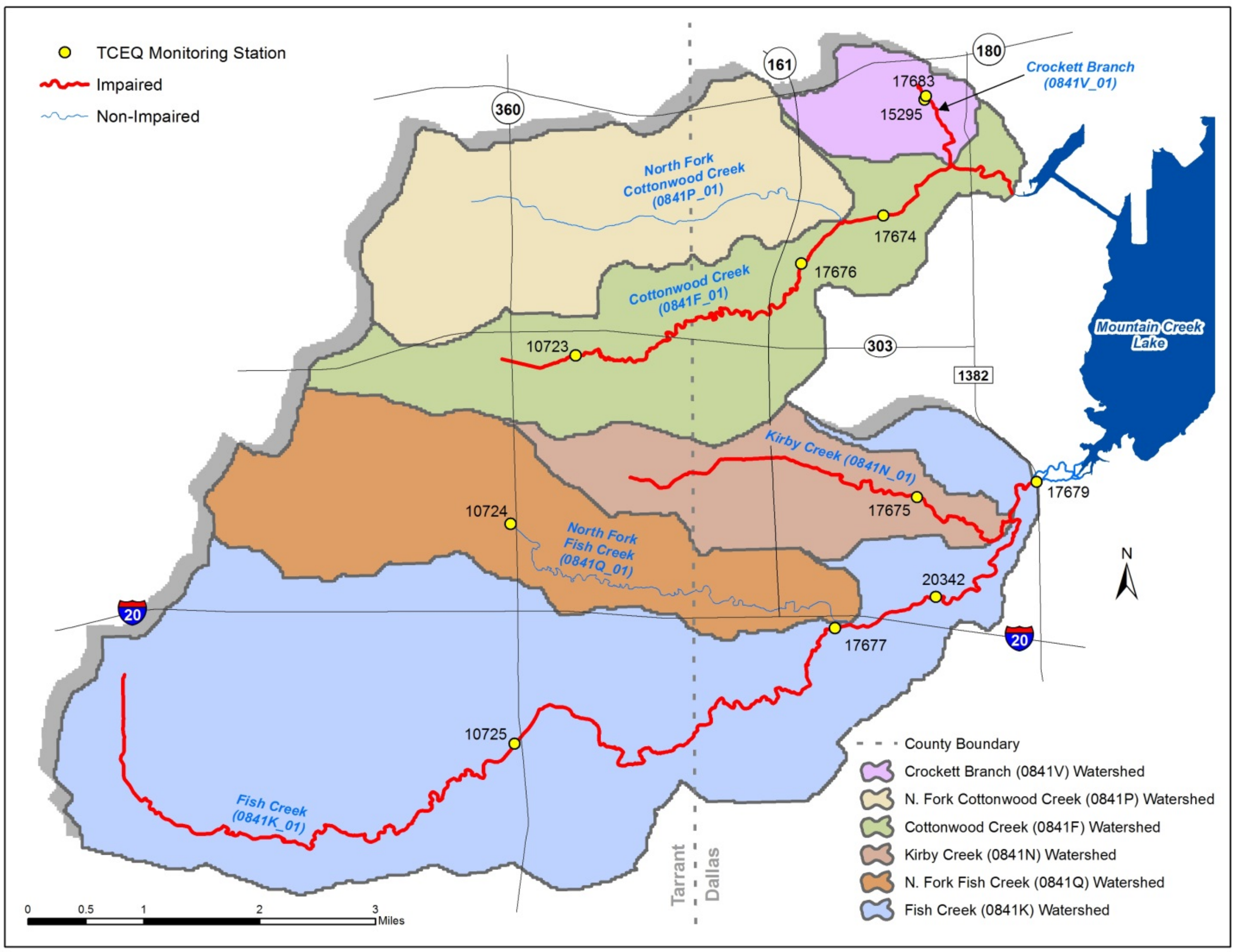

Figure 4. TMDL study area showing TCEQ surface water quality monitoring stations used to assess primary contact recreation.

Source: TCEQ (2012b)

Table 2. 2012 and Draft 2014 Integrated Report Summary for the TMDL watersheds. Source: TCEQ (2013b and 2015a)

Water Body	Segment	Parameter	Station(s)	Integrated Report Year	No. of Samples	Data Date Range	Geometric Mean (MPN/100 mL)
Cottonwood Creek	0841F	*E. coli*	10723, 17674, 17676	2012	200	2003 - 2010	275
				2014	229	2005 - 2012	252
Fish Creek	0841K	*E. coli*	10724*, 10725, 17677, 17679, 20342	2012	199	2003 - 2010	249
				2014	193	2005 - 2012	215
Kirby Creek	0841N	*E. coli*	17675	2012	99	2003 - 2010	621
				2014	100	2005 - 2012	582
Crockett Branch	0841V	*E. coli*	15295, 17683	2012	80	2003 - 2010	740
				2014	79	2005 - 2012	689

* The description of Station 10724 is North Fish Creek, though it was included in stations used to assess Fish Creek (See Figure 4).

2.5 Land Use

The land use/land cover data for the TMDL study area were obtained from the North Central Texas Council of Governments (NCTCOG, 2013a) and represent land use/land cover estimates for 2010. The land use/land cover is represented by the following categories and definitions:

- Commercial/Industrial – Commercial/Industrial includes land occupied by office, retail, industrial (manufacturing, warehouses, salvage yards, quarries, mines), utilities (sewage/water treatment plants, power infrastructure), stadiums, communication (radio, television, cable, and phone infrastructure), construction sites, and parking.
- Group Quarters – Group Quarters includes land occupied by nursing homes, dormitories, jails, military personnel quarters, and hotels/motels.
- Residential – Residential includes land occupied by single family, multi-family, and mobile home residences.
- Institution – Institution includes land occupied by churches, schools, museums, hospitals, medical clinics, libraries, government facilities, and military bases.
- Transit – Transit includes land occupied by roads, rail lines, rail stations, bus lines and bus facilities.
- Airport – Airport includes land occupied by airport terminals and runways.
- Dedicated – Dedicated includes land occupied by public and private parks, golf courses, tennis courts, pools, campgrounds, amusement parks, and cemeteries.

§ Vacant – Vacant includes land that is undeveloped with the potential to be developed or reserved for recreational use.

§ Ranch/Farmland – Ranch/Farmland includes land occupied by livestock or crops.

§ Timberland – Timberland includes land covered by trees.

§ Water – Water includes land covered by lakes, rivers, and ponds.

The 2010 land use/land cover data from the NCTCOG is provided for the entire Cottonwood Creek and Fish Creek watersheds in Figure 5. A summary of the land use/land cover data for each of the TMDL watersheds is provided in Table 3. The dominant land uses vary slightly throughout the study area with Residential and Transit covering the largest portion of each TMDL watershed except for Cottonwood Creek (0841F), wherein Commercial (30%) and Residential (22%) are the two dominate land uses. In summary and as anticipated, the land use mix reflects that of a large urban area with some variations in category of dominance by geographic location.

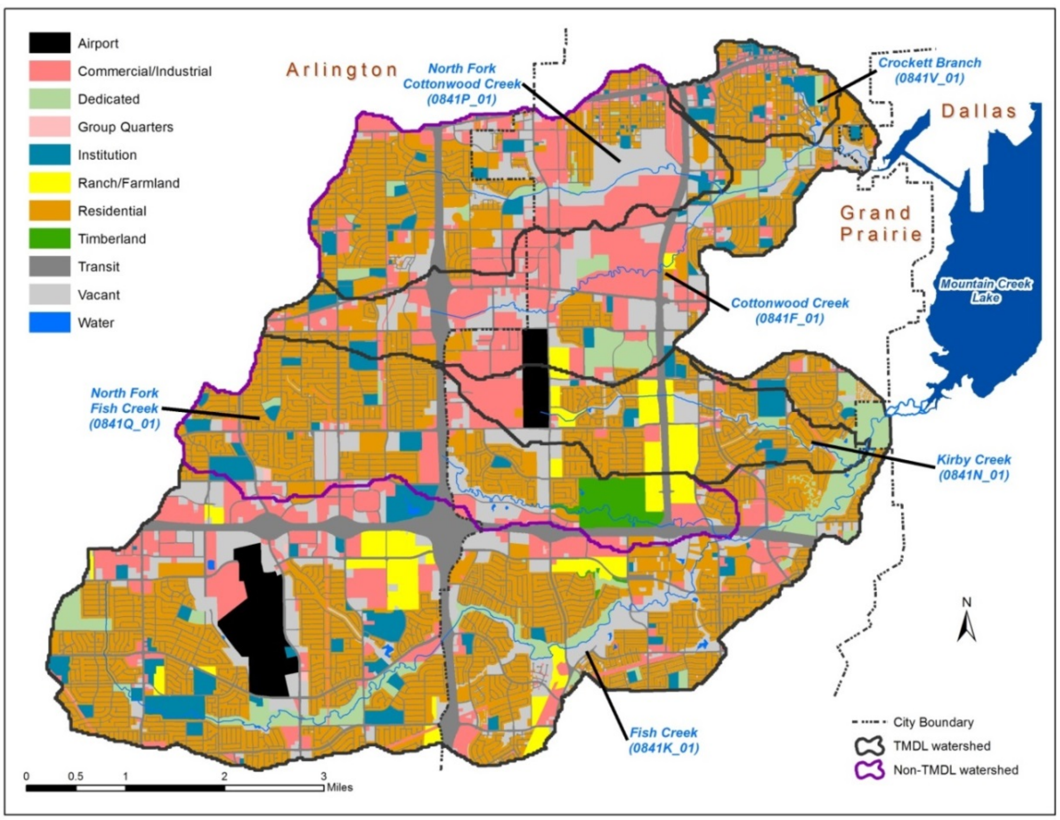

Figure 5. 2010 land use/land cover within the TMDL study area.

Source: NCTCOG (2013a)

Table 3. Land Use/Land Cover within the TMDL study area.
Source: NCTCOG (2013a)

NCTCOG 2010 LULC	Cottonwood Creek (0841F)		N. F. Cottonwood Creek (0841P)		Crockett Branch (0841V)		Cottonwood Creek Grand Total	
Classification	Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Airport	59	1.6%	NA[a]	NA	NA	NA	59	0.7%
Commercial/Industrial	1,153	30.4%	766	21.6%	86	11.2%	2,006	24.7%
Dedicated	299	7.9%	94	2.6%	17	2.2%	409	5.0%
Group quarters	2	0.0%	5	0.1%	3	0.4%	10	0.1%
Institution	131	3.5%	169	4.8%	101	13.2%	402	5.0%
Ranch/Farmland	42	1.1%	NA	NA	NA	NA	42	0.5%
Residential	848	22.3%	1,237	34.9%	304	39.7%	2,390	29.5%
Timberland	NA	NA	NA	NA	NA	NA	NA	NA
Transit	618	16.3%	655	18.5%	202	26.3%	1,475	18.2%
Vacant	644	17.0%	617	17.4%	52	6.8%	1,313	16.2%
Water	1	0.0%	2	0.1%	2	0.2%	5	0.1%
Total	3,798	100%	3,546	100%	767	100%	8,111	100%
NCTCOG 2010 LULC	Fish Creek (0841K)		N. F. Fish Creek (0841Q)		Kirby Creek (0841N)		Fish Creek Grand Total	
Classification	Acres	% of Total	Acres	% of Total	Acres	% of Total	Acres	% of Total
Airport	425	3.9%	NA	NA	105	5.3%	530	3.2%
Commercial/Industrial	1,351	12.3%	349	9.5%	247	12.5%	1,946	11.7%
Dedicated	787	7.2%	16	0.4%	89	4.5%	892	5.4%
Group quarters	15	0.1%	11	0.3%	NA	NA	26	0.2%
Institution	578	5.3%	206	5.6%	117	5.9%	901	5.4%
Ranch/Farmland	453	4.1%	103	2.8%	246	12.4%	801	4.8%
Residential	3,759	34.2%	1502	41.0%	642	32.4%	5,903	35.5%
Timberland	8	0.1%	238	6.5%	0.0002	0.0%	247	1.5%
Transit	2,289	20.8%	778	21.2%	339	17.1%	3,406	20.5%
Vacant	1,304	11.9%	455	12.4%	193	9.8%	1,952	11.7%
Water	25	0.2%	4	0.1%	1	0.1%	30	0.2%
Total	10,993	100%	3,663	100%	1,978	100%	16,634	100%

[a] NA is Not Applicable.

2.6 Potential Sources of Fecal Indicator Bacteria

Potential sources of indicator bacteria pollution can be divided into two primary categories: *regulated* and *unregulated*. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and National

Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4) of cities.

Unregulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual waste load allocations or WLAs (see report Section 4.7.3, Waste Load Allocation), the regulated and unregulated sources in this section are presented to give a general account of the potential sources of bacteria in the watershed.

2.6.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the NPDES programs. WWTF outfalls and stormwater discharges from industries, construction, and MS4s represent the potential permitted sources in the TMDL watersheds.

2.6.1.1 Domestic Wastewater Treatment Facility Discharges

No permitted WWTFs exist in the TMDL study area. Domestic wastewater is collected by and transported to the Trinity River Authority (TRA) Central Regional Wastewater System located outside the study area (Figure 6).

2.6.1.2 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris. Inflow and infiltration (I&I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

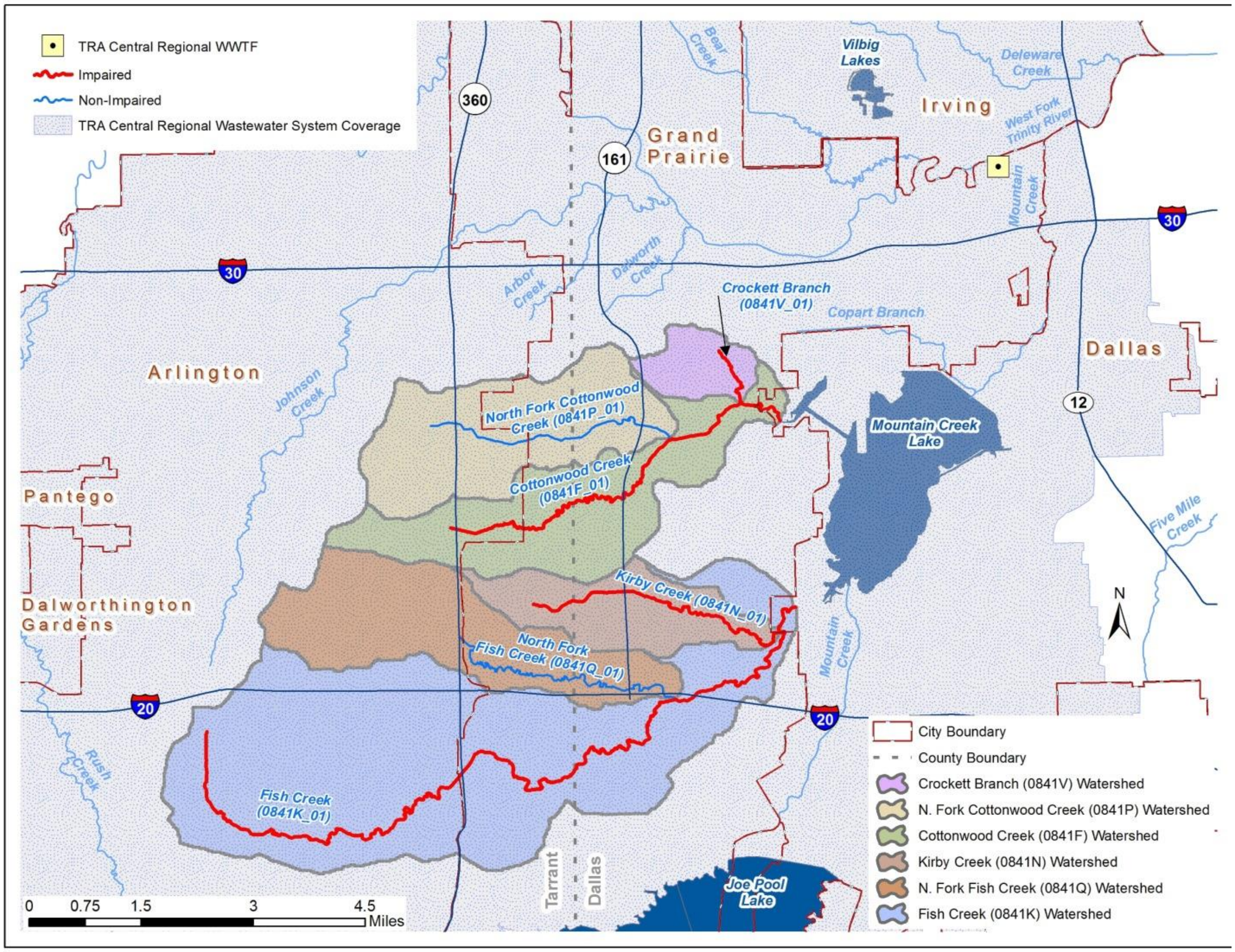

Figure 6. Coverage area of the TRA Central Regional Wastewater within the TMDL study area. Sources: TCEQ (2015c) and NCTCOG (2013b)

The TCEQ Region 4 Office maintains a database of SSO data reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. SSO incidents that occurred from 2007 to 2011 for this dataset were refined by the NCTCOG by assigning latitude and longitude coordinates to each SSO event and plotted using Geographic Information System (GIS) software in an effort to characterize the frequency and magnitude of SSO events within the impaired segments covered in this report (Figure 7). A summary of the NCTCOG refined data within the TMDL study area is shown in Table 4. Efforts were made to extract only the incidents that occurred within the TMDL study area from the SSO dataset as well, however, incomplete geo-referenced SSO events made geospatial distinction of SSOs that occurred from 2012 – 2014 difficult. Thus, a summary of the reported SSO incidents from January 2012 through August 2014 for the cities of Arlington and Grand Prairie can be found in Table 5.

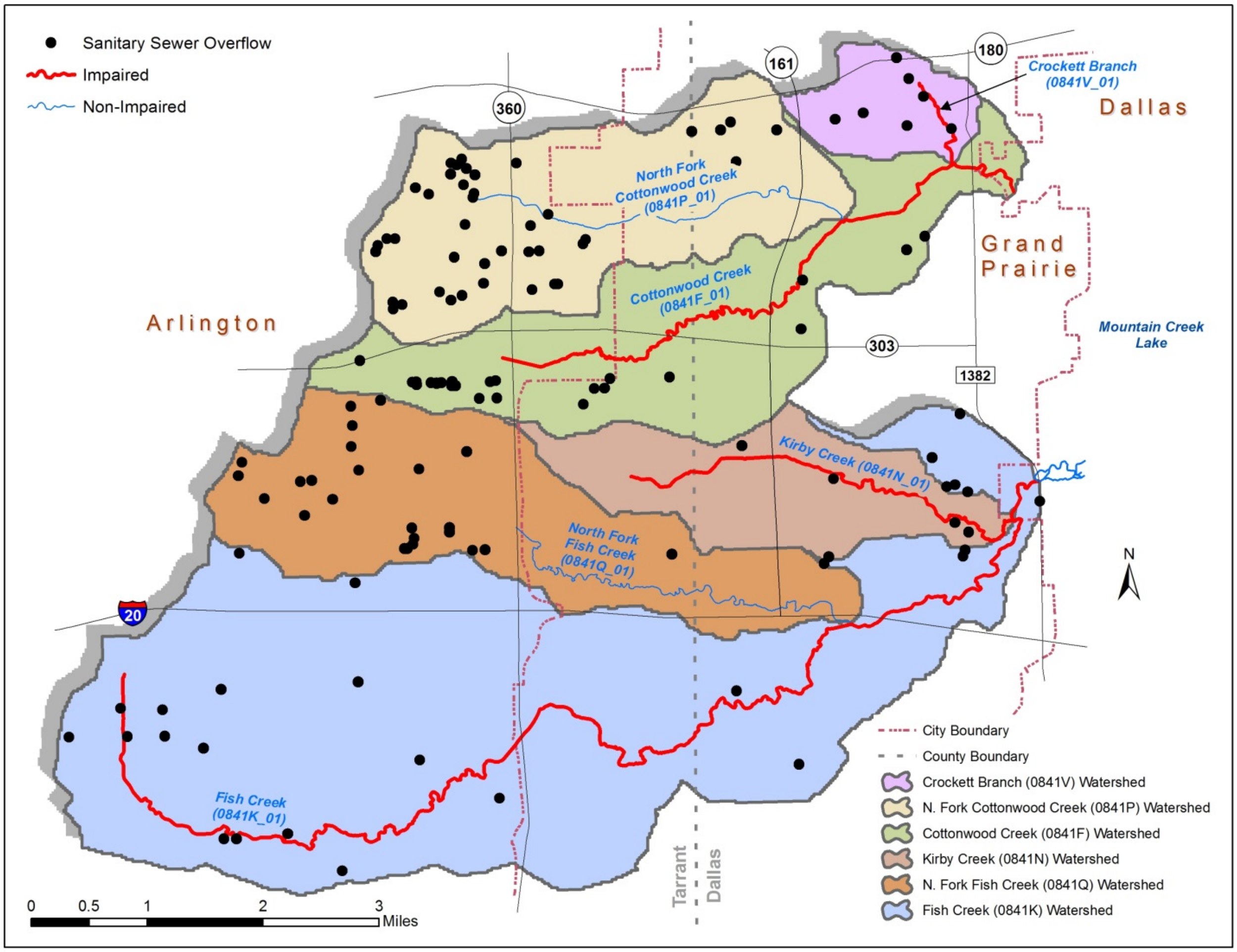

Figure 7. Sanitary Sewer Overflows that occurred from January 2007 – December 2011 within the TMDL study area.

Source: NCTCOG (2012a)

Table 4. Summary of SSO incidences reported in the TMDL study area from Jan. 2007 – Dec. 2011.

Source: NCTCOG (2012a)

Segment	No. of Incidents	Total Volume (gallons)	Average Volume (gallons)	Minimum Volume (gallons)	Maximum Volume (gallons)
0841F	26	14,815	570	10	10,000
0841K	25	18,623	745	7	6,000
0841N	5	1,295	259	15	600
0841V	7	552	79	2	200
0841P	43	35,085	816	15	22,500
0841Q	25	18,592	744	7	6,000

Table 5. Summary of SSO incidences reported for the cities of Arlington and Grand Prairie from Jan. 2012 – Aug. 2014.

Source: TCEQ (2014)

Municipality	No. of Incidents	Total Volume (gallons)	Average Volume (gallons)	Min. Volume (gallons)	Max. Volume (gallons)
Arlington	187	65,444	350	2	15,895
Grand Prairie	48	24,755	516	10	15,000

2.6.1.3 TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES- or NPDES-regulated discharge permit and stormwater originating from areas not under a TPDES- or NPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1) stormwater subject to regulation, which is any stormwater originating from TPDES-regulated Phase I or Phase II MS4, stormwater discharges associated with industrial activities, and stormwater discharges from regulated construction activities; and
2) stormwater runoff not subject to regulation.

The TPDES/NPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Both the Phase I and II permits include any conveyance such as ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities within an EPA-defined urbanized area that are regulated by a general permit. The purpose of a MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge detection and elimination;
- Construction site runoff control;
- Post-construction runoff control; and
- Pollution prevention/good housekeeping.

The geographic region of the TMDL watersheds covered by Phase I and II MS4 permits is that portion of the area within the jurisdictional boundaries of the regulated entity. For Phase I permits the jurisdictional area is defined by the city limits and for Phase II permits the jurisdictional area is defined as the intersection or overlapping areas of the city limits and the 2000 or 2010 Census Urbanized Area.

For the TMDL watersheds containing entities with Phase II general permits and Phase I individual permits, the areas included under these MS4 permits were used to estimate the regulated stormwater areas (RSA) for construction, industrial and MS4 permits (Figure 8). The regulated area for the Phase II permits was based on the 2010 Urbanized Area from the U.S. Bureau of Census. The entities regulated under MS4 permits for the TMDL watersheds are provided in Table 6.

A review of active stormwater general permits coverage (TCEQ, 2015d) and a review of the central registry for Phase I MS4 permit coverage (TCEQ, 2015c) in the TMDL study area revealed that two Phase I and three Phase II permits (Table 6) exist providing 100% MS4 coverage for the TMDL study area (Figure 8).

Table 6. TPDES and NPDES MS4 permits associated with the TMDL study area.
Source: TCEQ (2015b and 2015d)

Entity	TPDES Permit	NPDES Permit
City of Arlington	WQ004635-000	TXS000301
City of Dallas	WQ004396-000	TXS000701
City of Grand Prairie	Phase II General Permit	TXR040065
Dallas County	Phase II General Permit	TXR040120
Tarrant County	Phase II General Permit	TXR040052

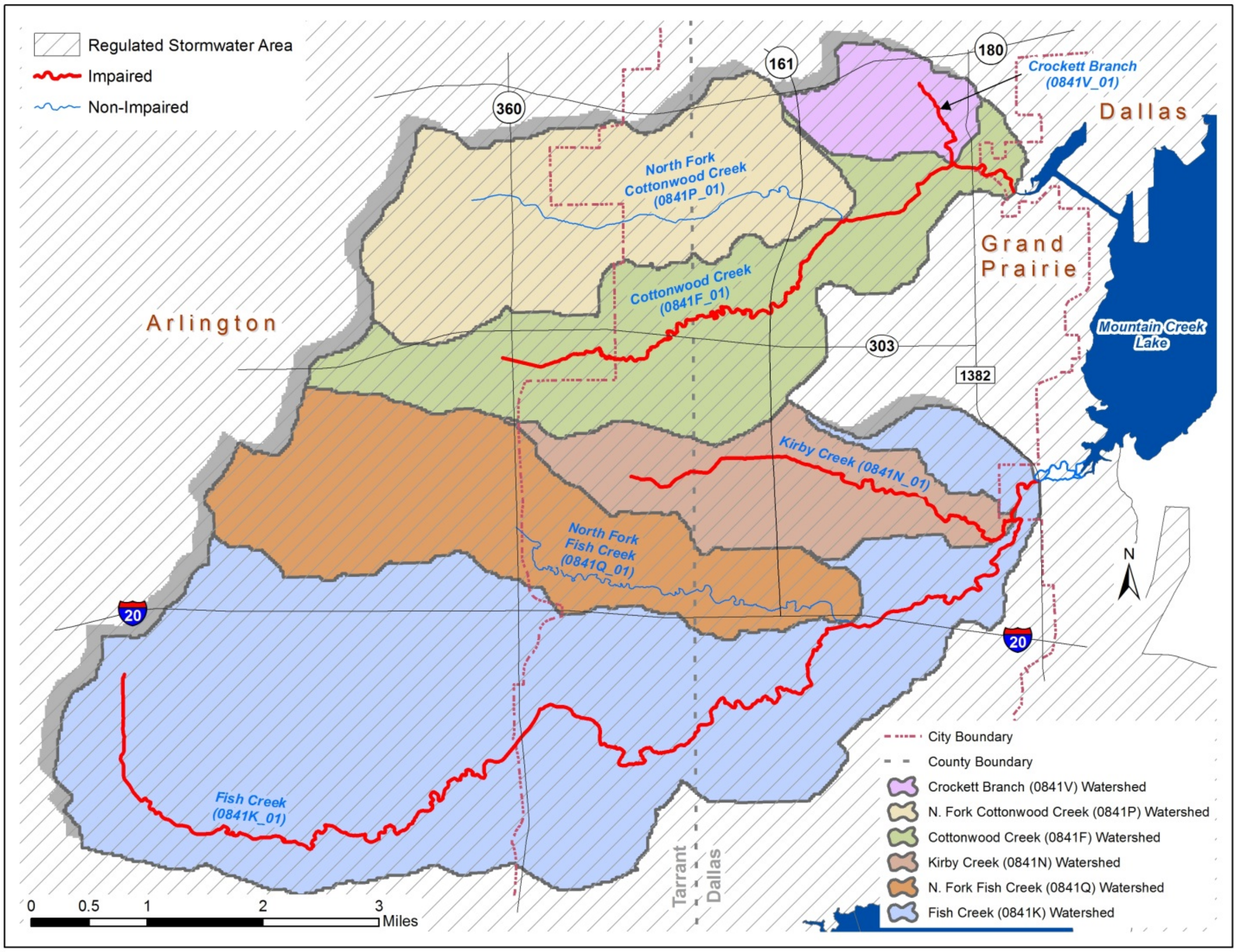

Figure 8. Regulated stormwater area based on Phase I and Phase II MS4s permits within the TMDL study area.

Source: USCB (2014b)

2.6.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from regulated stormwater can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II Municipal Separate Storm Sewer Systems as "Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC, 2003) include:

Examples of direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (e.g., used motor oil) that have been dumped illegally into a storm drain catch basin;
- a shop floor drain that is connected to the storm sewer; and
- a cross-connection between the municipal sewer and storm sewer systems.

Examples of indirect illicit discharges:

- an old and damaged sanitary sewer line that is leaking fluids into a cracked storm sewer line; and
- a failing septic system that is leaking into a cracked storm sewer line or causing surface discharge into the storm sewer.

2.6.1.5 TPDES General Wastewater Permits

Discharges of processed wastewater from certain types of facilities are required to be covered by one of several TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production facilities
- TXG340000 – petroleum bulk stations and terminals
- TXG670000 – hydrostatic test water discharges
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG920000 – concentrated animal feeding operations
- WQG20000 – livestock manure compost operations (irrigation only)

A review performed July 2015 of active general permit coverage (TCEQ, 2015d) in the TMDL study area found no operations or facilities of the type described above.

2.6.2 Unregulated Sources

Unregulated sources of indicator bacteria are generally nonpoint and can emanate from wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

2.6.2.1 Wildlife and Unmanaged Animal Contributions

E. coli bacteria are common inhabitants of the intestines of all warm-blooded animals, including feral hogs and wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife and feral hogs. Wildlife and feral hogs are naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife and feral hog waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife and feral hogs are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff.

2.6.2.2 On-Site Sewage Facilities

Failing OSSFs were not considered a major source of bacteria loading in the TMDL watersheds, because the entire TMDL study area is served by a centralized wastewater collection and treatment system. Areas serviced by centralized treatment and collection systems typically contain very few OSSFs, and this is the situation for the TMDL watersheds, where NCTCOG information indicates that only 31 OSSFs exist in the TMDL study area (Figure 9; NCTCOG, 2012b).

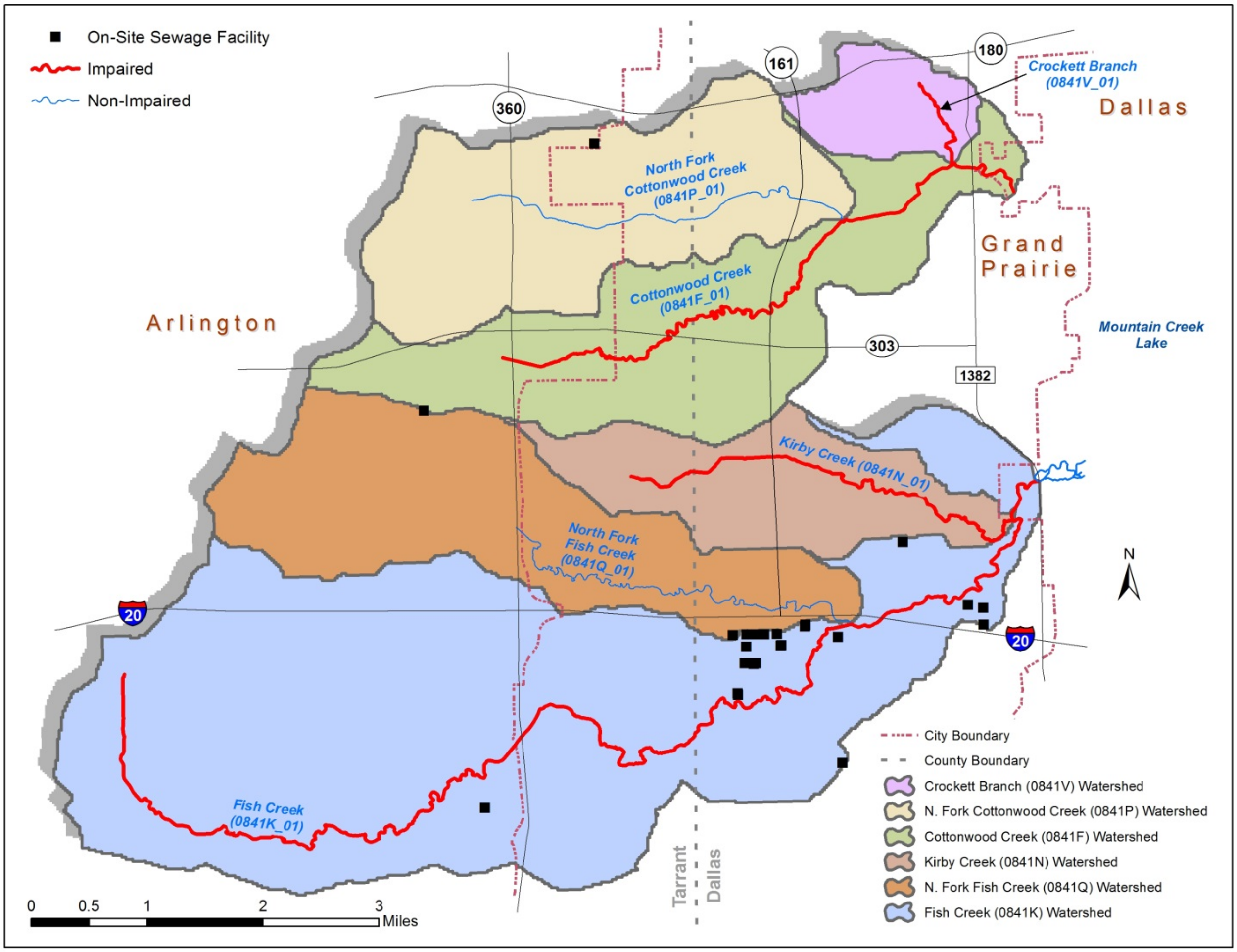

Figure 9. OSSFs located within the TMDL study area.

Source: NCTCOG (2012b)

2.6.2.3 Non-Permitted Agricultural Activities and Domesticated Animals

Activities, such as livestock grazing close to water bodies and farmers' use of manure as fertilizer, can contribute fecal indicator bacteria such as *E. coli* to nearby water bodies.

Due to the highly urbanized nature of the TMDL study area, livestock were not considered a major source of bacteria loading.

Pets can also be sources of *E. coli*, because storm runoff carries the animal wastes into streams (USEPA, 2013).

The number of domestic pets in the TMDL watershed was estimated based on human population and number of households obtained from the U.S. Census Bureau (USCB, 2014a). The information obtained from the U.S. Census Bureau included population and household projections based on the 2010 census for census blocks that encompassed the watersheds of each AU. The block level data were multiplied by the proportion of each census block within the watershed to generate an estimate of the watershed's population and number of households. This estimation assumes that the population/households are uniformly distributed within the area of each census block, which is the best estimate that can be made with the available data.

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 7 summarizes the estimated number of dogs and cats for each segment in the TMDL study area with elevated bacteria levels. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household according to data from the American Veterinary Medical Association 2012 U.S Pet Statistics (AVMA, 2015). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the TMDL watersheds is unknown.

Table 7. Estimated distribution of dog and cat populations.
Source: AVMA (2015).

Segment	Households	Dogs	Cats
0841F	9,454	5,521	6,032
0841P	10,056	5,873	6,416
0841V	1,850	1,081	1,180
0841K	22,422	13,094	14,305
0841Q	9,962	5,818	6,356
0841N	3,342	1,952	2,132

2.6.2.4 Bacteria Survival and Die-off

Bacteria are living organisms that survive and die in the environment. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (e.g., warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic rich materials such as compost and sludge. While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their re-growth is less well understood. Both processes (replication and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body in the TMDL watersheds.

SECTION 3

BACTERIA TOOL DEVELOPMENT

This section describes the rationale of the bacteria tool selection for TMDL development and details the procedures and results of load duration curve development.

3.1 Model Selection

The TMDL allocation process for bacteria involves assigning bacteria, e.g., *E. coli*, loads to their sources such that the total loads do not violate the pertinent numeric criterion protecting contact recreation use. To perform the allocation process, a tool must be developed to assist in allocating bacteria loads. Selection of the appropriate bacteria tool for impaired AUs in the TMDL watersheds considered availability of data and other information necessary for supportable application of the selected tool and guidance in the Texas bacteria task force report (TWRI, 2007). In general, two basic tools are commonly used for bacteria TMDLs—mechanistic computer models and an empirical approach referred to as the load duration curve (LDC).

Mechanistic computer models provide analytical abstractions of a real or prototype system. Mechanistic models, also referred to as process models, are based on theoretical principles that provide a representation of governing physical processes that determine the response of certain variables, such as stream flows and bacterial concentrations, to precipitation. Under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides an understanding of the important biological, chemical, and physical processes of the prototype system and reasonable predictive capabilities to evaluate alternative allocations of pollutant load sources.

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, the load duration curve method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations, often associated with bacteria TMDLs, that constrain the use of more powerful mechanistic models. Further, the bacteria task force appointed by the TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) supports application of the load duration curve method within their three-tiered approach to TMDL development (TWRI, 2007). The

LDC method provides a means to estimate the difference in bacteria loads and relevant criterion, and can give indications of broad sources of the bacteria, i.e., point source and nonpoint source.

3.1.1 Situational Limitations of Mechanistic Modeling

The present surface water bacteria standards do not restrict what streamflow conditions the primary contact recreation criteria should meet; therefore, the allocation process must consider all streamflow conditions ranging from low flows to high flows. The TMDL allocation tool, therefore, must be capable of characterizing streamflow and bacteria loads at desired locations under the wide variety of environmental conditions experienced in the TMDL watersheds. If a mechanistic modeling tool is applied, it must be capable of simulating response of bacterial loadings to streamflow conditions during base flow as well as during times of response to rainfall runoff and those intermediate conditions between well-defined base flow and strong rainfall-runoff response. The type of mechanistic tool with capabilities to simulate all these complexities is often referred to as a combined watershed loading and hydrologic/water quality model. These models simulate the hydrologic response of the watershed's land uses and land covers to rainfall, route runoff water through the conveyance channels of the watershed, add in point source contributions, and may include other hydrologic processes such as interaction of surface waters with shallow ground water.

The bacteria component of the model is in many ways even more complex than the hydrologic component and typically must include many different processes. Point sources and nonpoint sources of bacteria need to be defined and simulated by the model. Movement or washoff of bacteria from the various landscapes (e.g., urban yards, roads, pastures, wooded areas, areas of animal concentration), potential illegal connections of sewage lines to stormwater lines, broken sewer lines, and sewer overflows in response to rainfall are only some of the sources possibly needing to be represented in the model. Streamflow transport of the bacteria in tributaries and in the mainstem river and the response of the bacteria while in transport to settling, die-off, resuspension, regrowth in the water column, regrowth in the sediment, etc. need to be defined with adequate certainty to allow proper model representation for each of these physical and biological processes.

While admittedly the hydrologic processes requiring simulation are complex, these processes are generally better understood and more readily simulated than the bacterial processes. Nonetheless, mechanistic bacteria modeling has progressed significantly over the last several decades beginning in the late 1960s to early 1970s as increasing computer resources have made such endeavors possible. Regrettably for the application of mechanistic bacteria models, while the numerical equations to represent many pertinent processes exist and are incorporated into readily available models, these processes are appreciably more watershed specific than hydrologic processes. As one simple example, failing on-site treatment systems, such as septic systems, rarely makes measurable differences to streamflow, but can dramatically impact fecal bacteria concentrations present in the same streamflow. In the vast majority of circumstances and the TMDL watersheds are no exception, only very limited watershed-specific information is available to define many of the physical and biological processes that affect bacteria concentrations and loadings. Consequentially, the operator of the mechanistic model must specify, in many circumstances, numerous input parameters governing bacteria processes for which actual numeric values may not be known within a reasonable range of certainty.

3.1.2 Data Resources of Mountain Creek Lake Tributaries

Streamflow and *E. coli* data availability were used to provide guidance in the allocation tool selection process. As already mentioned, the necessary information and data are largely unavailable for watersheds upstream of Mountain Creek Lake to allow adequate definition of many of the physical and biological processes influencing in-stream bacteria concentrations for mechanistic model application, and these limitations became an important consideration in the allocation tool selection process.

Hydrologic data in the form of daily streamflow records were unavailable for the TMDL watersheds; however, streamflow records were available for the Walnut Creek watershed which was determined to be the nearest and most comparable watershed with respect to size and demographic characteristics, e.g., urbanized area, though this watershed is appreciably more rural than the TMDL study area. Streamflow records for Walnut Creek watershed are collected and made readily available by the U.S. Geological Survey (USGS, 2015), which operates the Walnut Creek streamflow gage (Table 8; Figure 10). USGS streamflow gage 080497000 is located along the mainstem of the Walnut Creek within Segment 0838C and serves as the primary source for streamflow records used in this document.

Table 8. Basic information on Walnut Creek USGS streamflow gage

Gage No.	Site Description	Segment	Drainage Area (acres)	Daily Streamflow Record (beginning & end date)
08049700	Walnut Creek near Mansfield, TX.	0838C	40,179	Oct. 1960 - present

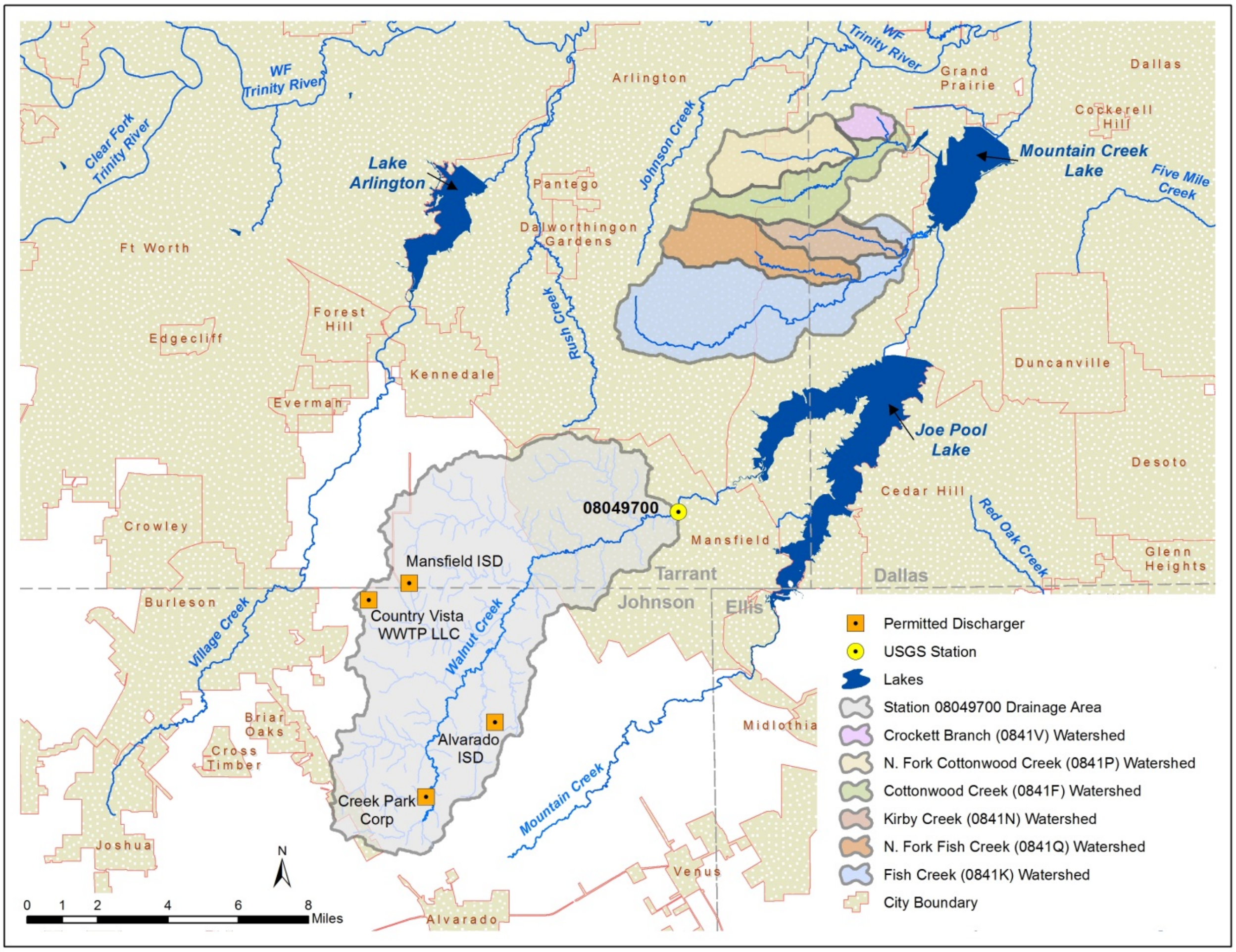

Figure 10. TMDL study area, Walnut Creek watershed and USGS Station 08049700 location near Mansfield, Texas.

Source: USGS (2015) and TCEQ (2015c)

Ambient *E. coli* data were available through the TCEQ SWQMIS for four stations in Segment 0841F, six stations in Segment 0841K, one station in Segment 0841N, and one station in Segment 0841V (Table 9).

Table 9. Summary of historical data set of *E. coli* concentrations.

Water Body	Segment	Station (s)	Station Location	No. of *E. coli* Samples	Data Date Range
Cottonwood Creek	0841F	10723	Tributary of Cottonwood Creek	36	2002-2013
		17674	Cottonwood Creek at SW 3rd St.	152	2001 - 2013
		17676	Cottonwood Creek at Robinson St.	143	2002 - 2013
		20837	Cottonwood Creek at Great Southwest Parkway	49	2009 - 2013
Fish Creek	0841K	10724	North Fork Fish Creek	35	2002-2013
		10725	Fish Creek at SH 360	35	2002-2013
		15294	Fish Creek at Great Southwest Parkway	58	2009 - 2013
		17677	Fish Creek at Robinson Road	82	2002 - 2008
		17679	Fish Creek at FM 1382	139	2002 - 2013
		20342	Fish Creek in Fish Creek Preserve	15	2008-2009
Kirby Creek	0841N	17675	Kirby Creek at Corn Valley Road	160	2002 - 2013
Crockett Branch	0841V	17683	Crockett Branch near Grand Prairie Road	139	2002 - 2013

3.1.3 Allocation Tool Selection

Based on good availability of historical daily streamflow records and ambient *E. coli* data as well as deficiencies in data to describe bacterial landscape and in-stream processes, the decision was made to use the load duration curve method as opposed to a mechanistic watershed loading and hydrologic/water quality model.

3.2 Methodology for Flow Duration & Load Duration Curve Development

To develop the flow duration curves (FDCs) and LDCs, the previously discussed data resources were used in the following series of sequential steps.

- **Step 1:** Determine the hydrologic period of record to be used in developing the flow duration curves.
- **Step 2:** Determine desired stream locations for which flow and load duration curves will be developed. (The stream location will be at monitoring stations along the impaired segments for which adequate *E. coli* data are available as shown in Table 9).

- **Step 3:** Develop daily streamflow records at desired stream locations using the daily gaged streamflow records and drainage area ratios.
- **Step 4:** Develop FDCs at desired stream locations, segmented into discrete flow regimes.
- **Step 5** Develop the allowable bacteria LDCs at the same stream locations based on the relevant criteria and the data from the FDCs.
- **Step 6:** Superpose historical bacteria data on the allowable bacteria LDCs.

Additional information explaining the LDC method may be found in Cleland (2003) and NDEP (2003).

3.2.1 Step 1: Determine Hydrologic Period

A 54-year daily hydrologic (streamflow) record was available for USGS gage 08049700 located on nearby Walnut Creek (Table 8, Figure 10). The period of record is more than adequate to capture a reasonable variation in meteorological patterns of high and low rainfall periods.

Optimally, the period of record to develop FDCs should include as much data as possible in order to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the *E. coli* data were collected. Therefore, a 25-year record of daily streamflow from 1 January 1989 through 31 December 2013 was selected to develop the FDCs at each station, and this period includes the collection dates of all available *E. coli* data at the time this work effort was undertaken. A 25-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is short enough in duration to contain a hydrology that is responding to recent and current conditions in the watershed. A 25-year period of record of 1 July 1986 through 30 June 2011 was used on the TMDLs developed for the Lower West Fork Trinity River watershed (TCEQ, 2013b). The common duration of period used between the Mountain Creek Lake tributary TMDLs and those for the Lower West Fork Trinity River TMDLs provides a level of continuity of approach between two projects within the watershed of the same classified segment (0841) while at the same time the more recent ending date of the 25-year period for the present project allows more recently collected *E. coli* data to be displayed on the LDCs in Step 6.

3.2.2 Step 2: Determine Desired Stream Locations

The SWQM stations that were located within the impaired reaches and for which adequate *E. coli* data were available determined the stream locations for which FDCs and LDCs were developed. Adequacy of data was defined as any station having at least 40 measured *E. coli* data (Table 9). For Cottonwood and Fish Creeks, multiple stations meet the requirement of 40 *E. coli* measurements, whereas only one station was available for both Kirby Creek and Crockett Branch (Figure 11). The most downstream monitoring station in each of the four impaired water bodies was selected as the location for developing the pollutant load allocation in order to maximize the amount of each watershed included above the sampling location. For Cottonwood and Fish Creeks, the other, more upstream sampling stations are used to provide additional information.

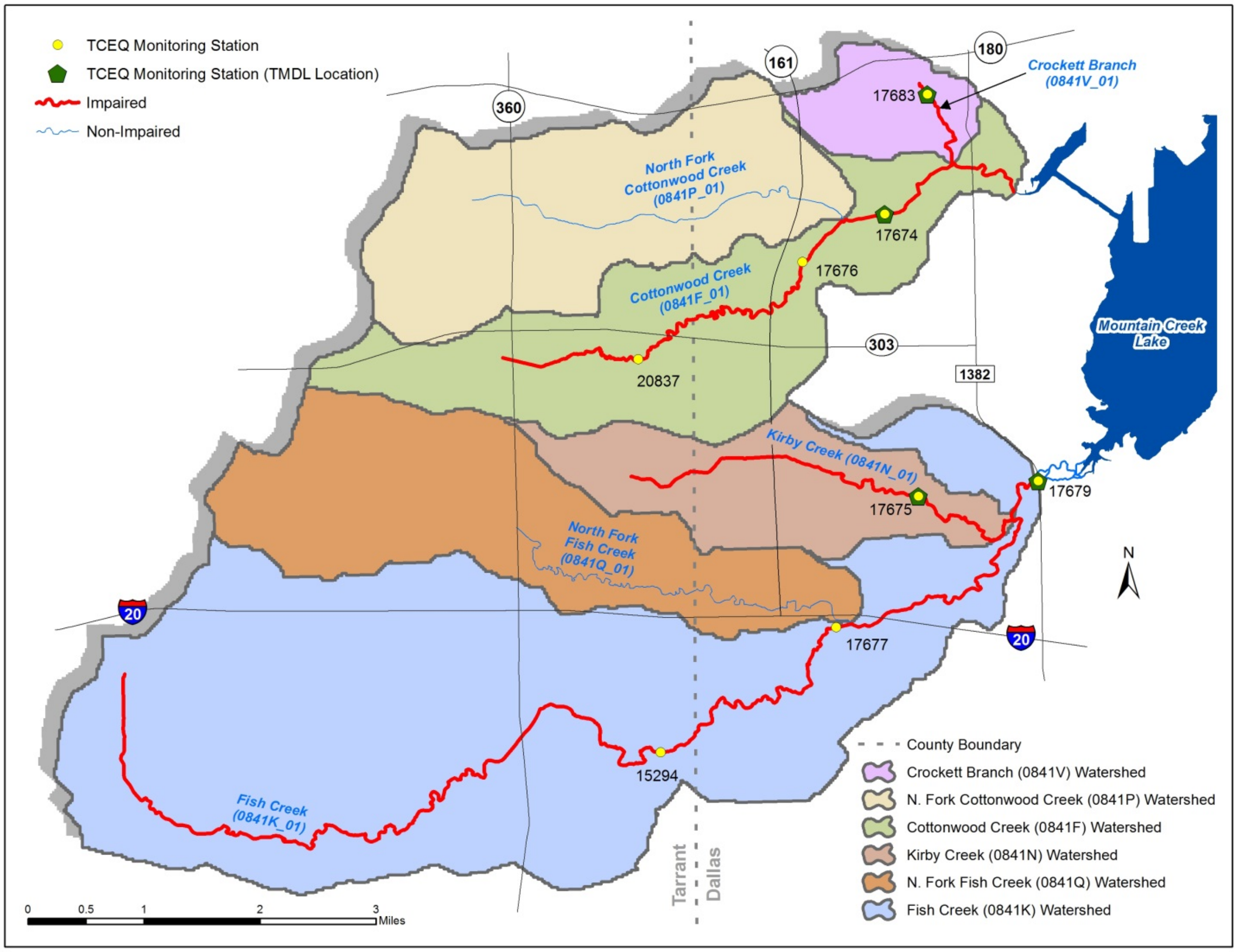

Figure 11. TMDL study area showing TCEQ monitoring stations selected for FDC/LDC development.
Source: TCEQ (2012b)

3.2.3 Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and station locations were determined, the next step was to develop the 25-year daily streamflow record for each monitoring station. The daily streamflow records were developed from extant USGS records (Table 8).

The method to develop the necessary streamflow record for each FDC/LDC location (SWQM stations location) involved a drainage-area ratio (DAR) approach. With this basic approach, the USGS gage 08049700 daily streamflow value within the 25-year period was multiplied by a factor to estimate the flow at a desired SWQM station location. The factor was determined by dividing the drainage area above the desired monitoring station location by the drainage area above the USGS gage.

Because an assumption of the DAR approach is similarity of hydrologic response based on commonality of landscape features such as geology, soils, and land use/land cover, point source derived flows should first be considered for removal from the flow record of the Walnut Creek gage prior to application of the ratio. There are four active WWTF discharges above the USGS gage on Walnut Creek (Figure 10); however, each of these discharges is small (largest permitted discharge of 0.04 million gallons per day) and all are greater than 10 stream miles from the gage location. The combination of the small size of the discharges, their distance from the gage and the fact that the USGS gage location for the 25-year period of record experienced zero streamflow 9 percent of the time and flow less than 0.05 cubic feet per second (cfs) 17 percent of the time lead to the assumption that the existing discharges are not significantly impacting the gaged streamflow record. Therefore, no adjustments for WWTF discharges were made to the Walnut Creek USGS gage record prior to application of the DARs.

The DARs for locations within the TMDL study area are presented in Table 10. The computation of the daily streamflow record at each station was performed by multiplying each daily streamflow in the 25-year Walnut Creek gaged record by the appropriate DAR for that station.

Table 10. DARs for locations within the TMDL watersheds based on the drainage area of the Walnut Creek USGS gage.

Water Body	Segment	Gage/Station	Drainage Area (acres)	Drainage Area Ratio (DAR)
Walnut Creek	0838C	8049700	40,179	1.0
Cottonwood Creek	0841F	20837	1,109	0.028
		17676	2,787	0.069
		17674 [a]	6,791	0.169
Fish Creek	0841K	15294	7,735	0.193
		17677	9,441	0.235
		17679	16,633	0.414
Kirby Creek	0841N	17675	1,634	0.041
Crockett Branch	0841V	17683	111	0.003

[a] Note that for purposes of the pollutant load allocation being calculated at a watershed level and to included Crockett Branch as a tributary loading to Cottonwood Creek, the 111 acres drainage area of Crockett Branch Station 17683 was added to the 6,680 acre drainage area of Station 17674 to determine the DAR.

Since none of the impaired watersheds contained any permitted WWTFs, there was no need to make any adjustments to the streamflow record computed using the DAR approach.

3.2.4 Steps 4-6: Flow Duration Curve and Load Duration Curve Methods

FDCs and LDCs are graphs indicating the percentage of time during which a certain value of flow or load is equaled or exceeded. To develop a FDC for a location the following steps were undertaken:

- order the daily streamflow data for the location from highest to lowest and assign a rank to each data point (1 for the highest flow, 2 for the second highest flow, and so on);
- compute the percent of days each flow was exceeded by dividing each rank by the total number of data point plus 1; and
- plot the corresponding flow data against exceedance percentages.

Further, when developing a LDC:

- multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 MPN/100 mL) and by a conversion factor (2.44658×10^7), which gives a loading in units of MPN/day; and
- plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of *E. coli*.

The resulting curve represents the maximum allowable daily loadings for the geometric mean criterion. The next step was to plot the sampled *E. coli* data, when such data existed at the LDC locations, on the developed LDC using the following two steps:

- using the unique data for each monitoring station, compute the daily loads for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding streamflow on that day and the conversion factor (2.44658×10^7); and
- plot on the LDC for each station the load for each measurement at the exceedance percentage for its corresponding streamflow.

The plots of the LDC with the measured loads (*E. coli* concentration multiplied by the daily streamflow) display the frequency and magnitude that measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

3.3: Flow Duration Curves for Sampling Stations within TMDL Watersheds

FDCs were developed for monitoring stations within the TMDL watersheds (Figures 12 and 13). For this report, FDCs were developed by applying the DAR method and using the Walnut Creek USGS gage and period of record (1998-2013) described in the previous sections. Flow exceedances less than 10% typically represent streamflows influenced by storm runoff while higher flow exceedances represent receding hydrographs after a runoff event, base flow and no flow conditions. The stair-step pattern in each LDC between the 80 and 90 percentiles of flow exceedance is an artifact that the low flows in the gaged streamflow record are reported to two significant digits to the right of the decimal point (e.g., 0.o1 cfs and o.02 cfs). Also, as contained in the streamflow record for Walnut Creek, almost 10 percent of the time each FDC shows the condition of no flow, which is anticipated to be reflective of actual conditions in these creeks.

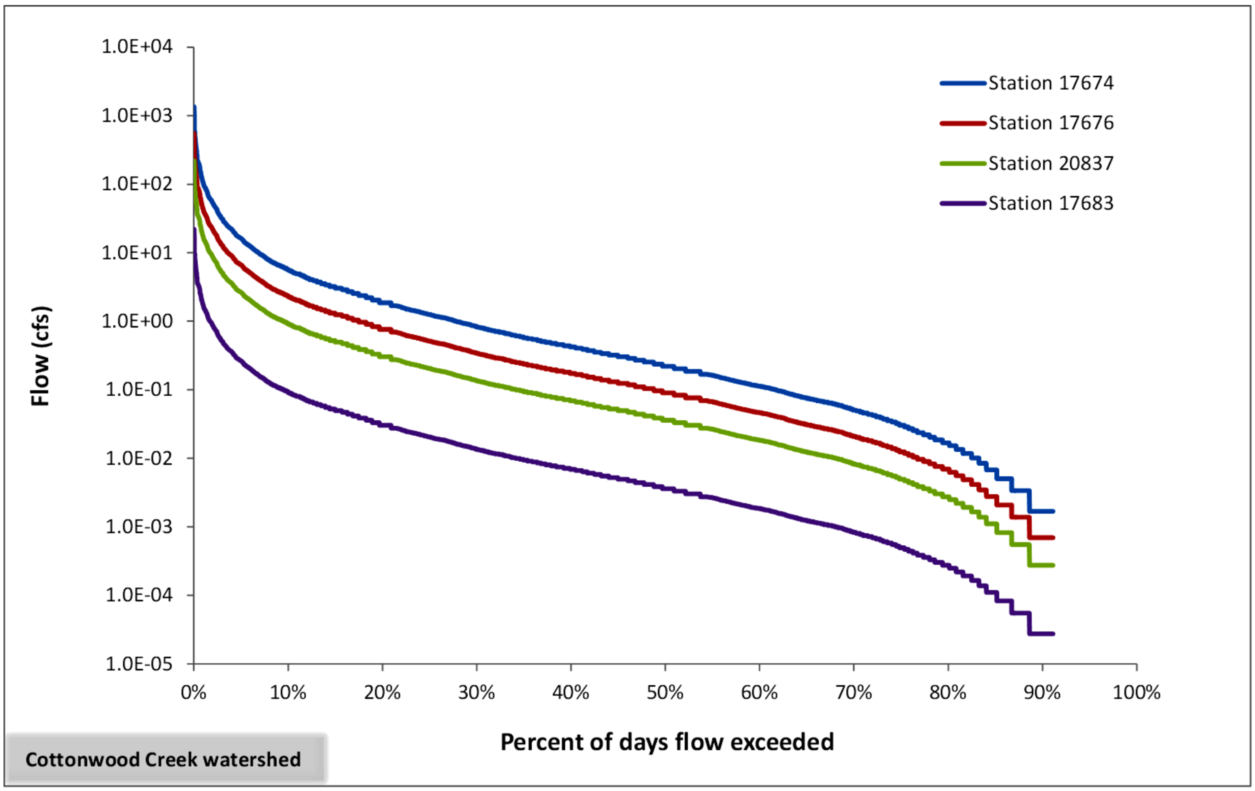

Figure 12. Flow duration curves for Cottonwood Creek (Stations 17674, 17676 and 20837) and Crockett Branch (Station 17683).

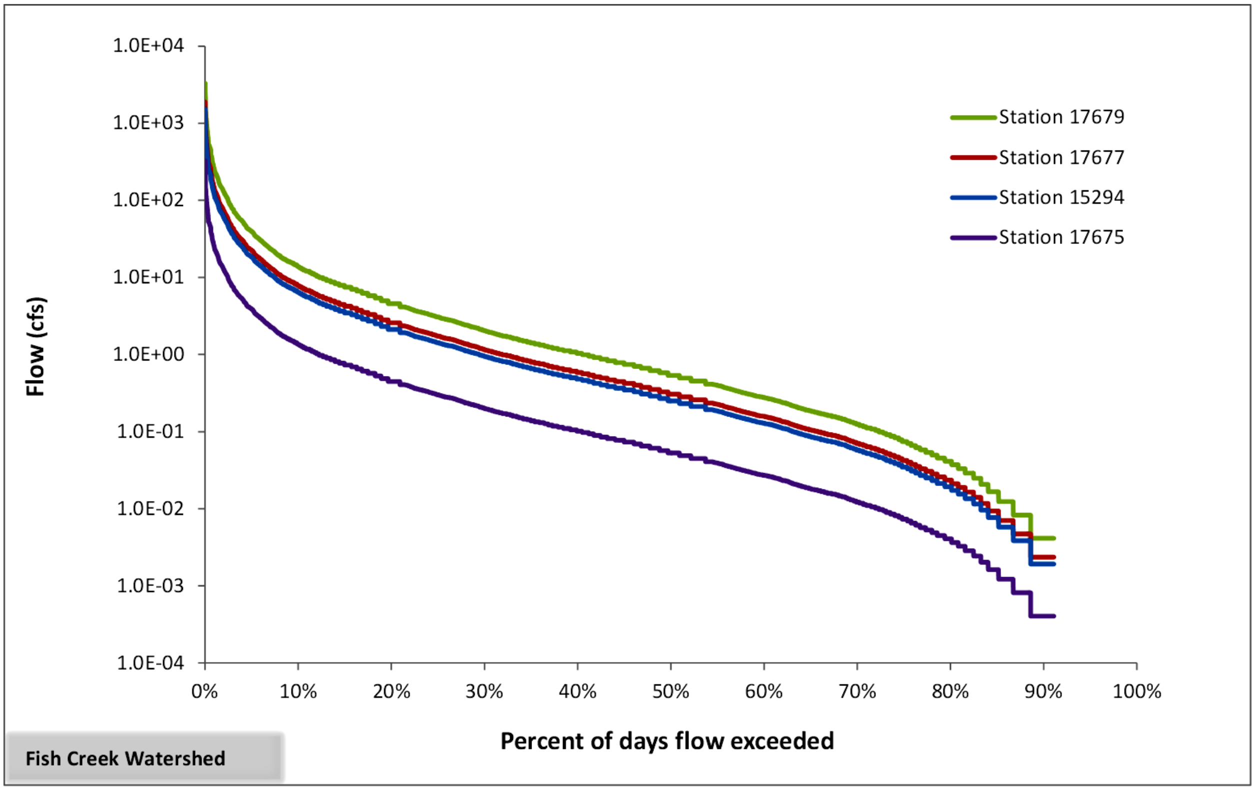

Figure 13. Flow duration curves for Fish Creek (Stations 17679, 17677 and 15294) and Kirby Creek (Station 17675).

3.4: Load Duration Curves for Sampling Stations within TMDL Watersheds

LDCs were developed for each monitoring station within the TMDL watersheds. A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0-10% (high flows); (2) 10-40% (moist conditions); (3) 40-60% (mid-range flows); (4) 60-90% (dry conditions); and (5) 90-100% (low flows).

For the TMDL watersheds, a three-interval division was selected:

- High flow regime: 0-10% range, related to flood conditions and non-point source loading
- Mid-range flow regime: 10-60% range, intermediate conditions of receding hydrographs after storm runoff and base line conditions
- Low flow regime: 60-100% range, related to dry conditions

The selection of the flow regime intervals was based on general observations of all the monitoring station LDCs. Both the 10 and 60 percentile divisions are convenient, as data collected during wet weather occurs more frequently below the 10th percentile, and non-wet weather data occurs more frequently above the 60th percentile. (Wet and non-wet weather events are defined in the next section.) Additionally, for the high flow regime, the 0-10% range generally represents the steepest portion of the LDC.

The load duration curves with these three flow regimes for water quality monitoring stations are provided in Figures 14 through 21, and were constructed for developing the TMDL allocation for each of the TMDL watersheds. Geometric mean loadings for the data points within each flow regime have also been distinguished on each figure to aid interpretation. The LDCs for the water quality monitoring stations provide a means of identifying the streamflow conditions under which exceedances in *E. co*li concentrations have occurred. The LDCs depict the allowable loadings at the stations under the geometric mean criterion (126 MPN/100 mL) and show that existing loadings often exceed the criterion. In addition, the LDCs also present the allowable loading at the stations under the single sample criterion (399 MPN/100 mL).

On each graph the measured *E. coli* data are presented as associated with a "wet weather event" or a "non-wet weather event." A sample was determined to be influenced by a wet weather event based on the reported "days since last precipitation" (DSLP) as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic and hydrologic conditions. Because of the large range in sizes of the monitoring station watersheds (i.e., smallest at 111 acres and largest at 16,633 acres, Table 10) and the concomitant variation in hydrologic response time to precipitation by watershed size, different values of DSLP were determined to best represent samples collected under wet weather conditions based on drainage area above each monitoring station. For monitoring stations with drainage areas of less than or equal to 4,000 acres, a sample with DSLP ≤ 1 day was defined as wet-weather influenced. For stations with a drainage area greater than 4,000 acres, a sample taken with DSLP ≤ 2 days was defined as a wet weather event. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low base flow in the stream.

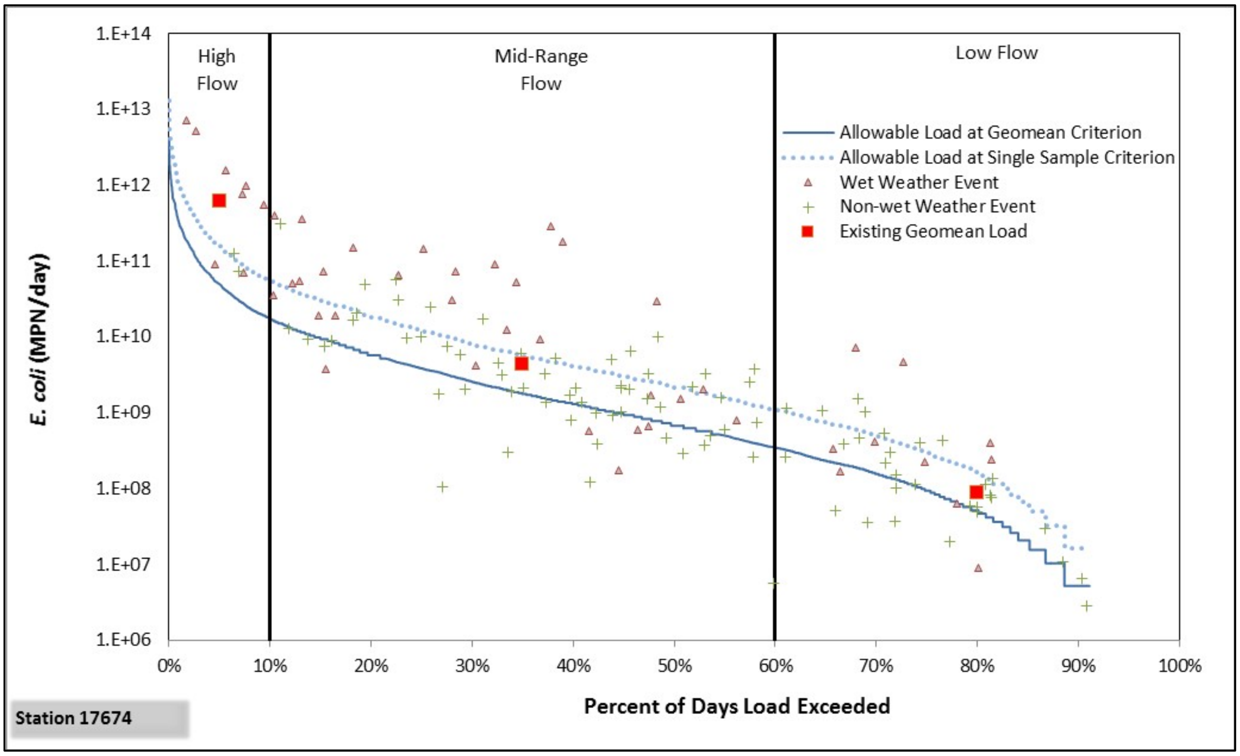

Figure 14. Load duration curve for Station 17674, Cottonwood Creek.

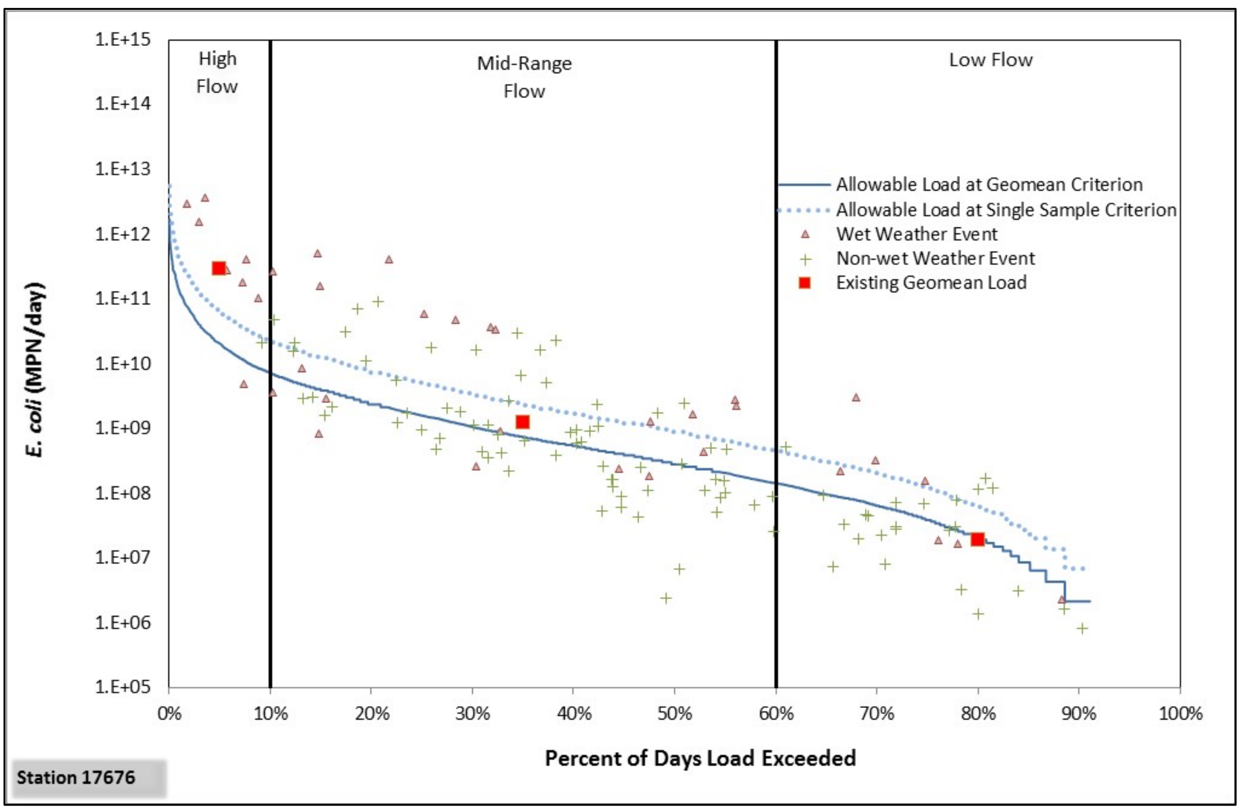

Figure 15. Load duration curve for Station 17676, Cottonwood Creek.

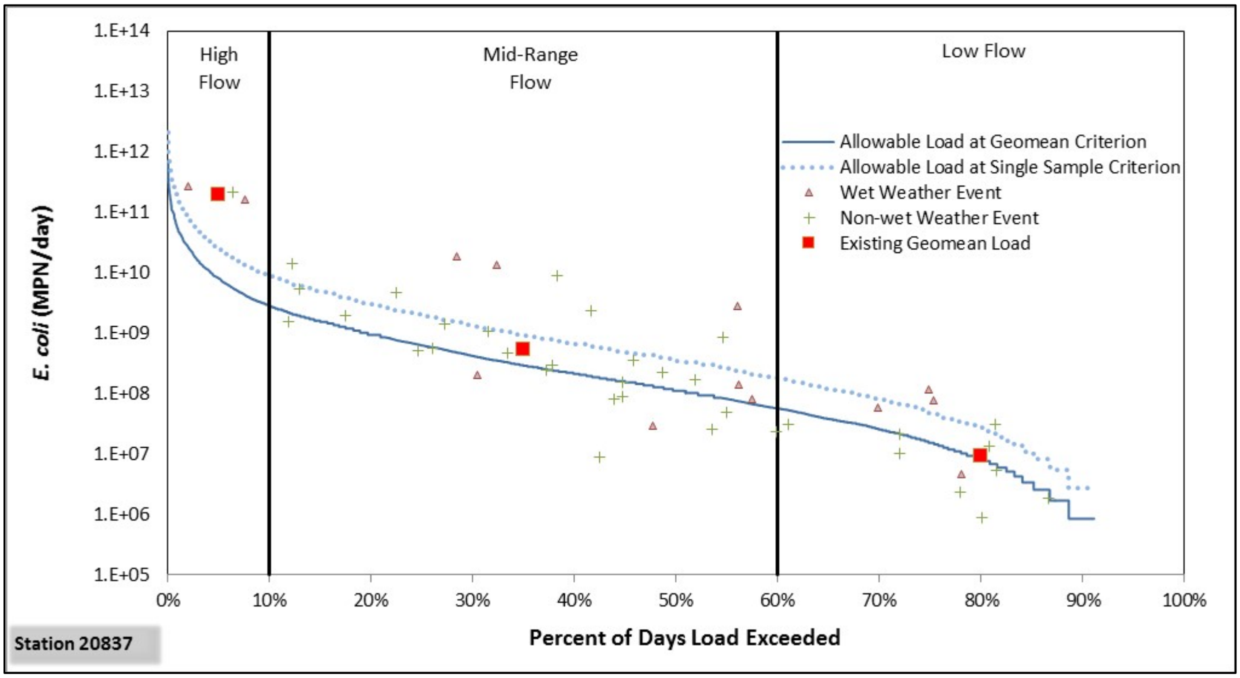

Figure 16. Load duration curve for Station 20837, Cottonwood Creek.

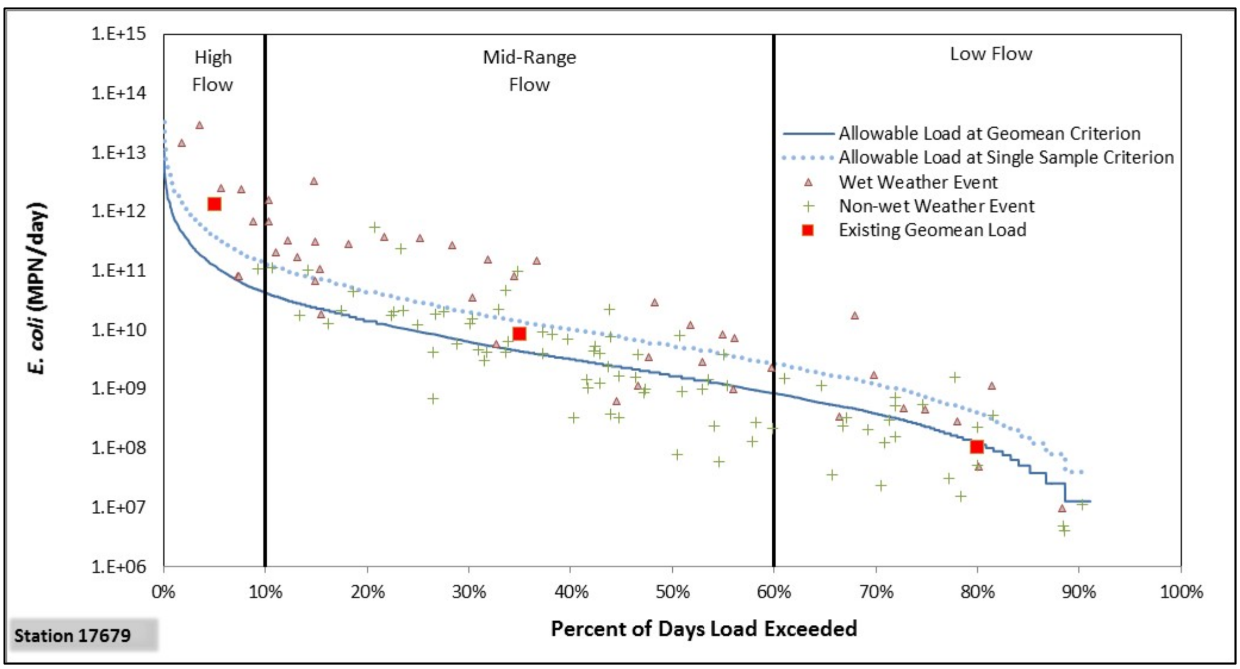

Figure 17. Load duration curve for Station 17679, Fish Creek.

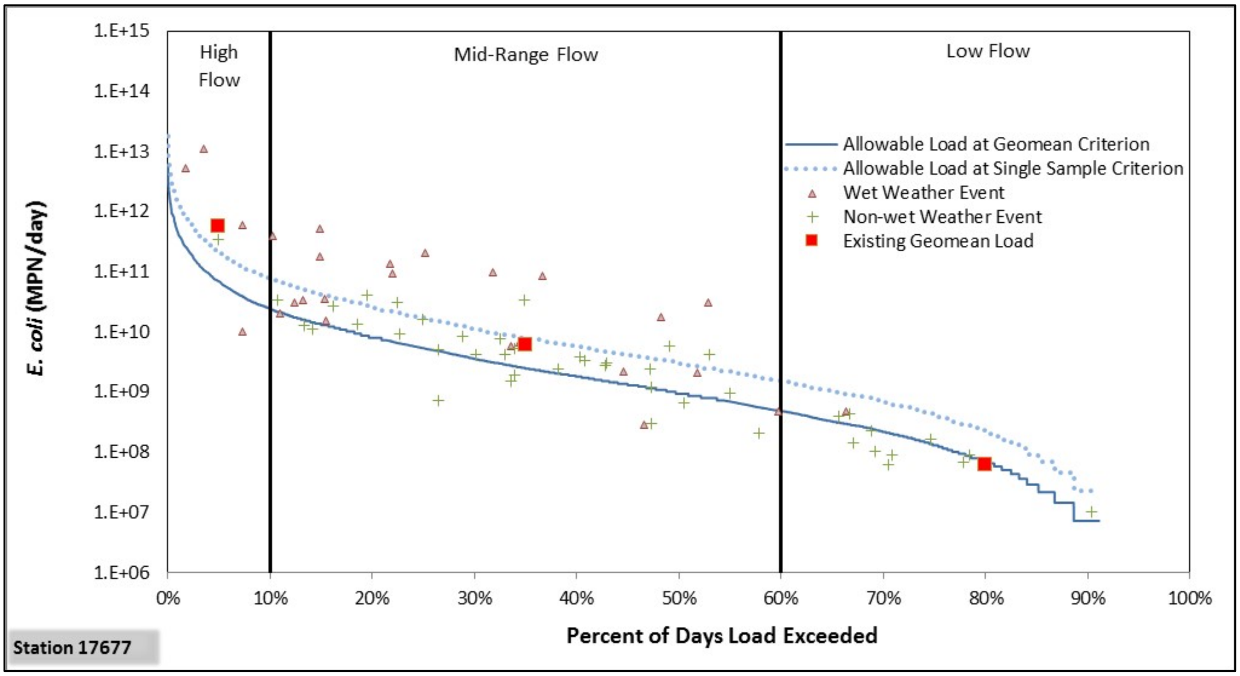

Figure 18. Load duration curve for Station 17677, Fish Creek.

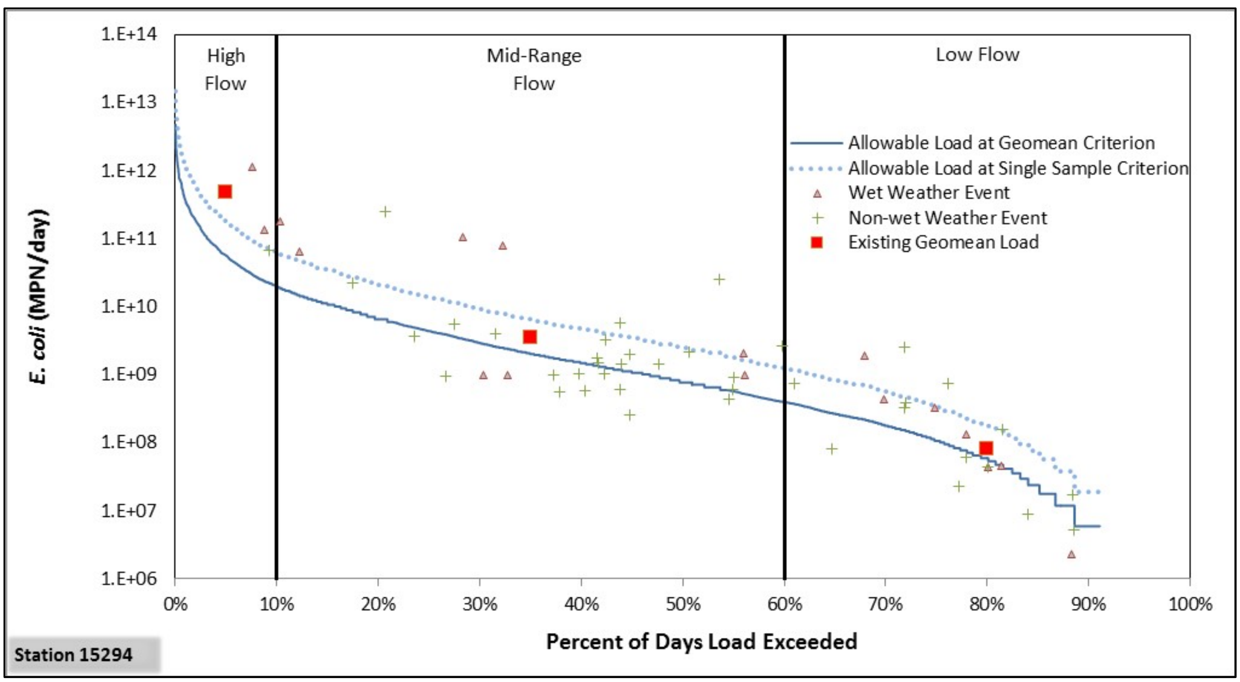

Figure 19. Load duration curve for Station 15294, Fish Creek.

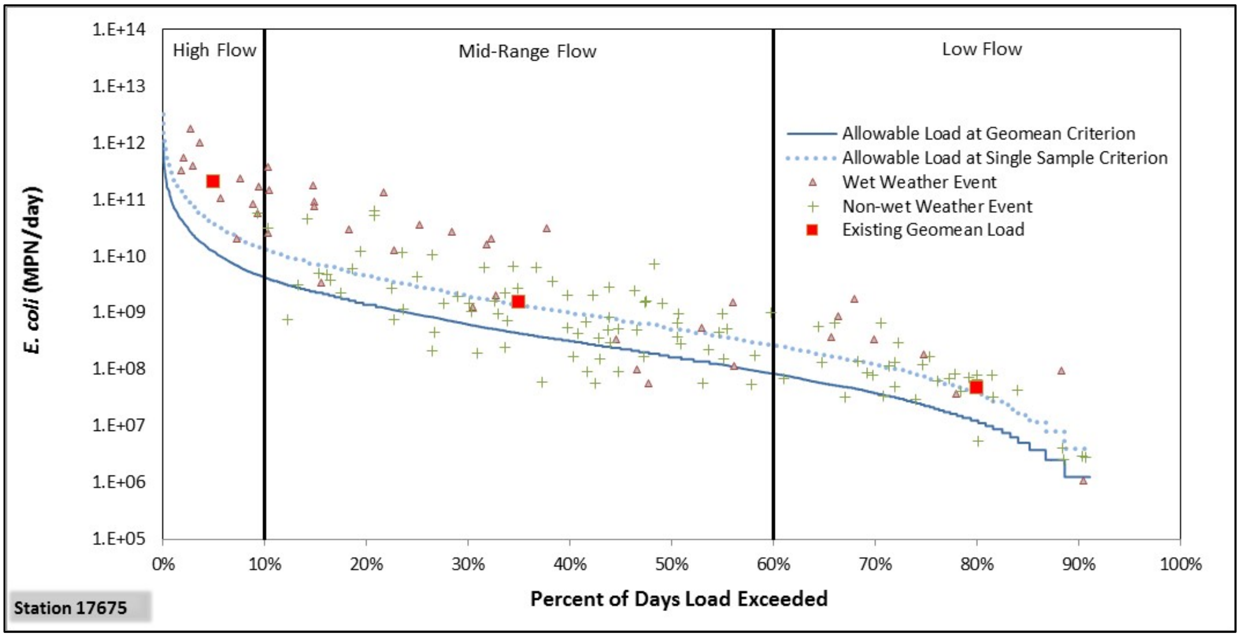

Figure 20. Load duration curve for Station 17675, Kirby Creek.

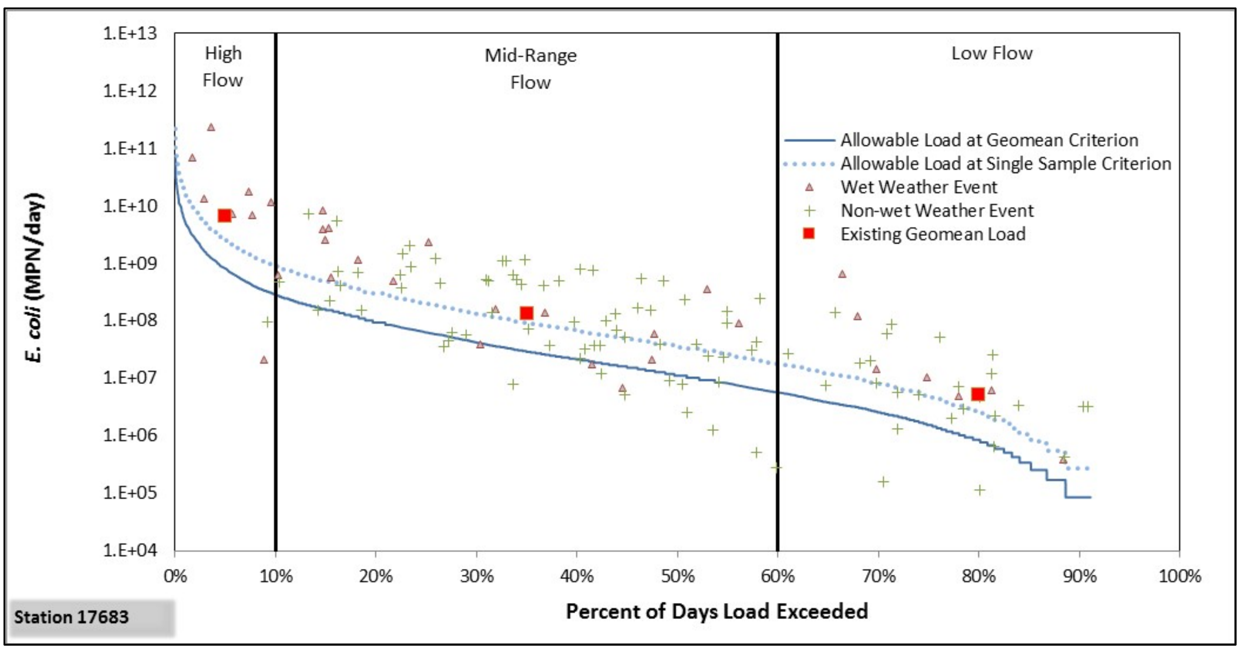

Figure 21. Load duration curve for Station 17683, Crockett Branch.

SECTION 4

TMDL ALLOCATION ANALYSIS

Presented in this report section is the development of the bacteria TMDL allocation for the four TMDL watersheds. The tool used for developing each TMDL allocation was the LDC method previously described in Section 3– Bacteria Tool Development. Endpoint identification, margin of safety, load reduction analysis, TMDL allocations, and other TMDL components are described herein.

The LDC method provided a flow-based approach to determine necessary reductions in bacteria loadings and allowable loadings within the four TMDL watersheds. As developed previously in this report, the LDC method uses frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loadings and the load reduction necessary to achieve support of the primary contact recreation use.

For the purposes of this TMDL study, the TMDL watersheds are considered to be the entire Cottonwood Creek watershed (Segment 0841F), Fish Creek (Segment 0841K), Kirby Creek (0841N) and Crockett Branch watershed (Segment 0841V) as shown in the overview map (Figure 1). Although the LDCs were computed for all eight of the SWQM stations that are located in the impaired segments, TMDLs are only calculated for the most downstream SQWM stations (17674 for Cottonwood Creek; 17679 for Fish Creek; 17675 for Kirby Creek; and 17683 for Crockett Branch; Figure 11). The most downstream SWQM stations were selected because these locations encompass more of the drainage area of each watershed and are representative of conditions in more of each watershed than stations located further upstream.

Additionally, a drainage area ratio approach using a historical streamflow gage in the Walnut Creek watershed for the reference flow record was employed to estimate the daily flow for SWQM stations within the TMDL watersheds.

4.1 Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions. The water bodies within these 4 TMDL watersheds have a use of primary contact recreation, which is measured against a numeric criterion for the indicator bacteria *E. coli*. Indicator bacteria are not generally pathogenic and are indicative of potential viral, bacterial, and protozoan contamination originating from the feces of warm-blooded animals. The *E. coli* criterion to protect contact recreation in freshwater streams consists of a geometric mean concentration not to exceed 126 MPN/100 mL (TCEQ, 2010).

The endpoint for these TMDLs is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100 mL. This endpoint was applied to all four watersheds addressed by this TMDL. This endpoint is identical to the geometric mean criterion in the 2010 Surface Water Quality Standard (TCEQ, 2010).

4.2 Seasonality

Seasonal variations or seasonality occur(s) when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* concentrations obtained from 12 years (2002 – 2013) of routine monitoring collected in the warmer months (April - September) against those collected during the cooler months (October – March). Differences in *E. coli* concentrations obtained in warmer versus cooler months were then evaluated by performing a t-test on the natural log transformed dataset. This analysis of *E.coli* data indicated that there was a significant difference (α=0.05) in indicator bacteria between cool and warm weather seasons for Cottonwood Creek (α=0.0085) and Crockett Branch (α=0.0024) with the warm season having the higher concentrations. Seasonality was not detected in the Fish Creek and Kirby Creek watersheds.

4.3 Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely to be point sources and direct fecal material deposition into the water body. During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources and direct deposition is typically diluted, and would therefore be a smaller part of the overall concentrations.

Bacteria load contributions from regulated and unregulated stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of lower concentrations in the water body just before the rain event, followed by a rapid increase in bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

Load duration curves were used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a 1 to 1 relationship between instream loadings and loadings originating from point sources and the landscape as regulated and non-regulated sources. Further this 1 to 1 relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7). That is the allocation of pollutant loads was based on apportioning the loadings based on a fractional proportioning of flow based on the area of the watershed under stormwater regulation and assigning the remaining portion to non-regulated stormwater.

4.4 Load Duration Curve Analysis

A LDC method was used to examine the relationship between instream water quality, the broad sources of indicator bacteria loads, and are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders, and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of the basic LDC approach to characterize pollutant sources. In addition, many other states are using this basic method to develop TMDLs. As discussed in more detail in Section 4.7 (Pollutant Load Allocation), the TMDL loads were based on the median flow within the high flow regime (or 5% flow), where exceedances of the primary contact recreation criteria are most pronounced.

The LDC method allows for estimation of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (*i.e.*, point source and stormwater) and provides a means to allocate allowable loadings.

Based on the LDCs to be used in the pollutant load allocation process with historical *E. coli* data added to the graphs (Figures 14, 17, 20, and 21) and Section 2.6 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made. For the TMDL watersheds, the historical *E. coli* data indicate that elevated bacteria loadings occur especially under the highest flow and mid-range flow regimes. There is generally some moderation of the elevated loadings under the lowest flow regime, except for Kirby Creek and Crockett Branch where loadings remain at the same elevated levels across flow regimes (Figures 20 and 21). The supporting LDCs developed for Cottonwood and Fish Creek exhibit a similar pattern to the TMDL stations on both creeks with the most elevated loadings above allowable amounts under the highest flow regime, followed by the mid-range flow regime, and even at times a majority of measured loadings below the allowable loadings under the lowest flow regime (Figures 15, 16, 18 and 19). Regulated stormwater comprises a majority portion of the TMDL watersheds and must be considered a major contributor. Most likely unregulated stormwater comprises the minority of high flow related loadings. In some situations, elevated *E. coli* loadings under the lower flow conditions can be attributed to point sources such as WWTFs; however, this rational is nullified due to the absence of permitted dischargers within the TMDL study area. Therefore, other sources of bacteria loadings under lower flows and in the absence of permitted discharger contributions (i.e., without WWTF contribution) are occurring though the sources cannot be determined through this analysis.

4.5 Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (USEPA, 1991), the MOS can be incorporated into the TMDL using two methods:

1) Implicitly incorporating the MOS using conservative model assumptions to develop allocations; or
2) Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The margin of safety is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The TMDLs covered by this report incorporate an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target for *E. coli* of 119.7 MPN/100 mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.6 Load Reduction Analysis

While the TMDLs for the four TMDL watersheds were developed using LDCs and associated load allocations, additional insight may, in certain situations, be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical

E. coli data obtained from the most downstream station within each impaired water body.

For each station used in the pollutant load allocation calculations and each flow regime, the percent reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean concentration and the 126MPN/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 11).

Table 11. Percent reduction calculations for most downstream station within each impaired water body.

Watershed (Station)	Segment	High Flows (0-10%)		Mid-Range Flow (10-60%)		Low Flows (60-100%)	
		Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction
Cottonwood Creek (17674)	0841F	1,546	91.8%	307	59.0%	213	40.7%
Fish Creek (17679)	0841K	1,370	90.8%	248	49.2%	104	-21.2%
Kirby Creek (17675)	0841N	2,178	94.2%	454	72.3%	476	73.5%
Crockett Branch (17683)	0841V	1,034	87.8%	569	77.9%	750	83.2%

4.7. Pollutant Load Allocation

The bacteria TMDLs for the four impaired water bodies were developed as a pollutant load allocation based on information from the most downstream LDCs in each segment (Figures 14, 17, 20, and 21). As discussed in more detail in Section 3, bacteria LDCs were developed by multiplying each flow value along the flow duration curves by the *E. coli* criterion (126 MPN/100 mL) and by the conversion factor used to represent maximum loading in MPN/day. Effectively, the "Allowable Load" displayed in the LDC at 5% exceedance (the median value of the high-flow regime) is the TMDL:

TMDL (MPN/day) = Criterion * Flow (cfs) * Conversion Factor (Eq. 1)

Where:

Criterion = 126 MPN/100 mL (*E. coli*)

Conversion Factor (to MPN/day) = 283.168 100 mL/ft^3 * 86,400 sec/day

4.7.1 Definition of TMDL Components

A TMDL represents the maximum amount of a pollutant that the water body can receive in a single day without exceeding water quality standards. The pollutant load allocations for the selected scenarios were calculated using the following basic equation:

$$TMDL = WLA + LA + FG + MOS \qquad \text{(Eq. 2)}$$

Where:

TMDL = total maximum daily load

WLA = waste load allocation, the amount of pollutant allowed by existing regulated or permitted dischargers

LA = load allocation, the amount of pollutant allowed by unregulated or non-permitted sources

FG = loadings associated with future growth from potential permitted facilities

MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli*, TMDLs are expressed as MPN/day, and represent the maximum one-day load the stream can assimilate while still attaining the standards for surface water quality.

The TMDL components for the TMDL watersheds covered in this report are derived using the median flow within the high flow regime (or 5% flow) of the LDC developed for the most downstream SWQM station in each Segment.

The Waste Load Allocation (WLA) consists of two parts – the waste load that is allocated to TPDES-regulated wastewater treatment facilities (WLA_{WWTF}) and the waste load that is allocated to regulated stormwater dischargers (WLA_{SW}).

$$WLA = WLA_{WWTF} + WLA_{SW} \qquad \text{(Eq. 3)}$$

TPDES-permitted wastewater treatment facilities are allocated a daily waste load (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by one half the instream geometric criterion. One-half of the water quality criterion (63 MPN/100mL) is used as the WWTF target to provide instream and downstream load capacity and is consistent with the approach taken in the previously completed TMDLs of the Lower West Fork Trinity River (TCEQ, 2013b). Thus WLA_{WWTF} is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow * Conversion\ Factor \qquad \text{(Eq. 4)}$$

Where:

Target= 63 MPN/100 mL

Flow = full permitted flow (MGD)

Conversion Factor (to MPN/day) = 1.54723 cfs/MGD *283.168 100 mL/ft3 * 86,400 s/d

Due to the absence of any permitted dischargers in the TMDL watersheds, the WLA_{WWTF} component is zero.

Stormwater discharges from MS4, industrial, and construction areas are also considered permitted or regulated point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading. The percentage of the land area included in each watershed that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL.

WLA_{SW} is the sum of loads from regulated stormwater sources and is calculated as follows:

$$WLA_{SW} = (TMDL - WLA_{WWTF} - LA_{TRIB} - FG - MOS) * FDA_{SWP} \qquad \text{(Eq. 5)}$$

Where:

WLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

LA_{TRIB} = loadings from tributary water bodies for which TMDLs are developed

FG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area under jurisdiction of stormwater permits

As will be discussed in more detail immediately below, the LA_{TRIB} term is computed from Equation 1 for Kirby Creek as a tributary of Fish Creek and for Crockett Branch as a tributary of Cottonwood Creek.

The LA component is the sum of loads from unregulated sources within the TMDL watershed. A complexity to the LA term occurs as a result of loadings from tributaries that have developed TMDLs, which must be factored into the LA component. Therefore, the total load allocation (LA_{TOTAL}) is defined as the bacteria load that arises from unregulated sources within the AU (LA_{AU}) plus the tributary TMDL from impaired tributaries entering the AU (LA_{TRIB}). The LA term becomes fully expressed as:

$$LA_{TOTAL} = LA_{AU} + LA_{TRIB} \quad \text{(Eq. 6)}$$

Where:

LA_{TOTAL} = total allowable load from unregulated sources (predominately nonpoint sources)

LA_{AU} = allowable loads from unregulated sources assigned to the AU

LA_{TRIB} = loadings from tributary water bodies for which TMDLs are developed

The TMDL equation can thus be expanded to show the components of WLA and LA:

$$TMDL = WLA_{WWTF} + WLA_{SW} + LA_{AU} + LA_{TRIB} + FG + MOS \quad \text{(Eq. 7)}$$

The margin of safety is only applied to the allowable loading for an AU and is not applied to the LA_{TRIB} that enters the segment as an external loading from another TMDL water body. Therefore the margin of safety is expressed mathematically as the following:

$$MOS = 0.05 * (TMDL - LA_{TRIB}) \quad \text{(Eq. 8)}$$

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

LA_{TRIB} = loadings from tributary water bodies for which TMDLs are developed

The Future Growth (FG) component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that may occur as a result of population growth, changes in community infrastructure, and development. The assimilative capacity of streams increases as the amount of flow increases due to future growth of permitted discharges. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

Due to 100% coverage of wastewater collection by the TRA Central Regional WWTF Collection System and the absence of WWTFs in the TMDL study area, the FG component for all four impaired segments is zero.

4.7.2 AU-Level TMDL Calculations

The allowable loading of *E. coli* that the impaired AUs within the TMDL watersheds can receive on a daily basis was determined using Equation 1 based on the median value within the high flows regime of the FDC (or 5% flow exceedance value) for the selected station of each AU (Table 12).

Table 12. Summary of allowable loading calculations for segments within the TMDL watersheds.

Water Body	Segment	5% Exceedance Flow (cfs)	5% Exceedance Load (MPN/day)	TMDL (Billion MPN/day)
Cottonwood Creek	0841F	16.057	4.9498E+10	49.498
Fish Creek	0841K	39.327	1.21234E+11	121.234
Kirby Creek	0841N	3.863	1.1910E+10	11.910
Crockett Branch	0841V	0.2625	8.0905E+08	0.809

Using the values of TMDL for each AU provided in Table 12, the MOS may be readily computed by proper substitution into Equation 8 (Table 13).

Table 13. MOS calculations for downstream stations within the TMDL watersheds.

All loads expressed as billion MPN/day *E. coli*

Water Body	Segment	TMDL	LA_{TRIB}	MOS
Cottonwood Creek	0841F	49.498	0.809	2.434
Fish Creek	0841K	121.234	11.910	5.466
Kirby Creek	0841N	11.910	0	0.595
Crockett Branch	0841V	0.809	0	0.040

In order to calculate the WLA_{SW} component of the TMDL, the fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the combined area under regulated stormwater permits. As described in Sections 2.6.1.3, each TMDL watershed is covered 100% by MS4 Phase II general permits and\or a Phase I individual permit (Figure 8). However, even in highly urbanized areas such as the TMDL study area, there remain small areas of streams within each watershed that are not strictly regulated stormwater and which may receive bacteria loadings from unregulated sources such as wildlife and feral hogs. To account for these small unregulated areas in each impaired watershed, the stream length based on the TCEQ definition of each AU and a stream width estimated from aerial imagery was used to compute an area of unregulated stormwater contribution (Table 14).

Table 14. Basis of unregulated stormwater area and computation of FDA_{SWP}.

Water Body	Total Area (acres)	Stream Length (feet)	Estimated Average Stream Width (feet)	Estimated Stream Area (acres)	Fraction Unregulated Area	FDA_{SWP}
Cottonwood Creek	3,798	34,857	23	18.4	0.0048	0.9952
N. F. Cottonwood Creek	3,546	19,808	30	13.6	0.0038	0.9962
Entire Cottonwood Creek (Excluding Crockett Branch)	7,344	54,664	25.5	32.0	0.0044	0.9956
Crockett Branch	767	4,920	11	1.2	0.0016	0.9984
Fish Creek	10,993	73,354	30	50.5	0.0046	0.9954
N. F. Fish Creek	3,663	25,328	26	15.1	0.0041	0.9959
Entire Fish Creek (Excluding Kirby Creek)	14,656	98,682	29.0	65.6	0.0045	0.9955
Kirby Creek	1,978	22,114	18	9.1	0.0046	0.9954

Due to the absence of any permitted dischargers in the TMDL study area, the WLA_{WWTF} term is zero. Likewise, since it is unforeseen that any permitted discharges with a human waste component will occur in the TMDL study area, the FG term is also zero. With the information provided in Tables 12 – 14 and the zero values for WLA_{WWTF} and FG, the WLA_{SW} term was calculated using Equation 5 as provided in Table 15.

Table 15. Regulated stormwater calculations for the TMDL watersheds.
All loads expressed as billion MPN/day *E. coli*

Water Body	Segment	TMDL	WLA_{WWTF}	LA_{TRIB}	FG	MOS	FDA_{SWP}	WLA_{SW}
Cottonwood Creek	0841F	49.498	0	0.809	0	2.434	0.9956	46.053
Fish Creek	0841K	121.234	0	11.910	0	5.466	0.9955	103.393
Kirby Creek	0841N	11.910	0	0	0	0.595	0.9954	11.263
Crockett Branch	0841V	0.809	0	0	0	0.040	0.9984	0.768

Once the WLA_{SW} and WLA_{WWTF} terms are known, the WLA term can be calculated based on Equation 3, as shown in Table 16

Table 16. Waste load allocation calculations for the TMDL watersheds.
All loads expressed as billion MPN/day *E. coli*

Water Body	Segment	WLA_{WWTF}	WLA_{SW}	WLA
Cottonwood Creek	0841F	0	46.053	46.053
Fish Creek	0841K	0	103.393	103.393
Kirby Creek	0841N	0	11.263	11.263
Crockett Branch	0841V	0	0.768	0.768

The last term in the TMDL requiring computation is LA_{AU}, which is the allowable bacteria loading assigned to unregulated sources within each TMDL watershed. All AUs within the TMDL watersheds were assigned a small area not regulated by stormwater permits as detailed in Table 14. The LA_{AU} for each TMDL watershed was computed by first algebraically manipulating Equation 7 to allow the computation of this final term and then substituting in the correct loading for each term (Table 27). As discussed previously, the LA_{TRIB} term represents the tributary loading of the Crockett Branch TMDL as part of the Cottonwood Creek TMDL and the tributary loading of the Kirby Creek TMDL as part of the Fish Creek TMDL.

Table 17. Unregulated stormwater calculations for the TMDL watersheds.
Units expressed as billion MPN/ day *E. coli*

Water Body	Segment	TMDL	WLA_{WWTF}	WLA_{SW}	LA_{TRIB}	FG	MOS	LA_{AU}
Cottonwood Creek	0841F	49.498	0	46.053	0.809	0	2.434	0.202
Fish Creek	0841K	121.234	0	103.393	11.910	0	5.466	0.465
Kirby Creek	0841N	11.910	0	11.263	0.000	0	0.595	0.052
Crockett Branch	0841V	0.809	0	0.768	0.000	0	0.040	0.001

4.8 Summary of TMDL Calculations

Table 18 summarizes the TMDL calculations for TMDL watersheds. Each of the TMDLs was calculated based on the median flow in the 0-10 percentile range (5% exceedance, high flow regime) for flow exceedance from the LDC developed for the downstream SWQM station within each watershed. Allocations are based on the current geometric mean criterion for *E. coli* of 126 MPN/100 mL for each component of the TMDL.

Table 18. TMDL allocation summary for the TMDL watersheds.
Units expressed as billion MPN/ day *E. coli*

Water Body	Segment	TMDL	WLA_{WWTF}	WLA_{SW}	LA_{AU}	LA_{TRIB}	FG	MOS
Cottonwood Creek	0841F	49.498	0	46.053	0.202	0.809	0	2.434
Fish Creek	0841K	121.234	0	103.393	0.465	11.910	0	5.466
Kirby Creek	0841N	11.910	0	11.263	0.052	0	0	0.595
Crockett Branch	0841V	0.809	0	0.768	0.001	0	0	0.040

The final TMDL allocations (Table 19) needed to comply with the requirements of 40 CFR 130.7 include the future growth component within the WLA_{WWTF}, which for all the TMDL watersheds was zero due to the absence of any permitted discharges and the anticipation of no future permitted discharges with a human waste component. The final TMDL allocation also included allocations to permitted MS4 entities and permitted construction and industrial activities, which are designated as WLAsw. The LA_{TOTAL} component of the final TMDL allocations is comprised of the sum of unregulated stormwater loadings arising from within each AU and any loadings associated with TMDL water bodies that are tributaries to another TMDL water body.

Table 19. Final TMDL allocations for the TMDL watersheds.
Units expressed as billion MPN/ day *E. coli*

Water Body	Segment	TMDL	WLA_{WWTF} [a]	WLA_{SW}	LA_{TOTAL} [b]	MOS
Cottonwood Creek	0841F	49.498	0	46.053	1.011	2.434
Fish Creek	0841K	121.234	0	103.393	12.375	5.466
Kirby Creek	0841N	11.910	0	11.263	0.052	0.595
Crockett Branch	0841V	0.809	0	0.768	0.001	0.040

[a] $WLA_{WWTF} = WLA_{WWTF}$ + FG from Table 16

[b] $LA_{TOTAL} = LA_{AU} + LA_{TRIB}$ from information in Table 18

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix A provides guidance for recalculating the allocations in Table 19. Figures A-1 through A-4 of Appendix A were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for *E. coli*. The equations provided, along with Figures A-1 through A-4, allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion for *E. coli*.

Section 5
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APPENDIX A

EQUATIONS FOR CALCULATING TMDL ALLOCATIONS FOR CHANGED CONTACT RECREATION STANDARD

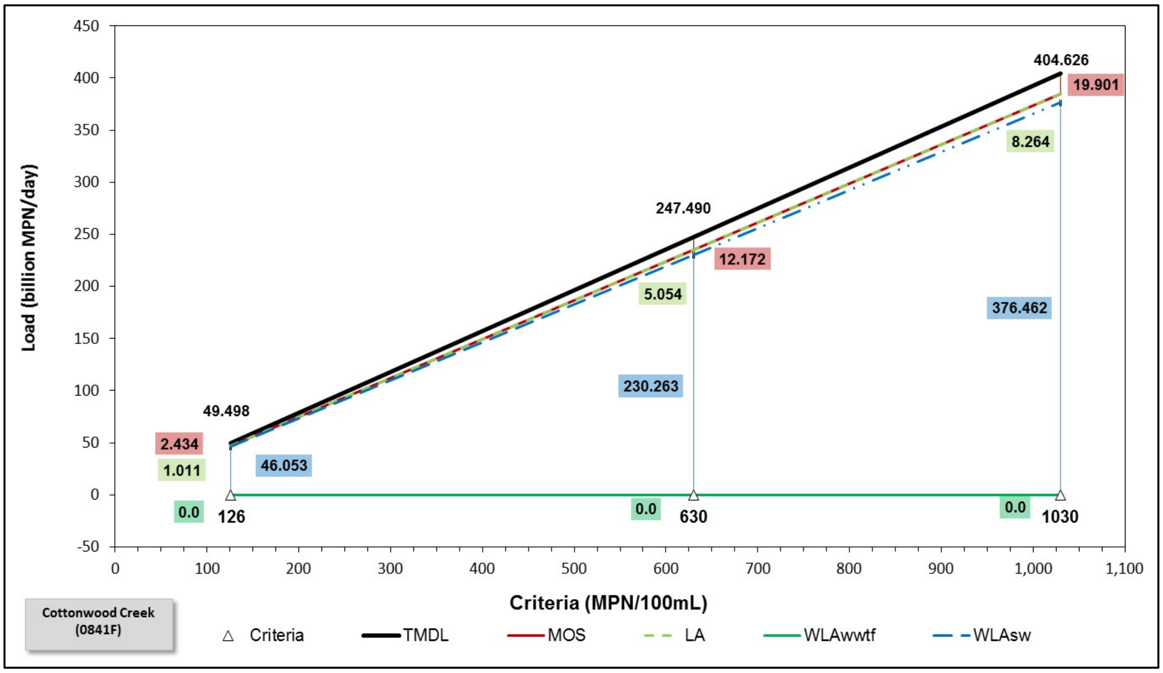

Figure A-1. Allocation loads for the Cottonwood Creek watershed (0841F) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day)

TMDL	$=0.39284 * \text{Std}$
MOS	$= 0.01932 * \text{Std}$
LA	$= 0.00802 * \text{Std}$
WLA_{WWTF}	$= 0$
WLA_{sw}	$=0.36550 * \text{Std}$

Where:

Std =	Revised Contact Recreation Standard
MOS =	Margin of Safety
LA =	Total load allocation (unregulated sources)
WLA_{WWTF} =	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} =	Waste load allocation (permitted stormwater)

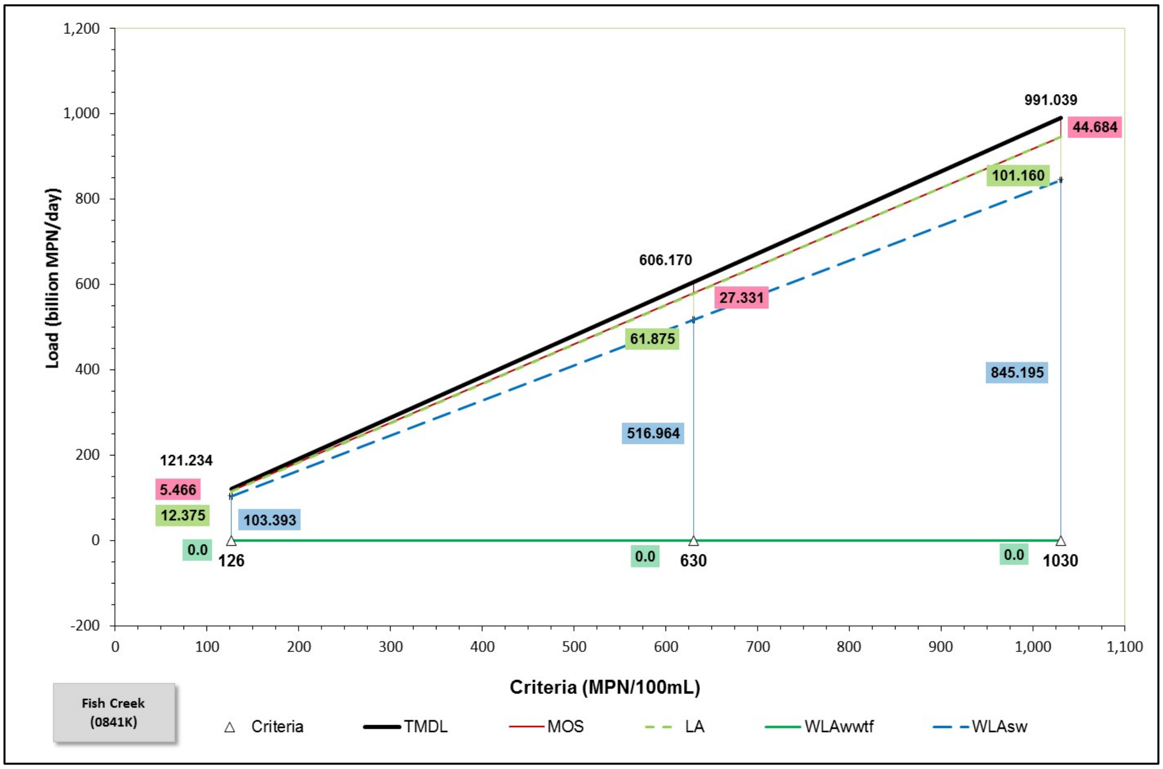

Figure A-2. Allocation loads for the Fish Creek watershed (0841K) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day)

TMDL	=0.96217 * Std
MOS	= 0.04338 * Std
LA	= 0.09821 * Std
WLA_{WWTF}	= 0
WLA_{sw}	= 0.82058 * Std

Where:

Std =	Revised Contact Recreation Standard
MOS =	Margin of Safety
LA =	Total load allocation (unregulated sources)
WLA_{WWTF} =	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} =	Waste load allocation (permitted stormwater)

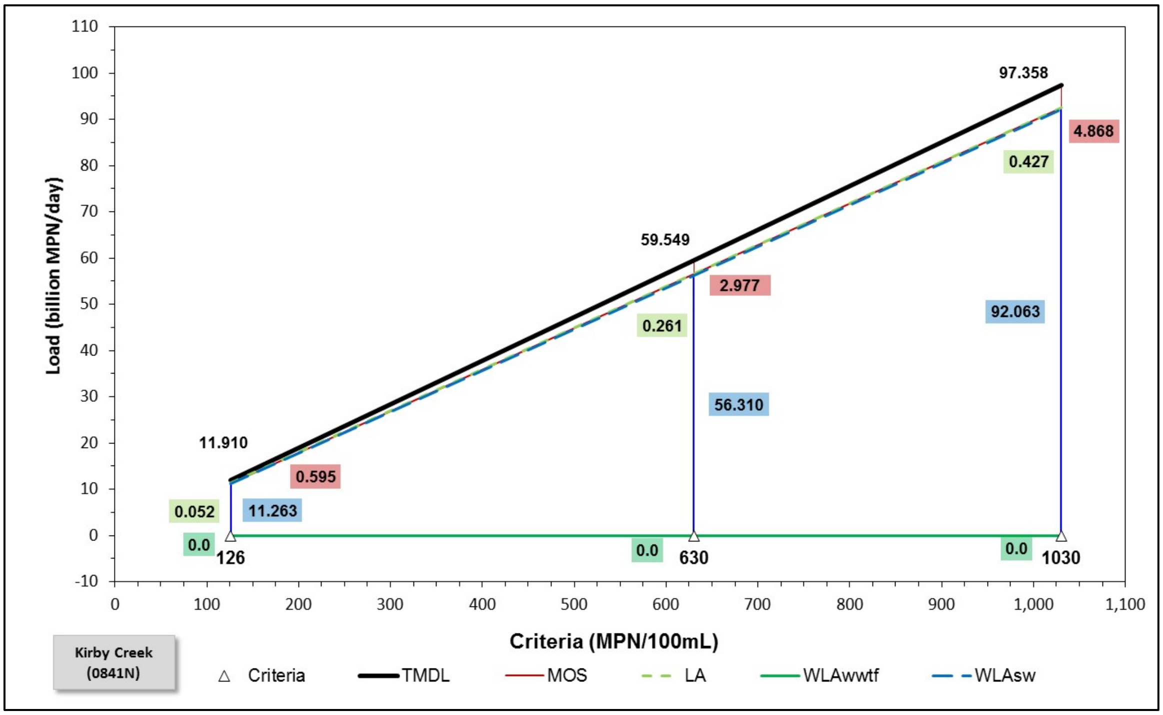

Figure A-3. Allocation loads for the Kirby Creek watershed (0841N) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day)

TMDL =0.094522 * Std
MOS = 0.004727 * Std
LA = 0.000415 * Std
WLA_{WWTF} = 0
WLA_{sw} = 0.089382 * Std

Where:

Std = Revised Contact Recreation Standard
MOS = Margin of Safety
LA = Total load allocation (unregulated sources)
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} = Waste load allocation (permitted stormwater)

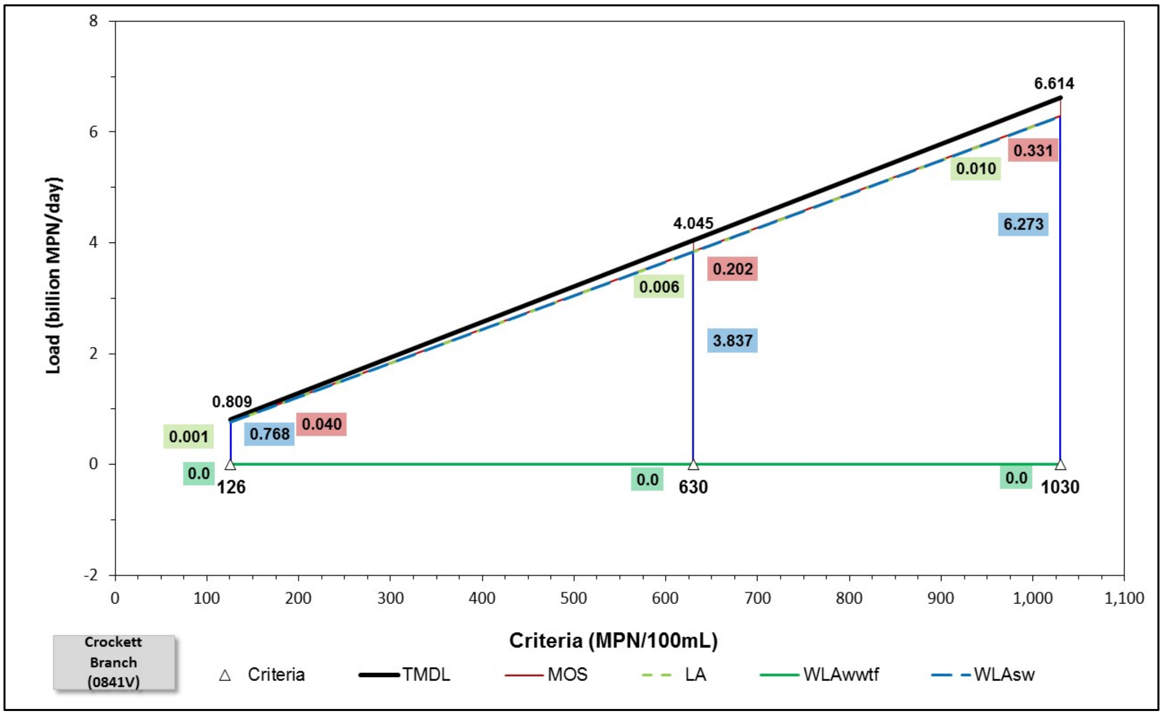

Figure A-4. Allocation loads for the Crockett Branch watershed (0841V) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day)

TMDL	=0.0064214 * Std
MOS	= 0.0003219 * Std
LA	= 0.0000100 * Std
WLA_{WWTF}	= 0
WLA_{sw}	= 0.0060907 * Std

Where:

Std =	Revised Contact Recreation Standard
MOS =	Margin of Safety
LA =	Total load allocation (unregulated sources)
WLA_{WWTF} =	Waste load allocation (permitted WWTF load + future growth)
WLA_{SW} =	Waste load allocation (permitted stormwater)