Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Quinlan Creek and Town Creek

Segments 1806D and 1806E

Assessment Units 1806D_01, 1806E_01

View of Town Creek at the Town Creek Road crossing.

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Prepared for
Total Maximum Daily Load Program
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PR1702

August 2017

Acknowledgements

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

The ready willingness of Ms. Tara Bushnoe and Mr. Travis Linscomb of the Upper Guadalupe River Authority to share data resources and knowledge of the study area watersheds was instrumental in the development of this report. The guidance and thorough review of the draft versions of this report by the TCEQ Program Manager, Mr. Jason Leifester, was important in developing the contents of this report.

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List of Acronyms and Abbreviations

AU	assessment unit
cfs	cubic feet per second
CCN	Certificate of Convenience and Necessity
CRP	Clean Rivers Program
DAR	drainage-area ratio
DMU	Deer Management Unit
DMR	Discharge Monitoring Report
E. coli	*Escherichia coli*
ECHO	Enforcement & Compliance History Online
FDC	flow duration curve
FG	future growth
FIB	fecal indicator bacteria
GIS	Geographic Information System
gpcd	gallons per capita per day
ICIS	Integrated Compliance Information System
I&I	inflow and infiltration
I-Plan	implementation plan
IRNR	Institute of Renewable Natural Resources (Texas A&M)
LA	load allocation
LDC	load duration curve
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
NEIWPCC	New England Interstate Water Pollution Control Commission
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	onsite sewage facility
SSO	sanitary sewer overflow
SWQM	surface water quality monitoring
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
TPWD	Texas Parks and Wildlife Department
TSSWCB	Texas State Soil and Water Conservation Board

TWDB	Texas Water Development Board
UGRA	Upper Guadalupe River Authority
USCB	U.S. Census Bureau
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WLA	wasteload allocation
WUG	water user group
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 Guadalupe River Above Canyon Lake in 2002 (TCEQ, 2007), and within both Quinlan Creek (Segment 1806D) and Town Creek (Segment 1806E) in 2010 and then in each subsequent edition through the *2014 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)* (formerly called the *Texas Water Quality Inventory and 303(d) List*).

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

1. Quinlan Creek 1806D_01
2. Town Creek 1806E_01

Because the two 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, Quinlan Creek may be referred to as AU 1806D_01 or Segment 1806D.

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).

Quinlan Creek and Town Creek are approved for primary contact recreation and have the associated *E. coli* geometric mean criterion of a 126 MPN per 100 mL and the single sample criterion of 399 MPN per 100 mL.

1.3 Report Purpose and Organization

The Quinlan Creek and Town Creek watersheds TMDL project was initiated through a contract between the TCEQ and Texas Institute for Applied Environmental Research (TIAER). This project is considered to be an addendum to the exiting bacteria TMDL for the Guadalupe River Above Canyon Lake (TCEQ, 2007) that was adopted by the TCEQ Commission on July 25, 2007 and approved by the USEPA on September 25, 2007. The watershed of the Guadalupe River Above Canyon Lake TMDL and the watersheds of Quinlan and Town Creeks within the larger Guadalupe River watershed are shown in Figure 1. 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 the impaired watersheds of Quinlan and Town Creeks. This report contains:

- information on historical data,
- watershed properties and characteristics,
- summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to the presence of indicator bacteria (*E. coli*),
- development of load duration curves (LDCs), and
- application of the LDC approach for the pollutant load allocation process.

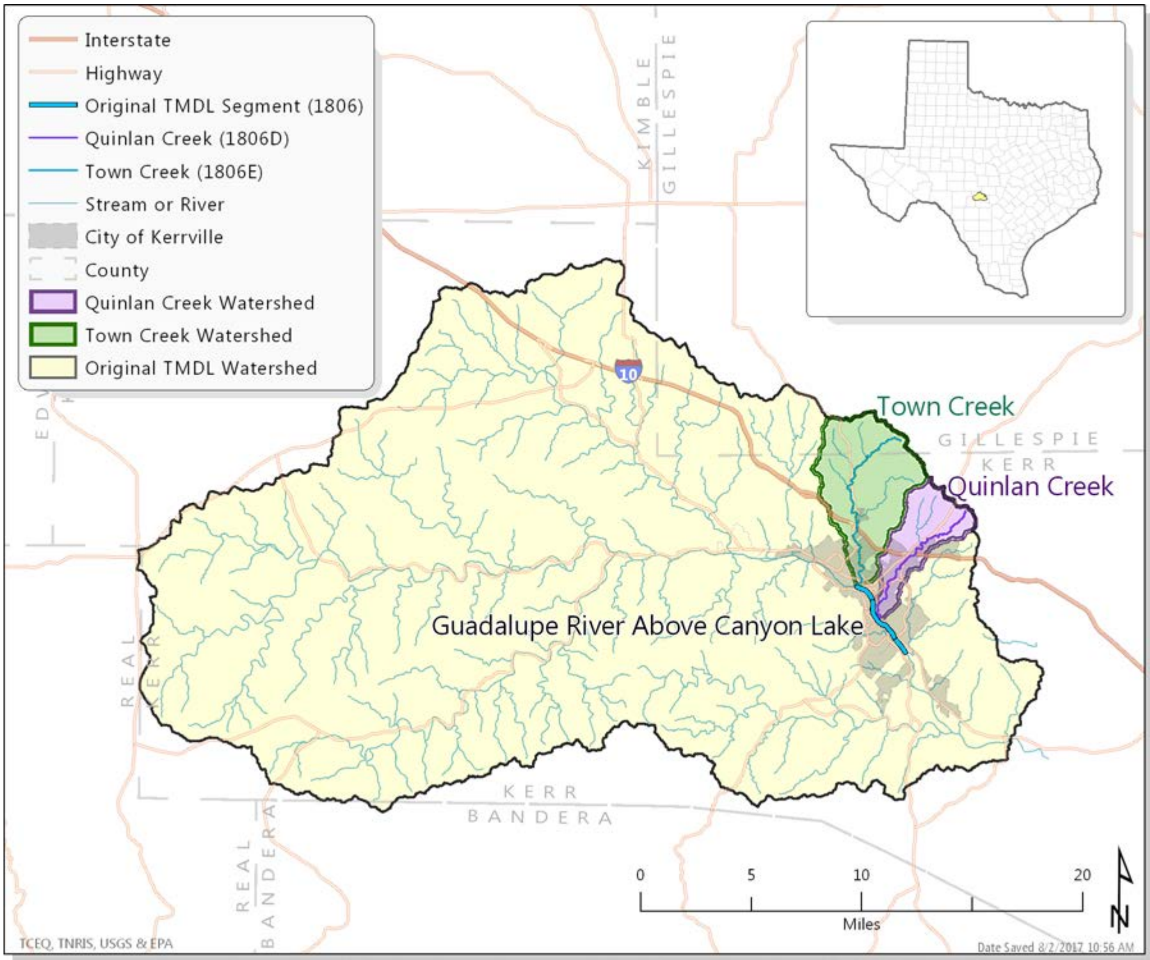

Figure 1. Map showing the Guadalupe River Above Canyon Lake watershed and the two watersheds considered in this addendum.

Section 2
HISTORICAL DATA REVIEW AND WATERSHED PROPERTIES

2.1 Description of the Study Area

Quinlan Creek (Segment 1806D) and Town Creek (Segment 1806E) are adjacent water bodies and tributaries of the Upper Guadalupe River above Canyon Lake (Segment 1806). Both are unclassified, freshwater streams. Quinlan Creek's flow type is designated intermittent with pools, while Town Creek is designated as a perennial flow type. This study incorporates a watershed approach where the drainage area of the each creek is considered.

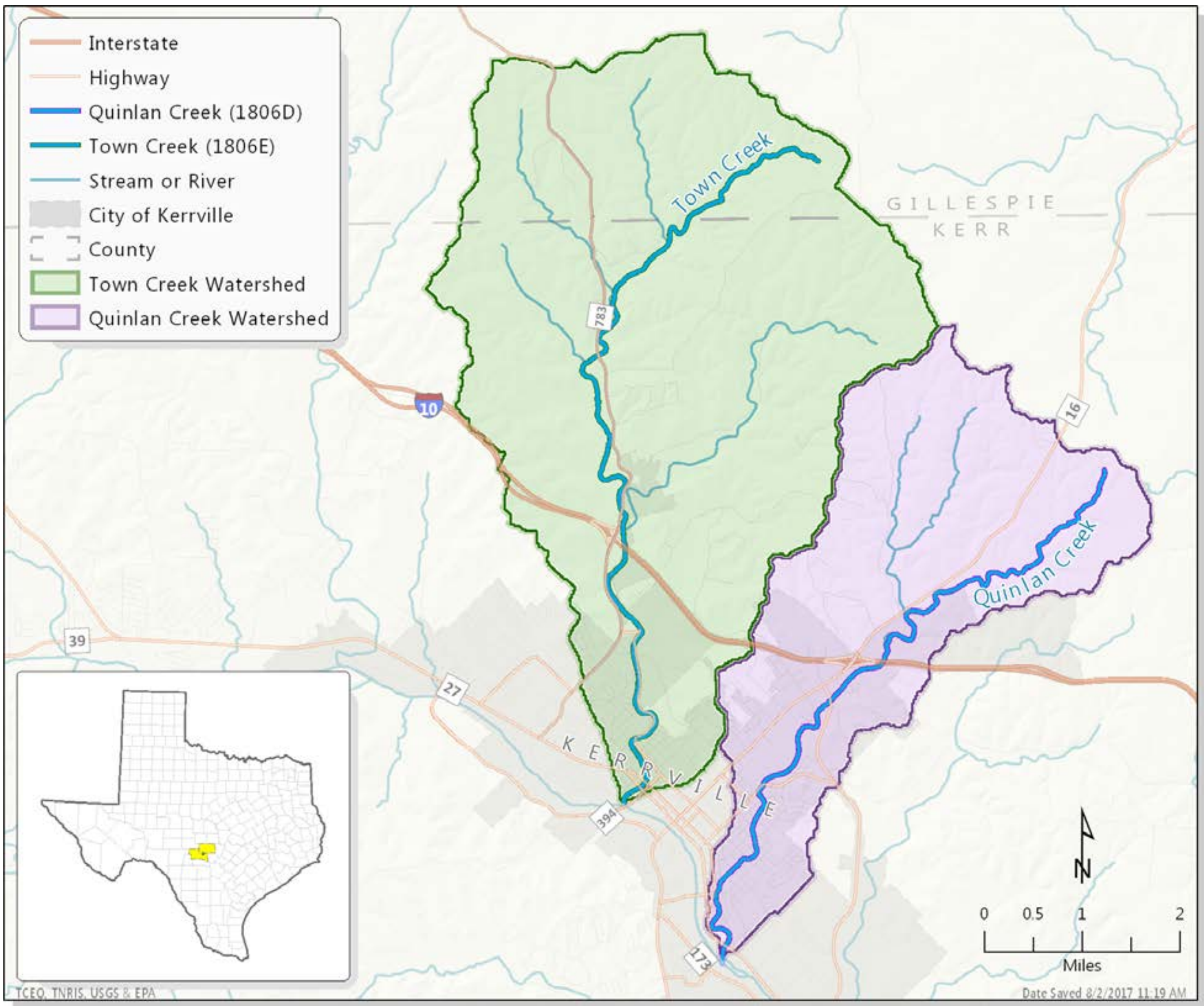

Figure 2. Overview map showing the study watersheds for Segments 1806D and 1806E.

Source: (USGS & USEPA, 2012)

Quinlan Creek (Segment 1806D) debouches into the Guadalupe River in Kerrville, and is approximately 8.2 miles in length. At its mouth, Quinlan Creek drains an area of 11.7 square miles in Kerr County.

Town Creek (Segment 1806E) debouches into the Guadalupe River in Kerrville about 2 miles upstream of the Quinlan Creek confluence. Town Creek is approximately 9.6 miles long, and drains an area of 23.5 square miles in Kerr and Gillespie counties.

The segment and AU descriptions for the water bodies considered in this document are as follows:

- SegID 1806D Quinlan Creek (AU 1806D_01) - From the confluence of the Guadalupe River in Kerrville in Kerr County to the upstream perennial portion of the stream north of Kerrville in Kerr County (TCEQ, 2015a)
- SegID 1806E Town Creek (AU 1806E_01) - From the confluence of the Guadalupe River just upstream of FM 394 in Kerrville in Kerr County upstream to the headwaters in Gillespie County approximately 4.5 miles (7.4 km) north of Kerrville (J. Leifester, personal communication, Mar. 16, 2017)

2.2 Watershed Climate

The watersheds of Quinlan and Town Creeks are in the central portion of Texas, classified as the Subtropical Subhumid climate region (Larkin and Bomar, 1983). As in much of the state, the region's subtropical climate is caused by the "predominant onshore flow of tropical maritime air from the Gulf of Mexico," while the increasing moisture content (from west to east) reflects variations in "intermittent seasonal intrusions of continental air" (Larkin and Bomar, 1983).

For the period from 1981 – 2010, average annual precipitation in the Quinlan Creek watershed was 31.5 inches, which is slightly higher than the average annual total precipitation for the Town Creek watershed of 31.0 inches (PRISM, 2012). This slight increase in precipitation, when moving from west to east, is concurrent with the statewide precipitation pattern (as shown in

Figure 3).

In Kerrville, average high temperatures generally reach their peak of 94 °F in August (Figure 4), and highs above 100 °F have occurred from May through September (Arguez et al., 2010a). Fair skies generally accompany the highest temperatures of summer when nightly average lows drop to about 69 °F (Arguez et al., 2010a). During winter, the average low temperature bottoms out at 34 °F in January, although below-freezing temperatures have occurred from October through April (Arguez et al., 2010a). The frost-free period in Kerrville generally lasts for about 224 days, with the average last frost occurring March 29th and the average first frost occurring on November 8th (Arguez et al., 2010b).

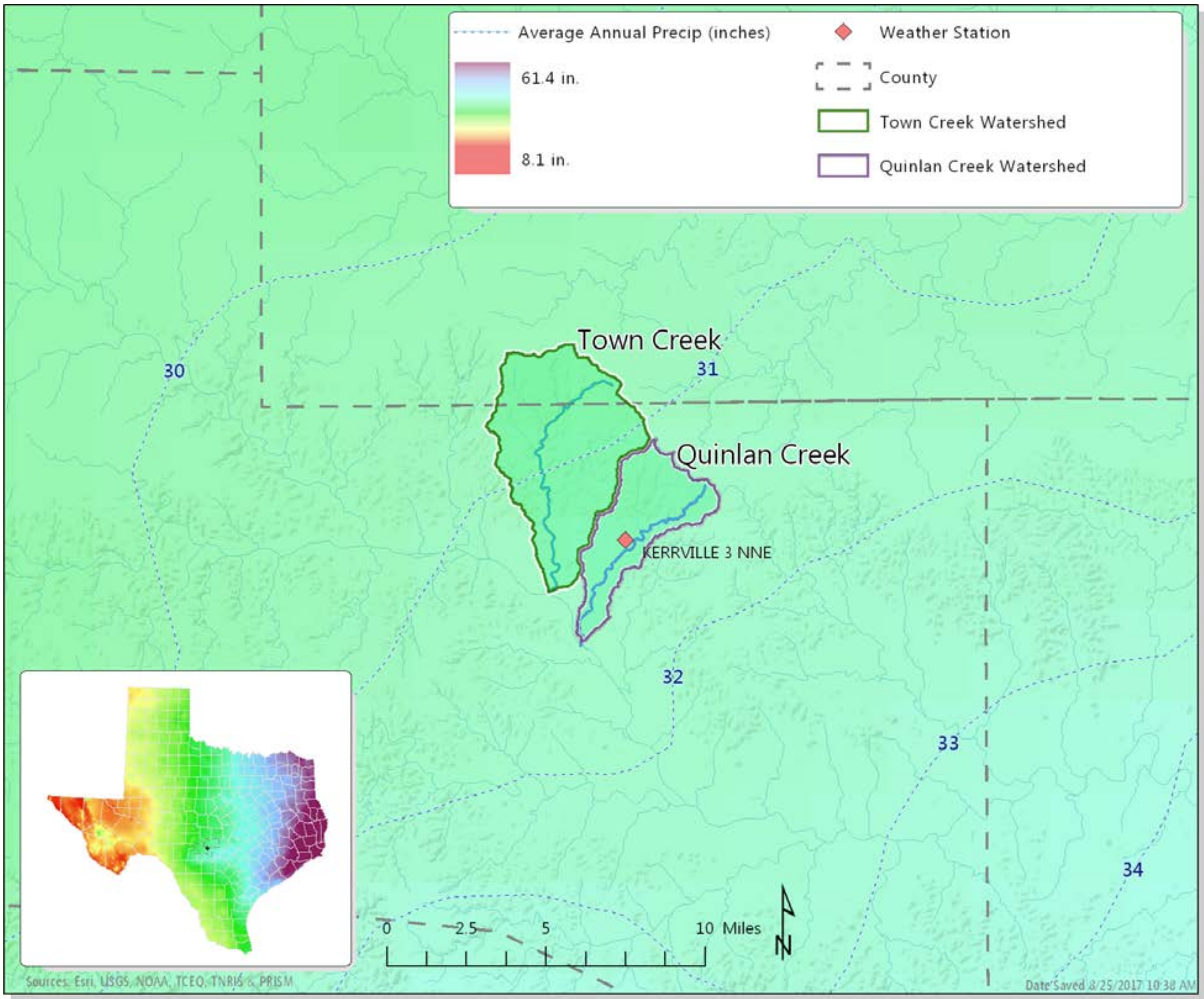

Figure 3. Annual average precipitation map showing isohyets (in inches) for areas in the vicinity of the Quinlan Creek and Town Creek watersheds (1981-2010).

Source: (PRISM Climate Group at Oregon State University, 2012)

Climate normals obtained from the National Oceanic and Atmospheric Administration (NOAA) for the Kerrville 3 NNE weather station (USC00414782, shown in

Figure 3) indicate a bimodal precipitation pattern (Figure 4). The wettest months are typically May and June (4.0 inches each), followed by September and October (3.7 inches each), while January and August (at 1.6 and 1.7 inches, respectively) are normally the driest months.

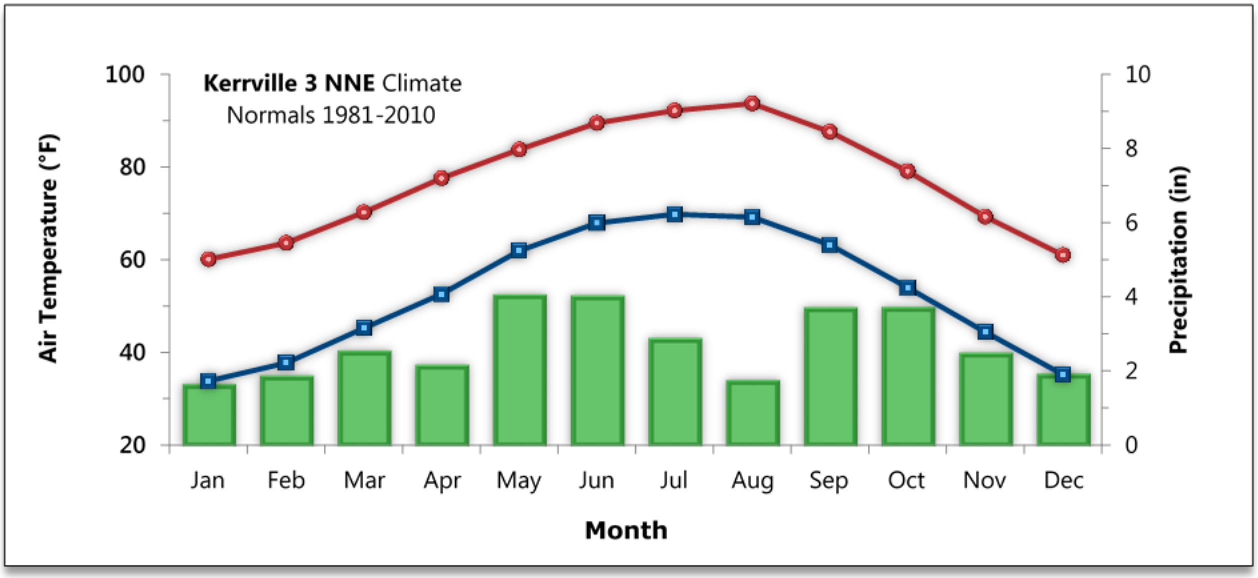

Figure 4. Chart showing the average minimum and maximum air temperature and total precipitation by month from 1981-2010 for the Kerrville 3 NNE weather station.

Source: (Arguez et al., 2010a)

2.3 Watershed Population and Population Projections

According to the 2010 Census (USCB and TNRIS, 2017), there are an estimated 5,901 people in the Quinlan Creek watershed, indicating a population density of 506 people/ square mile. The majority of the population (5,333 people, or 90 percent) live within the Kerrville city limits (Figure 5). Approximately 34 percent of the area is the watershed is included within the Kerrville city boundaries.

Also according to the 2010 Census, there are an estimated 5,314 people in the Town Creek watershed, indicating a population density of 226 people/ square mile. The majority of the population (3,903 people, or 73 percent) lived within the Kerrville city limits (Figure 5). Approximately 11 percent of the area is the watershed is included within the Kerrville city boundaries.

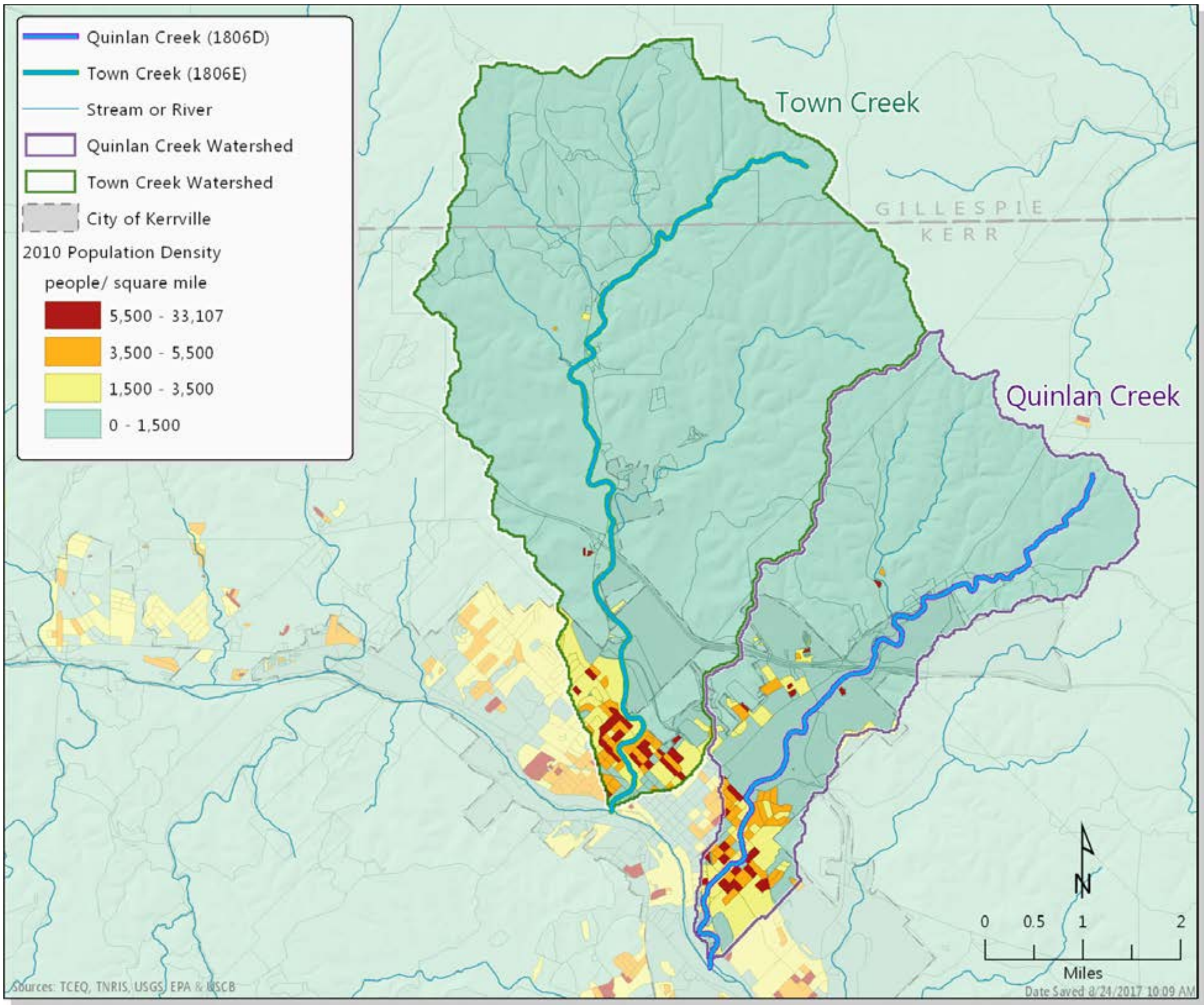

Figure 5. Population density map showing 2010 population by census block, along with the city of Kerrville boundary.

Source: (USCB & TNRIS, 2017)

Geospatial analysis based on water user groups (WUGs), which allows a refinement of county and city-level projections developed by the Office of the State Demographer and the Texas Water Development Board (TWDB, 2016), reveals that populations are predicted to increase 14.0 percent in the Quinlan Creek watershed and 15.8 percent for the Town Creek watershed between 2010 and 2050 (Table 1).

Table 1. 2010 Population and 2020 – 2050 Population Projections for the Quinlan Creek and Town Creek watersheds.

Sources: (USCB & TNRIS, 2017) (TWDB, 2016)

Watershed	Area (WUG)	2010 U.S. Census	Population Projections				Population Change (2010-2050)	Percent Increase (2010-2050)
			2020	2030	2040	2050		
Quinlan Creek	Kerrville	5,333	5,569	5,782	5,907	6,032	+699	13.11%
	Kerr County, outside Kerrville	568	609	649	673	696	+128	22.54%
	Total	**5,901**	**6,178**	**6,431**	**6,580**	**6,728**	+827	**14.01%**
Town Creek	Kerrville	3,903	4,076	4,231	4,323	4,415	+512	13.11%
	Kerr County, outside Kerrville	1,103	1,184	1,261	1,306	1,351	+248	22.48%
	Gillespie County, outside Fredericksburg	308	317	343	363	388	+80	25.97%
	Total	**5,314**	**5,577**	**5,835**	**5,992**	**6,154**	+840	**15.81%**

2.4 Land Use

The land use/land cover data for the Quinlan Creek and Town Creek watersheds were obtained from the 2011 National Land Cover Database (NLCD) (Homer et al., 2015) and are displayed in Figure 6.

The land use/land cover is represented by the following categories and definitions:

- Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.
- Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
- Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 percent to 49 percent of total cover. These areas most commonly include single-family housing units.
- Developed, Medium Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 percent to 79 percent of the total cover. These areas most commonly include single-family housing units.
- Developed, High Intensity - highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and

commercial/industrial. Impervious surfaces account for 80 percent to 100 percent of the total cover.

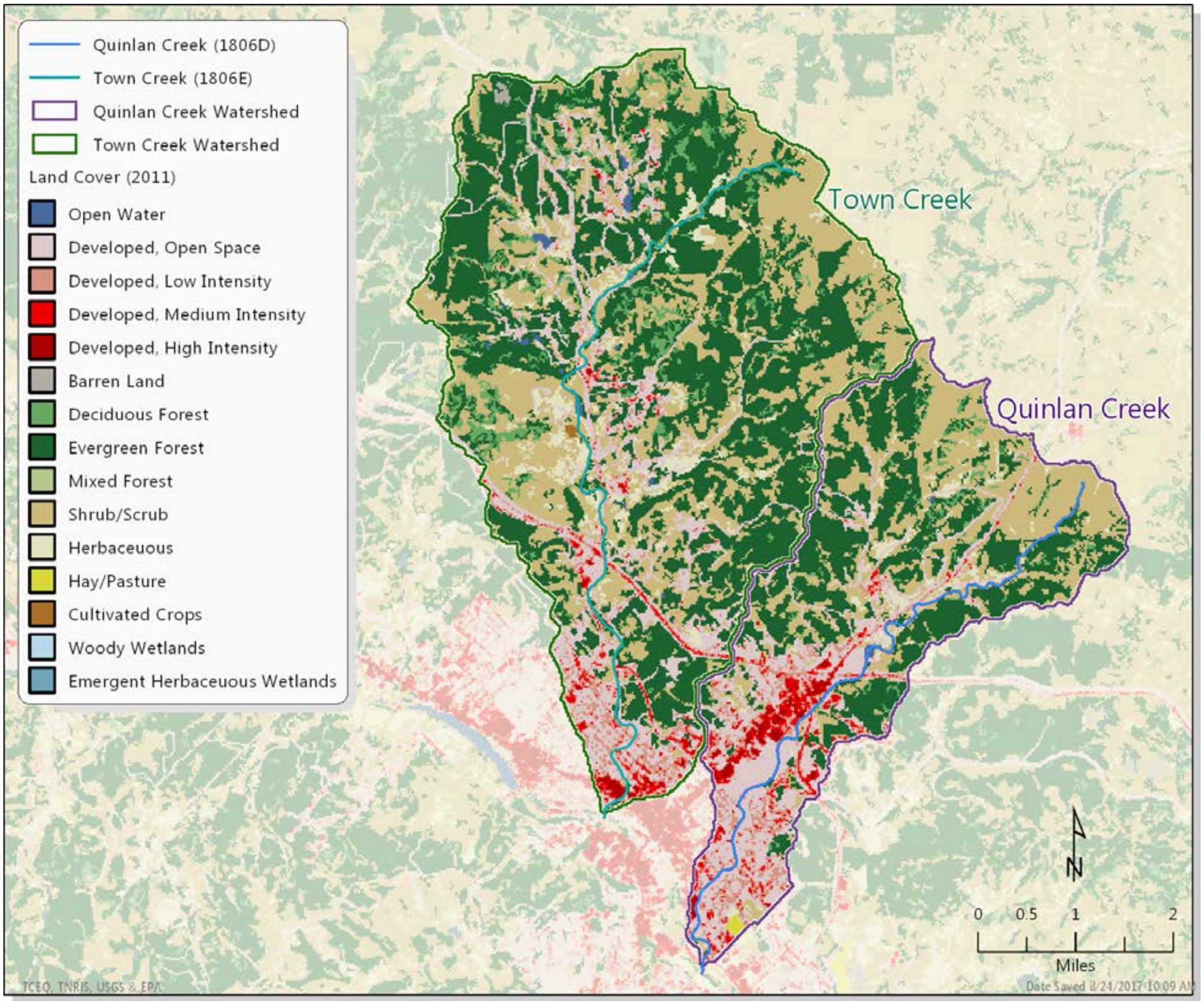

Figure 6. Land use/ land cover map showing categories within the Quinlan Creek and Town Creek watersheds.

Source: (Homer, Dewitz, Yang, & Jin, 2015)

- Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.
- Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.

- Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
- Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
- Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
- Herbaceous - areas dominated by graminoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
- Hay/Pasture - areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
- Cultivated Crops - areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
- Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
- Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

As shown in Table 2, the watershed area encompassing Segment 1806D (Quinlan Creek watershed) is approximately 7,463 acres. Dominant land uses in the Quinlan Creek watershed include Evergreen Forest and Shrub/Scrub (both at 31 percent).

The watershed area encompassing Segment 1806E (Town Creek watershed) is about 15,028 acres and is also dominated by Evergreen Forest (41 percent) and Shrub/Scrub (32 percent).

Both watersheds are mostly rural, with only about 23 percent of the combined area classified as Developed. The Quinlan Creek watershed is more developed (33 percent) than the Town Creek watershed (18 percent).

Table 2. Land/Use Land Cover within the Quinlan Creek and Town Creek watersheds.

Sources: (Homer et al., 2015)

2011 NLCD Classification	Quinlan Creek Watershed		Town Creek Watershed	
	Acres	% of Total	Acres	% of Total
Open Water	8.5	0.1%	65.4	0.4%
Developed, Open Space	1,491.4	20.0%	1,930.4	12.8%
Developed, Low Intensity	539.1	7.2%	494.6	3.3%
Developed, Medium Intensity	289.8	3.9%	190.1	1.3%
Developed High Intensity	112.8	1.5%	50.3	0.3%
Barren Land (Rock/Sand/Clay)	-	-	15.8	0.1%
Deciduous Forest	154.6	2.1%	740.6	4.9%
Evergreen Forest	2,332.9	31.3%	6,169.0	41.1%
Shrub/Scrub	2,320.5	31.1%	4,770.8	31.7%
Herbaceous	193.5	2.6%	589.3	3.9%
Hay/Pasture	19.8	0.3%	-	-
Cultivated Crops	-	-	8.7	0.1%
Woody Wetlands	-	-	2.9	0.0%
Total	7,462.7	100%	15,027.8	100%

2.5 Soils

Soils within the Quinlan and Town Creek watersheds were categorized by their Hydrologic Soil Group as shown in Figure 7. The Hydrologic Soil Groups are represented by the following categories and definitions:

- Group A soils consist of deep, well-drained sands or gravelly sands with high infiltration and low runoff rates.
- Group B soils consist of deep, well-drained soils with a moderately fine to moderately coarse texture and a moderate rate of infiltration and runoff.
- Group C consists of soils with a layer that impedes the downward movement of water or fine-textured soils and a slow rate of infiltration.
- Group D consists of soils with a very slow infiltration rate and high runoff potential. This group is composed of clays that have a high shrink-swell potential, soils with a high water table, soils that have a clay pan or clay layer at or near the surface.

Geospatial analysis reveals that both watersheds are primarily comprised of Group C and Group D soils, indicating that the watershed soils, generally, have high runoff potential. In the Quinlan Creek watershed, Group C and Group D soils comprise 35 percent and 64 percent of the area of the watershed, respectively; in the Town Creek watershed they are 30 percent and 66 percent.

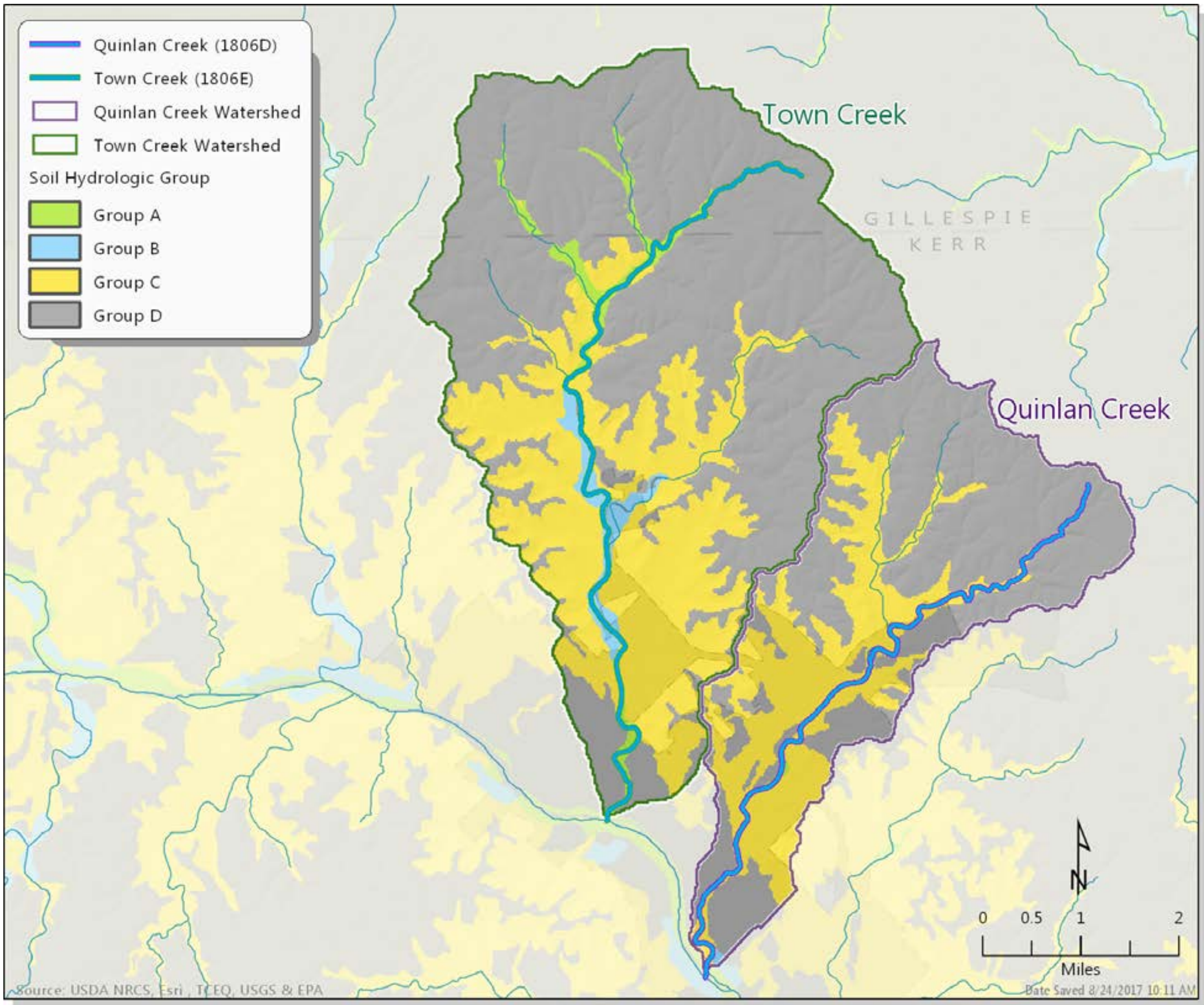

Figure 7. Hydrologic Soil Group categories within the Quinlan Creek and Town Creek watersheds.

2.6 Review of Routine Monitoring Data

2.6.1 Data Acquisition

Ambient *E. coli* data were obtained from two sources: (1) the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on 19 January 2017 (TCEQ, 2017a), and (2) the Upper Guadalupe River Authority (UGRA) via personal communication on February 16, 2017. The data represented all the historical routine ambient *E.coli* and other water quality data collected in the project area, and included *E. coli* data collected from March 1992 through December 2016.

Ambient *E. coli* data were available through the TCEQ SWQMIS (TCEQ, 2017a) for one station in Segment 1806D and two stations in Segment 1806E (Table 3). Additional ambient *E. coli* data besides those collected under the Clean River Program (CRP) were collected by the UGRA for two stations in each watershed (Table 4). Some of the data were not collected under a formal QAPP, but the UGRA used standard SWQM and CRP sampling protocol and the samples were analyzed by their accredited laboratory. Comparison of geometric means of the additional *E. coli* data provided in Table 4 indicates a possible trend of increasing concentrations in the downstream direction in both Quinlan and Town Creeks.

Monitoring stations at which *E. coli* data were collected are shown in Figure 8.

Table 3. Summary of historical data set of *E. coli* concentrations from SWQMIS.

Water Body	Segment	Station	Station Location	No. of *E. coli* Samples	Geometric Mean (MPN/100 mL)	Data Date Range
Quinlan Creek	1806D	12541	Quinlan Creek at Travis Street in Kerrville	150	293.88	1992-2016
Town Creek	1806E	12549	Town Creek at Hamilton Street in Kerrville	182	290.06	1992-2016
		12550	Town Creek in North Kerrville on Town Creek Rd	3	42.94	1994

Table 4. Summary of historical data set of *E. coli* concentrations from UGRA.

Source: (T. Bushnoe, personal communication, Feb. 16, 2017)

Water Body	Segment	Station	Station Location	No. of *E. coli* Samples	Geometric Mean MPN/100 mL)	Data Date Range
Quinlan Creek	1806D	12541	Quinlan Creek at Travis Street in Kerrville	77	236.04	2008-2016
		Quinlan C. @ 534	Quinlan Creek at Loop 534	25	122.50	2009-2016
Town Creek	1806E	12549	Town Creek at Hamilton Street in Kerrville	102	311.36	2008-2016
		12550	Town Creek in North Kerrville on Town Creek Rd	33	55.99	2008-2016

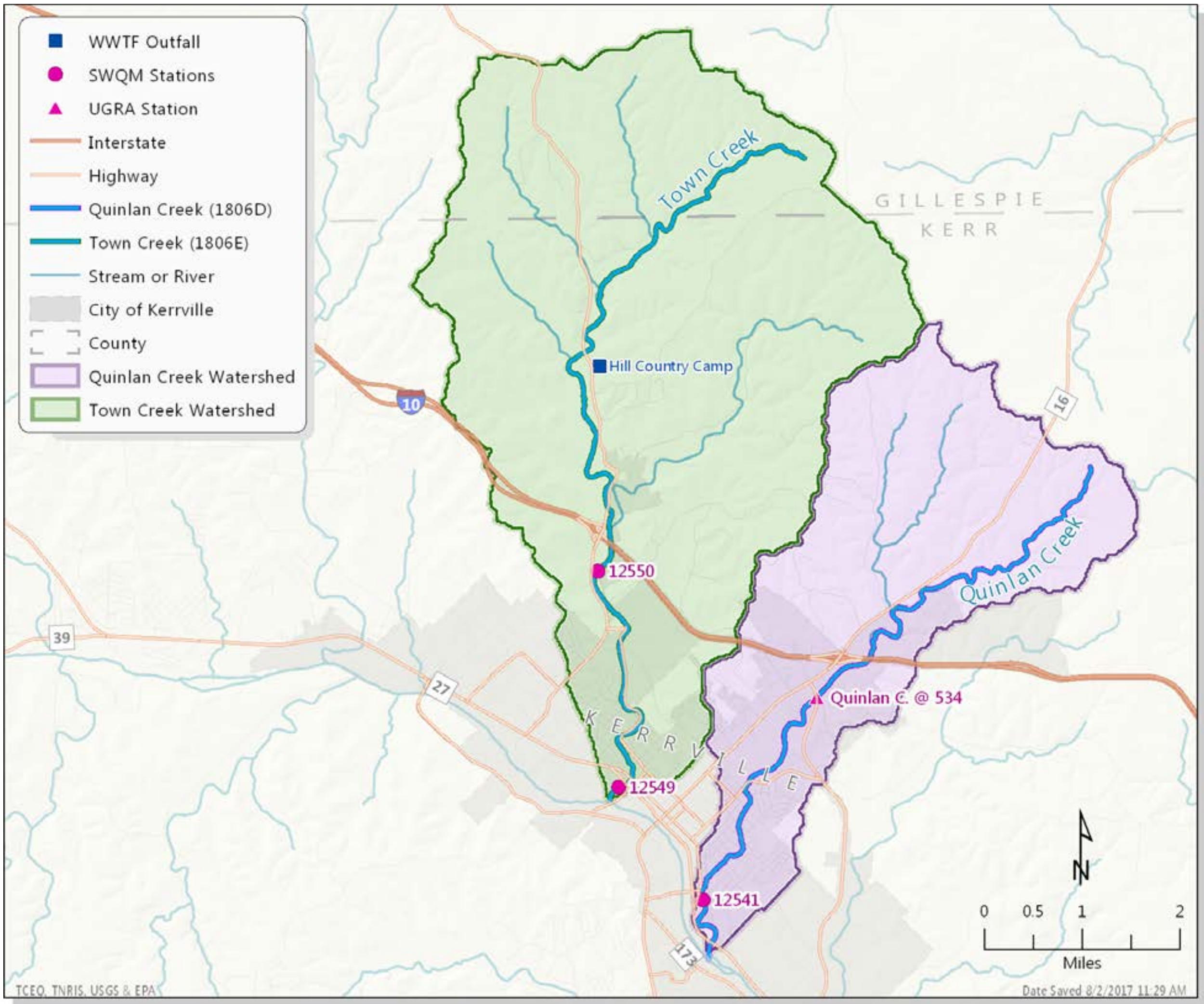

Figure 8. Map showing monitoring stations and the Hill County Camp wastewater treatment facility outfall within the Quinlan Creek and Town Creek watersheds.

Source: (USEPA, 2017a)

2.6.2 Analysis of Bacteria Data

Recent environmental monitoring within the Quinlan Creek and Town Creek segments has occurred at three TCEQ monitoring stations (Table 3, Figure 8). *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 in the 2014 Texas Integrated Report (TCEQ, 2015a) and as summarized in Table 5. The 2014 assessment data indicate non-support of the primary contact recreation use because geometric mean concentrations exceed the geometric mean criterion of 126 MPN/100 mL for Quinlan Creek (1806D) and Town Creek (1806E).

Table 5. 2014 Integrated Report Summary for Quinlan Creek and Town Creek.

Source: (TCEQ, 2015b)

Water Body	Segment Number	Assessment Unit (AU)	Parameter	Station	No. of Samples	Data Date Range	Station Geometric Mean (MPN/100 mL)
Quinlan Creek	1806D	1806D_01	*E. coli*	12541	81	2005-2012	306.69
Town Creek	1806E	1806E_01	*E. coli*	12549	66	2005-2012	251.20

2.7 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 (MS4s) 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 wasteload allocations or WLAs (see report Section 4.7.3, Wasteload 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.

2.7.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the NPDES programs. A single WWTF outfall and stormwater discharges from industries and construction activities represent the permitted sources in the Quinlan Creek and Town Creek watersheds.

2.7.1.1 Domestic Wastewater Treatment Facility Discharges

Currently, no WWTFs exist within the Quinlan Creek watershed, and a single facility exists within the Town Creek watershed which treats domestic wastewater (Figure 8). For that facility, the available Discharge Monitoring Report (DMR) data indicate that there has been no discharge from May 2016 through February 2017. The facility's original permit (TPDES WQ0014832001) expired, and the owners re-applied and were issued their current permit (TPDES WQ0014832002) on April 13, 2016 (T. Bushnoe, personal communication, Apr. 5, 2017 and TPDES permit issuance date). For information regarding bacteria permit limits see Section 2.7.1.6 (Review of Compliance Information on Permitted Sources).

Table 6. Permitted domestic WWTF in Town Creek watershed.

Source: TPDES Permit, EPA ECHO

TPDES Permit No.	NPDES Permit No.	Facility	AU	Receiving Waters	Final Permitted Discharge (MGD)	Recent Discharge* (MGD)
WQ0014832002	TX0136298	Hill Country Camp	1806E_01	unnamed tributary; thence to Town Creek	0.025	No Discharge

* From EPA ECHO, May 2016 – Feb 2017; indicated to be operating, using effluent for irrigation, no discharge per T Bushnoe, personal communications, Apr. 5, 2017

2.7.1.2 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.

The TCEQ Region 13 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. A summary of the reports of SSO events that were determined to have occurred within the Quinlan Creek and Town Creek watersheds between January 2012 and December 2016 are shown in Table 7.

Table 7. Summary of SSO incidences reported in the Quinlan Creek and Town Creek watersheds from 2012 - 2016.

Source: TCEQ Region 13

Segment	No. of Incidents	Total Volume (gallons)	Average Volume (gallons)	Minimum Volume (gallons)	Maximum Volume (gallons)
1806D	9	4555	506	15	2,940
1806E	13	3990	307	10	1,200

2.7.1.3 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) includes:

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.

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.

2.7.1.4 TPDES General Wastewater Permits

In addition to the individual wastewater discharge permit listed in Table 6, 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 of active general permit coverage (TCEQ, 2017b) in the Quinlan Creek watershed as of 30 March 2017 found one concrete production facility covered by the general permit. A review of active general permit coverage (TCEQ, 2017b) in the Town Creek watershed as of 30 March 2017 found no operations or facilities of the type described above. No other active general wastewater permit facilities or operations were found. There were no facilities covered under the general permits for aquaculture production, petroleum bulk stations and terminals, hydrostatic test water discharges, water contaminated by petroleum fuel or petroleum substances, concentrated animal feeding operations or livestock manure compost operations. The concrete production facility does not have bacteria reporting or limits in its permit. The facility was assumed to contain inconsequential amounts of indicator bacteria in its effluent; therefore, it was unnecessary to allocate bacteria load to this concrete production facility.

2.7.1.5 Stormwater General Permits

Discharges of stormwater from a Phase II urbanized area, industrial facility, construction site, or other facility involved in certain activities are required to be covered under the following TPDES general permits:

- TXR040000 – stormwater Phase II Municipal Separate Storm Sewer System (MS4) general permit for urbanized areas
- TXR050000 – stormwater multi-sector general permit (MSGP) for industrial facilities
- TXR150000 – stormwater from construction activities disturbing more than one acre
- TXG110000 – concrete production facilities
- TXG340000 – petroleum bulk stations and terminals

Three of these permits (MS4, MSGP, and construction) pertain solely to stormwater discharges. The other two – concrete production facilities and petroleum bulk stations and terminals – also authorize the discharge of process wastewater as discussed above under TPDES General Wastewater Permits.

A review of active stormwater general permits coverage (TCEQ, 2017b) in the Quinlan Creek watershed, as of 8 June 2017, found one active industrial (MSGP) facility and one active concrete production facility. A concurrent review of active stormwater general permits coverage in the Town Creek watershed found one active industrial (MSGP) facilities and two active construction sites. There are currently no Phase II MS4s or petroleum bulk stations and terminals facilities in either watershed. See Section 4.7.3 for more detailed information.

2.7.1.6 Review of Compliance Information on Permitted Sources

A review of the EPA Enforcement & Compliance History Online (ECHO) database (USEPA, 2017b), conducted 30 March 2017, did not reveal any non-compliance issues regarding the effluent from the only WWTF within the TMDL watersheds. For the Hill Country Camp WWTF, *E. coli* monitoring is a permit requirement. No *E. coli* data were available through ECHO when that database was searched, and this finding is consistent with the present no-discharge status of the facility (see Section 2.7.1.1. for more information).

Table 8. Bacteria monitoring requirements and compliance status for the WWTF in the Town Creek Watershed.

Source: Individual TPDES permit, EPA ECHO

TPDES Permit No.	Facility	Bacteria Monitoring Require-ment	Min. Self-Monitoring Requirement Frequency	Daily Average (Geometric Mean) Limitation	Single Grab (or Daily Max) Limitation	% Monthly Exceedances Daily Average	% Monthly Exceed-ances Single Grab
WQ0014832002	Hill Country Camp	*E. coli*	One/ quarter	126	399	n/a	n/a

2.7.2 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.

2.7.2.1 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.

For feral hogs, the Texas A&M Institute of Renewable Natural Resources (IRNR), recently renamed as the Texas A&M Natural Resources Institute, reported a range of feral hog densities within Texas of 1.33 to 2.45 hogs/ square mile (IRNR, 2013). The average hog density (1.89 hogs/ square mile) was multiplied by the hog-habitat area in the Quinlan Creek and Town Creek watersheds (7.85 and 19.19 square miles, respectively). Habitat deemed suitable for hogs followed as closely as possible to the land use selections of the IRNR study and include from the 2011 NLCD: hay/pasture, cultivated crops, shrub/scrub, herbaceous, deciduous forest, evergreen forest, mixed forest, woody wetlands, and emergent herbaceous wetlands. Using this methodology, there are an estimated 15 feral hogs in the Quinlan Creek watershed, and an estimated 36 feral hogs in the Town Creek watershed.

For deer, the Texas Parks and Wildlife Department (TPWD) publishes data showing deer population-density estimates by Deer Management Unit (DMU) across the state (TPWD, 2017). Spatial analysis using DMU and white-tailed deer range layers provided by TPWD reveals that for the Quinlan Creek watershed, 3,009 acres are within DMU 5, and 1,373 acres are within

DMU 7 North. For the Town Creek watershed, 13,023 acres are within DMU 5. The 2017 population densities for those DMUs are 9.58 acres/ deer (DMU 5) and 6.45 acres/deer (DMU 7 North). Applying those value to the calculated areas returns an estimated 527 deer within the Quinlan Creek watershed, and 1,359 deer within the Town Creek watershed.

2.7.2.2 On-Site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) and 2) aerobic systems that have an aerated holding tank and often an above-ground sprinkler system for distributing the liquid. In simplest terms household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system which may consist of buried perforated pipes or an above-ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters, if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weikel et al., 1996).

Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The TMDL watersheds are located within the Region II (which includes the Texas Hill Country), a region having a reported failure rate of about 12 percent, which provides insights into expected failure rates for the area. Failing OSSFs are a source of fecal pathogens and indicator bacteria loading to streams. Loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface discharge or from transport by stormwater runoff.

Work performed for the previous TMDL (TCEQ, 2007) was based on the 1990 census. For this TMDL, estimates of the number of OSSFs in the Quinlan Creek and Town Creek watersheds were based on 911 building locations received from the Kerr Emergency 9-1-1 Network (T. Bushnoe, personal communication, Apr. 6, 2017). For the areas of Quinlan Creek and Town Creek watersheds, OSSFs were estimated to be households that were outside of either a Certificate of Convenience and Necessity (CCN) sewer area (PUC, 2016) or a city boundary (TNRIS, 2016). The estimated number of OSSFs by watershed using the 911 addresses is provided in Table 9 and in Figure 9.

Table 9. OSSF estimate for the watersheds of Quinlan and Town Creeks.

Sources: Kerr Emergency 9-1-1 Network, Public Utility Commission of Texas (2016), TNRIS (2016)

Water Body	Segment Number	Estimated OSSFs
Quinlan Creek	1806D	298
Town Creek	1806E	933

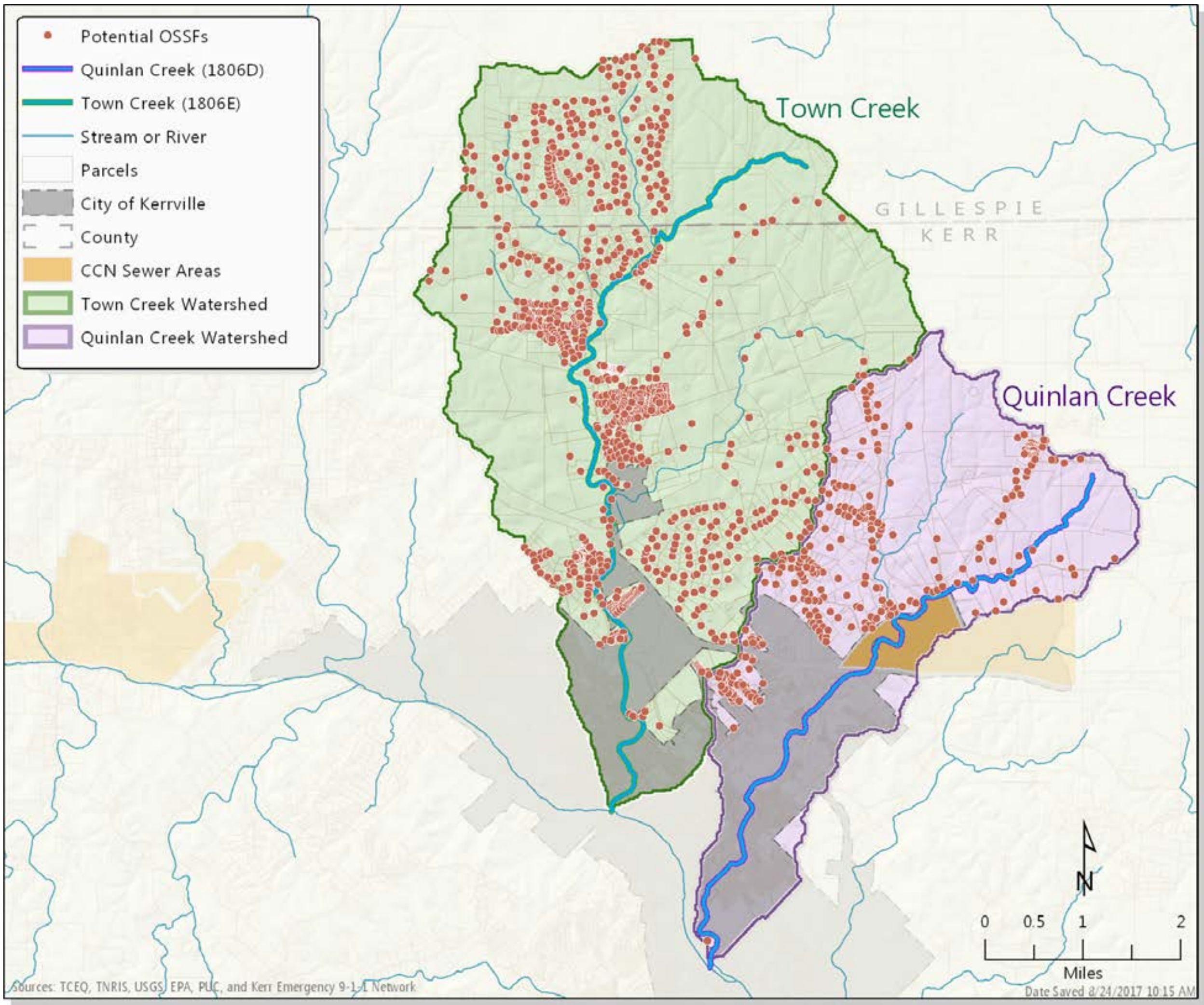

Figure 9. Map showing septic system locations within the Quinlan Creek and Town Creek watersheds. (TCEQ, 2007)

2.7.2.3 Non-Permitted Agricultural Activities and Domesticated Animals

The number of livestock that are found within the Quinlan Creek and Town Creek watersheds was estimated from county level data obtained from the 2012 Census of Agriculture (USDA NASS, 2014). The county-level data were refined to better reflect actual numbers within the impaired AU watersheds. Using the 2011 NLCD, the refinement was performed by determining the total area of the suitable livestock land cover categories of "Herbaceous/ Grassland" and "Hay/ Pasture" within the Quinlan Creek watershed and Kerr County. A ratio was then computed by dividing the livestock total land use area of the watershed by the livestock total land use area of the county. The county-level agricultural census data were then multiplied by the ratio to determine the estimated Quinlan Creek watershed domestic animal populations (Table 10). For Town Creek, the same approach was used, but Gillespie County was included in the calculations.

Table 10. Estimated total livestock inventory, by commodity, for Quinlan Creek and Town Creek watersheds in 2012.

Source: (USDA NASS, 2014)

Watershed	Segment Number	Cattle and Calves	Deer and Elk (Domestic)	Goats and Sheep	Horses, Ponies, Mules, Burros, and Donkeys	Poultry
Quinlan Creek	1806D	66	44	125	11	17
Town Creek	1806E	201	99	356	27	45

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 11 summarizes the estimated number of dogs and cats for the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.638) per household (AVMA, 2012). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the impaired AU watersheds is unknown.

Table 11. Estimated Households and Pet Populations for the Quinlan Creek and Town Creek watersheds.

Source: (AVMA, 2012)

Watershed	Segment Number	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
Quinlan Creek	1806D	2,583	1,508	1,648
Town Creek	1806E	2,472	1,444	1,577

2.7.2.4 Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (e.g., warm temperature). Fecal organisms can survive and replicate from improperly treated effluent 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 for choosing the LDC method to develop the pollutant load allocations for Quinlan and Town Creeks and then details the procedures and results of LDC development.

3.1 Model Selection

For consistency between the TMDLs of Quinlan and Town Creeks and the previously completed Guadalupe River Above Canyon Lake TMDL (TCEQ, 2007), the development activities for the present TMDLs build upon the LDC method used and reported in the previously completed TMDL. Details on the previous LDC development are found in a technical support document by James Miertschin & Associates, Inc. (2006) and the TCEQ TMDL report (2007). Development activities of LDCs under the present project were covered under a TCEQ-approved QAPP (TIAER, 2016).

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 LDC 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 LDC method within their three-tiered approach to TMDL development (Jones et al., 2009). 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.

3.2 Data Resources of Quinlan Creek and Town Creek

To develop the LDC method for Quinlan and Town Creeks various data resources are required. The two main sources are hydrologic data in the form of daily streamflow records for multiple years and historical indicator bacteria data, in this case, *E. coli*.

Hydrologic data in the form of daily streamflow records were unavailable for the TMDL watersheds. Streamflow records, however, were available for the Johnson Creek watershed, which was determined to be the nearest and most comparable watershed with respect to size and land cover, though the Johnson Creek watershed is more rural than the TMDL study area.

Further, the Johnson Creek streamflow record was used as the reference for developing LDCs for Quinlan and Town Creeks in the previous TMDL (TCEQ, 2007). Streamflow records for the Johnson Creek watershed are collected and made readily available by the U.S. Geological Survey (USGS, 2017), which operates the Johnson Creek streamflow gauge (Table 12 and Figure 10). USGS streamflow gauge 08166000 is located along the mainstem of Johnson Creek within Segment 1816 and serves as the primary source for streamflow records used in this document.

Table 12. Basic information on the Johnson Creek USGS streamflow gauge.

Gauge No.	Site Description	Segment	Drainage Area (sq. miles)	Daily Streamflow Record (beginning & end date)
08166000	Johnson Creek near Ingram, TX	1816	113.75	May 1987 – present[a]

[a] Gauge was inactive 10/1/1993 – 4/18/1999

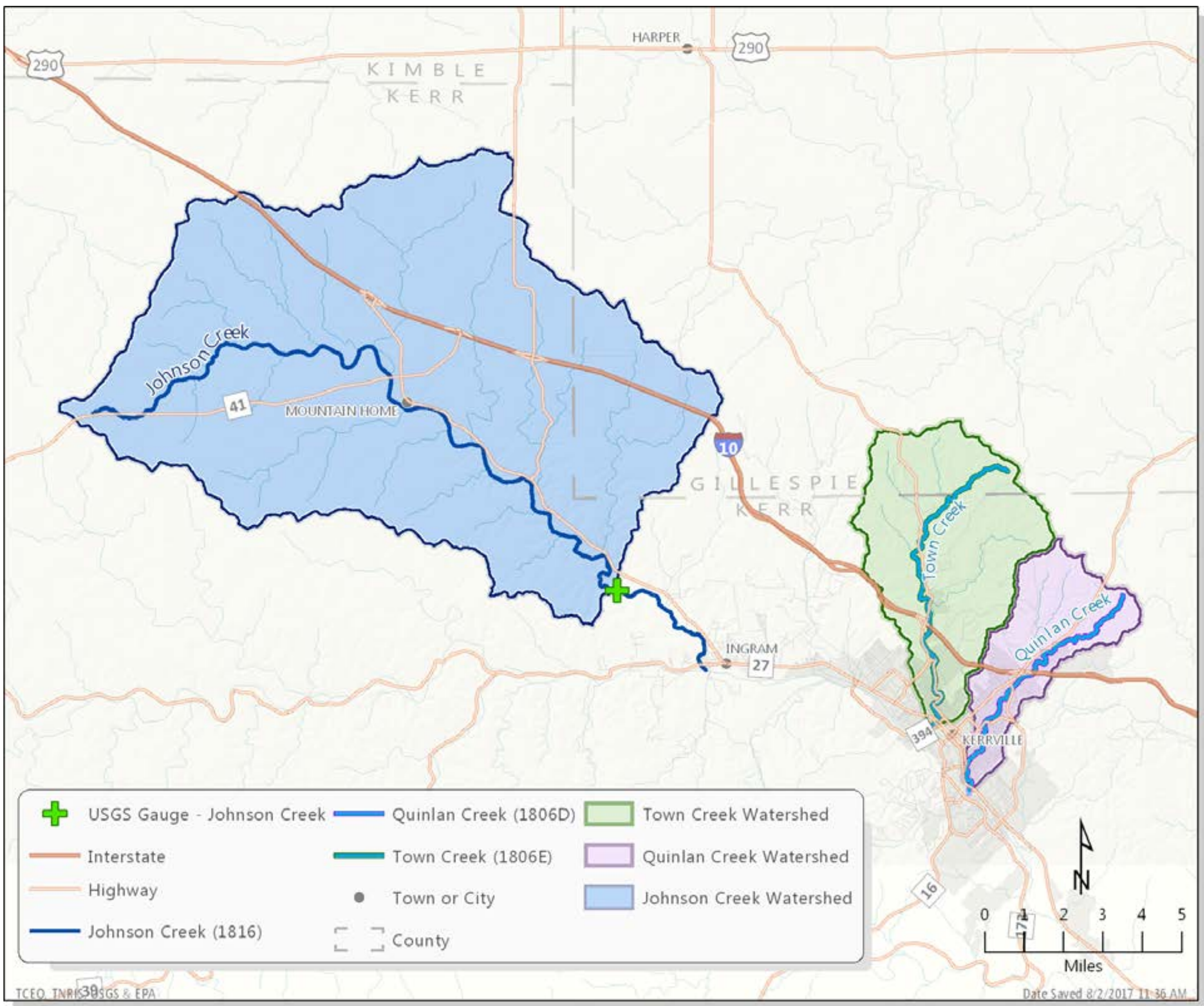

Figure 10. TMDL study area, Johnson Creek watershed and USGS Station 08166000 location near Ingram, Texas.

Indicator bacteria (i.e., *E. coli*) data were available for four stations; two each in Quinlan Creek and Town Creeks (Tables 3 and 4; Figure 8). On each creek, the lowermost sampling site was both an official SWQWM station with a station identification number and a location with an abundance of historical data. These stations were 12541 on Quinlan Creek and 12549 on Town Creek.

3.3 Methodology for Flow Duration & Load Duration Curve Development

- **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 locations will be at the downstream monitoring station for each impaired AU.)
- **Step 3**: Develop daily streamflow records at desired stream locations using the daily gauged streamflow records, drainage area ratios, and full permitted flows and future growth flows.
- **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).

3.3.1 Step 1: Determine Hydrologic Period

A roughly 30-year period of continuous daily streamflow was available for USGS gauge 08166000 located on nearby Johnson Creek with the notable exception of the period of 1 October 1993 through 18 April 1999 when the gauge was inactive (Table 12 and 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 streamflow 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. An 18-year record of daily streamflow from 23 April 1999 through 22 April 2017 was selected to develop the FDCs at each downstream station, based on the April 1999 time frame when daily flow data collection resumed at the USGS gauge on Johnson Creek. An 18-year period is of sufficient duration to contain a reasonable variation of dry and wet periods and, at the same time, is short enough in duration to reflect recent and current conditions in the watershed. The period selected does result in the exclusion from the LDC method of older *E.*

coli data collected prior to 23 April 1999 in both Quinlan and Town Creeks. With the a relative abundance of recent *E. coli* measurements collected during the selected 18-year period, the exclusion of the older data does not appreciably decrease the number of data points and actually allows an emphasis on data representing a more recent period of time when elevated *E. coli* concentrations were identified in both creeks.

3.3.2 Step 2: Determine Desired Stream Locations

When using the LDC method, the optimal location for developing the pollutant load allocation is a currently monitored SWQM station located near the outlet of the watershed with an abundance of historical bacteria data. The most downstream SWQM station on both impaired creeks meets the requirement of optimal location very well. Station 12541 on Quinlan Creek is located near the outlet of the watershed where the creek debouches into the Guadalupe River (Figure 8), is currently monitored by the UGRA, and has an abundance of *E. coli* data that are found in SWQMIS (Table 3) with additional data stored by UGRA (Table 4). The same pertains to station 12549 on Town Creek. Therefore, the decision was to use the locations of station 12541 on Quinlan Creek and station 12549 on Town Creek for the development of LDCs.

3.3.3 Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and station locations were determined, the next step was to develop the 18-year daily streamflow record for each monitoring station. The daily streamflow records were developed from extant USGS records (Table 12).

The method to develop the necessary streamflow record for each FDC/LDC location (i.e., SWQM station location) involved a drainage-area ratio (DAR) approach. With this basic approach, the USGS gauge 08166000 daily streamflow value within the 18-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 gauge.

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 Johnson Creek gauge prior to application of the ratio. A search for NPDES/TPDES permitted facilities within the Johnson Creek watershed returns one active permit upstream of the gauge (TCEQ, 2017b). Under the Aquaculture General Permit (TXG130000), the Heart of the Hills Fishery Science Center (TXG130006) does not have a permitted flow but does have reporting requirements. The reported discharge record is complete for the 125 months preceding the Integrated Compliance Information System (ICIS) search (USEPA, 2017a). All but 13 of those months reported “No Discharge”, and for those 13 months of discharge the average “daily average” value is only 0.15 million gallons per day (MGD). The small and intermittent nature of this reported discharge leads to the assumption that it does not significantly impact the gauged streamflow record.

Therefore, no adjustments for discharges were made to the Johnson Creek USGS gauge record prior to application of the DARs. This approach appears to be consistent with what was done in the previously completed TMDL (TCEQ, 2007) based on the absence of any information to the contrary.

The DARs for locations within the TMDL study area are presented in Table 13. The computation of the daily streamflow record at each station was performed by multiplying each daily streamflow in the 18-year Johnson Creek gauged record by the appropriate DAR for that station.

Table 13. DARs for locations within the TMDL watersheds based on the drainage area of the Johnson Creek USGS gauge.

Water Body	Segment	Gauge/Station	Drainage Area (sq. miles)	Drainage Area Ratio (DAR)
Johnson Creek	1806D	8166000	113.75	1.00
Quinlan Creek	1806D	12541	11.33	0.10
Town Creek	1806E	12549	23.43	0.21

After the application of the DAR, the full permitted flows for any permitted WWTFs within the impaired watersheds were added to the streamflow record. One WWTF exists within the impaired watersheds (Table 6 and Figure 8), which is permitted to discharge into a tributary of Town Creek. For Quinlan Creek, no adjustment was necessary.

Second, future growth flows (calculated in Section 4.7.4) were added to the streamflow record for both of the impaired watersheds. For each watershed, a future potential community of 1,000 persons was assumed. This number, which would be large enough to accommodate the construction of a residential development typical to areas of the Hill Country, greatly exceeds the projected population growth for the unsewered areas within each watershed (Table 1) but allows a reasonable buffer for uncertainty related to future development. Based on the TCEQ design guidance for WWTFs (TAC, 2008), the daily wastewater flow of 100 gallons/ person was assumed, resulting in a future growth flow of 0.1 MGD for each watershed.

3.3.4 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.

3.4 Flow Duration Curves for Sampling Stations within TMDL Watersheds

FDCs were developed for the most downstream monitoring station within each of the TMDL watersheds (Figure 11). For this report, FDCs were developed by applying the DAR method and using the Johnson Creek USGS gauge and 18-year period (1999-2016) described in the previous sections.

Flow exceedances less than 10 percent typically represent streamflows influenced by storm runoff, while higher flow exceedances represent receding hydrographs after a runoff event and base flow conditions. The stair-step pattern in each LDC between the 20 and 90 percentiles of flow exceedance is an artifact of the way in which the flows in the gauged watershed are reported (flows above 10 cfs are reported to the nearest cfs). In the Johnson Creek streamflow record, the lowest recorded flow in the 18-year period was 1.8 cfs, so the record does not contain no-flow conditions whereas for both Quinlan and Town Creeks, the measured streamflows indicates multiple low-flow or no-flow conditions (<0.1cfs). For the low flows in particular, some inaccuracies in the FDCs/LDCs is anticipated due to the use of Johnson Creek flows.

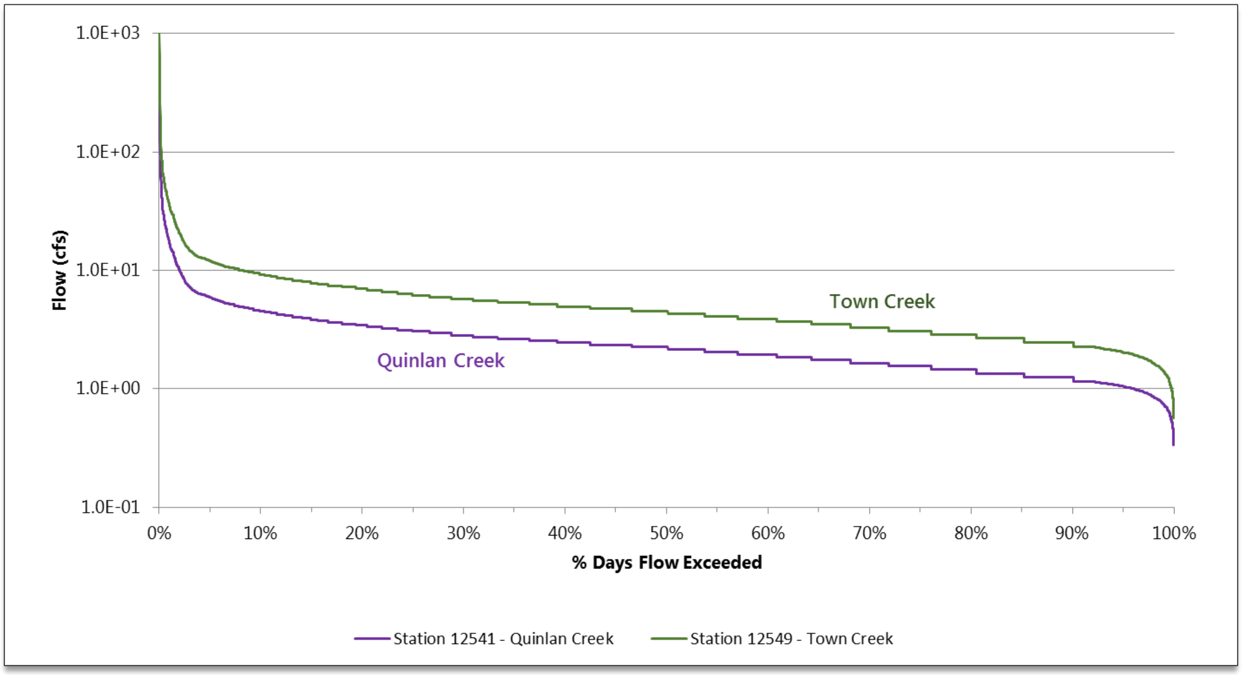

Figure 11. Flow duration curves for Quinlan Creek (Station 12541) and Town Creek (Station 12549)

3.5 Load Duration Curves for Sampling Stations within TMDL Watersheds

LDCs were developed for the most downstream monitoring station within each of 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 percent (high flows); (2) 10-40 percent (upper/mid-range flows); (3) 40-60 percent (mid-range flows); (4) 60-90 percent (lower/mid-range conditions); and (5) 90-100 percent (low flows). Consistent with the previously completed TMDL (TCEQ, 2007), these flow regimes were applied to the LDCs.

Additionally, historical bacteria measurements (*E. coli*) were aligned with the streamflow on the day of measurement. The historical bacteria measurements were then multiplied by the streamflow value and the conversion factor, as described in Section 3.3.4, to calculate a loading associated with each measured bacteria concentration. On each graph the measured *E. coli* data are presented as associated with a “wet weather event” or a “non-wet weather event.” Due to the variability in available data, this determination was made based on satisfying at least one of three following criteria:

- the total rainfall for that day and the preceding two days exceeded 0.1 inches (data from the Kerrville 3 NNE weather station,
- Figure 3); or

- the "days since last precipitation" (DSLP) value (if available) was less than or equal to 3 days (≤ 3); or
- the instantaneous flow value (if available) was in the top 10 percent of instantaneous flow values collected at that site.

The LDCs were constructed for development of the TMDL allocation for each of the TMDL watersheds. A trendline showing a regression of the loadings for the data points has been added to 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. coli* concentrations have occurred. The LDCs depict the allowable loadings at the stations under the geometric mean criterion (126 MPN/100 mL). In addition, the LDCs also present the allowable loading at the stations under the single sample criterion (399 MPN/100 mL).

For both LDCs (Figures 10 and 11), the wet weather data points occurred, as expected, predominately under the higher flow regimes and consistently exceeded the geometric mean criterion. Wet weather data points in the lowest flow regime typically represent bacteria data collected after a small rainfall-runoff event when conditions up to the event were very dry. Often the non-wet weather event data points also exceed the geometric mean criterion for Quinlan and Town Creeks. The geometric mean of existing data shown by flow regime and the trendline through the measured data further substantiate the elevated *E. coli* levels as both of these are consistently greater than the geometric mean criterion for the station on each creek. The magnitude of exceedances (based on a proportion of the actual loading and the allowable loading) decreased with flow for Quinlan and Town Creeks. In comparison, the LDCs are very similar, although the historical data on the Quinlan Creek LDC appear to have more scatter, indicating that the bacteria conditions at this location on Quinlan Creek are more variable than at the Town Creek location.

The actual interpretation of these curves in the context of the TMDL allocation process is reserved for the next report section.

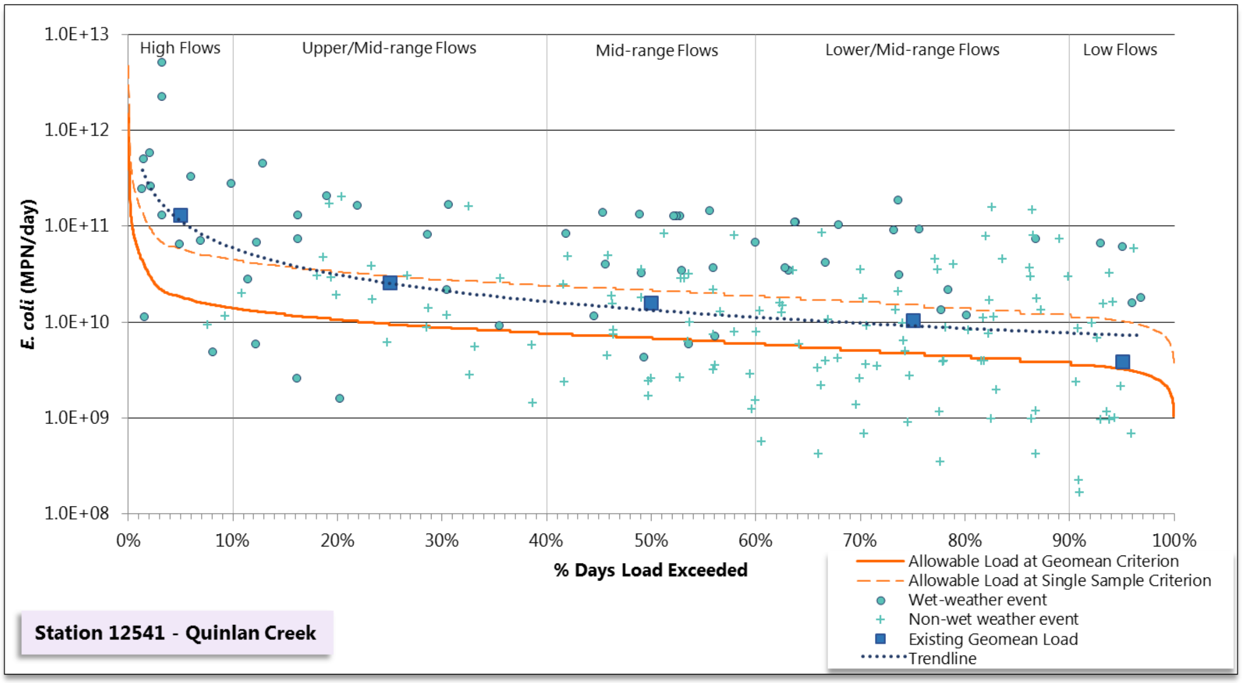

Figure 12. Load duration curve for Quinlan Creek (Station 12541).

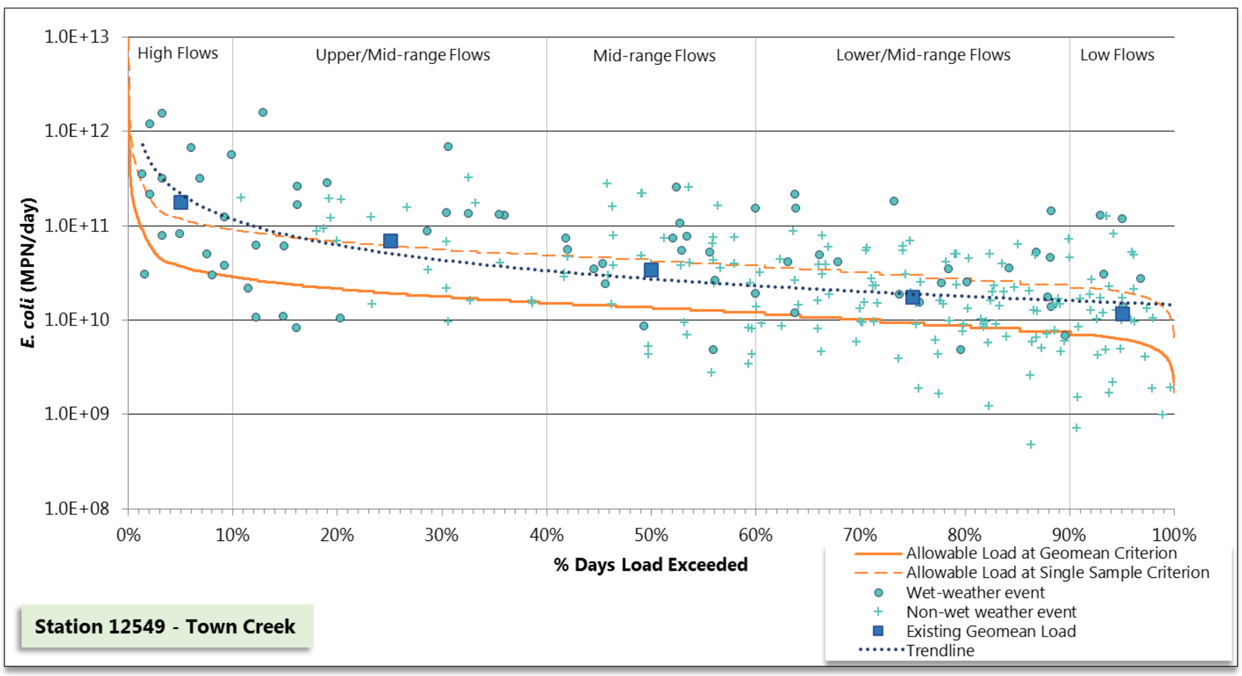

Figure 13. Load duration curve for Town Creek (Station 12549).

SECTION 4
TMDL ALLOCATION ANALYSIS

Presented in this report section is the development of the bacteria TMDL allocation for the two 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 two TMDL watersheds. As developed previously in this report, the modified 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 Quinlan Creek (AU 1806D_01) watershed and the entire Town Creek (AU 1806E_01) watershed as shown in the overview map (Figure 2). For both of the watersheds, the SWQM station selection was based on which of the available stations had the most downstream location combined with the most extensive time series of bacteria measurements and currently active monitoring. For the Quinlan Creek watershed, this was SWQM station 12541 and for Town Creek watershed, it was SWQM station 12549.

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 two 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 both watersheds addressed by this TMDL. This endpoint is identical to the geometric mean criterion in the 2010 Surface Water Quality Standards (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 (2005 – 2016) of routine monitoring collected in the warmer months (May - September) against those collected during the cooler months (October – April). 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 in indicator bacteria between cool and warm weather seasons for both Quinlan Creek (two-sample t (n = 188) = 3.58, p = 0. 436E-04) and Town Creek (two-sample t(n = 230) = 4.24, p=3.21E-05) with the warm season having the higher concentrations.

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 permitted and non-permitted stormwater sources are greatest during runoff events. Rainfall runoff, depending on 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 one-to-one relationship between instream loadings and loadings originating from point sources and the landscape as regulated and non-regulated sources. Further, this one-to-one relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.7).

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 USEPA 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 each of the five flow regimes (or 5 percent flow) to remain consistent with the approach of the previous TMDL (TCEQ, 2007).

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 (Figure 12 and Figure 13) and Section 2.7 (Potential Sources of Fecal Indicator Bacteria), the following broad linkage statements can be made. For both the Quinlan Creek and Town Creek watersheds, the historical *E. coli* data indicate that elevated bacteria loadings occur under all flow conditions, but become most elevated under the highest flows and are often below the single sample criterion under the lowest flows. Regulated stormwater comprises a small portion of the watershed (0.84 percent for the Quinlan Creek watershed and 0.53 percent for the Town Creek watershed, as shown in Table 18) and must be considered only a minor contributor. Most likely, non-regulated stormwater comprises the majority of high flow related loadings. The elevated *E. coli* loadings under the lower flow conditions cannot be reasonably attributed to WWTFs since the DMR records for the single WWTF in the Town Creek watershed indicate "no discharge" (Section 2.7.1.1) and the Quinlan Creek watershed contains no permitted WWTFs. Therefore, other sources of bacteria loadings under lower flows and in the absence of overland flow contributions (i.e., without stormwater contribution) are most likely contributing bacteria directly to the water as could occur through direct deposition of fecal material from wildlife, feral hogs and livestock. The actual contribution of bacteria loadings attributable to these direct sources of fecal material deposition cannot be determined using LDCs.

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 MOS 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 an MOS.

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 m. 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 two 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 five flow regimes was determined using the historical *E. coli* data obtained from stations within the impaired reaches.

For each station and 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 126 MPN/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 14).

Table 14. Percent reduction calculations for stations within the water bodies of the TMDL watersheds.

Watershed (Station)	AU	High Flows (0-10%)		Upper/Mid-range Flows (10-40%)		Mid-range Flows (40-60%)		Lower/Mid-range Flows (60-90%)		Low Flows (90-100%)	
		Geometric Mean (MPN/ 100 mL)	Required % Reduction	Geometric Mean (MPN/ 100 mL)	Required % Reduction	Geometric Mean (MPN/ 100 mL)	Required % Reduction	Geometric Mean (MPN/ 100 mL)	Required % Reduction	Geometric Mean (MPN/ 100 mL)	Required % Reduction
Quinlan Creek (12541)	1806D_01	749	83%	323	61%	297	58%	277	55%	146	14%
Town Creek (12549)	1806E_01	535	76%	434	71%	325	61%	245	49%	238	47%

4.7 Pollutant Load Allocation

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

$$\text{TMDL} = \text{WLA} + \text{LA} + \text{FG} + \text{MOS} \qquad \text{(Eq. 1)}$$

Where:

TMDL = total maximum daily load
WLA = wasteload allocation, the amount of pollutant allowed by existing regulated or permitted dischargers
LA = load allocation, the amount of pollutant allowed by non-regulated 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.

For the previous TMDL on the Guadalupe River (TCEQ, 2007), pollutant load allocations were determined from the median flow of each of the five flow regimes comprising the LDCs: 5 percent exceedance for the High Flows (0-10 percent), 25 percent exceedance for the Moist Conditions (10-40 percent), 50 percent exceedance for Mid-Range Flow (40-60 percent), 75 percent exceedance for the Dry Conditions (60-90 percent), and 95 percent exceedance for the Low Flows (90-100 percent). For more recent bacteria TMDLs across Texas, TCEQ considered only the 5 percent exceedance (the median value of the High Flows) in the pollutant load allocations. The 5 percent exceedance loading for the two impaired AUs covered in this report will be developed in the remainder of this Section. For consistency with the Guadalupe River TMDL; however, the pollutant load allocations for each of the five flow regimes are provided in Appendix A.

4.7.1 AU-Level TMDL Computations

The bacteria TMDLs for Quinlan and Town Creeks were developed as pollutant load allocations based on information from the most downstream LDCs (Figures 10 and 11). 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* geometric mean criterion (126 MPN/100 mL) and by the conversion factor used to represent the allowable loading in MPN/day. Effectively, the "Allowable Load" displayed in the LDC at 5 percent exceedance (the median value of the high-flow regime) is the TMDL:

TMDL (MPN/day) = Criterion * Flow (cfs) * Conversion factor (Eq. 2)

Where:

Criterion = 126 MPN/100 mL (*E. coli*)
Conversion factor (to MPN/day) = 283.168 100 mL/ft3 * 86,400 sec/day

At 5 percent load duration exceedance, the TMDL values are provided in Table 15.

Table 15. Summary of allowable loading calculations for AUs within the TMDL watersheds.

Watershed (Station)	AU	5% Exceedance Flow (cfs)	5% Exceedance Load (MPN/ day)	Indicator Bacteria	TMDL (Billion MPN/ day)
Quinlan Creek (12541)	1806D_01	5.9334	1.8291E+10	*E. coli*	18.291
Town Creek (12549)	1806E_01	12.1414	3.7428E+10	*E. coli*	37.428

4.7.2 Margin of Safety

The margin of safety (MOS) is only applied to the allowable loading for a watershed. Therefore the MOS is expressed mathematically as the following:

MOS = 0.05 * TMDL (Eq. 3)

Where:

MOS = margin of safety load
TMDL = total maximum allowable load

Since the MOS is based solely on the TMDL term, the calculation is straightforward (Table 16).

Table 16. MOS calculations for downstream stations within the TMDL watersheds.

Watershed	AU	Indicator Bacteria	TMDL[a] (Billion MPN/ day)	MOS (Billion MPN/ day)
Quinlan Creek	1806D_01	*E. coli*	18.291	0.915
Town Creek	1806E_01	*E. coli*	37.428	1.871

[a] TMDL from Table 15.

4.7.3 Wasteload Allocation

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

$$WLA = WLA_{WWTF} + WLA_{SW} \quad \text{(Eq. 4)}$$

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by the instream geometric criterion. To remain consistent with the presviously completed TMDL, no MOS was inlcuded in the WLA_{WWTF} computations. The fresh water *E. coli* criterion (126 MPN/100mL) is used as the WWTF target. This is expressed in the following equation:

$$WLA_{WWTF} = \text{Criterion} * \text{Flow} * \text{Conversion Factor} \quad \text{(Eq. 5)}$$

Where:

Criterion= 126 MPN/100 mL for *E. coli*
Flow = full permitted flow (MGD)
Conversion Factor (to MPN/day) = 1.54723 cfs/MGD *283.168 100 mL/ft3 * 86,400 s/d

Thus the daily allowable loading of *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of the single permitted WWTF within the TMDL watersheds, using Eq. 5. Table 17 presents the wasteload allocation for the single WWTF located within the Town Creek Watershed. No WWTFs were located within the Quinlan Creek watershed.

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. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

Table 17. Wasteload allocations for TPDES-permitted facilities with the TMDL watersheds.

Facility	Full Permitted Flow (MGD)[a]	Permit Limit (MPN/100 mL)	*E. coli* WLA_{WWTF} (Billion MPN/ day)
n/a	-	-	-
Quinlan Creek Watershed Total			0.000
Hill Country Camp	0.025	126	0.119
Town Creek Watershed Total			0.119

[a] Permitted flow from Table 6

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

$$WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP} \quad \text{(Eq. 6)}$$

Where:

WLA_{SW} = sum of all regulated stormwater loads
TMDL = total maximum daily load
WLA_{WWTF} = sum of all WWTF loads
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

The fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined in order 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 Section 2.7.1.5, a search for all five categories of stormwater general permits was performed. The search results are displayed in Table 18.

No MS4 permits are held in the watersheds of Quinlan and Town Creeks. For the Multi-sector and Concrete Production general permits, only the acreages associated with active permits were tallied. These acreages were calculated by importing the location information associated with the authorizations into a Geographic Information System (GIS), and measuring the estimated disturbed area based on the most recently available aerial imagery. For the Construction Activities general permits, the authorization contains an "Area Disturbed" field. Due to the variable and temporary nature of construction projects, it was preferable to average the acreages (on a monthly basis) associated with active permits over the most recent 10 years of the available period of record. The results of this temporal averaging were used as representative of the average area under Construction Activities stormwater permits.

Table 18. Stormwater General Permit areas and calculation of the FDA_{SWP} term for the TMDL watersheds.

Water-shed	AU	MS4 General Permit (acres)	Multi-sector General Permit (acres)	Construction Activities (acres)	Concrete Production Facilities (acres)	Petroleum Bulk Stations (acres)	Total Area of Permits (acres)	Watershed Area (acres)	FDA_{SWP}
Quinlan Creek	1806D_01	-	14	45	4	-	63	7,463	0.8442%
Town Creek	1806E_01	-	27	53	-	-	80	15,028	0.5323%

In order to calculate WLA_{SW} (Eq. 6), the Future Growth (FG) term must be known. The calculation for the FG term is presented in the next section, but the results will be included here for continuity. Table 19 provides the information needed to compute WLA_{SW}.

Table 19. Regulated stormwater calculations for the TMDL watersheds.

Load units expressed as billion MPN/day *E. coli*

Watershed	AU	Indicator	TMDL [a]	WLA_{WWTF} [b]	FG [c]	MOS [d]	FDA_{SWP} [e]	WLA_{SW}
Quinlan Creek	1806D_01	*E. coli*	18.291	0.000	0.477	0.915	0.8442%	0.143
Town Creek	1806E_01	*E. coli*	37.428	0.119	0.477	1.871	0.5323%	0.186

[a] TMDL from Table 15
[b] WLA_{WWTF} from Table 17
[c] FG from Table 20
[d] MOS from Table 16
[e] FDA_{SWP} from Table 18

4.7.4 Future Growth

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. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

For this TMDL, the conventional future growth calculation is hampered by the deficiency of WWTFs. In this case, the single WWTF (located within the Town Creek watershed) is associated with a camp (Table 6), rather than a community or municipality. By using TCEQ design guidance for domestic WWTFs, and assuming the potential for a residential development of a density sufficient to require centralized sewer collection, an alternative method was implemented.

According to Rule §217.32 of Texas Administrative Code, new WWTFs are to be designed for a daily wastewater flow of 75-100 gallons per capita per day (gpcd; TAC, 2008). Conservatively taking the higher daily wastewater flow capacity (100 gallons) and multiplying it by a potential population change would result in a future growth permitted flow. Based on the information in Table 1, the projected population change for unincorporated areas of the subject watersheds for the 2010-2050 time period is 128 for the in the Quinlan Creek watershed, and 328 in the Town Creek watershed. Conservatively assuming a larger population consistent with a potential residential development - 1,000 people - and multiplying that by the higher daily wastewater flow capacity, yields a value of 0.10 MGD. This value would be considered the full permitted discharge of a potential future WWTF.

To remain consistent with the presviously completed TMDL, no MOS was included in the computation of FG. The FG term is calcuated as follows:

$$FG = Criterion * WWTF_{FP} * Conversion\ Factor \qquad \text{(Eq. 7)}$$

Where:

Criterion = 126 MPN/100 mL for *E. coli*
$WWTF_{FP}$ = full permitted discharge (MGD) of potential future WWTF
Conversion Factor = 1.54723 cfs/MGD *283.168 100 mL/ft3 * 86,400 s/d

The calculation results for the impaired AU watershed are shown in Table 20.

Table 20. Future growth calculations for the TMDL watersheds.

Watershed	AU	Indicator Bacteria	Assumed Service Population	Daily Wastewater (gpcd)	Future Growth Permitted Flow (MGD)	*E. coli* FG (Billion MPN/ day)
Quinlan Creek	1806D_01	*E. coli*	1,000	100	0.10	0.477
Town Creek	1806E_01	*E. coli*	1,000	100	0.10	0.477

4.7.5 Load Allocation

The load allocation (LA) is the loads from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \qquad \text{(Eq. 8)}$$

Where:

LA = allowable loads from unregulated sources within the AU
TMDL = total maximum daily load
WLA_{WWTF} = sum of all WWTF loads
WLA_{SW} = sum of all regulated stormwater loads
FG = sum of future growth loads from potential permitted facilities
MOS = margin of safety load

The calculation results are shown in Table 21.

Table 21. Load allocation calculations for the TMDL watersheds.

Units expressed as billion MPN/ day *E. coli*.

Watershed	AU	Indicator	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	FG[d]	MOS[e]	LA
Quinlan Creek	1806D_01	*E. coli*	18.291	0.000	0.143	0.477	0.915	16.756
Town Creek	1806E_01	*E. coli*	37.428	0.119	0.186	0.477	1.871	34.775

[a] TMDL from Table 15
[b] WLA_{WWTF} from Table 17
[c] WLA_{SW} from Table 19
[d] FG from Table 20
[e] MOS from Table 16

4.8 Summary of TMDL Calculations

Table 22 summarizes the TMDL calculations for Quinlan Creek (1806D_01) and Town Creek (1806E_01) watersheds. The TMDL was calculated based on the median flow in the 0-10 percentile range (5 percent exceedance, high flow regime) for flow exceedance from the LDC developed for the downstream SWQM station in each watershed (12541 and 12549, respectively). Allocations are based on the current geometric mean criterion for *E. coli* of 126 MPN/100 mL for each component of the TMDL.

Table 22. TMDL allocation summary for the Quinlan Creek and Town Creek watersheds.

Units expressed as billion MPN/ day *E. coli*.

AU	Stream Name	Indicator	TMDL [a]	MOS [b]	WLA_{WWTF} [c]	WLA_{SW} [d]	LA [e]	FG [f]
1806D_01	Quinlan Creek	*E. coli*	18.291	0.915	0	0.143	16.756	0.477
1806E_01	Town Creek	*E. coli*	37.428	1.871	0.119	0.186	34.775	0.477

[a] TMDL from Table 15
[b] MOS from Table 16
[c] WLA_{WWTF} from Table 17
[d] WLA_{SW} from Table 19
[e] LA from Table 21
[f] FG from Table 20

The final TMDL allocations (Table 23) needed to comply with the requirements of 40 CFR §130.7 include the future growth component within the WLA_{WWTF}.

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix B provides guidance for recalculating the allocations in Table 23. Figure B-1 for Quinlan Creek and Figure B-2 for Town Creek 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 B-1 and B-2, allow calculation of a new TMDL and pollutant load allocation based on any potential new water quality criterion for *E. coli*.

Table 23. Final TMDL allocations for the impaired Quinlan Creek and Town Creek watersheds.

Units expressed as billion MPN/ day *E. coli*.

AU	TMDL	WLA_{WWTF} [a]	WLA_{SW}	LA	MOS
1806D_01	18.291	0.477	0.143	16.756	0.915
1806E_01	37.428	0.596	0.186	34.775	1.871

[a] WLA_{WWTF} includes the FG component.

SECTION 5
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Appendix A.
Pollutant Load Allocations by Flow Regime for Quinlan and Town Creek

For the previous TMDL on the Guadalupe River (TCEQ, 2007), pollutant load allocations were determined from the median flow of each of the five flow regimes comprising the LDCs:

1) 5 percent exceedance for the High Flows (0-10 percent),
2) 25 percent exceedance for the Upper/Mid-range Conditions (10-40 percent),
3) 50 percent exceedance for Mid-Range Flow (40-60 percent),
4) 75 percent exceedance for the Lower/Mid-range Conditions (60-90 percent), and
5) 95 percent exceedance for the Low Flows (90-100 percent).

For more recent bacteria TMDLs across Texas, TCEQ considered only the 5 percent exceedance (the median value of the High Flows) in the pollutant load allocations.

Within this appendix is provided the pollutant load allocation information for each of the five flow regimes of Quinlan and Town Creeks. Table A-1 contains the summary of allowable loadings provided in Table 15 for only the High Flows regime; Table A-2 contains the TMDL allocation summary provided in Table 22, again, only for the High Flow regime; and Table A-3 contains the final TMDL allocation provided in Table 23, but expanded to include the values for each of the five flow regimes. The values contained in Appendix A tables were derived from the information and equations provided in Section 4.7

Table A-1. Summary of allowable loading calculations for each flow regime for AUs within the TMDL watersheds.

Watershed (Station)	Segment	Flow Regime	Median Flow of Flow Regime (cfs)	Exceedance Load (MPN/ day)	Indicator Bacteria	TMDL (Billion MPN/ day)
Quinlan Creek (12541)	1806D	High Flows	5.9334	1.8291E+10	*E. coli*	18.291
		Upper/Mid-range Flows	3.0441	9.3840E+09	*E. coli*	9.384
		Mid-range Flows	2.247	6.9270E+09	*E. coli*	6.927
		Lower/Mid-range Flows	1.5496	4.7770E+09	*E. coli*	4.777
		Low Flows	1.0514	3.2410E+09	*E. coli*	3.241
Town Creek (12549)	1806E	High Flows	12.1414	3.7428E+10	*E. coli*	37.428
		Upper/Mid-range Flows	6.1674	1.9012E+10	*E. coli*	19.012
		Mid-Range Flows	4.5194	1.3932E+10	*E. coli*	13.932
		Lower/Mid-range Flows	3.0774	9.4866E+09	*E. coli*	9.487
		Low Flows	2.0474	6.3115E+09	*E. coli*	6.311

Table A-2. TMDL allocation summary by flow regime for the Quinlan Creek and Town Creek watersheds.

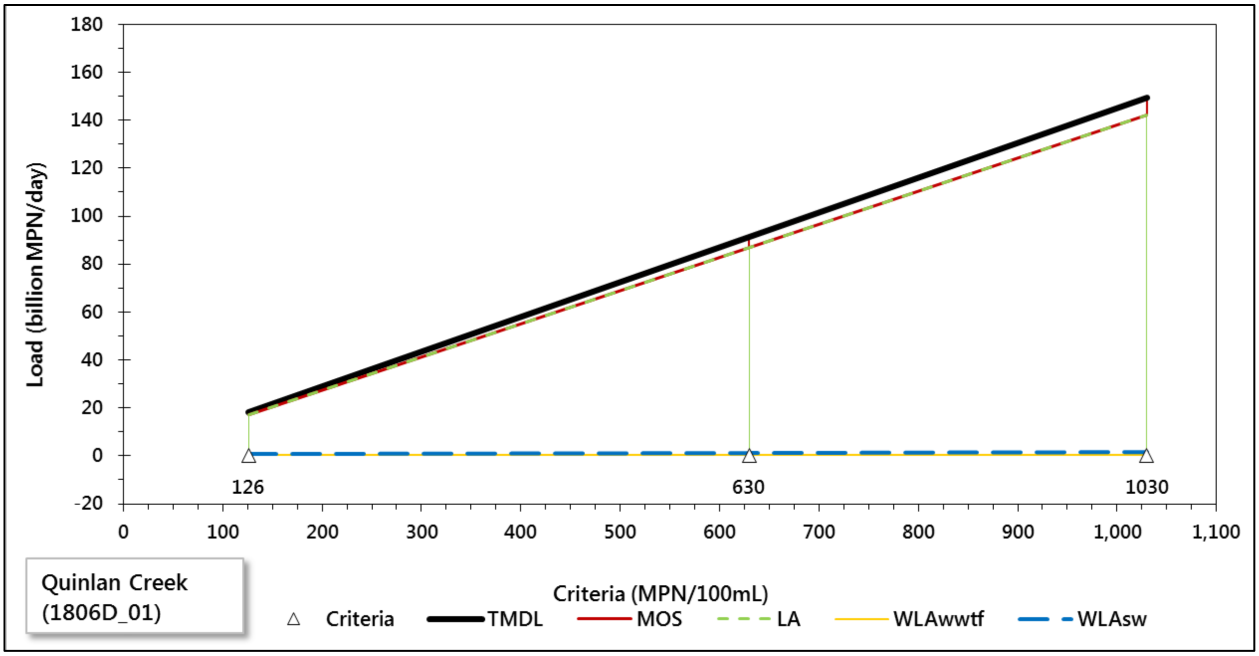
AU	Stream Name	Indicator	Flow Regime	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA	Future Growth
1806D_01	Quinlan Creek	*E. coli*	High Flows	18.291	0.915	0	0.143	16.756	0.477
			Upper/Mid-range Flows	9.384	0.469	0	0.071	8.367	0.477
			Mid-Range Flows	6.927	0.346	0	0.052	6.052	0.477
			Lower/Mid-range Flows	4.777	0.239	0	0.034	4.027	0.477
			Low Flows	3.241	0.162	0	0.022	2.580	0.477
1806E_01	Town Creek	*E. coli*	High Flows	37.428	1.871	0.119	0.186	34.775	0.477
			High/Mid-range Flows	19.012	0.951	0.119	0.093	17.372	0.477
			Mid-Range Flows	13.932	0.697	0.119	0.067	12.572	0.477
			Low/Mid-range Flows	9.487	0.474	0.119	0.045	8.372	0.477
			Low Flows	6.311	0.316	0.119	0.029	5.370	0.477

Table A-3. TMDL allocation summary by flow regime for the Quinlan Creek and Town Creek watersheds.

AU	Stream Name	Indicator	Flow Regime	TMDL	WLA_{WWTF} [a]	WLA_{SW}	LA	MOS
1806D_01	Quinlan Creek	*E. coli*	High Flows	18.291	0.477	0.143	16.756	0.915
			Upper/Mid-range Flows	9.384	0.477	0.071	8.367	0.469
			Mid-Range Flows	6.927	0.477	0.052	6.052	0.346
			Lower/Mid-range Flows	4.777	0.477	0.034	4.027	0.239
			Low Flows	3.241	0.477	0.022	2.580	0.162
1806E_01	Town Creek	*E. coli*	High Flows	37.428	0.596	0.186	34.775	1.871
			Upper/Mid-range Flows	19.012	0.596	0.093	17.372	0.951
			Mid-Range Flows	13.932	0.596	0.067	12.572	0.697
			Lower/Mid-range Flows	9.487	0.596	0.045	8.372	0.474
			Low Flows	6.311	0.596	0.029	5.370	0.316

[a] WLA_{WWTF} includes the FG component.

Appendix B.
Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard



All loads below are in billion MPN/day

Term	Criterion 126 MPN/100 mL	Criterion 630 MPN/100 mL	Criterion 1030 MPN/100 mL
TMDL	18.291	91.454	149.520
MOS	0.915	4.573	7.476
LA	16.757	85.675	140.372
WLA_{WWTF}	0.477	0.477	0.477
WLA_{SW}	0.143	0.729	1.195

Figure B-1. Allocation loads for Quinlan Creek (1806D_01) as a function of water quality criteria.

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

TMDL =0.14516487 * Std

MOS =0.00725824 * Std

LA =0.13674242 * Std -0.47297317

WLA_{WWTF} = 0.47700000

WLA_{SW} =0.00116421 * Std -0.00402683

Where:

Std = Revised Contact Recreation Standard

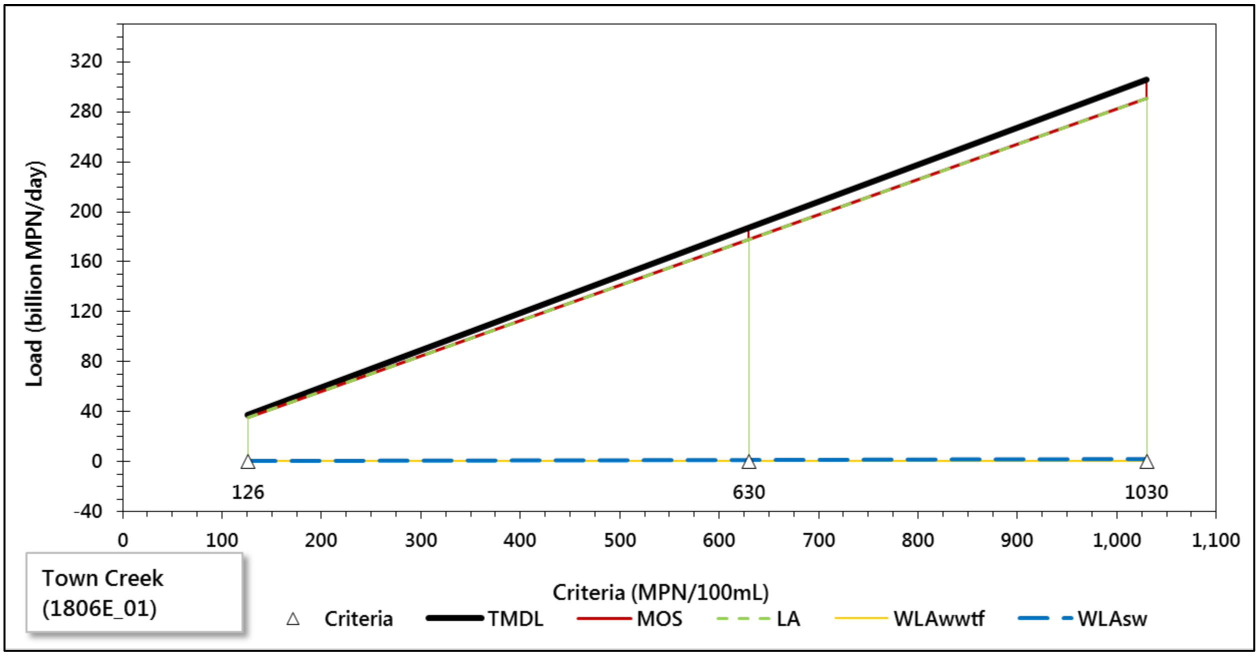
MOS = Margin of Safety

LA = Total load allocation (non-permitted source contributions)

WLA_{WWTF} = Wasteload allocation (permitted WWTF load + future growth)

[Note: WWTF load held at Primary Contact (126 MPN/ 100 mL) criterion]

WLA_{SW} = Wasteload allocation (permitted stormwater)



All loads below are in billion MPN/day

Term	Criterion 126 MPN/100 mL	Criterion 630 MPN/100 mL	Criterion 1030 MPN/100 mL
TMDL	37.428	187.140	305.959
MOS	1.871	9.357	15.298
LA	34.775	176.244	288.521
WLA_{WWTF}	0.596	0.596	0.596
WLA_{SW}	0.186	0.943	1.544

Figure B-2. Allocation loads for Town Creek (1806E_01) as a function of water quality criteria.

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

TMDL =0.29704802 * Std

MOS =0.01485240 * Std

LA =0.28069349 * Std -0.5928749

WLA_{WWTF} =0.59600000

WLA_{SW} =0.00150213 * Std -0.00317251

Where:

Std = Revised Contact Recreation Standard

MOS = Margin of Safety

LA = Total load allocation (non-permitted source contributions)

WLA_{WWTF} = Wasteload allocation (permitted WWTF load + future growth)

[Note: WWTF load held at Primary Contact (126 MPN/ 100 mL) criterion]

WLA_{SW} = Wasteload allocation (permitted stormwater)