

Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in the Lavaca River and Rocky Creek

Segments 1602B and 1602

Assessment Units 1602B_01 and 1602_03

Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in Lavaca River

Segment 1602 and 1692B

Assessment Unit 1602B_01 and 1602B_03

Prepared for
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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 impairment within Rocky Creek (Segment 1602B) in the draft 2014 *Texas Water Quality Integrated Report for Clean Water Sections 305 (b) and 303 (d)*. The Lavaca River (Segment 1602) was first identified in 2008 and in each subsequent edition through the 2012 *Texas Water Quality Integrated Report for Clean Water Sections 305(b) and 303 (d)* (formerly called the *Texas Water Quality Inventory and 303(d) List*). Segment 1602 is also listed for bacteria impairment in the 2014 Integrated Report; however, assessment unit (AU) 1602_02 was removed from the 2014 Integrated Report as it is no longer experiencing bacteria impairments; therefore, this AU is not directly addressed in this report.

This document will, therefore, considers bacteria impairments in two water bodies (segment), consisting of (AUs: Lavaca River (1602_03) and Rocky Creek (1602B_01).

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 are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Both *E. coli* (*Escherichia coli*) and *Enterococcus* spp. are present in the intestinal tracts of humans and other warm blooded animal. 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). *E. coli* is widely used as an indicator in freshwater, while *Enterococci* are more often used as an indicator in high saline inland waters. *E. coli* are the relevant indicator Lavaca River (1602).

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 (EPA) approved the categorical levels of recreational use and their associated criteria. For saltwater, 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 cfu per 100 ml. In addition, the single sample criterion for *E. coli* of 399 cfu 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 cfu per 100 ml.

- Secondary contact recreation 2 covers activities with limited body contact with a less significant chance of ingestion than secondary contact recreation 1, and has a geometric mean criterion for *E. coli* of 1,030 cfu per 100 ml.
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions, and has a geometric mean criterion for *E. coli* of 2,060 cfu per 100 ml.

The impaired AUs for the Lavaca River (1602_03) and Rocky Creek (1602B_01) are not meeting their standards for primary contact recreation, and, the associated *E. coli* geometric mean criterion of a 126 cfu per 100 mL and single sample of 399 cfu per 100 mL is applied. As the Rocky Creek watershed lies entirely within the Lavaca River watershed, future mention of the watershed includes Rocky Creek.

1.3 Report Purpose and Organization

The TMDL project for the watershed of Lavaca River was initiated through a contract between the TCEQ and the Texas Water Resources Institute (TWRI). The activities of this project to be performed by TWRI were to (1) acquire existing (historical) data and information necessary to support assessment activities; (2) perform the appropriate activities necessary to allocate *E. coli* loadings; and (3) assist the TCEQ in preparing the TMDL.

Using historical bacteria and flow data, this portion of the project is intended to: (1) review the characteristics of the watershed and explore the potential sources of *E. coli* for the impaired segment; (2) develop an appropriate tool for development of a bacteria TMDL for the impaired segment; and (3) submit the draft and final technical support document for the impaired segment. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDL for the Lavaca River watershed. 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 presence of indicator bacteria (*E. coli*),
- development of load duration curves, and
- application of the load duration curve approach for the pollutant load allocation process.

SECTION 2

WATERSHED OVERVIEW AND DATA REVIEW

2.1 Description of Study Area

The Lavaca River, located in the Matagorda Bay watershed near the Texas Gulf, is comprised of two segments- the upstream segment is designated as “Above Tidal (Segment 1602)” and the downstream as “Tidal (Segment 1601)” (Figure 1). The above tidal portion of the creek is a perennial freshwater stream, while the below tidal portion is influenced by seawater from Lavaca Bay. Rocky Creek is perennial stream and is a tributary of the Lavaca River, and joins it just below Hallettsville.

The entire Lavaca watershed is covered in the overview; however, the focus will be on the water body AU bacterial impairments: 1602_03 Lavaca River Above Tidal and 1602B_01 Rocky Creek. All data referencing the Lavaca River watershed include Rocky Creek data, but since Rocky Creek is listed as impaired separately, its unique watershed information is also being listed.

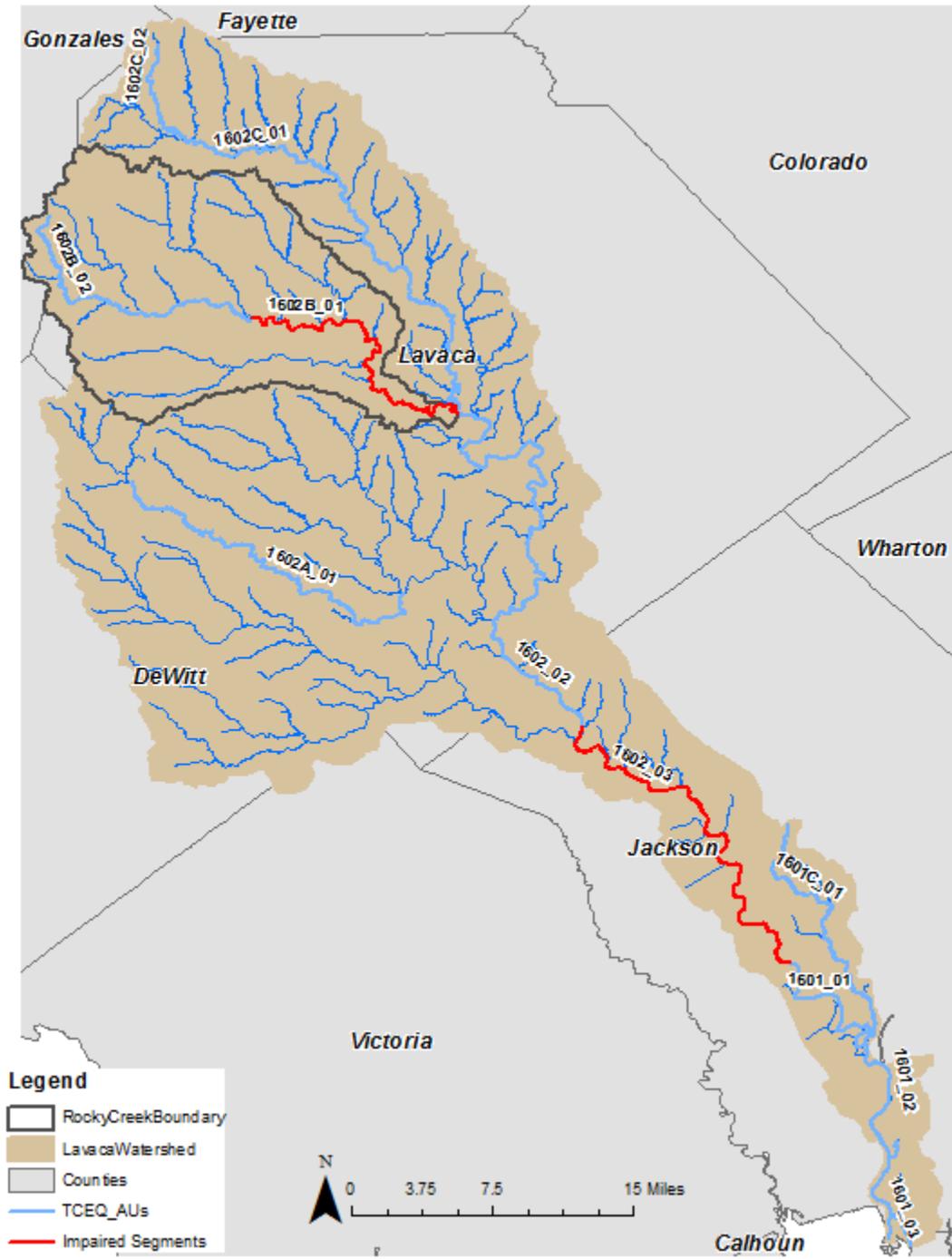


Figure 1. Overview map showing the Lavaca Creek AUs and watershed.

Rocky Creek (Segment 1602B) arises in northwest Lavaca County west of State Highway 95 near Shiner. It flows 23.5 miles through Lavaca County and ends at the confluence of Lavaca River.

Lavaca River Above Tidal (Segment 1602) flows from a point 8.6 km (5.3 miles) downstream of US 59 in Jackson County to a point 5.5 km (3.4 miles) upstream of SH 95 in Lavaca County. Lavaca River Tidal (Segment 1601) begins at its outlet into Lavaca Bay and ends at the point 8.6 km downstream of US 59, where Segment 1602 begins. At its mouth, the Lavaca River drains an area of approximately 2,316 square miles in Calhoun, Colorado, DeWitt, Fayette, Gonzales, Jackson, Lavaca, Victoria, and Wharton counties.

2.2 Watershed Climate and Hydrology

The Lavaca River watershed is located in the eastern portion of the state of Texas, where the climate is classified as “Subtropical Humid” (Larkin & Bomar, 1983). 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 & Bomar, 1983). For the period from 1981 to 2010, average annual precipitation over the Lavaca River watershed was around 41 inches (PRISM, 2012) (Figure 2).

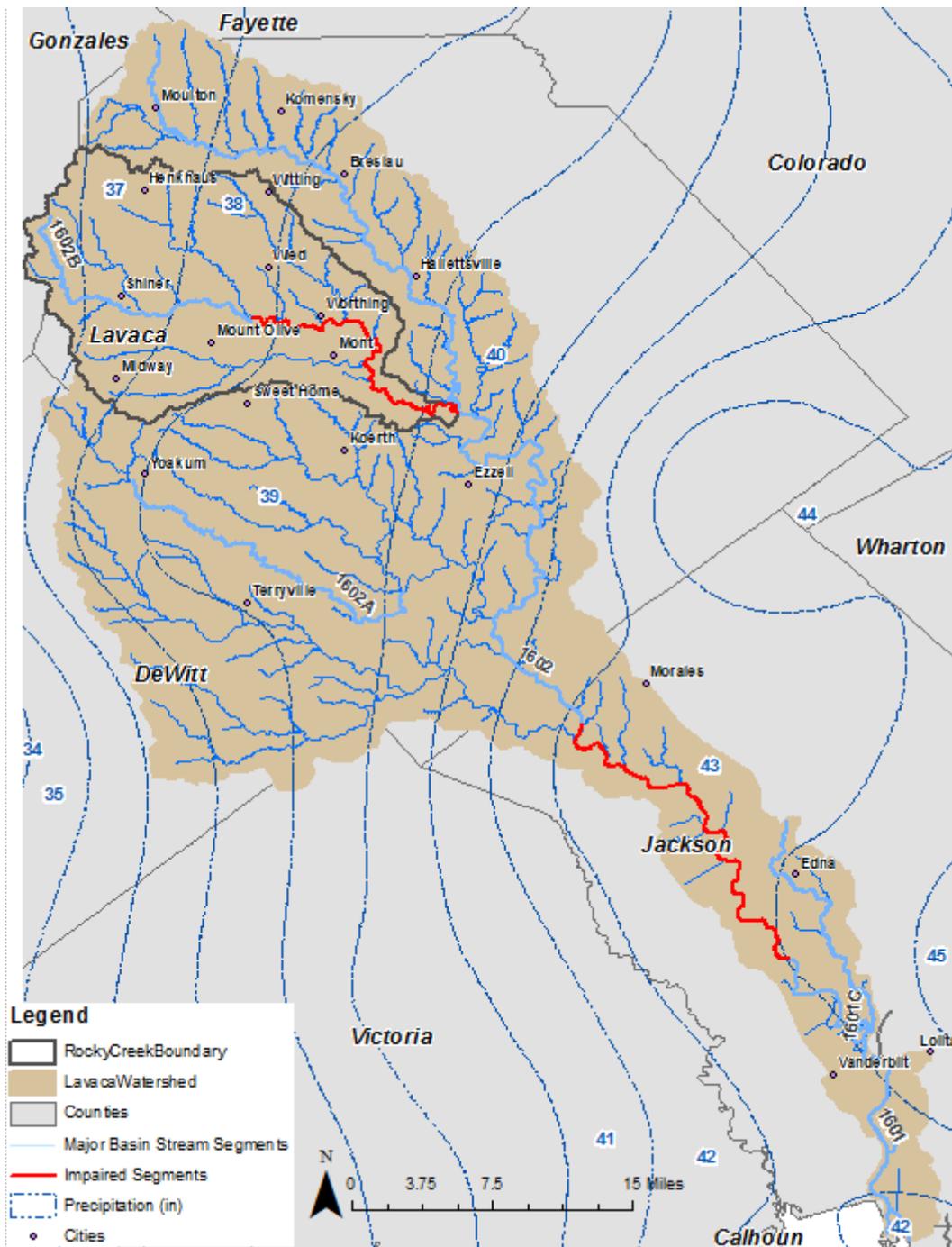


Figure 2. Annual average precipitation isohyets (in inches) in the Lavaca River and Rocky Creek watershed (1981-2010). Major cities within the watershed are shown.

At the Victoria Regional Airport, average high temperatures generally peaked in August with an average temperature of 85°F and a typical high of 94.5°F; highs above 100°F are not uncommon and have occurred from April through September. Fair skies generally accompany the highest temperatures of summer when nightly average lows drop to about 74°F. During winter, the average low temperatures typically reach 45°F in January; although below freezing temperatures

have occurred from September through April. The wettest month is normally May (5.19 in), and the driest month is normally February (2.08 inches), although some rainfall typically occurs year-round (Figure 3).

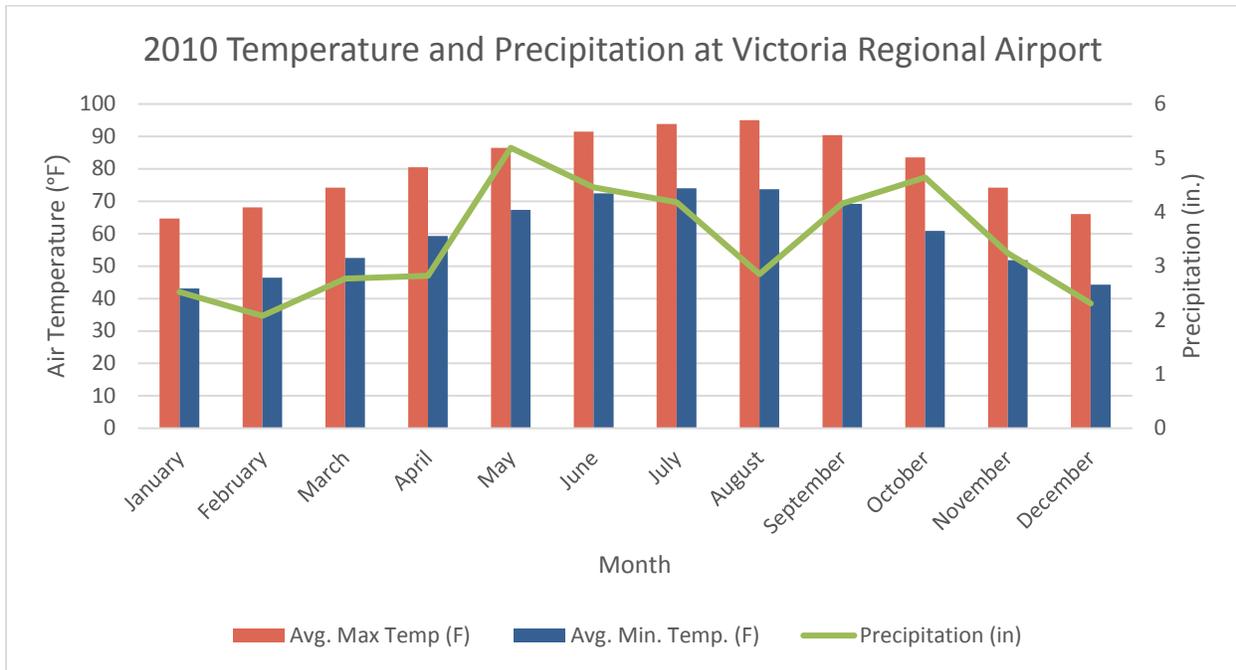


Figure 3. Annual average precipitation (in inches) and min and max temperatures for Basin 16 (1981-2010).
 Source: NOAA (2015b)

2.3 Watershed Population and Population Projections

According to the 2010 Census (UCSB, 2012), Lavaca River watershed has a total population of 30,156 and a population density of about 33 people/sq. mi. (Figure 4). The municipalities include Shiner, Hallettsville, Yoakum, and Edna. Population projections developed by the Office of the State Demographer and the Texas Water Development Board (TWDB, 2014) indicate that the populations of the seven counties within the Lavaca River watershed are projected to increase, with the exception of Lavaca County (Table 2). Data on Table 2 were based on US Census block population data for the portion of the county within the Lavaca River watershed. Percent increase was determined by looking at estimated population increases for the whole county and applying them to the specific population estimates within the watershed.

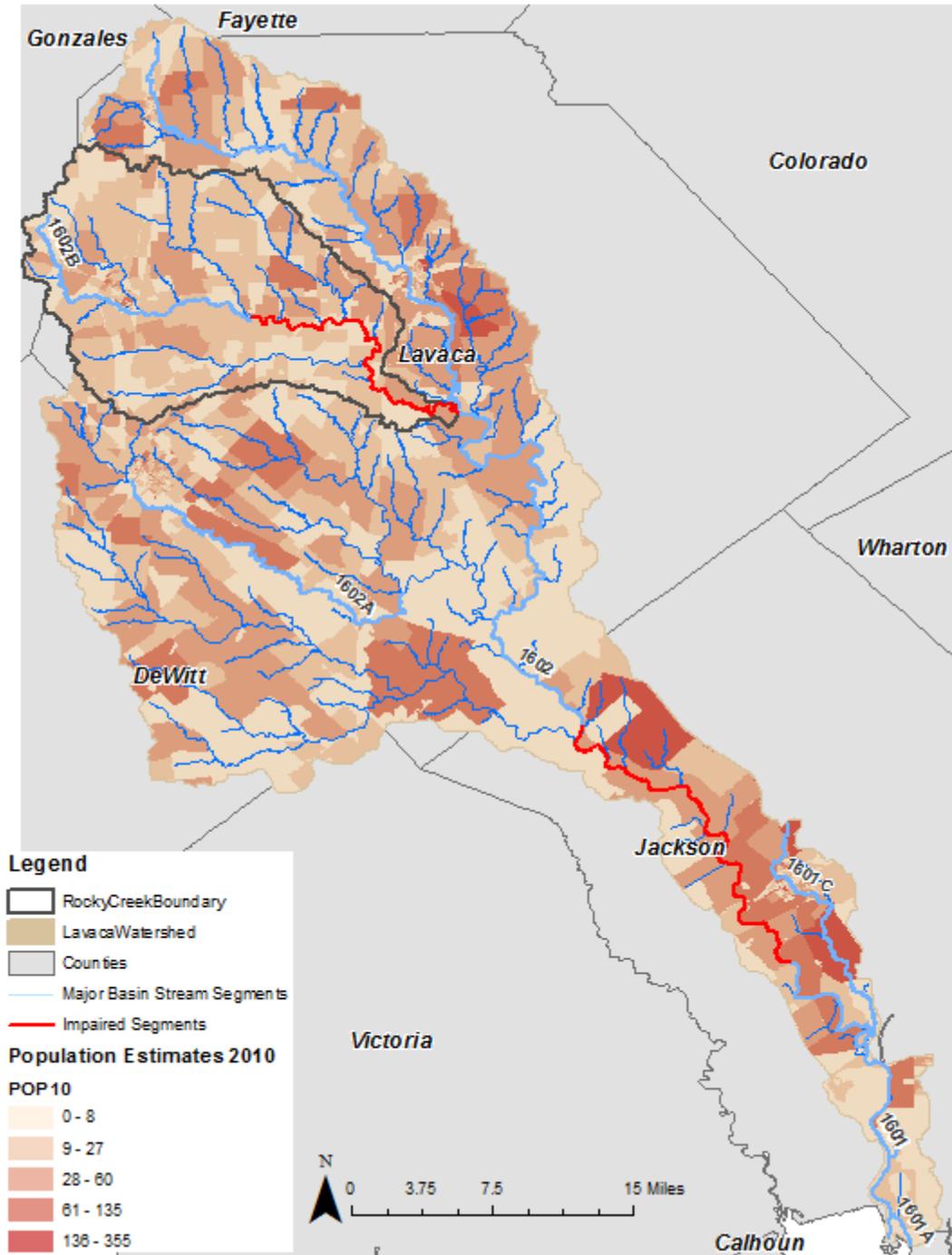


Figure 4. 2010 Total Population by Census Block.
 Sources: Census information obtained from Census Blocks (USCB, 2010)

Table 1. 2010 Population for the Lavaca River and Rocky Creek watershed.

Source: Calculated from Census Blocks (USCB, 2010)

Watershed	Segment	2010 Census Population
Lavaca River (incl. Rocky Creek)	Above Tidal (1602) & Tidal (1601)	30,156
Rocky Creek	Rocky Creek (1602B)	5,884

Table 2. 2010 Population and 2070 Population Projections for Water User Groups in the Lavaca River and Rocky Creek watershed.

Source: Calculated from 2016 Regional State Water Plan Projections Data (TWDB, 2014)

County Population Data	2010 U.S. Census	2070 Population Projection	Percent Increase (2010-2070)
DeWitt County	3,070	3,456	12.57%
Lavaca County	11,734	11,734	0%
Jackson County	2,620	2,938	12.14%
Fayette County	35	57	62.90%
Calhoun County	36	63	75%
Gonzales County	190	320	68.42%
Victoria County	532	717	34.77%

2.4 Review of Lavaca River Watershed Routine Monitoring Data

2.4.1 Data Acquisition

Ambient *E. coli* from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) was collected on February 3, 2016. The data represented all the historical routine ambient bacteria and other water quality data collected in the project area, and included bacteria data collected in Lavaca River and Rocky Creek for the entire period of record. General assessment criteria methodologies established by TCEQ were used in data evaluations.

2.4.2 Analysis of Bacteria Data

Recent environmental bacteria monitoring in AU 1602_02 has occurred at TCEQ monitoring station 18190; monitoring in AU 1602_03 has occurred at stations 12525 and 12524 (Table 3 and Figure 5). *E. coli* data collected at these stations over the seven-year period of December 1, 2005 through November 30, 2012 were used in assessing attainment of the primary contact recreation use as reported in the 2014 Texas Integrated Report (TCEQ, 2014e). The 2014 assessment data indicate non-support of the primary contact recreation use because geometric mean concentrations exceed the criteria of 126 cfu/100 mL for *E. coli*.

Table 3. 2014 Integrated Report Summary for the Impaired AUs. (The geometric mean criterion for primary contact recreation use is 126 cfu/100 mL for *E. coli*.)

Source: (TCEQ, 2014e)

Water Body	Parameter	Data Date Range	Segment	Assessment Unit (AU)	Stations	# Samples	Station Geometric Mean (cfu/100 mL)
Lavaca River Above Tidal	<i>E. coli</i>	02/1972-05/2015	1602	1602_03	12524	55	229.4
					12525	55	188.37
Rocky Creek	<i>E. coli</i>	03/2004-03/2015	1602B	1602B_01	18190	35	277.6

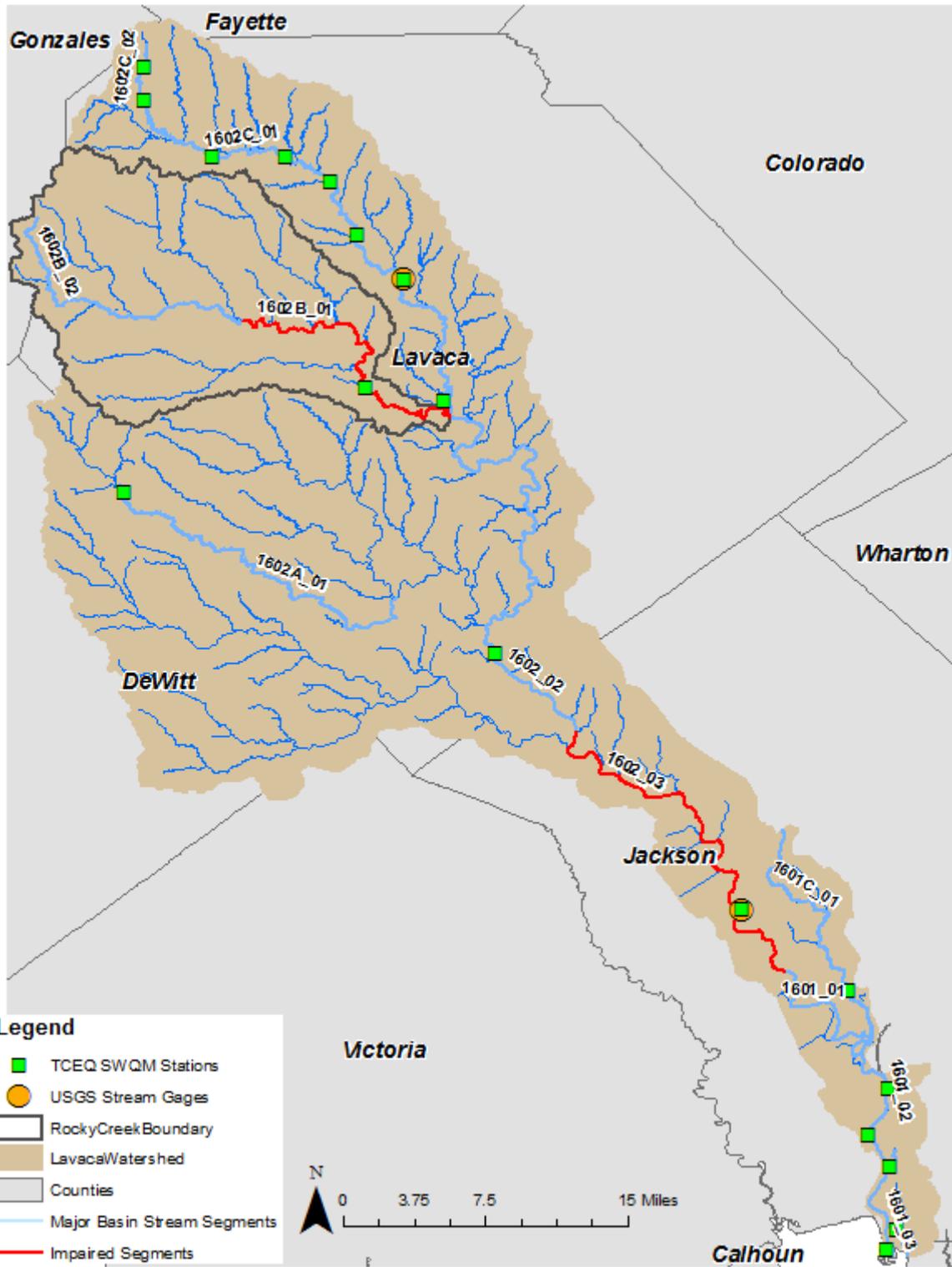


Figure 5. Lavaca River and Rocky Creek watershed showing selected TCEQ surface water quality monitoring (SWQM) stations and the USGS stream gage station for Lavaca River and Rocky Creek.

Source: (TCEQ, 2014c)

2.5 Land Use

The land use/land cover data for the Lavaca River watershed was obtained from the U.S. Geological Survey 2011 National Land Cover Database (NLCD) and is displayed in Figure 6.

The land use/land cover is represented by the following categories and definitions (USGS, 2014):

- *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% 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% to 79% 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% to 100% of the total cover.
- *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% of total cover.
- *Deciduous Forest* - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% 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% of total vegetation cover. More than 75% 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% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
- *Shrub/Scrub* - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
- *Grassland/Herbaceous* - areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
- *Pasture/Hay* - 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% 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% 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% 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% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

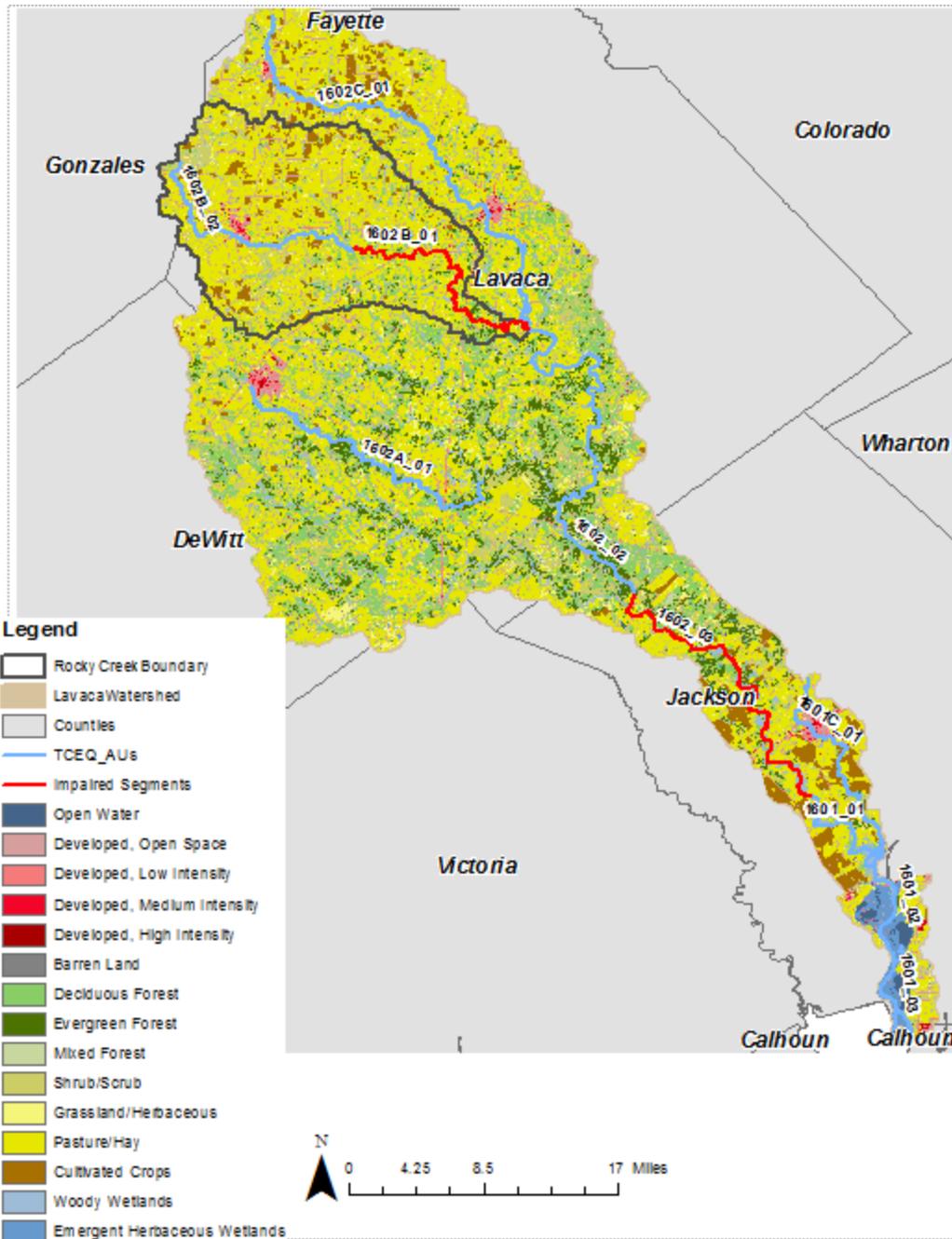


Figure 6. 2011 NLCD land use/ land cover within the Lavaca River and Rocky Creek watershed.

Source: (USGS, 2014)

Table 4. Land use/land cover within the Lavaca River and Rocky Creek watershed.

Source: (USGS, 2014)

2011 NLCD Classification	Lavaca Watershed Total		Rocky Creek Watershed Total	
	Acres	% of Total	Acres	% of Total
Open Water	4,287.32	0.74%	147.67	0.13%
Developed, Open Space	29,417.23	5.05%	6,421.86	5.65%
Developed, Low Intensity	4,329.35	0.74%	704.77	0.62%
Developed, Medium Intensity	1,381.29	0.24%	231.74	0.20%
Developed, High Intensity	527.07	0.09%	68.72	0.06%
Barren Land	662.51	0.11%	33.58	0.03%
Deciduous Forest	80,410.07	13.81%	7,782.92	6.84%
Evergreen Forest	36,604.80	6.29%	1,930.16	1.70%
Mixed Forest	7,431.09	1.28%	742.13	0.65%
Shrub/Scrub	82,232.15	14.12%	18,310.18	16.10%
Herbaceous	19,505.33	3.35%	3,011.00	2.65%
Hay/Pasture	258,964.83	44.48%	64,035.16	56.32%
Cultivated Crops	26,085.99	4.48%	7,214.70	6.35%
Woody Wetlands	24,186.07	4.15%	2,929.60	2.58%
Emergent Herbaceous Wetlands	6,229.94	1.07%	140.33	0.12%
Total	582,255.04	100%	113,704.5	100%

As displayed in Table 4, the dominant land use in the watershed area encompassing both the Tidal and Above Tidal segments of Lavaca River, which includes the Rocky Creek watershed, is Hay/Pasture (44.48%) followed by Shrub/Scrub (14.12%). The watershed is predominantly rural in land use, as only approximately 6% of the area is classified as Developed (open space, low intensity, medium intensity, and high intensity).

In solely the Rocky Creek Watershed, the predominant land use is also Hay/Pasture (56.32%) followed by shrub/scrub (16.10%) as displayed in Table 4. The watershed is only about 7% developed (open space, low intensity, medium intensity, and high intensity) and therefore designates this watershed as predominately rural as well.

2.6 Soils

Soils within the Lavaca River watershed, categorized by their Hydrologic Soil Group, are shown in Figure 7. Data were obtained through the USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (NRCS, 2013). Within the Lavaca River watershed, approximately 65% of the soils are classified in Hydrologic Soil Group D, and

therefore have the following characteristics: a high runoff potential when thoroughly wet, restricted water movement through the soil, and a high shrink-swell potential (NRCS, 2007). Soil Group A accounted for 14.5% of soils in the Lavaca River watershed, mostly representing area along the far right and left sides of the watershed. Soils classified in Group A have the following characteristics: a high infiltration rate when thoroughly wet and therefore have a low runoff potential. Soils classified within Hydrologic Soil Group C (12.16%) occur along portions of the Lavaca River Tidal segment (1601_01) and upper watershed; these soils have a moderately high runoff potential when thoroughly wet (NRCS, 2007).

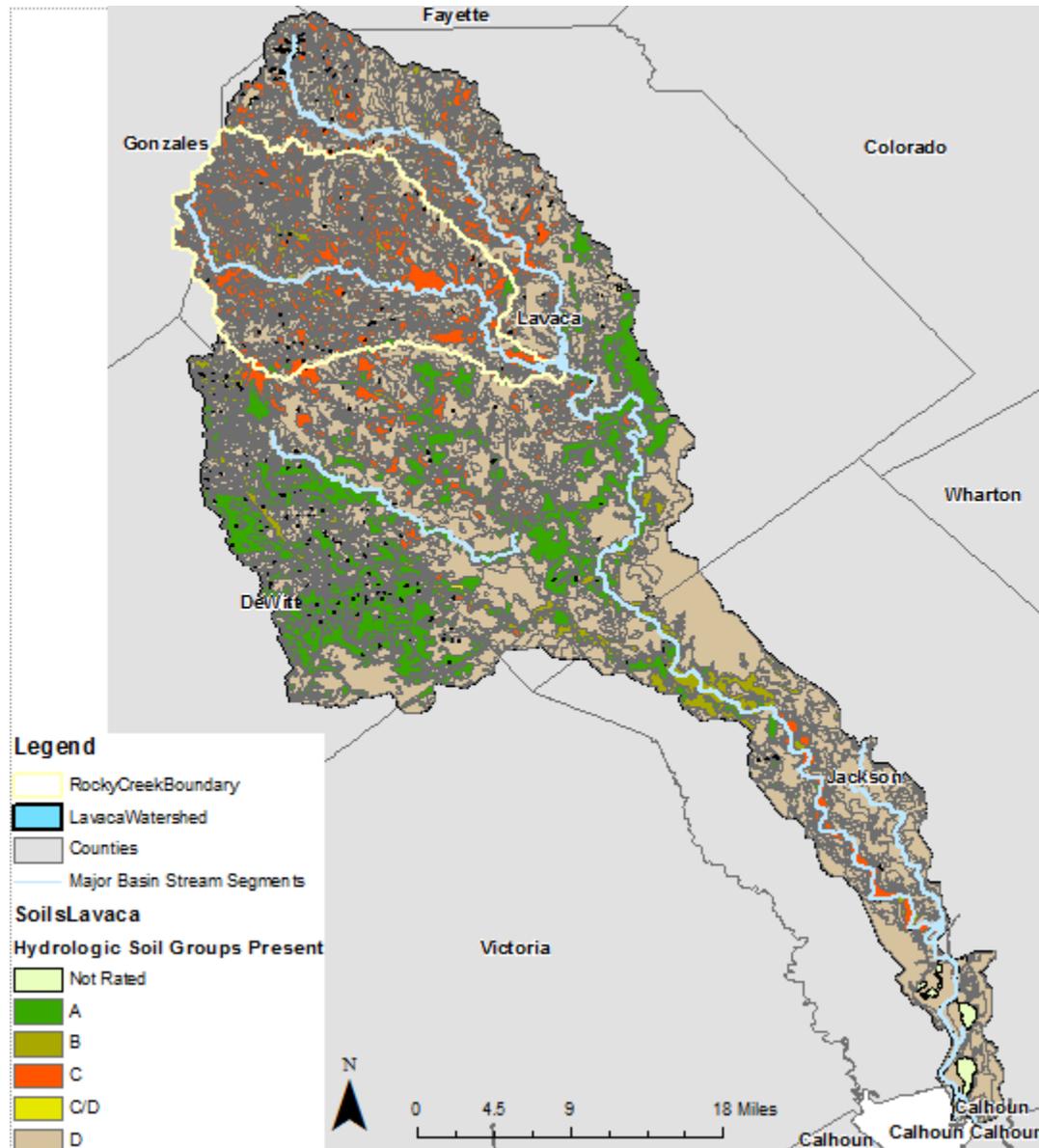


Figure 7. Lavaca River and Rocky Creek watershed soil map, soils categorized by Hydrologic Soil Group.

Source: (NRCS, 2013) (NRCS, 2013) (NRCS, 2014)

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 include 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 within the watershed.

2.7.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the NPDES programs. WWTF outfalls and stormwater discharges from industries represent the permitted sources in the Lavaca River watershed.

2.7.1.1 Domestic and Industrial Wastewater Treatment Facilities

As of March, 2016 there are seven facilities with TPDES/NPDES permits that operate within the watershed (Figure 8 and Table 5); four of the WWTFs are located in the Above Tidal portion of Lavaca River (Segment 1602) with one of them also in the boundaries of the Rocky Creek watershed (Segment 1602B). These four facilities treat solely domestic wastewater. Two discharge directly into the non-tidal section of Lavaca River, one discharges into Rocky Creek, and the last one discharges into Big Brushy Creek. In the tidal section of Lavaca River there are three more facilities. One discharges directly into the Lavaca River Tidal (1601), one discharges into Dry Creek (1601C), and the third discharges into a drainage ditch. Two facilities treat domestic wastewater, while the third treats wastewater from a plastics film and sheets facility.

2.7.1.2 TPDES General Wastewater Permits

In addition to the individual wastewater discharge permits listed in Table 5, 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)

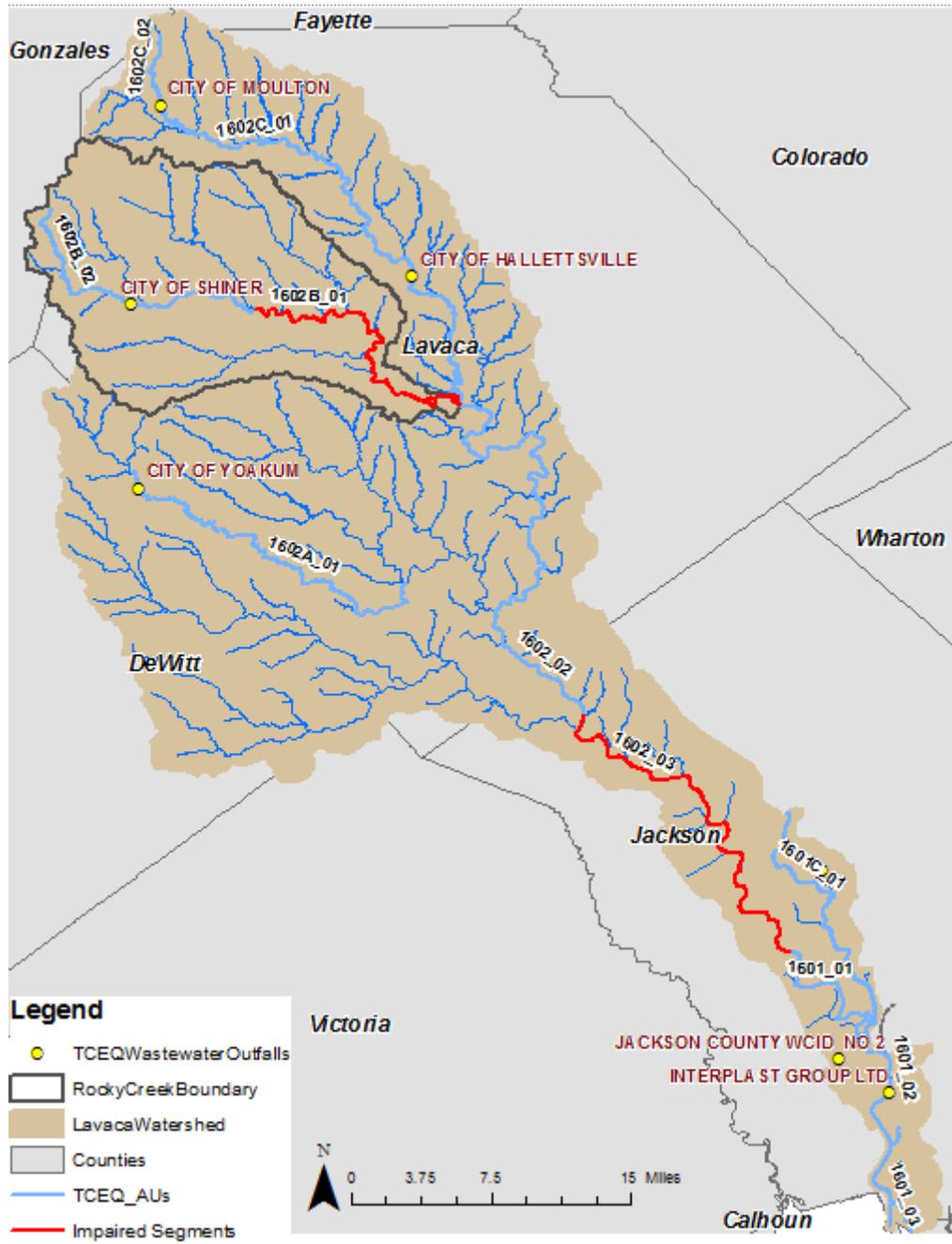


Figure 8. Lavaca River and Rocky Creek watershed showing WWTF outfalls.

Source: Permitted outfalls (TCEQ, 2012b)

A review of active general permit coverage (TCEQ, 2015b) in the Lavaca River watershed as of June 9, 2016 found three concrete production facilities covered by the general permit. These facilities are located in Jackson and Lavaca counties. The facilities are located in segment 1602 Lavaca River above tidal, 1602B – Rocky Creek, and 1601C Dry Creek. The three concrete production facilities do not have bacteria reporting or limits in their permit. All three facilities

were assumed to contain inconsequential amounts of indicator bacteria in their effluent; therefore, it was unnecessary to allocate bacteria load to these concrete production facilities.

No other active general wastewater permit facilities or operations were found. There were no facilities covered under the general permits for aquaculture, petroleum bulk stations and terminals, petroleum fuel or petroleum substances, hydrostatic test water discharges, concentrated animal feeding operations, or livestock manure compost operations.

Table 5. Permitted wastewater treatment facilities in the Lavaca River and Rocky Creek watershed.

Source: Individual TPDES Permits

TPDES Permit Number	Facility	Held By	AU	Receiving Waters	Discharge Type	Permitted Discharge (MGD)	Recent Discharge (MGD) ^a
WQ0010013001	City of Hallettsville WWTP	City of Hallettsville	1602	Lavaca River above tidal	Treated domestic wastewater	0.80	0.78
WQ0010280001	City of Shiner WWTP	City of Shiner	1602B	Rocky Creek to Lavaca River	Treated domestic wastewater	0.85	0.736
WQ0010227001	City of Moulton WWTP	City of Moulton	1602	Lavaca River above tidal	Treated domestic wastewater	0.242	0.111
WQ0010196001	Jackson County WCID NO 2 WWTP	Jackson County WCID NO 2	n/a	Drainage Ditch, unnamed tributary	Treated domestic wastewater	0.045	0.027
WQ0010463001	City of Yoakum WWTP	City of Yoakum	1602A	Big Brushy Creek	Treated domestic wastewater	0.95	0.686
WQ0003477000	Inteplast Group LTD	Inteplast Group LTD	1601	Lavaca River Tidal	Wastewater (> or = 1 MGD domestic sewage or process water including WTP discharge)	0.045	0.032
WQ0010164001	Edna WWTP	City of Edna	Tributary to 1601C	Dry Creek to Lavaca River Tidal	Wastewater (> or = 1 MGD domestic sewage or process water including WTP discharge)	1.8	0.479

^a Recorded discharge numbers are from measured discharge on March 31, 2016 at each of the sites.

2.7.1.3 TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES or NPDES regulated discharge permit and

stormwater originating from areas not under a TPDES or NPDES-regulated discharge permit. Stormwater discharges fall into two categories:

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

Phase I MS4 permits are associated with large urban areas and as such, no permits of this nature occur for the Lavaca River watershed. Discharges of stormwater from a Phase II MS4 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 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, 2015b) in the Lavaca River watershed, as of June 28, 2016, found seven active construction notice of intents and twelve stormwater MSGPs for industrial facilities. There are currently no Phase II MS4s in the watershed. Based on the low number of construction activities and stormwater MSGPs, regulated stormwater is considered to contribute minimally to the Lavaca River watershed.

2.7.1.4 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 12 Office maintains a database of SSO data reported by municipalities. This SSO data typically contains estimates of the total gallons spilled, responsible entity, and a

general location of the spill. A search of the database, based on six domestic facilities in Segment 1602, revealed that ten SSOs have been reported since January 2009 (TCEQ, 2014c).

Table 6. SSOs in the Lavaca River and Rocky Creek watershed along segments 1601 and 1602 between 2011 and 2015.

Source: TCEQ 2014c

Permit Number	Facility Name	Discharge Date	24 Hour Date	Duration hr-min	Gallons	Cause	Corrective/Preventive Actions Taken	Location of Discharge
WQ0010463001	City of Yoakum WWTP	10/4/2009	10/5/2009	unknown		I&I	None	various manholes in collection system overflowed due to I/I
WQ0010463001	City of Yoakum WWTP	4/25/2010	4/27/2010	2 hrs 18 min	3000	Grease Blockage	Contained, Vacuumed, Disinfected	Ellen May Rd
WQ0010227001	City of Moulton	10/14/2013	10/14/2013	3 hrs	1000	Line blockage (grease)	line was cleared and degreaser injected	204 E. Rose
WQ0010164001	City of Edna	11/11/2013	11/13/2013	5 hr	2000	sewer line thru the creek to include a steel casing for protection	affected area treated w/ HTH to sterilize and disinfect: No danger to humans or Env.	Corner of W. Cedar and Pumphrey
WQ0010164001	City of Edna	11/11/2013	11/13/2013	20 minutes	200	massive flow of rags coming through the bar screen	increase bar screen cleaning, cleaned area and treated w/ HTH.	900 Parkmoor Blvd

Permit Number	Facility Name	Discharge Date	24 Hour Date	Duration hr-min	Gallons	Cause	Corrective/Preventive Actions Taken	Location of Discharge
WQ0010463001	City of Yoakum WWTP	12/5/2014	12/5/2014	35 min	3000	Back up in collection system (trapped piece of wood)	Wastewater was pumped back into the collection system and area was treated with granular chlorine.	1510 West Grand
WQ0010227001	City of Moulton	3/12/2015	3/17/2015	Unknown		40% bacteriological permit exceedance	increase sewage wasting schedule	outfall
WQ0010164001	City of Edna	6/16/2015	6/18/2015	12 hours	93,600	I&I due to 9.5" of rain from Tropical Storm Bill	Smoke testing collection system, conducting repairs, replacing customer cleanouts	Throughout the city-16 manholes overflowing
WQ0010227001	City of Moulton	12/3/2015	12/3/2015	1 hour	250 gallons	Lift station malfunctioned (breaker tripped), causing lift station to overflow	Debris was picked up and area will be disinfected with HTH	Lift station on corner of Longhorn and Lancaster

Permit Number	Facility Name	Discharge Date	24 Hour Date	Duration hr-min	Gallons	Cause	Corrective/Preventive Actions Taken	Location of Discharge
WQ0010227001	City of Moulton	12/3/2015	12/3/2015	24 minutes	250 gallons	breakers in lift station pump tripped causing the discharge	disinfected affected area/checked all electric connections for malfunctioning parts	lift station located at the intersection of Longhorn and Lancaster streets

2.7.1.5 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 MS4s 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:

Examples of direct illicit discharges:

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

Examples of indirect illicit discharges:

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

2.7.1.5 Review of Compliance Information on Permitted Sources

A review of the EPA Enforcement & Compliance History Online (ECHO) database (USEPA, 2014) between January 1, 2013 and March 31, 2016 revealed several non-compliance issues within three of the seven WWTPs. As of March 2016 the City of Moulton had experienced one quarter out of a 12 quarter – 3-year period of non-compliance due to high levels of bacteria levels. The City of Hallettsville experienced four quarters out of the 12 quarter period of non-compliance due to high bacteria levels. City of Edna had 11 quarters of the 12 quarter cycle be in non-compliance due to high bacteria levels. None of the bacteria effluent violations were reported as “Significant Non-compliance” effluent violations.

The City of Shiner, City of Yoakum, Jackson County WCID No. 2 WCID, and Inteplast Group LTD had no compliance issues within the past three years due to bacteria loads within the same time period (January 1, 2013 to March 31, 2016).

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.

Table 7. Bacteria monitoring requirements and compliance status for WWTFs in the Lavaca River and Rocky Creek watersheds.

Data available through the EPA Enforcement & Compliance History Online (ECHO) database (USEPA, 2014), assessed through the Discharge Monitoring Report (DMR) Pollutant Loading Tool. “% Monthly Exceedances” were calculated based on reported monthly records for bacteria.

TPDES Permit No.	Facility	Held By	Bacteria Monitoring Requirements	Min. Self-Monitoring Requirement Frequency	Daily Average (Geo Mean) Limitation	Single Grab (Daily Max) Limitation	% Monthly Exceedances Daily Avg	% Monthly Exceedances Single Grab
TX005 3287	City of Moulton WWTP	City of Moulton	<i>E. coli</i>	One/month	126	399	3.57% ^a	3.57% ^a
TX002 6042	City of Shiner WWTP	City of Shiner	<i>E. coli</i>	One/month	126	399	0.00% ^b	0.00% ^b
TX002 5232	City of Hallettsville	City of Hallettsville	<i>E. coli</i>	Two/month	126	399	14.29% ^c	19.05% ^c
TX002 7669	Jackson County WCID NO 2 WWTP	Jackson County WCID NO 2	<i>E. coli</i>	Quarterly	126	399	0.00% ^d	0.00% ^d
TX002 6034	City of Yoakum WWTP	City of Yoakum	<i>E. coli</i>	One/month	126	399	0.00% ^e	0.00% ^e
TX010 8405	Inteplast Group LTD	Inteplast Group LTD	Enterococci	One/month	35	104	0.00% ^f	0.00% ^f
TX002 4252	Edna WWTP	City of Edna	<i>E. coli</i>	One/month	126	399	2.70% ^g	69.44% ^g

^a 28 monthly *E. coli* records (1/2014 – 4/2016)

^b 19 monthly *E. coli* records (11/2014 – 5/2016)

^c 21 monthly *E. coli* records (9/2014 – 5/2016)

^d 6 monthly *E. coli* records (1/2015 – 4/2016)

^e 20 monthly *E. coli* records (10/2014 - 6/2016)

^f 19 monthly Enterococci records (10/2014 – 4/2016)

^g 37 monthly *E. coli* records (4/2013 – 4/2016)

2.7.2.1 Wildlife and Unmanaged Animal Contributions

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

Unfortunately, quantitative estimates of wildlife are rare, inexact, and often limited to discrete taxa groups or geographical areas of interest so that even county-wide approximations of wildlife numbers are difficult or impossible to acquire. However, population estimates for feral hogs and deer, are readily available for the Lavaca watershed.

For feral hogs, estimates were generated by looking at feral hog estimates in surrounding watershed plans and consulting with local Texas Parks and Wildlife Biologists. The average hog

density generated was 1 hog/33 ac. The average hog density (1 hog/ 33 ac) was multiplied by the hog-habitat area in the Lavaca River watershed (541,650 acres). Habitat deemed suitable for hogs followed as closely as possible to the land use selections of the Institute of Renewable Natural Resources 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 16,414 feral hogs in the Lavaca River and Rocky Creek watershed.

For deer, the Texas Parks and Wildlife Department (TPWD) published data showing deer population-density estimates by Resource Management Unit (RMU) and Ecoregion in the state (TPWD, 2012). The Lavaca River watershed incorporates areas of RMU 12, for which the average deer density over the period 2005-2011 was calculated to be 1 deer/ 19 ac. Applying this value to the area of the entire watershed returns an estimated 30,645 deer within the entire study area (Lavaca River and Rocky Creek watershed).

2.7.2.2 Non-Permitted Agricultural Activities and Domesticated Animals

The number of livestock that are found within the Lavaca River watershed was estimated from county level data obtained from the 2012 Census of Agriculture (USDA NASS, 2014b). The county level data were refined to better reflect actual numbers within the impaired AU watershed. The refinement was performed by determining the total area of each county as well as the subject watershed that was designated as either “Herbaceous/ Grassland” or “Hay/ Pasture” in the 2011 National Land Cover Dataset (USGS, 2014). A ratio was then developed by dividing the selected land use area of the watershed area within a county by the total area of the county. This ratio was then applied to the county level data.

Activities, such as livestock grazing close to water bodies and farmers’ use of manure as fertilizer, can contribute fecal indicator bacteria to nearby water bodies. The livestock numbers in Table 8 are provided to demonstrate that livestock are a potential source of bacteria in the Lavaca River watershed. The Lavaca River watershed livestock estimates include the entire watershed including the Rocky Creek watershed, while the Rocky Creek livestock estimates only account for livestock that are within the Rocky Creek boundaries. These numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

Table 8. Estimated distributed livestock populations within the Lavaca River and Rocky Creek watershed, based on proportional area.

Source: (USDA NASS, 2014b).

Watershed	Segment	Cattle and Calves	Goats	Feral Hogs	Horses and Ponies	Deer	Poultry	Sheep and Lambs
Lavaca River	Above Tidal & Tidal (1602 & 1601)	72,182	937	16,414	803	30,645	494,844	632
Rocky Creek	1602 B	16,727	195	3,215	209	5,984	279,673	146

2.7.2.3 On-site Sewage Facilities

Private residential on-site sewage facilities (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. Lavaca River and Rocky Creek are located within the east-central Texas area which has a reported failure rate of about 12 percent, providing insights into expected failure rates for the area.

Estimates of the number of OSSFs in the Lavaca River watershed were based on 911 phone line data. For the area of the Lavaca River watershed, OSSFs were estimated to be households that were outside of either a Certificate of Convenience and Necessity (CCN) sewer area or a city boundary. The total estimate of the whole watershed, as well as specifically for the Rocky Creek watershed is shown in Table 9, and the OSSF density is shown in Figure 9.

Table 9. OSSF estimate for the Lavaca River and Rocky Creek watershed.

Watershed	Segment	Estimated OSSFs
Lavaca River (incl. Rocky Creek)	1601 & 1602	5,246
Rocky Creek	1602B	1,507

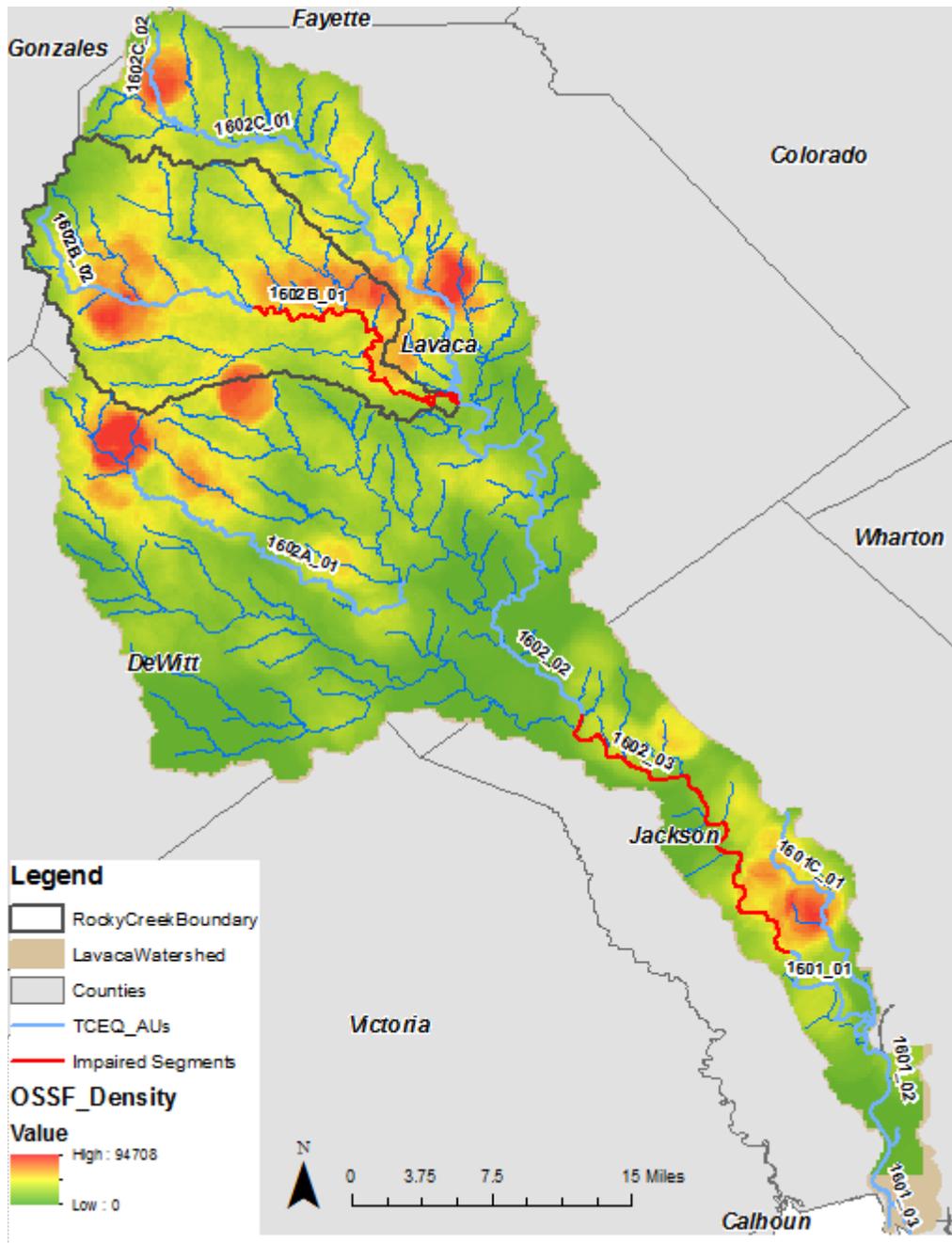


Figure 9. OSSF densities within the Lavaca River and Rocky Creek watershed.

2.7.2.4 Domestic Pets

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 10 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 (American Veterinary Medical Association), 2012). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the watershed is unknown.

Table 10. Estimated Households and Pet Populations for the Lavaca River and Rocky Creek watershed.

Watershed	Segment	Est. Number of Households	Est. Dog Population	Est. Cat Population
Lavaca River (incl. Rocky Creek)	Above Tidal (1602) & Tidal (1601)	14,713	8,592	9,387
Rocky Creek	1602B	3,149	1,839	2,009

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 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 replication is less well understood. Both processes (replication and die-off) are in-stream processes and are not considered in the bacteria source loading estimates for the TMDL watershed.

SECTION 3 DEVELOPMENT OF BACTERIA TOOLS

An essential component of a TMDL is to establish a linkage, or relationship, between pollutant sources and the water criteria. It is possible through this linkage to determine the capacity of the water body to assimilate bacteria loadings while still supporting its designated use. This section describes development of the tools used to provide this linkage and to provide the data for computing the pollutant load allocations of the project water bodies.

3.1 Model Selection

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

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

processes of the prototype system and reasonable predictive capabilities to evaluate alternative allocations of pollutant load sources.

The LDC method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, the 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, which 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 (TWRI, 2007). The LDC method provides a means to estimate the difference in bacteria loads and relevant criterion, and can give indications of broad sources of the bacteria, i.e., point source and nonpoint source.

3.1.1 Situational Limitations of Mechanistic Modeling

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

While admittedly the streamflow processes requiring simulation are complex, these processes are generally better understood and more readily simulated than the bacterial processes. Nonetheless, mechanistic bacteria modeling has progressed significantly over the last several decades beginning in the late 1960s to early 1970s, as increasing computer resources made such endeavors possible. Regrettably for the application of mechanistic bacteria models, while the numerical equations to represent many pertinent processes exist and are incorporated in readily available models, these processes are appreciably more watershed specific than hydrologic processes. As one simple example, failing on-site treatment systems, such as septic systems,

rarely makes measurable differences to streamflow, but can dramatically impact fecal bacteria concentrations present in the same streamflow. In the vast majority of circumstances, and the Lavaca River watershed is no exception; only very limited watershed-specific information is available to define many of the physical and biological processes that affect bacteria concentrations and loadings. Consequentially, the operator of the mechanistic model must specify, in many circumstances, numerous input parameters governing bacteria processes for which actual numeric values may not be known within a reasonable range of certainty.

3.1.2 Lavaca River Data Resources

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

Hydrologic data in the form of daily streamflow records were available for the AU 1602 portion of Lavaca River watershed. Streamflow records are collected and made readily available by the U.S. Geological Survey (USGS), which operates one streamflow gage on Lavaca River (Table 1; USGS, 2015). USGS streamflow gage 08164000 is co-located with SWQM Station 12524, within segment 1602. This gage serves as the primary source for streamflow records used in this document. Rocky Creek did not have a USGS gage and flow estimates were gathered from manual flow measurements.

Table 11. Basic information on the USGS streamflow gage in the project area.

Source: (USGS, 2015)

Gage No.	Site Description	Assessment Unit (AU)	Daily Streamflow Record (beginning & end date)
08164000	Lavaca River near Edna, TX	1602	August 1938 – present
n/a	Rocky Creek	1602B	n/a

Table 12. Summary of historical bacteria data sets.

Source: (TCEQ, 2014c)

Water Body	Assessment Unit (AU)	Station	Station Location	Indicator Bacteria	No. of Bacteria Samples	Data Date Range
Lavaca River above Tidal	1602_03	12524	Lavaca River at US 59	<i>E. coli</i>	55	10/2001-4/2015
		12525	Lavaca River at SH 111	<i>E. coli</i>	55	10/2001-4/2015
Rocky Creek	1602B_01	18190	2.9 km upstream of CR 364 NW of Shiner	<i>E. coli</i>	35	3/2004-3/2015

3.1.3 Allocation Tool Selection

Based on good availability of historical daily streamflow records, discharge information for large municipal WWTFs, and ambient *E. coli* data and deficiencies in data to describe bacterial landscape and in-stream processes, the decision was made to use the LDC method as opposed to a mechanistic watershed loading and hydrologic/water quality model.

3.2 Methodology for Flow Duration & Load Duration Curve Development

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

Step 1: Determine the hydrologic period of record to be used in developing the flow duration curves.

Step 2: Determine desired stream locations for which flow and load duration curves will be developed (The stream locations will be at monitoring stations along the impaired AUs for which adequate *E. coli* data are available.).

Step 3: Develop daily streamflow records at desired stream locations using the daily gauged streamflow records and Surface Water Quality Monitoring Tool data.

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 streamflow duration curve.

Step 6: Superpose historical bacteria data, if such data exist at the location, on the allowable bacteria LDCs.

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

3.2.1 Step 1: Determine Hydrologic Period

Daily hydrologic (streamflow) records were available for multiple USGS gauge locations in the TMDL watersheds. Optimally the period of record to develop flow duration curves should include as much data as possible in order to capture extremes of streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of conditions experienced when the *E. coli* data were collected. A 14-year period of record from October 2001 through April 2015 was selected for Lavaca, and an 11-year period from March 2004 through March 2015 for Rocky Creek. This 14 and 11-year period of records were selected in an effort to capture a reasonable range of extremes in high and low streamflows and represents a period in which most of the *E. coli* data were collected.

3.2.2 Step 2: Determine Desired Stream Locations

Sampling stations which have historic *E. coli* data collection determined the stream locations for which flow and bacteria load duration curves would be developed. This was determined by downloading station data from the Surface Water Quality Monitoring Web Reporting Tool (<http://www80.tceq.texas.gov/SwqmisPublic/public/default.html>).

3.2.3 Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and station locations were determined, the next step was to develop the daily streamflow record for each station. The daily streamflow records were developed from extant USGS records modified by the imposition of certain rules necessitated by hydrologic complicating factors. The historical data for stream flow at Rocky Creek and Lavaca River were extensive; however, not all records could be used. Only streamflow data with an associated *E. coli* measurement were used to develop the LDC.

3.2.4 Step 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 an 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 an 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 cfu/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 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.

3.2.5 Flow Duration Curves for Sampling Stations within TMDL Watersheds

FDCs were developed for monitoring stations within the Lavaca watershed that were deemed impaired. FDCs were developed by using the period of record described in earlier sections. Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100% occur during low flow or drought conditions while values approaching 0% occur during periods of high flow or flood conditions. This graphical procedure provides information on basic hydrological characteristics in the stream based upon flows observed within specific reaches.

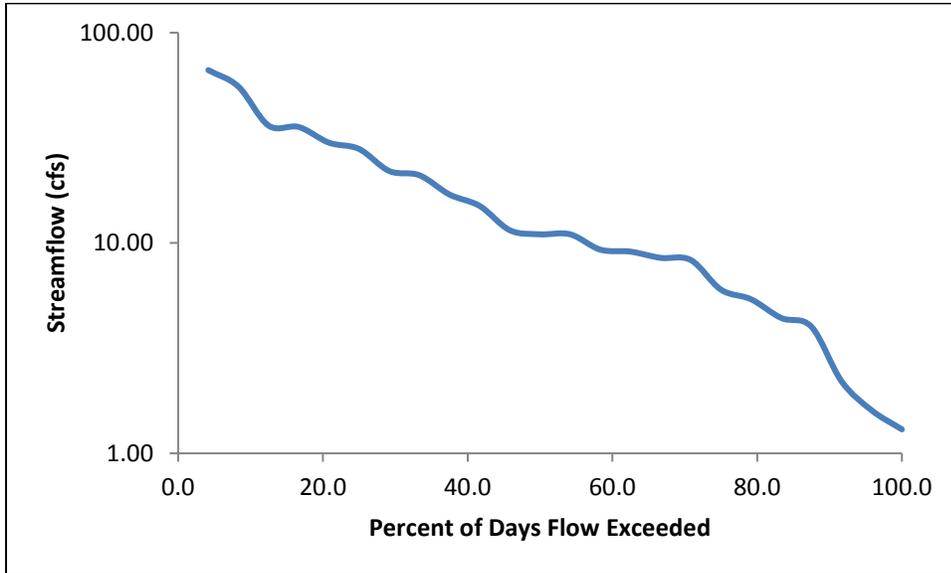


Figure 10: Flow Duration Curve at monitoring station 18190 on Rocky Creek (1602B_01).

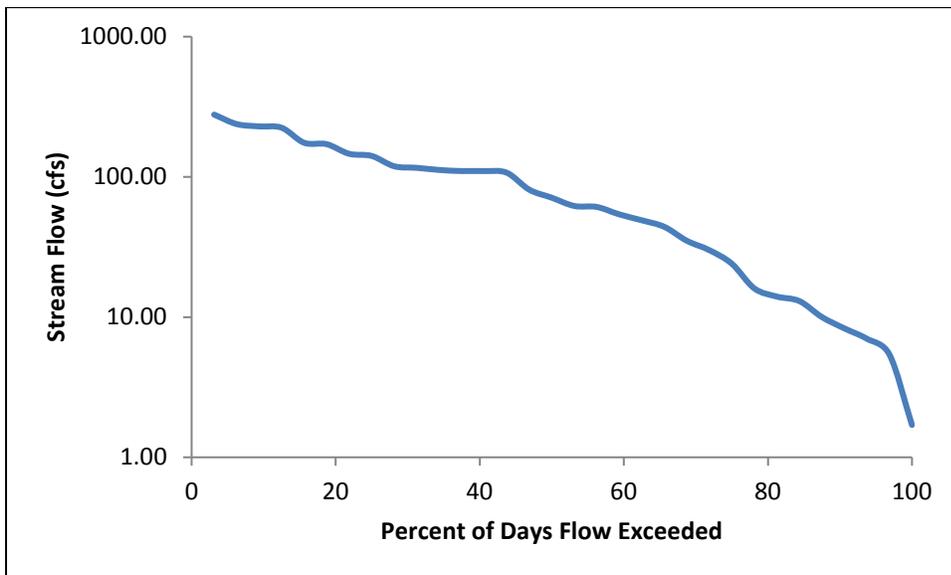


Figure 11: Flow Duration Curve at monitoring station 12524 on the Lavaca River (1602_03).

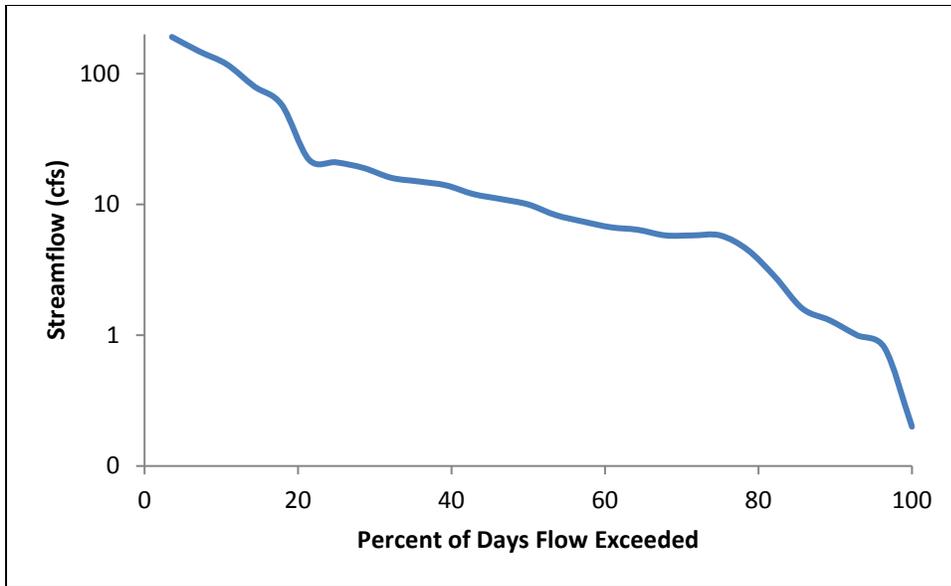


Figure 12: Flow Duration Curve at monitoring station 12525 on the Lavaca River (1602_03).

3.3 Load Duration Curves for Monitoring Stations within the TMDL Watersheds

The shape of each LDC is identical to that of the FDC for the same station, because the data in the FDCs have all been multiplied by the same conversion factor. The label on the y-axis simply changes from Flow (cfs) to *E. coli* (cfu / day), and the label on the x-axis changes from “percent of days flow exceeded” to “percent of days load exceeded.”

A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. A commonly used set of regimes that is provided in Cleland (2003) is based on the following five intervals along the x-axis of the FDCs and LDCs: (1) 0-10% (high flows); (2) 10-40% (moist conditions); (3) 40-60% (mid-range flows); (4) 60-90% (dry conditions); and (5) 90-100% (low flows) (Table 12).

Table 13: Flow Regime Classifications

Flow Regime Classification	Flow Exceedance Percentile
High Flow	0-10%
Moist Conditions	10-40%
Mid-Range Conditions	40- 60%
Dry Conditions	60-90%
Low Flows	90-100%

The LDCs developed for the Lavaca and Rocky Creek indicated that geomean *E. coli* loadings exceeded allowable loadings under all 5 flow regimes. Rocky Creek appeared to have the most loadings above the allowable amount (Figure 16); however, Rocky Creek had the least amount of usable data. This could be a reason for so many data points above the TMDL line. Station 12524 at Lavaca River, had a higher proportion of exceedances in mid-range and dry conditions (Figure

15). Station 12525 at Lavaca River had a higher proportion of exceedances under high flow, moist, and mid-range conditions (Figure 16).

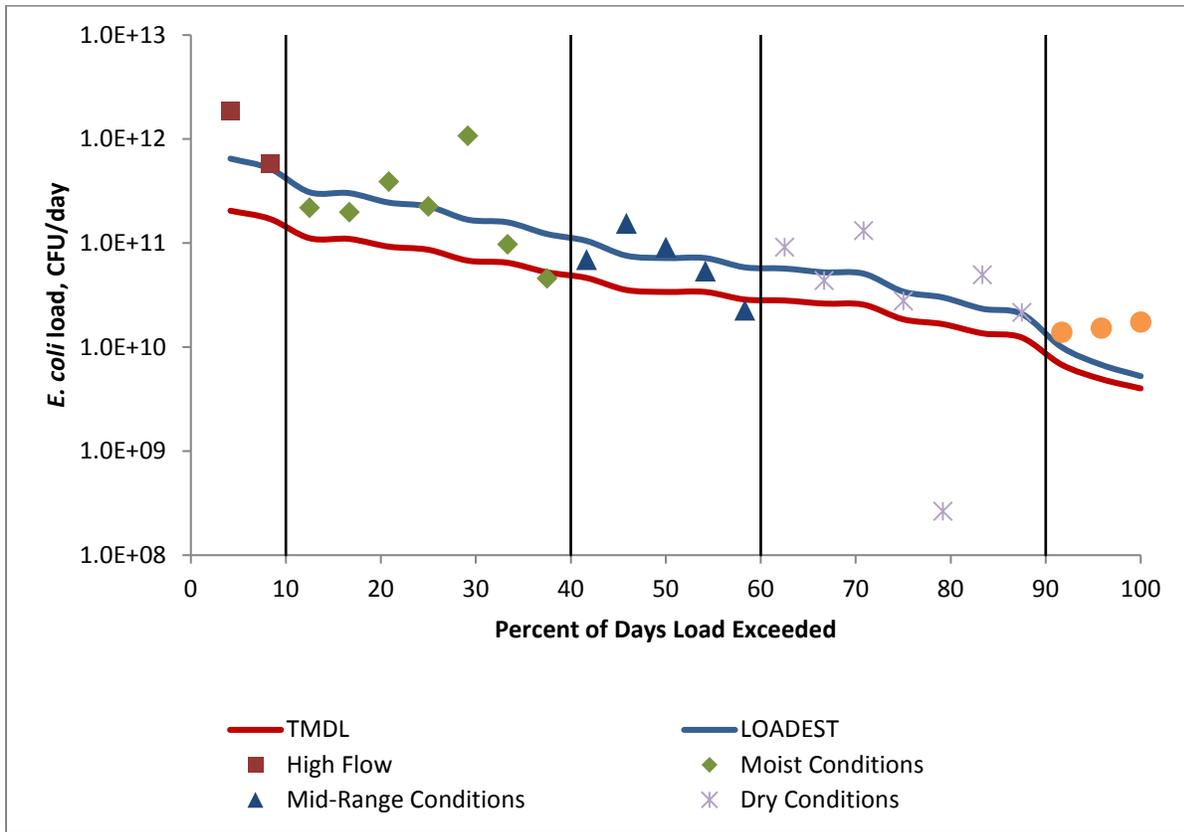


Figure 13: Load Duration Curve for station 18190 for Rocky Creek from 2005-2008.

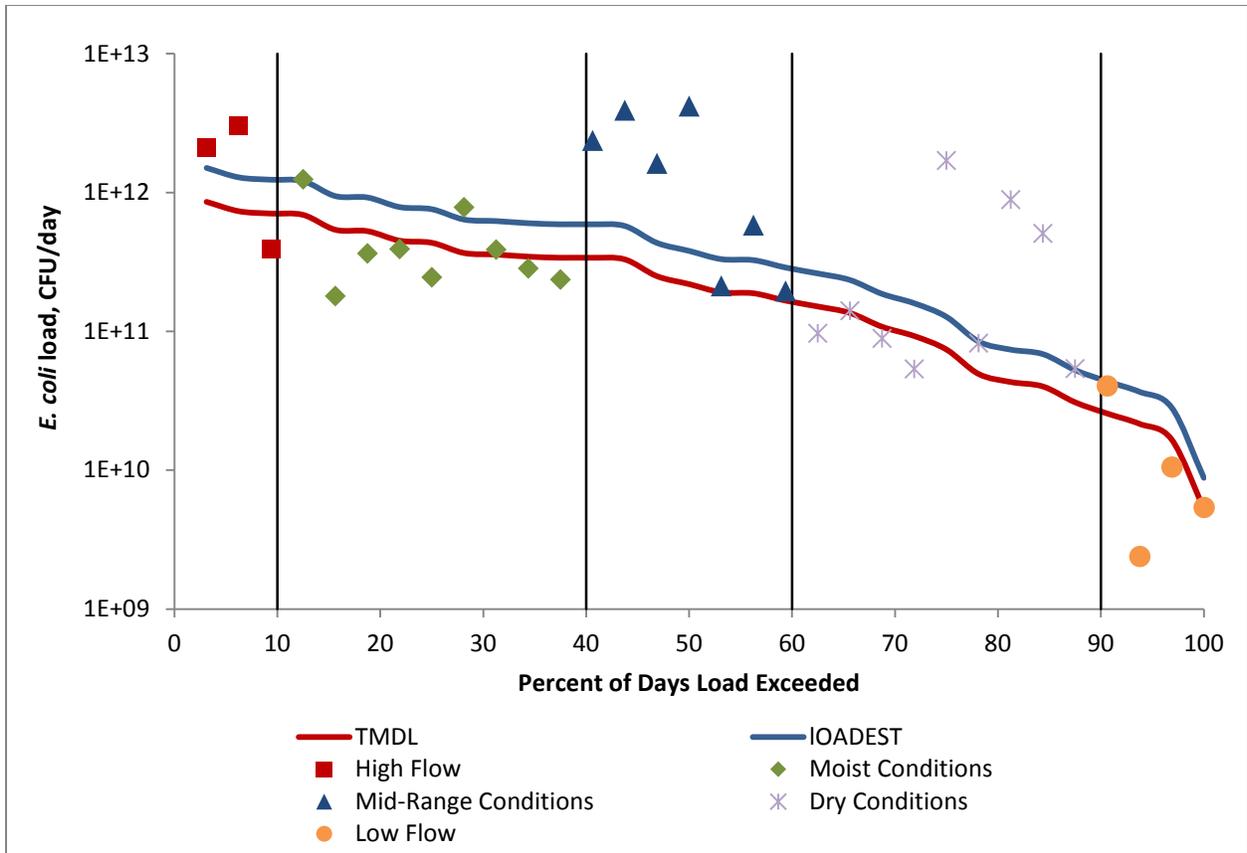


Figure 14: Load Duration Curve for station 12524 at Lavaca River (1602_03) from 2003 to 2015.

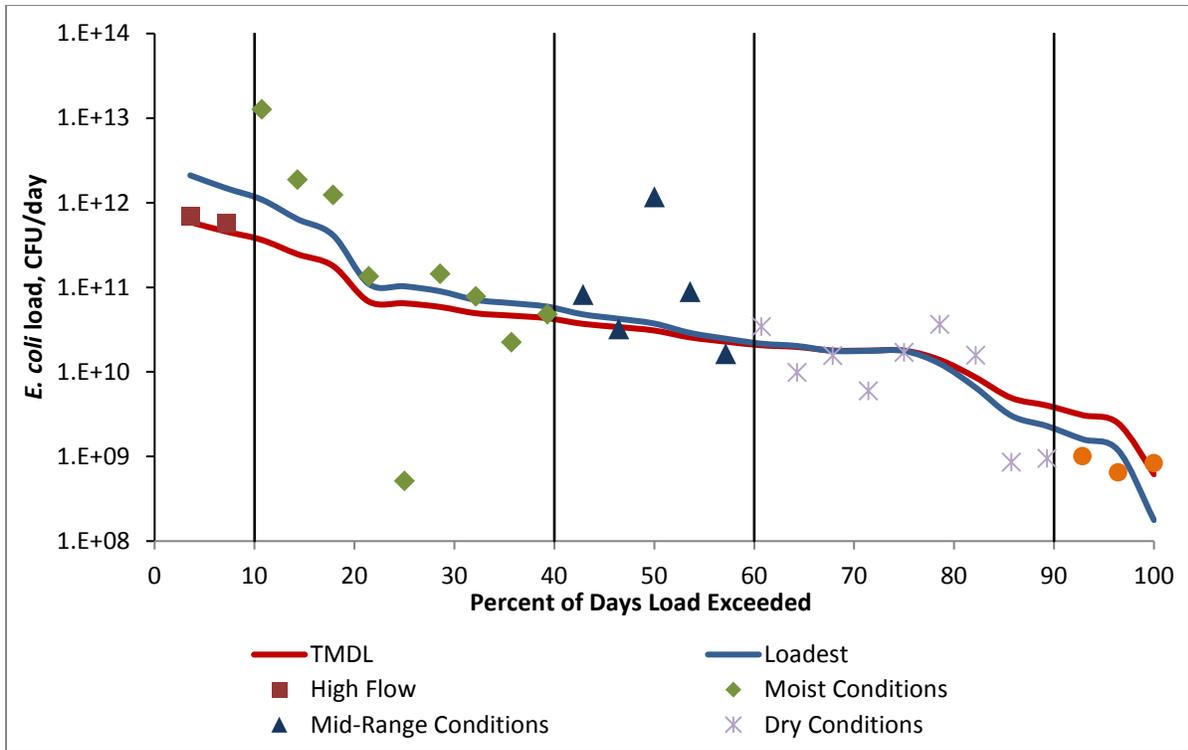


Figure 15: Load Duration Curve for station 12525 at Lavaca River (1602_03) from 2008 to 2015.

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