Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria for Walnut Creek

Assessment Unit: 1008I_01

Walnut Creek at sampling station 20462

Technical Support Document for One Total Maximum Daily Load for Indicator Bacteria for Walnut Creek

Assessment Unit: 1008I_01

Prepared for
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087

Prepared by
Todd Adams
Jimmy Millican
Texas Institute for Applied Environmental Research
Tarleton State University
Stephenville, Texas

PR2001

August 2020

Acknowledgements

Financial support for this study was provided by the Texas Commission on Environmental Quality (TCEQ). The lead agency for this study was the TCEQ. The administrative oversight, technical input, and review of this document by the TCEQ Project Manager, Mr. Jason Leifester, were important to the completion of this project and the development of this document.

Table of Contents

List of Figures

List of Tables

Abbreviations

AU	assessment unit
cfs	cubic feet per second
cfu	colony forming units
DAR	drainage area ratio
DMU	Deer Management Unit
DSLP	days since last precipitation
ECHO	Enforcement and Compliance History Online
E. coli	*Escherichia coli*
FDA_{SWP}	fractional drainage area stormwater permit
FDC	flow duration curve
FIB	fecal indicator bacteria
FG	future growth
GIS	geographic information system
I&I	inflow and infiltration
IRNR	Institute of Renewable Natural Resources
ISD	independent school district
LA	load allocation
LDC	load duration curve
MCM	minimum control measure
MGD	million gallons per day
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
MSGP	multi-sector general permit
MUD	Municipal Utility District
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
OSSF	on-site sewage facility
PCR1	primary contact recreation 1
SSO	sanitary sewer overflow
SWMP	stormwater management program
SWQM	surface water quality monitoring
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
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

USCB	United States Census Bureau
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	wasteload allocation
WLA_{SW}	wasteload allocation stormwater
WLA_{WWTF}	wasteload allocation wastewater treatment facilities
WWTF	wastewater treatment facility

SECTION 1
INTRODUCTION

1.1 Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a total maximum daily load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The 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 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 water quality uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

The TCEQ identified the bacteria impairment within Walnut Creek in the *2020 Texas Integrated Report of Surface Water Quality*, which in this document will be referred to as the 2020 Integrated Report.

This document will consider a bacteria impairment in one water body consisting of a single assessment unit (AU) as shown below:

- Walnut Creek AU 1008I_01.

Because the impaired water body is composed of only one AU that encompasses its entire length, the AU descriptor (_01) is often unnecessarily cumbersome. From this point forward, the impaired water body may be referred to as Walnut Creek or as AU 1008I_01. The phrase "TMDL watershed" will be used when referring to only the area of the impaired AU addressed in this report.

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 that are monitored in an effort to assess the quality of available water for specific uses. The TCEQ is charged with monitoring and assessing water bodies based on these water quality standards and publishes the Integrated Report list biennially.

The *Texas Surface Water Quality Standards* (TCEQ, 2018) 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 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; and*
- *general use.*

Fecal indicator bacteria (FIB) are used to assess the risk of illness during contact recreation (*e.g.*, swimming) from ingestion of water. FIB 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 because 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 Texas as the FIB in freshwater. *E. coli* is typically expressed as colony forming units (cfu).

On February 7, 2018, the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ, 2018) and on May 19, 2020, the United States Environmental Protection Agency (USEPA) approved the categorical levels of recreational use and their associated criteria that were first submitted to the USEPA in the 2014 Texas Water Quality Standards (TCEQ, 2014); thereby confirming the 2018 levels of recreational use and criteria. Recreational use consists of five categories:

- Primary contact recreation 1 (PCR1) is associated 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 milliliter (mL) and an additional single sample criterion of 399 cfu per 100 mL;
- Primary contact recreation 2 is similar to PCR1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 206 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 is similar to secondary contact recreation 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 cfu per 100 mL; and
- Noncontact recreation is associated with activities that do not involve 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 cfu per 100 mL (TCEQ, 2018).

Walnut Creek is presumed for PCR1 and has the associated *E. coli* geometric mean criterion of 126 cfu per 100 mL and single sample criterion of 399 cfu per 100 mL.

1.3 Report Purpose and Organization

The Walnut Creek TMDL project was initiated through a contract between the TCEQ and Texas Institute for Applied Environmental Research. 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 watershed; 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 TMDL for the impaired watershed of Walnut Creek. 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 a load duration curve (LDC), and
- application of the LDC approach for the pollutant load allocation process.

Whenever it was feasible, the data development and computations for developing the LDC and pollutant load allocation were performed in a manner to remain consistent with the previously completed *Addendum One*: *Six Additional Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2013), *Addendum Two: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch* (TCEQ, 2019), and the original TMDL *Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2011).

SECTION 2
HISTORICAL DATA REVIEW AND WATERSHED PROPERTIES

2.1 Description of Study Area

The Walnut Creek watershed is located in portions of Grimes, Waller, and Montgomery counties west of Magnolia, Texas (Figure 1). Walnut Creek has a drainage area of 76.5 square miles (48,987 acres). Walnut Creek (1008I) is a tributary of Spring Creek (1008). Walnut Creek is approximately 25.5 miles long and contains only one AU (1008I_01).

Walnut Creek is an unclassified, perennial freshwater stream that eventually feeds into Lake Houston. There are three non-impaired, unclassified streams with TCEQ AU designations (Arnold Branch AU 1008K_01, Mink Branch AU 1008L_01, and Sulphur Branch AU 1008M_01) within the Walnut Creek watershed. The watershed is predominantly rural with four cities (Magnolia, Stagecoach, Pinehurst, and Todd Mission) located at least partially in the watershed (Figure 1). Walnut Creek was considered a fully supporting contributing watershed in previous TMDL efforts within the Lake Houston watershed (Figure 2; TCEQ, 2011 and 2013). This study incorporates a watershed approach where the drainage area of the stream is considered.

The 2020 Integrated Report (TCEQ, 2020a) provides the following water body and AU descriptions for Walnut Creek:

- 1008I (Walnut Creek; AU 1008I_01) – From the Spring Creek confluence to a point 41.1 km (25.5 mi) upstream

Using a watershed-based approach, the entire watershed of Walnut Creek will be considered in this report.

2.2 Watershed Climate and Hydrology

The Walnut Creek watershed is located within the Lake Houston watershed of the San Jacinto River Basin.

The Walnut Creek watershed is within the Upper Coast and East Texas climatic divisions categorized as subtropical humid (Larkin & Bomar, 1983). The Gulf of Mexico is the principal source of moisture that drives precipitation in the region. For the 15-year period from 2005-2019 weather data were obtained from the National Climatic Data Center for the Conroe North Houston Regional Airport (NOAA, 2020). Data from this 15-year period indicates that the average high temperatures typically peak in August (95.0 °F). During winter, the average low temperature generally reaches a minimum of 38.4 °F in January (Figure 3). Annual rainfall averages 46.0 inches. The wettest month was October (5.2 inches), while February (2.9 inches) was the driest month, with rainfall occurring throughout the year.

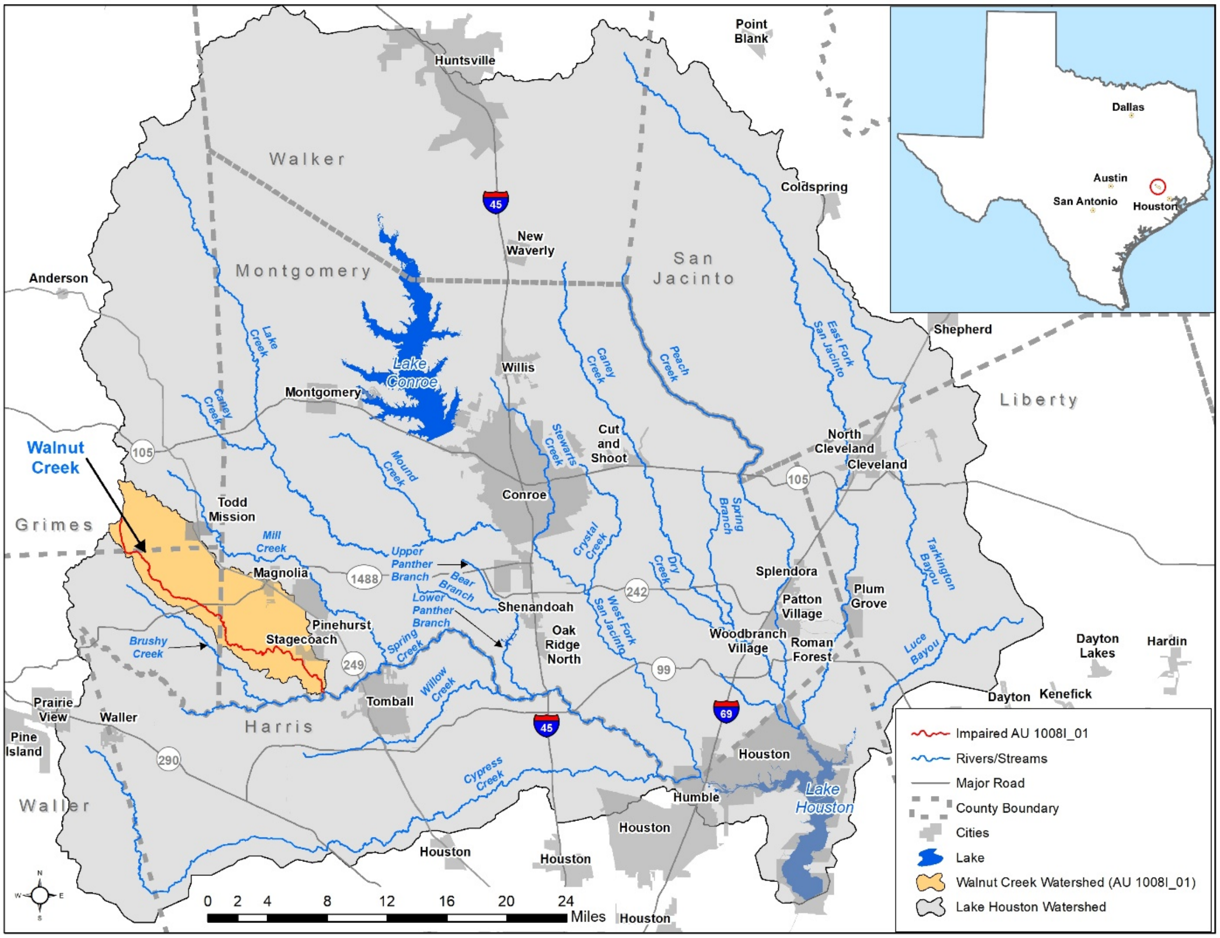

Figure 1. **Overview map showing the total contributing drainage area for the Walnut Creek watershed and the drainage areas for the existing TMDLs for the Lake Houston watershed**

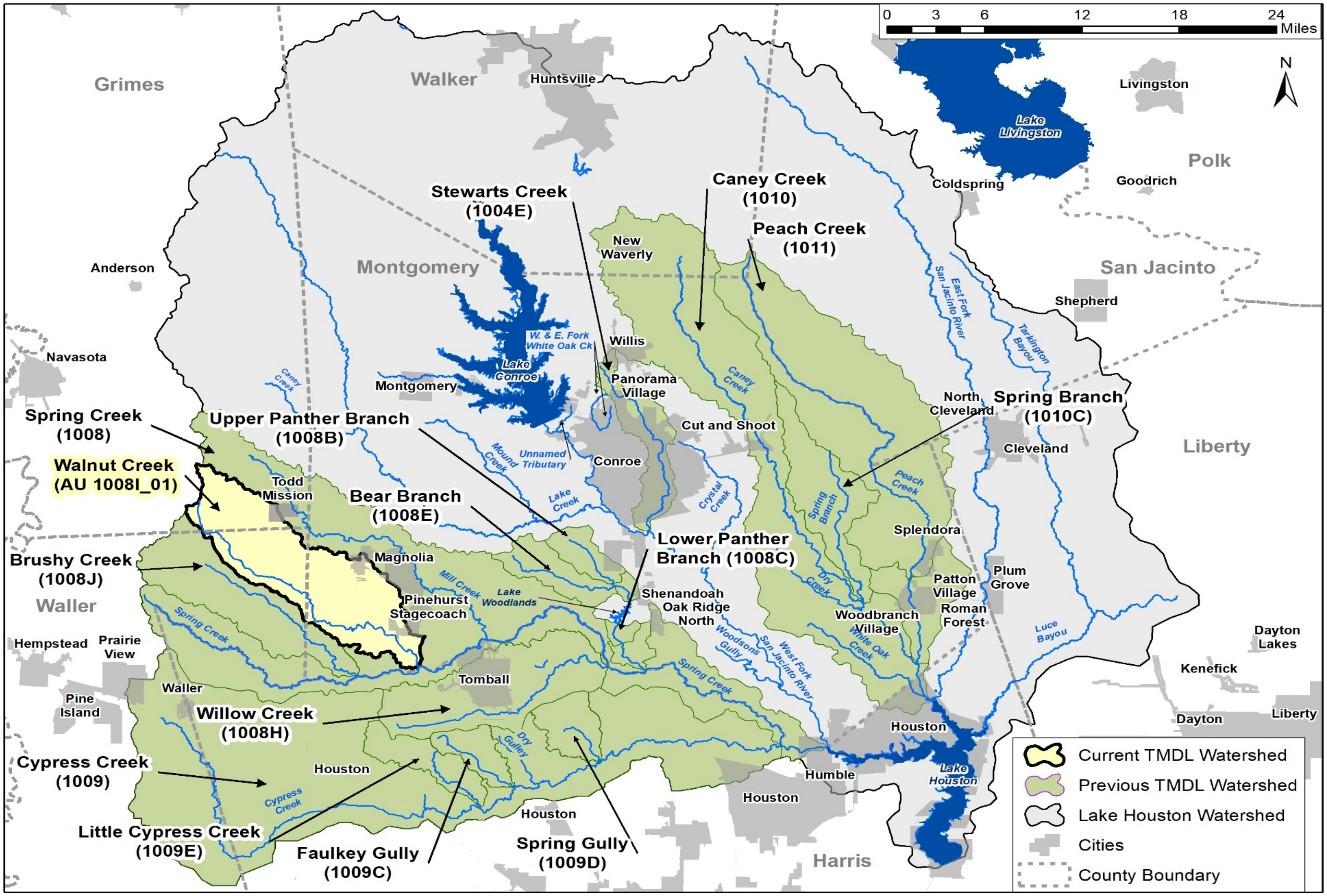

Figure 2. Map showing the previous TMDL watersheds and the current Walnut Creek watershed considered in this addendum

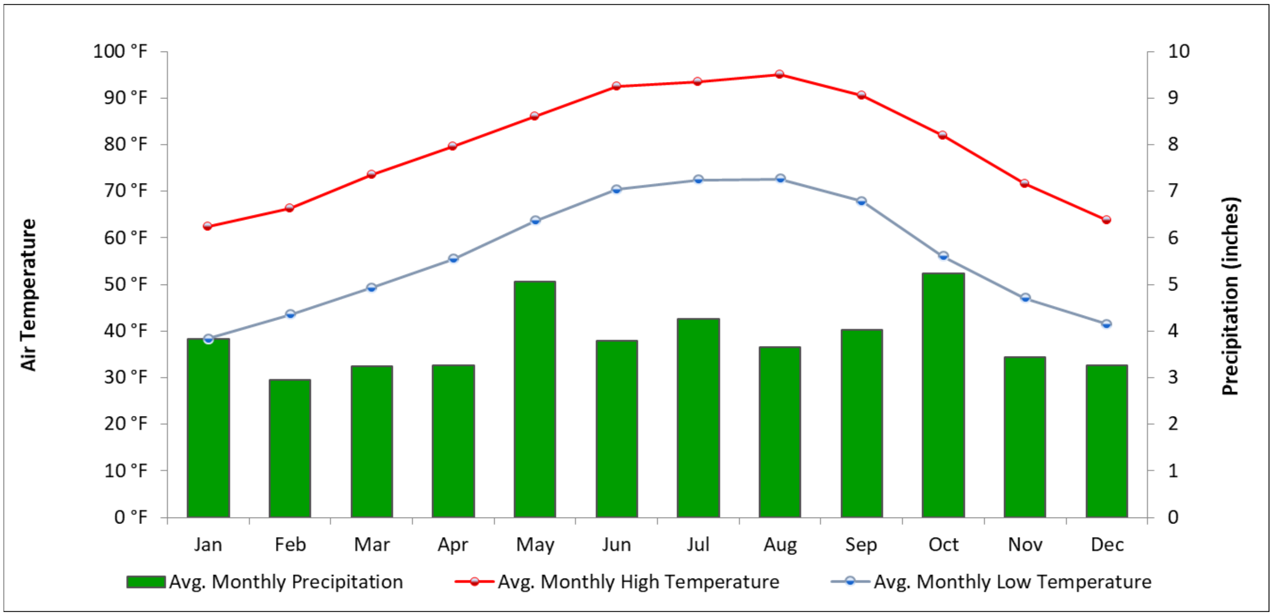

Figure 3. Average minimum and maximum air temperature and total precipitation by month from Jan 2005–Dec 2019 for Conroe North Houston Regional Airport

2.3 Watershed Population and Population Projections

As depicted in Figure 1, the Walnut Creek watershed is geographically located within portions of Grimes, Montgomery, and Waller counties and includes portions of three municipal boundaries. The rural nature of the watershed is evident in that the predominant current population densities found throughout the watershed is zero to one person per acre (Figure 4). According to the 2010 United States Census Bureau (USCB) data (USCB, 2010), the Walnut Creek watershed had an estimated population of 20,748 people in 2010.

Population projections from 2020 – 2070 were developed by utilizing data from the 2016 Texas Water Development Board (TWDB) Regional Water Plan (TWDB, 2015). The 2010 and projected 2020 through 2070 populations were allocated based on proportion of the area within the TMDL watershed. According to the growth projections, a population increase of 198.0% is expected in the Walnut Creek watershed between 2020 and 2070. Table 1 provides a summary of the 2010 population and projected 2020 through 2070 populations for the Walnut Creek watershed.

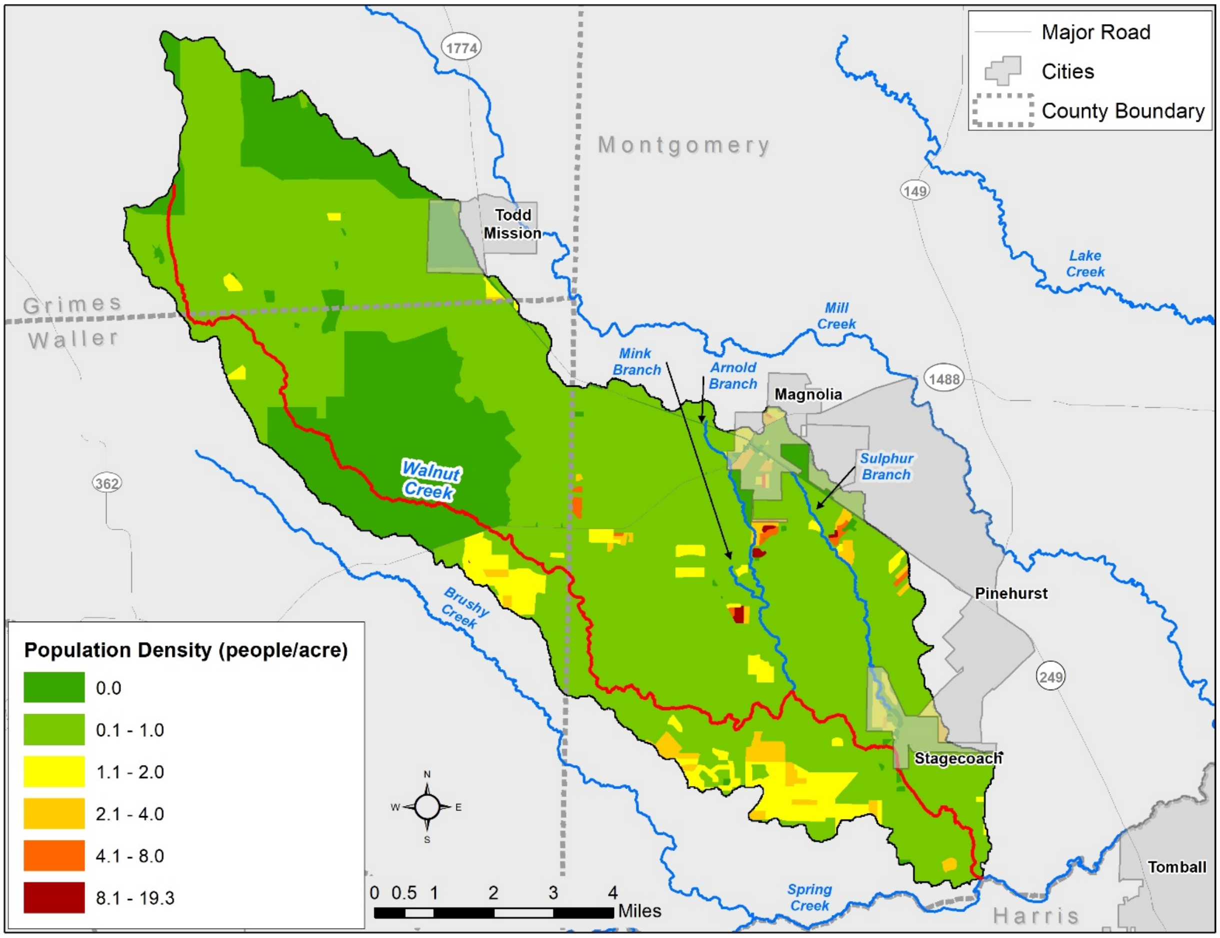

Figure 4. Population density for the Walnut Creek watershed based on the 2010 U.S. Census blocks

Table 1. 2010 Population and Population Projections for the Walnut Creek watershed

Location	2010 U. S. Census	2020 Population Projection	2030 Population Projection	2040 Population Projection	2050 Population Projection	2060 Population Projection	2070 Population Projection	Projected Population Increase (2020-2070)	Percent Change (2020-2070)
Walnut Creek Watershed	20,748	24,666	31,556	39,338	48,581	59,945	73,499	48,833	198.0%

2.4 Review of Routine Monitoring Data

2.4.1 Analysis of Bacteria Data

Environmental monitoring within the Walnut Creek watershed has occurred at TCEQ surface water quality monitoring (SWQM) station 20462 (Figure 5). *E. coli* data collected at station 20462 on Walnut Creek over the seven-year period of December 1, 2011, through November 30, 2018, were used in assessing attainment of the PCR1 use as reported in the 2020 Integrated Report (TCEQ, 2020a) and are summarized in Table 2.

The 2020 assessment data for the TMDL watershed indicate non-support of the PCR1 use because geometric mean concentrations exceed the *E. coli* geometric mean criterion of 126 cfu/100 mL.

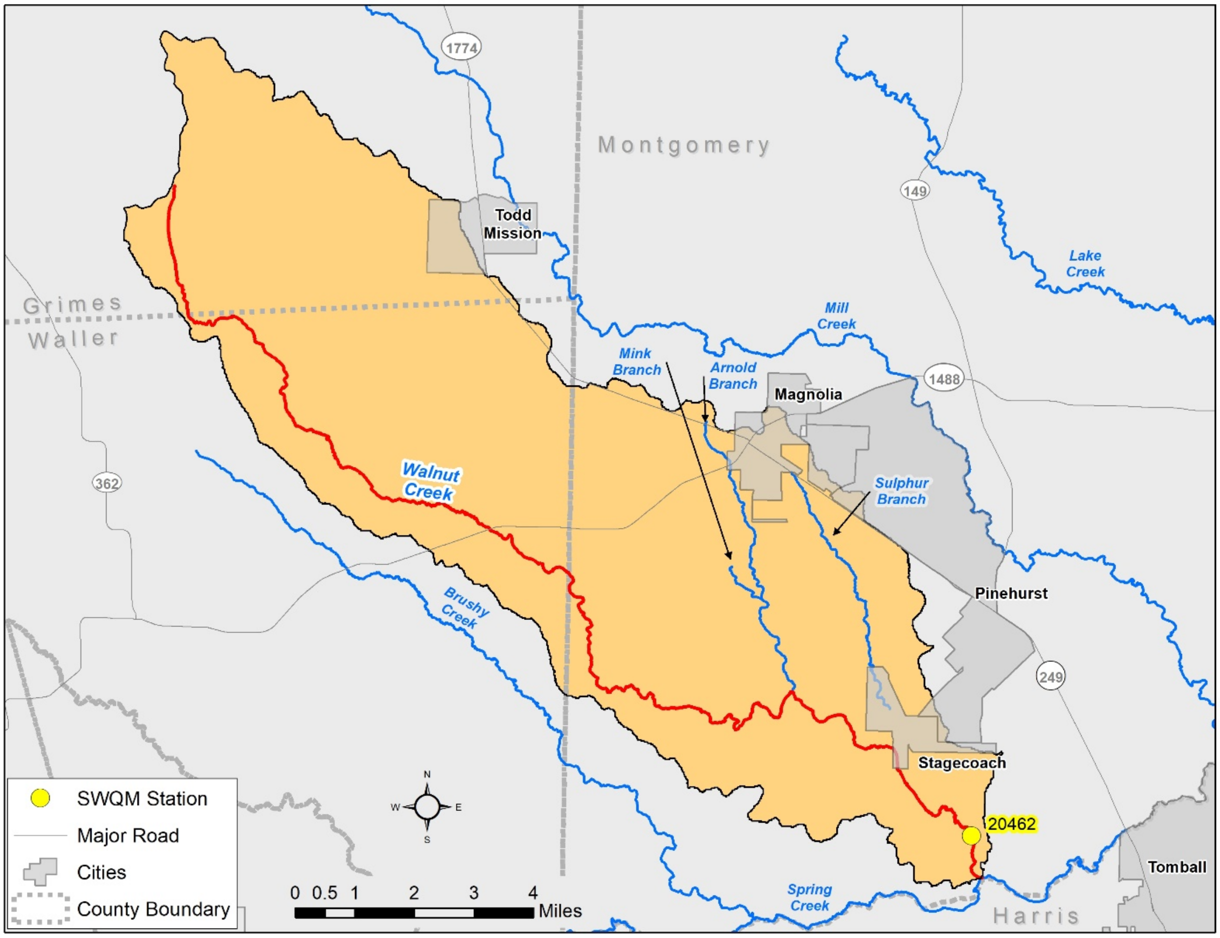

Figure 5. **Walnut Creek watershed showing TCEQ SWQM station used to assess PCR1**

Table 2. **2020 Integrated Report Summary for the Walnut Creek watershed**

Watershed	AU	Parameter	Station	No. of Samples	Data Date Range	Geometric Mean (cfu/100 mL)
Walnut Creek	1008I_01	*E. coli*	20462	25	2011-2018	171

2.5 Land Cover

The land cover data presented in this report were obtained from the United States Geological Survey (USGS) 2016 National Land Cover Database (NLCD) (USGS, 2019). The land cover is represented by the following categories and definitions:

- **Barren Land** – 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.

- **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.
- **Developed, Low Intensity** – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. These areas most commonly include single-family housing units. Constructed surfaces account for 21% to 49% of total cover.
- **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, 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.
- **Deciduous Forest** – Areas dominated by trees generally greater than five 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 five 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 five meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
- **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.
- **Scrub/Shrub** – Areas dominated by shrubs less than five 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.
- **Open Water** – Areas of open water, generally with less than 25% cover of vegetation or soil.

- **<u>Emergent Herbaceous Wetlands</u>** – 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.
- **<u>Woody Wetlands</u>** – 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.

The land cover data is provided for the entire Walnut Creek watershed in Figure 6. For the Walnut Creek watershed, Evergreen Forest (41.1%) and Developed, Open Space (16.4%) are the dominant land covers comprising approximately 57.5% of the total land cover. A summary of the land cover data for the TMDL watershed is provided in Table 3.

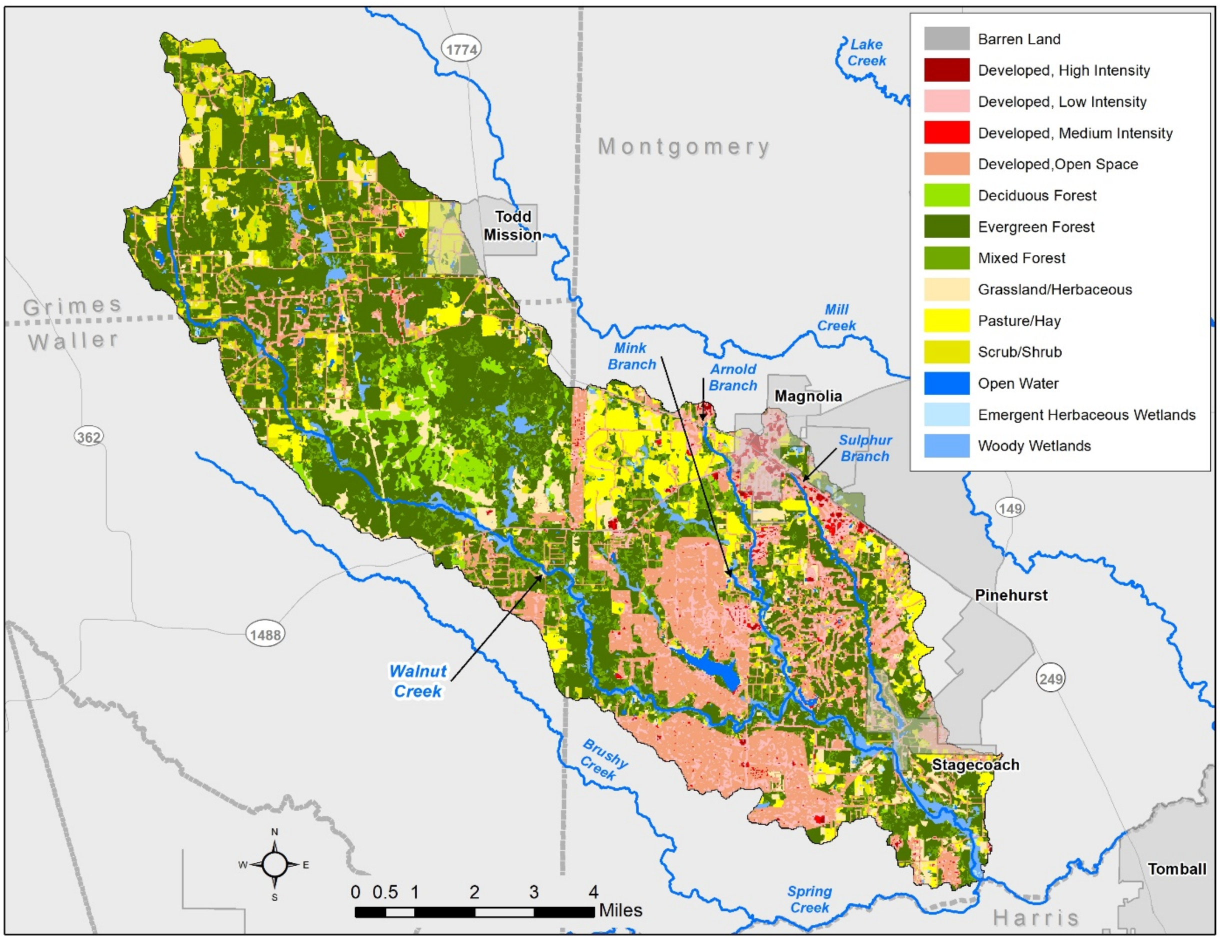

Figure 6. Land cover within the Walnut Creek watershed

Table 3. Land cover within the Walnut Creek watershed

Classification	Area (Acres)	% of Total
Barren Land	51.6	0.1%
Developed, High Intensity	144.5	0.3%
Developed, Low Intensity	3,449.8	7.0%
Developed, Medium Intensity	473.0	1.0%
Developed, Open Space	8,018.5	16.4%
Deciduous Forest	1,397.6	2.9%
Evergreen Forest	20,117.9	41.1%
Mixed Forest	3,933.8	8.0%
Grassland/Herbaceous	2,765.4	5.6%
Pasture/Hay	3,521.0	7.2%
Scrub/Shrub	2,654.5	5.4%
Open Water	376.6	0.8%
Emergent Herbaceous Wetlands	115.0	0.2%
Woody Wetlands	1,967.4	4.0%
Total	**48,986.6**	**100%**

2.6 Soils

Soils within the TMDL watershed, categorized by their septic tank absorption field ratings, are shown in Figure 7. These data were obtained through the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Gridded Soil Survey Geographic database (NRCS, 2019).

Soil properties and features such as saturated hydraulic conductivity, flooding, depth to bedrock, depth to cemented pan, ponding, rocks, fractured bedrock, subsidence, and excessive slope can affect septic tank effluent absorption, construction, maintenance and public health (NRCS, 2019). The dominant soil condition within a septic drainage field can be used to identify soils that may prove problematic regarding septic system installation/performance and potentially lead to system failures such as effluent surfacing or downslope seepage.

Soils are rated based on the limiting factors (or conditions) affecting proper effluent drainage and filtering capacity. Soil conditions for septic tank drainage fields are expressed by the following rating terms and definitions (NRCS, 2019):

- *Not Limited – Indicates that the soil has features that are very favorable for the specific use. Good performance and very low maintenance can be expected.*
- *Somewhat Limited – Indicates that the soil has one or more features that are moderately favorable for the specified use. The limitations can be overcome or minimized with special planning, design, and installation procedures. Fair performance and moderate maintenance can be expected.*

- *Very Limited – Indicates that the soil has one or more features that are unfavorable for the specified use. The limitations generally cannot be overcome without major soil reclamation, special design, or expensive installation procedures. Poor performance and high maintenance can be expected.*
- *Not Rated – Indicates insufficient data exists for soil limitation interpretation.*

The majority of the soils within the Walnut Creek watershed are categorized as "Very Limited" with a fraction rated "Not Rated" and the balance rated as "Somewhat Limited" based on the dominant soil condition for septic drainage field installation and operation.

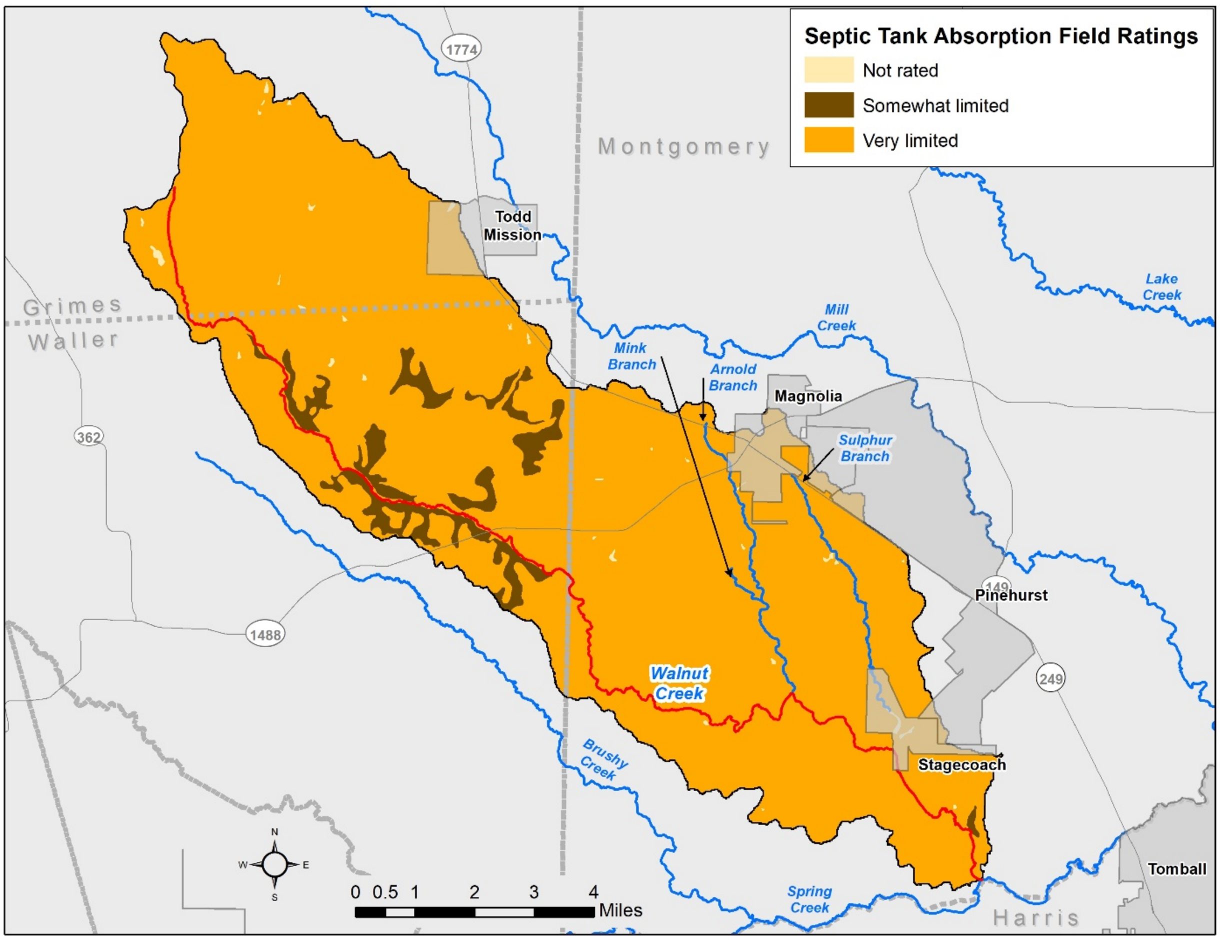

Figure 7. Septic tank absorption field limitation ratings within the Walnut Creek watershed

2.7 Source Analysis

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) program. 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 (WLAs) (see report Section 4.7.3, WLA), 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 Regulated Sources

Regulated sources are controlled by permit under the TPDES program. Seven WWTFs, and stormwater discharges from one Phase II MS4 permittee, concrete production facilities, construction, and multi-sector general permittees represent the permitted sources in the Walnut Creek watershed.

2.7.1.1 Domestic WWTF Discharges

As of July 3, 2020, there were six domestic WWTFs with TPDES permits and one proposed facility within the Walnut Creek watershed (Table 4 and Figure 8). Recent discharge data are presented in Table 4 from Discharge Monitoring Report data (USEPA, 2020).

2.7.1.2 SSOs

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. These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. A summary of SSO incidents that occurred during a four-year period from 2016-2019 in the project counties (Grimes, Montgomery, and Waller) was obtained from the TCEQ Central Office in Austin. The summary data indicated no SSO incidents were reported for any locations within the Walnut Creek watershed.

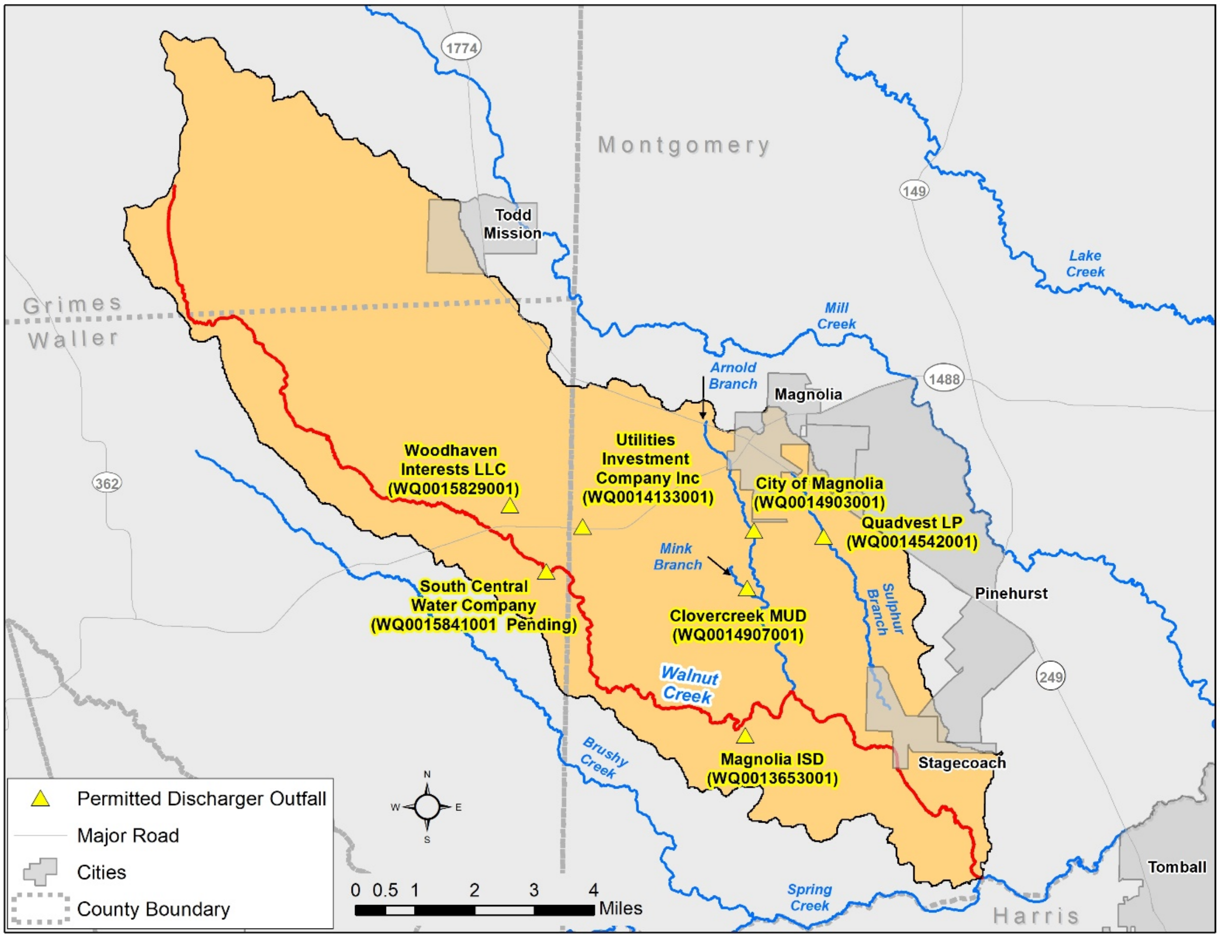

Figure 8. Walnut Creek watershed showing WWTFs

Table 4. Permitted domestic WWTFs in the Walnut Creek watershed

Watershed	Permittee	Facility	TPDES No.	NPDES[a] No.	Permitted Discharge (MGD)[b]	Recent Discharge (MGD)[c]
Walnut Creek	Magnolia Independent School District (ISD)	J. L. Lyons Elementary School WWTF	WQ0013653001	TX0110663	0.015	0.005
Walnut Creek	Utilities Investment Company Inc.	Ranchcrest WWTF	WQ0014133001	TX0119857	0.49	0.061
Walnut Creek	Quadvest L.P.	Magnolia Lakes WWTF	WQ0014542001	TX0126934	0.15	0.048
Walnut Creek	City of Magnolia	City of Magnolia WWTF	WQ0014903001	TX0072702	2.0	0.330
Walnut Creek	Clovercreek Municipal Utility District (MUD)	Clovercreek MUD WWTF	WQ0014907001	TX0097969	0.12	0.050
Walnut Creek	Woodhaven Interests, LLC	Woodhaven WWTF	WQ0015829001	TX0139637	0.45	-------[d]
Walnut Creek	South Central Water Company	Fair Oaks WWTF	WQ0015841001[e]	TX0139751	0.10	-------[d]

[a] NPDES = National Pollutant Discharge Elimination System.
[b] MGD = million gallons per day.
[c] Reflects discharges available from June 1, 2015 – May 31, 2020.
[d] No available records.
[e] Pending permit.

2.7.1.3 TCEQ/TPDES Water Quality General Permits

In addition to the individual wastewater discharge permits listed in Table 4, discharges of processed wastewater from certain types of facilities must be covered by one of several TCEQ/TPDES general permits:

- TXG110000 – concrete production facilities
- TXG130000 – aquaculture production facilities
- TXG340000 – petroleum bulk stations and terminals
- TXG670000 – hydrostatic test water
- TXG830000 – water contaminated by petroleum fuel or petroleum substances
- TXG870000 – pesticides (application only)
- TXG920000 – concentrated animal feeding operations
- WQG100000 – wastewater evaporation
- WQG200000 – livestock manure compost operations (irrigation only)

A review of active general permit coverage (TCEQ, 2020b) in the Walnut Creek watershed as of May 20, 2020, found three concrete production facilities covered by the general permit with two of the facilities permitted for wastewater discharge. The same review revealed three pesticide permittees were covered by the general permit. The concrete production facilities and pesticide management areas do not have bacteria reporting or limits in their permits. These industrial facilities and management areas were assumed to contain inconsequential amounts of indicator bacteria in its effluent; therefore, it was unnecessary to allocate bacteria loads to these facilities. No other active general wastewater permit facilities or operations were found.

2.7.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from regulated stormwater can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II (Small) 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) include:

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.

2.7.1.5 TPDES-Regulated Stormwater

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

1. Stormwater subject to regulation, which is any stormwater originating from TPDES regulated MS4 entities, industrial facilities, and regulated construction activities; and
2. stormwater runoff not subject to regulation.

The TPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permit coverage for their stormwater systems. A regulated MS4 is a publicly owned system of conveyances and includes ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium-sized communities with populations of 100,000 or more based on the 1990 U.S. Census, whereas the Phase II general permit regulates smaller communities within a USCB defined urbanized area.

The purpose of an MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a stormwater management program (SWMP). The SWMP describes the stormwater control practices that will be implemented consistent with permit requirements to minimize the discharge of pollutants from the MS4. The permits require that the SWMPs specify the best management practices to meet several minimum control measures (MCMs) that, when implemented in concert, are expected to result in significant reductions of pollutants discharged into receiving waterbodies. Phase II MS4 MCMs include:

- Public education, outreach, and involvement;
- Illicit discharge detection and elimination;
- Construction site stormwater runoff control;
- Post-construction stormwater management in new development and redevelopment;
- Pollution prevention and good housekeeping for municipal operations; and
- Industrial stormwater sources.

Phase I MS4 individual permits have similar MCMs organized a little differently and are further required to perform water quality monitoring.

For Phase I permits the jurisdictional area is defined by the city limits and for Phase II permits the jurisdictional area is defined as the intersection or overlapping areas of the city limits and the 2010 Census urbanized area.

There is currently one combined Phase I and Phase II MS4 permit within the urbanized area of the Walnut Creek watershed (Table 5). A review of active MS4 general permit coverage (TCEQ, 2020b) in the Walnut Creek watershed as of May 20, 2020, found one active Phase II MS4 permit (Table 5 and Figure 9).

Table 5. TPDES MS4 permits in the Walnut Creek watershed

Watershed	Entity	TPDES Permit	NPDES Permit	Permit Type
Walnut Creek	Texas Department of Transportation	WQ0005011000	TXS002101	Combined Phase I/II
Walnut Creek	Montgomery County	TXR040000 (General Permit)	TXR040348	Phase II

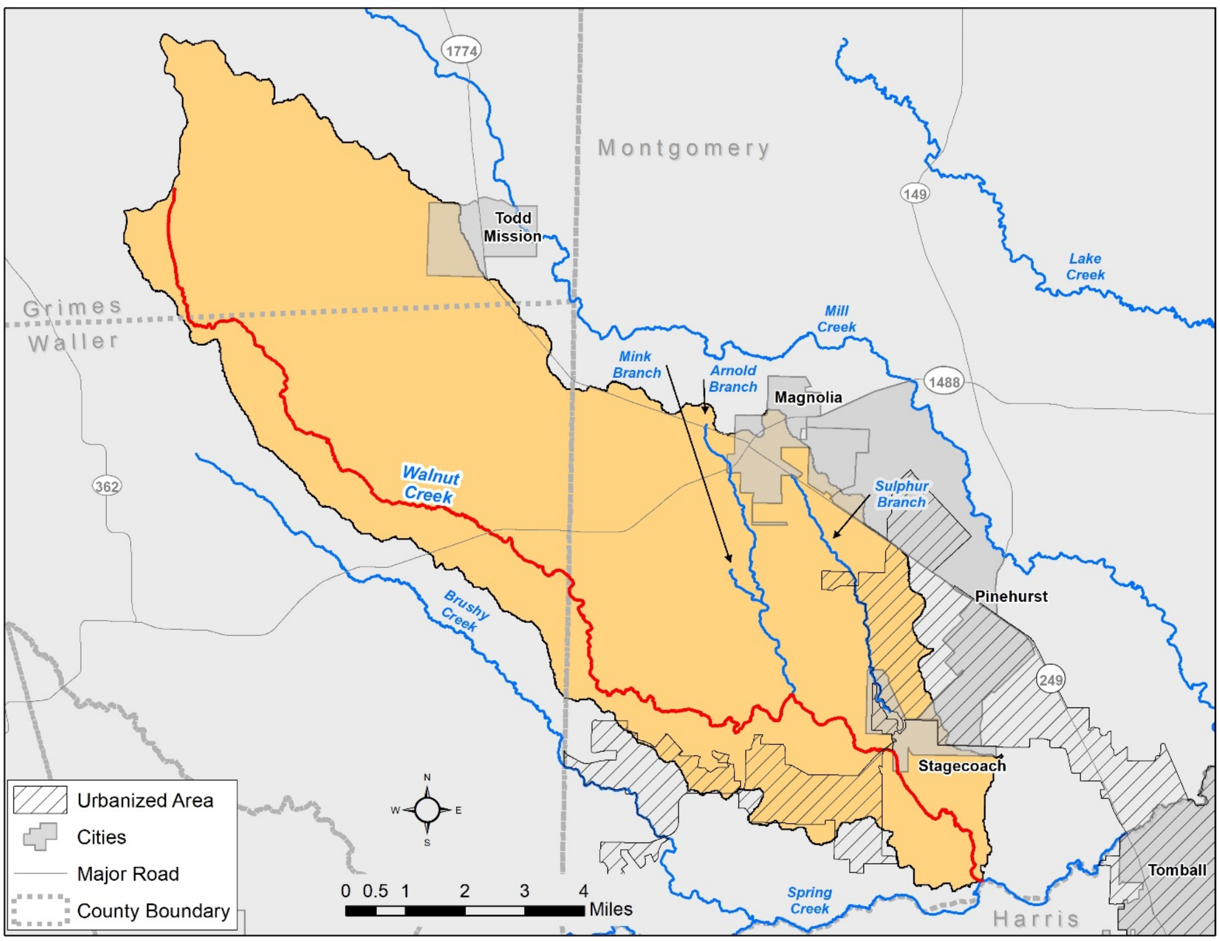

Figure 9. Regulated stormwater areas based on MS4 permits (defined by the urbanized area) within the Walnut Creek watershed

2.7.1.6 Stormwater General Permits

Discharges of Stormwater from a Phase II MS4 entity, 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
- TXR050000 – stormwater multi-sector general permit (MSGP) for industrial facilities
- TXR150000 – stormwater from construction activities disturbing more than one acre

A review of active stormwater general permit coverage (TCEQ, 2020b) in the Walnut Creek watershed as of May 20, 2020, found one Phase II MS4 general permit (see previous section), three active MSGPs, and eight construction permits within the Walnut Creek watershed. See Section 4.7.3 for more detailed information.

2.7.1.7 Review of Compliance Information on Permitted Sources

A review of the USEPA Enforcement and Compliance History Online (ECHO) database (USEPA, 2020), conducted June 22, 2020, revealed non-compliance issues at the Clovercreek WWTF (WQ0014907001) regarding *E. coli* limit violations (Table 6). At the time of this report, two of the WWTFs (Woodhaven Interests and South Central Water Company) are not operational and have no data to evaluate. Permitting data for the proposed WWTFs was limited to TPDES numbers, monitoring requirements, and discharge limits. No other non-compliance issues were revealed for the other WWTFs in the Walnut Creek watershed.

Table 6. Bacteria monitoring requirements and compliance status for the WWTFs in the Walnut Creek watershed

Watershed	Facility	TPDES No.	Min. Self-Monitoring Requirement Frequency	Daily Average (Geometric Mean) Limitation	Single Grab (or Daily Max Limitation	% Reported Exceedances Daily Average	% Reported Exceedances Single Grab
Walnut Creek	J. L. Lyons Elementary School WWTF	WQ0013653001	One/quarter	63	200	0	0
Walnut Creek	Ranchcrest WWTF	WQ0014133001	One/month	63	200	0	0
Walnut Creek	Magnolia Lakes WWTF	WQ0014542001	One/month	63	200	0	0
Walnut Creek	City of Magnolia WWTF	WQ0014903001	One/week	63	200	0	0
Walnut Creek	Clovercreek MUD WWTF	WQ0014907001	One/quarter	63	200	15.79[a]	26.32[a]
Walnut Creek	Woodhaven WWTF	WQ0015829001	One/month	63	200	-----[b]	-----[b]
Walnut Creek	Fair Oaks WWTF	WQ0015841001	-----[b]	63	200	-----[b]	-----[b]

[a] 19 quarterly records of *E. coli* self-monitoring data available (2015 – 2020)

[b] No data available

2.7.2 Unregulated Sources

Unregulated sources of 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 on-site sewage facilities (OSSFs), and domestic pets.

2.7.2.1 Wildlife and Unmanaged Animals

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.

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. Bird diversity is high in the counties where the TMDL watershed is located (eBird, 2020), but population sizes for individual species are not known. However, population estimates for feral hogs and deer are readily available for the TMDL watershed.

For feral hogs, the Institute of Renewable Natural Resources (IRNR; IRNR, 2013) estimated a range of feral hog densities within suitable habitat in Texas (1.33 to 2.45 hogs/square mile). The average hog density (1.89 hogs/square mile) was multiplied by the hog-habitat area (56.99 square miles) in the Walnut Creek watershed. Habitat deemed suitable for hogs followed as closely as possible to the land cover selections of the IRNR study and include from the 2016 NLCD land cover: Forest, Wetlands, Pasture/Hay, Scrub/Shrub, and Grassland/Herbaceous. Using this methodology, there are an estimated 108 feral hogs in the Walnut Creek watershed.

For deer, the Texas Parks and Wildlife Department (TPWD) published data showing deer population-density estimates by Deer Management Unit (DMU) and Ecoregion in the state (TPWD, 2020). The Walnut Creek watershed is located entirely within the DMU Urban Houston for which there is no deer density data. Due to the close proximity of the Walnut Creek watershed to DMU 14, density data from this DMU was used to estimate deer populations for the Walnut Creek watershed. For the 2018 TPWD survey year, the estimated deer population density for DMU 14 was 25.25 deer/1,000 acres and applies to all habitat types within the DMU area. Applying this value to the entire area of the watershed returns an estimated 1,237 deer within the Walnut Creek watershed.

2.7.2.2 OSSFs

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 that 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 drain field of a septic system (Weiskel et al., 1996). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. Walnut Creek is located within the east-central Texas Regions IV and V, which have a reported failure rate of about 12-19%, providing insight into expected failure rates for the area.

Estimates of the number of OSSFs in the Walnut Creek watershed were determined using data supplied by Grimes County 911 Addressing for Grimes County and, the Houston-Galveston Area Council supplied data for Montgomery and Waller Counties. Data from these sources indicate that there are 5,162 OSSFs located within the Walnut Creek watershed. (Figure 10).

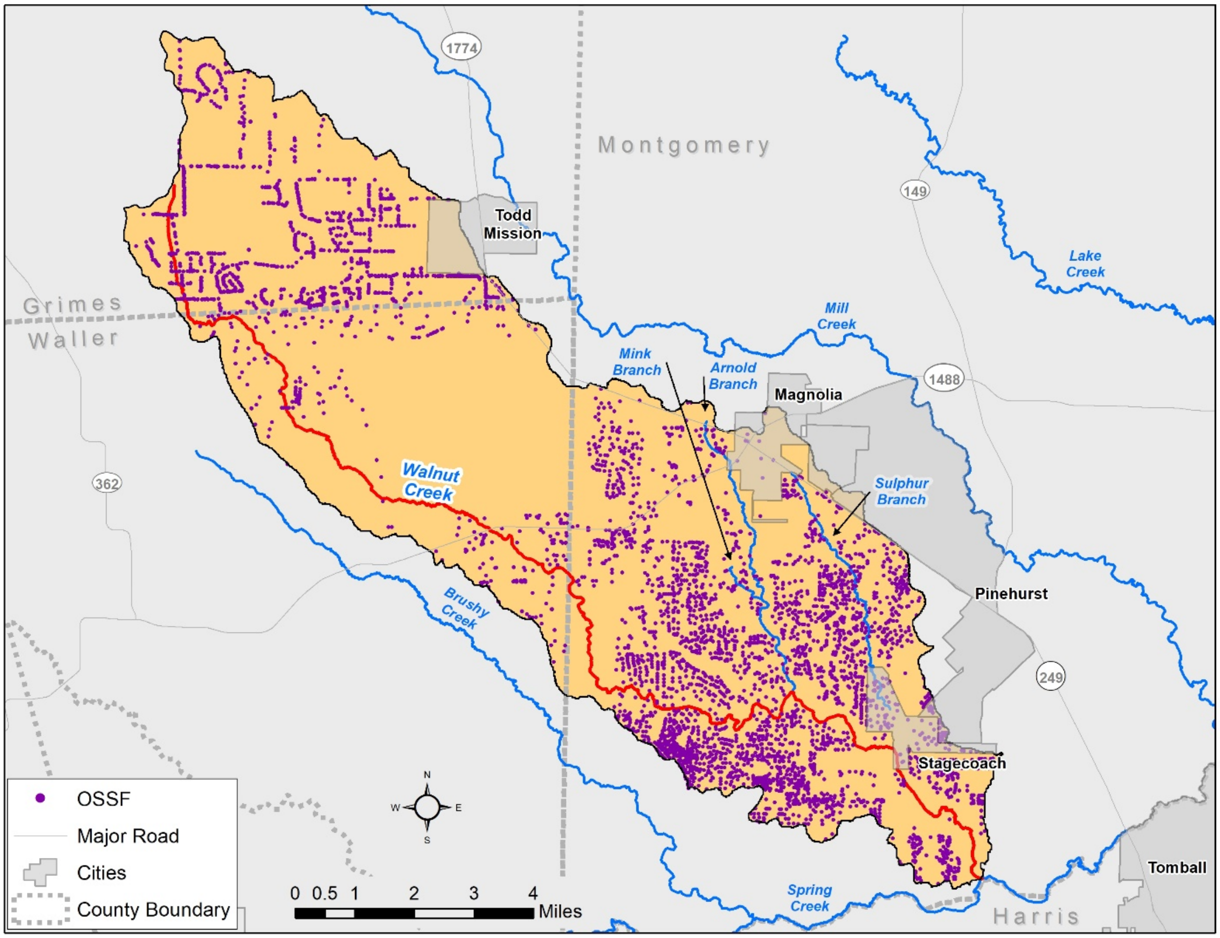

Figure 10. OSSFs located within the Walnut Creek watershed

2.7.2.3 Unregulated Agricultural Activities and Domesticated Animals

The number of livestock within the TMDL watershed was estimated from county-level data obtained from the 2017 Census of Agriculture (USDA NASS, 2019). The county-level data for Grimes, Montgomery, and Waller counties were refined to better reflect actual numbers within the Walnut Creek watershed. The refinement was performed by dividing the total area of the watershed within each county by the total area of each county. This ratio was then applied to the county-level livestock data (Table 7). A further refinement to the Cattle and Calves estimated population was performed by dividing the ratio-derived estimate by one-half using data provided by the Texas State Soil and Water Conservation Board (TSSWCB; TSSWCB, 2020). The livestock numbers in Table 7 are provided to demonstrate that livestock are a potential source of bacteria in the TMDL watershed. These livestock numbers are not used to develop an allocation of allowable bacteria loading to livestock.

Table 7. Estimated distributed domesticated animal populations within the Walnut Creek watershed, based on proportional area

Watershed	Cattle and Calves	Hogs and Pigs	Sheep and Lambs	Goats	Horses and Ponies	Mules, Burros, and Donkeys	Poultry	Deer (captive)
Walnut Creek	1,938	83	128	168	390	63	921	114

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 8 summarizes the estimated number of dogs and cats within the TMDL watershed. Pet population estimates were calculated as the estimated number of dogs (0.614) and cats (0.457) per household according to data from the American Veterinary Medical Association 2017-2018 U.S. Pet Statistics (AVMA, 2018). The number of households in the TMDL watershed were estimated using 2010 Census data (USCB, 2010). Actual contribution and significance of bacteria loads from pets reaching Walnut Creek is unknown.

Table 8. Estimated distribution of dog and cat populations within the Walnut Creek watershed

Watershed	Households	Dogs	Cats
Walnut Creek	7,045	4,326	3,220

2.7.2.4 Bacteria Survival and Die-off

Bacteria are living organisms that survive and die in the environment. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (*e.g.*, warm temperature). Fecal organisms from improperly treated effluent can survive and replicate during their transport in pipe networks, and they can survive and replicate in organic rich materials such as compost and sludge. While the die-off of 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 for Walnut Creek.

SECTION 3
BACTERIA TOOL DEVELOPMENT

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

3.1 Tool Selection

For consistency between the Walnut Creek TMDL and the previously completed TMDLs in the Lake Houston watershed, the pollutant load allocation activities for Walnut Creek used the LDC method. The LDC method has been previously used on TCEQ-adopted and USEPA-approved TMDLs for the *TMDL Addendum One*: *Six Additional Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2013), Addendum *Two: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch* (TCEQ, 2019), and *Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2011).

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 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.

3.2 Walnut Creek Data Resources

Successful application of the LDC method requires two basic types of data: continuous daily streamflow data and historical bacteria data for the relevant indicator bacteria, which in this case is *E. coli*.

Hydrologic data in the form of daily streamflow records were unavailable for the Walnut Creek watershed; however, streamflow records were available for the nearby Bear Branch watershed. Streamflow records for Bear Branch are collected and made readily available by the United States Geological Survey (USGS, 2020), which operates the streamflow gauge (Figure 11, Table 9). USGS streamflow gauge 08068390 is located along the mainstem of Bear Branch and is in close enough proximity to Walnut Creek that the same precipitation events would likely impact each watershed. The determination was made to modify the streamflow records for Bear Branch by using a drainage area ratio (DAR) approach. This approach is explained in more detail in Section 3.3.3. The modified streamflow records from Bear Branch serve as the primary source for streamflow records in this document.

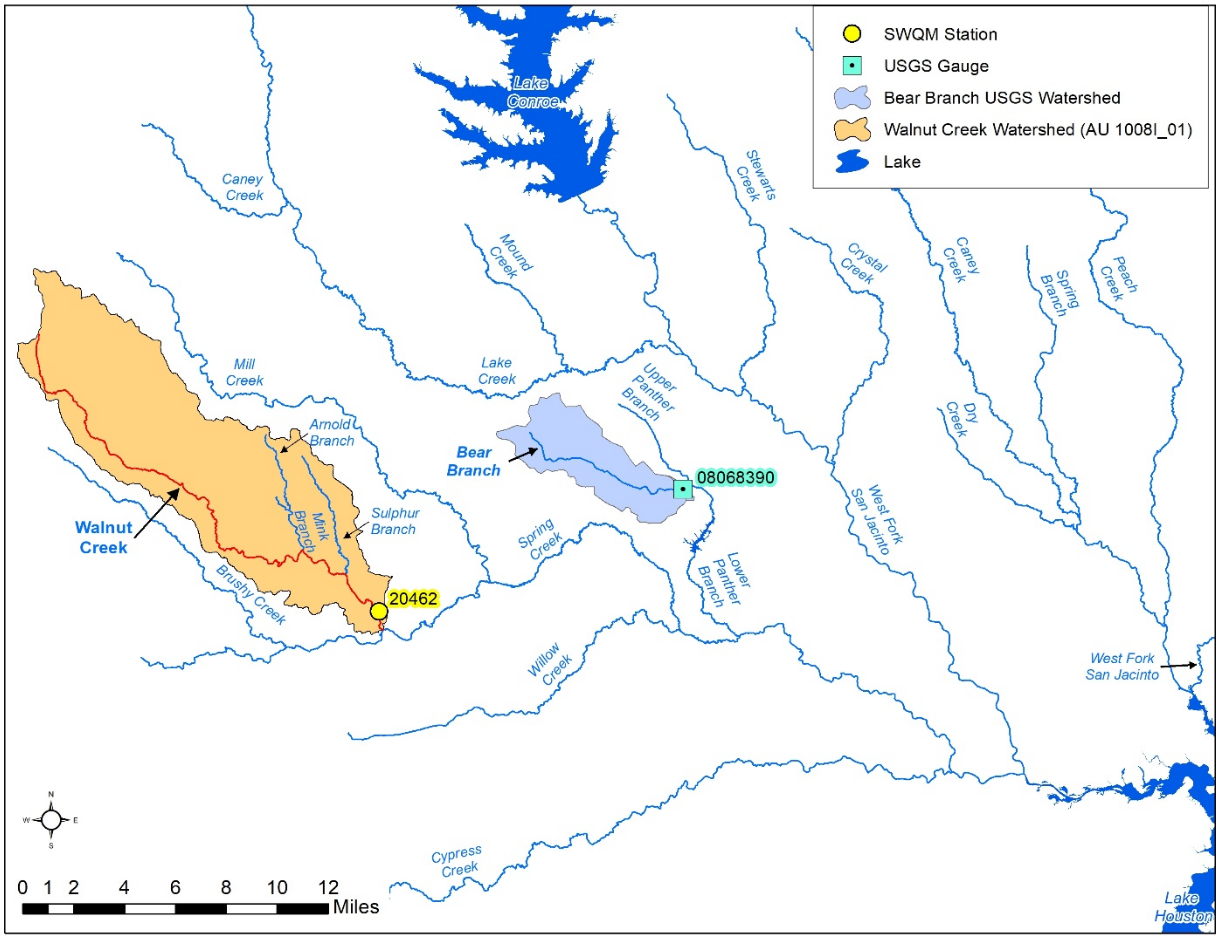

Figure 11. Walnut Creek and Bear Branch watersheds including USGS Station 08068390 and SWQM station 20462

Table 9. Basic information on Bear Branch USGS streamflow gauge

Gauge No.	Site Description	Drainage Area (acres)	Daily Streamflow Record (beginning & end date)
08068390	Bear Branch at Research Boulevard, The Woodlands, TX	9,856	Jan. 1999 – present

Ambient *E. coli* data were available through the TCEQ Surface Water Quality Monitoring Information System for Walnut Creek sampling station 20462 and consisted of 44 *E. coli* sample results with a geometric mean of 193 cfu/100 mL collected over a period from October 2007 to April 2019.

3.3 Methodology for FDC and LDC Development

To develop the flow duration curve (FDC) and LDC, 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 FDC.
- **Step 2:** Determine stream location for which FDC and LDC development is desired.
- **Step 3:** Develop daily streamflow records at the desired stream location using the daily gauged streamflow records and DAR.
- **Step 4:** Develop an FDC at the desired stream location, segmented into discrete flow regimes.
- **Step 5** Develop the allowable bacteria LDC at the same stream location based on the relevant criteria and the data from the FDC.
- **Step 6:** Superpose historical bacteria data on each allowable bacteria LDC.

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

3.3.1 Step 1: Determine Hydrologic Period

A 20-year daily hydrologic (streamflow) record was available for USGS gauge 08068390 located on nearby Bear Branch (Table 9, Figure 11). 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. Therefore, a 10-year record of daily streamflow from January 2010 through December 2019 was selected to develop the FDC at the sampling station location, and this period is within the range of the collection dates of available *E. coli* data at the time this work effort was undertaken. A 10-year period is of sufficient duration to contain a reasonable variation from dry months and years to wet months and years and at the same time is short enough in duration to contain a hydrology that is responding to recent and current conditions in the watershed. A 10-year hydrologic period was also used in the previously completed *TMDL Addendum One: Six Additional Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston* (TCEQ, 2013) and Addendum *Two: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch* (TCEQ, 2019), which maintains consistency of the Walnut Creek TMDL with the previous TMDLs.

3.3.2 Step 2: Determine Desired Stream Locations

SWQM station 20462 (Figure 11) is the only location within Walnut Creek where an adequate number of *E. coli* data have been collected. The 36 *E. coli* sampling results for station 20462 collected over a period from February 2010 to April 2019 and during the

10-year hydrologic period were determined to be adequate to develop pollutant load allocations and exceed the minimum of 24 samples suggested in Jones *et al*. (2009).

3.3.3 Step 3: Develop Daily Streamflow Records

Once the hydrologic period of record and station location were determined, the next step was to develop the 10-year daily streamflow record for monitoring station 20642 in the Walnut Creek watershed. The daily streamflow records were developed from extant USGS records.

The method to develop the necessary streamflow record for the FDC/LDC location (SWQM station location) involved a DAR approach. The DAR approach involves multiplying a USGS gaging station daily streamflow value by a factor to estimate the flow at a desired SWQM station location. The factor is determined by dividing the drainage area upstream of the desired monitoring station by the drainage area upstream of the USGS gauge (Table 10).

Because an assumption of the DAR approach is similarity of hydrologic response based on commonality of landscape features such as geology, soils, and land cover, point source derived flows from within the USGS gauge watershed should first be removed from the flow record prior to application of the ratio. In practice, this complication was addressed by determining the average discharge for each of the WWTFs located above the Bear Branch USGS gauge. The average discharge for each WWTF was computed by averaging the data obtained from the USEPA ECHO database (USEPA, 2020). The WWTF discharge averages were summed and then subtracted from the Bear Branch USGS daily record.

In addition to the WWTF discharges, surface water diversions associated with water rights permits have the potential of impacting stream hydrology with regard to the application of the DAR approach. A spatial query of water rights features (diversions, withdrawals, return flows) revealed that the TMDL watershed did not contain any active water rights permits, and only one active water rights permit was located in the Bear Branch watershed upstream of the USGS gauge 08068390 (TCEQ, 2020c). A review of the water use data file containing historical reported water diversions (TCEQ, 2020c) indicates that the only water user reported a diversion for only one month in 2003. Due to only one month of historical reported water diversions upstream of USGS 08068390, the absence of any recently reported diversions, and the lack of diversions within the TMDL watershed, it is assumed that water diversions will have an insignificant impact on stream hydrology and pollutant load allocations. Therefore, diversions associated with water rights permits were not considered in the development of the streamflow record. Additionally, water rights permits allow withdrawals of water, as opposed to discharges, and do not need to be assigned loadings in a TMDL.

After removing the average daily WWTF discharge values from the daily streamflow gauge record, each daily flow record was multiplied by the DAR. Following application of the DAR, the full permitted flows from WWTFs located within the Walnut Creek watershed (Table 4) were added to the streamflow record along with future growth (FG) flows (calculated in Section 4.7.4) that account for the probability that additional flows from WWTF discharges may occur as a result of population increases.

Table 10. DAR for the Walnut Creek watershed based on the drainage area of the Bear Branch USGS gauge

Water Body	Gauge/Station	Drainage Area (acres)	DAR
Bear Branch	USGS Gauge 08068390	9,856	1.0
Walnut Creek	Station 20462	48,344	4.905

3.3.4 Steps 4-6: FDC and LDC Method

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 one; 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 cfu/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 on the developed LDC using the following two steps:

- using the unique data for the 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), which gives a loading in units of cfu/day; and
- plot on the LDC 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 FDC for Monitoring Station within the TMDL Watershed

The FDC was developed for the monitoring station within the TMDL watershed (Figure 12). For this report, the FDC was developed by applying the DAR method using the Bear Branch USGS gauge 10-year period of record described in the previous sections. Flow exceedances less than 30% typically represent streamflow influenced by storm runoff while higher flow exceedances represent receding hydrographs after a runoff event, base flow, and no flow conditions.

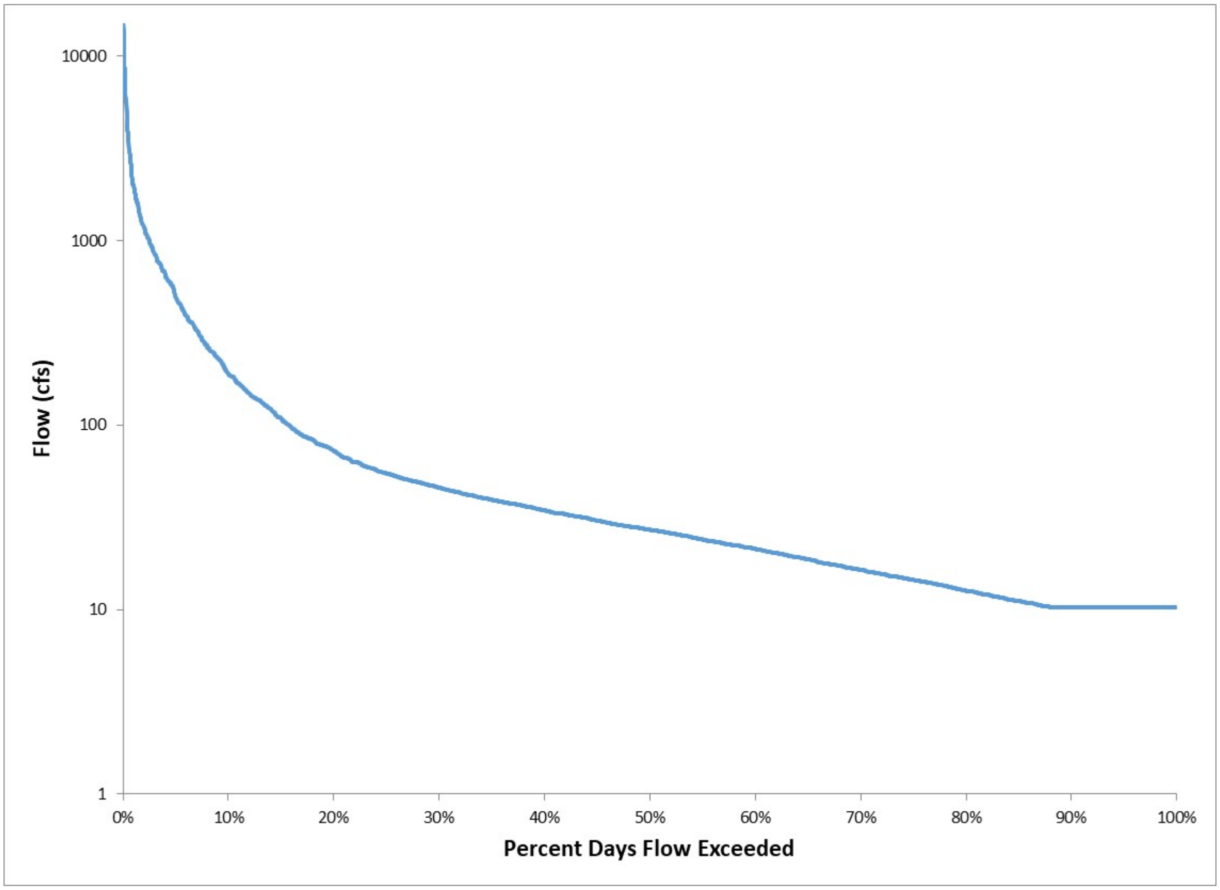

Figure 12. FDC for Walnut Creek AU 1008I_01 (Station 20462)

3.5 LDC for the Sampling Station within the TMDL Watershed

An LDC was developed for the monitoring station within the TMDL watershed (Figure 13). 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 curve. 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 FDC and LDC: (1) 0-10% (high flows); (2) 10-40% (moist conditions); (3) 40-60% (mid-range flows); (4) 60-90% (dry conditions); and (5) 90-100% (low flows).

For the TMDL watershed, streamflow distribution was divided into three flow regimes: Wet, Moderate, and Dry conditions, which maintains consistency with the previously completed TMDLs (TCEQ, 2011 and 2013). Wet conditions correspond to large storminduced runoff events. Moderate conditions typically represent periods of medium base flows but can also represent small runoff events and periods of flow recession following large storm events. Dry conditions represent relatively low flow conditions, resulting from extended periods of little or no rainfall and are maintained primarily by WWTF flows (Table 11).

Table 11. Flow regime classifications

Flow Regime Classification	Flow Exceedance Percentile
Wet Conditions	0 – 30%
Moderate Conditions	30 – 70%
Dry Conditions	70 – 100%

The LDC with these three flow regimes for the monitoring station is provided in Figure 13 and was constructed for developing the TMDL allocation for the TMDL watershed. Geometric mean loadings for the data points within each flow regime have also been distinguished on the figure to aid interpretation. The LDC for the water quality monitoring station provides a means of identifying the streamflow conditions under which exceedances in *E. coli* concentrations have occurred. The LDC depicts the allowable loadings at the station under the geometric mean criterion (126 cfu/100 mL) and shows that existing loadings often exceed the criterion. In addition, the LDC also presents the allowable loading at the station under the single sample criterion (399 cfu/100 mL).

On the graph, the measured *E. coli* data are presented as associated with a "wet weather event" or a "non-wet weather event." A sample was determined to be influenced by a wet weather event based on the reported "days since last precipitation" (DSLP) as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic and hydrologic conditions. A sample taken with a DSLP ≤ 3 days was defined as a wet weather event. Note that a wet weather event can be indicated even under low flow conditions as a result of only a small runoff event during a period of very low base flow in the stream.

The *E. coli* event data plotted on the LDC for station 20462 (Walnut Creek) in Figure 13 show a subtle pattern of increasing tendency for the *E. coli* event data to plot below the geometric mean criterion allowable loading curve as flows decrease, which is indicated in a left to right direction along the graph. This pattern of decreasing occurrence of exceedances in the event data are summarized by the geometric means of the existing data plotted for each of the three flow regimes as compared to the allowable load line for the geometric mean criterion.

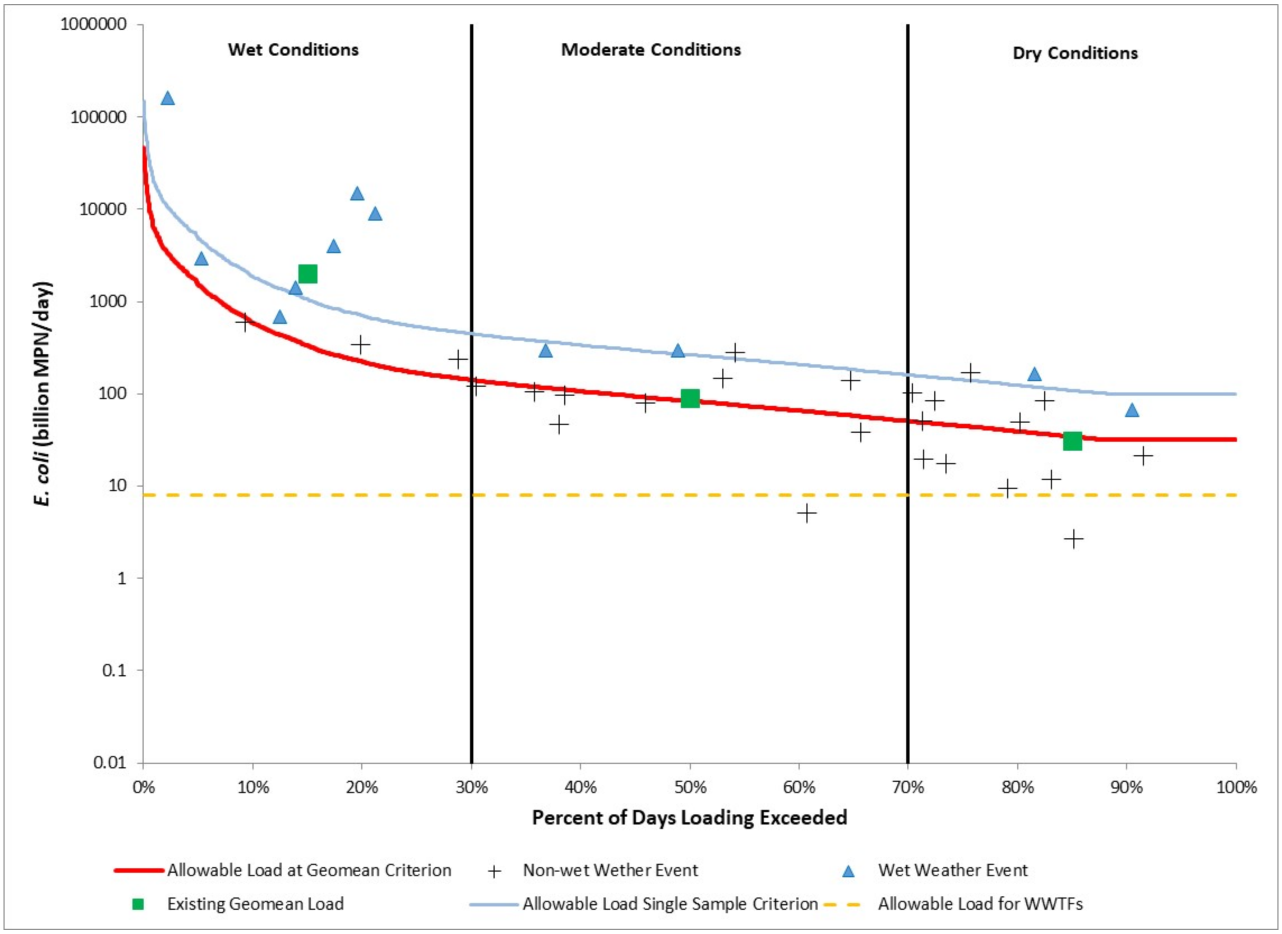

Figure 13. LDC for Walnut Creek AU 1008I_01 (Station 20462)

SECTION 4
TMDL ALLOCATION ANALYSIS

Presented in this report section is the development of the bacteria TMDL allocations for the Walnut Creek watershed. The tool used for developing TMDL allocations was the LDC method previously described in Section 3– Bacteria Tool Development. Endpoint identification, margin of safety (MOS), 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 TMDL watershed. As developed previously in this report, the LDC method uses frequency distributions to assess a bacteria criterion over the historical range of flows, providing a means to determine maximum allowable loadings and the load reduction necessary to achieve support of the PCR1 use.

For the purposes of this TMDL study, the TMDL watershed is considered to be the entire Walnut Creek watershed (AU 1008I_01) as shown in the overview map (Figure 1). An adequate amount of data from one SWQM station in the watershed was available for TMDL development; therefore, TMDL calculations are based on the location of the SWQM station 20462 within the Walnut Creek watershed.

Additionally, a DAR approach using historical streamflow records from a nearby USGS gauge on Bear Branch was employed to estimate the daily flow for station 20462 within the TMDL watershed.

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 Walnut Creek watershed has a use of PCR1, 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 cfu/100 mL (TCEQ, 2018).

The endpoint for this TMDL is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 cfu/100 mL. This endpoint is identical to the geometric mean criterion in the 2018 Surface Water Quality Standards (TCEQ, 2018).

4.2 Seasonal Variation

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 ten years (2010 – 2019) of routine monitoring collected in the warmer months (April – September) against those collected during the cooler months (October – March). Differences in *E. coli* concentrations obtained in warmer versus cooler months were then evaluated by performing a Wilcoxon Rank Sum test on the natural log transformed dataset. This analysis of *E. coli* data indicated that there was no significant difference ($\alpha=0.05$) in indicator bacteria between cool and warm weather seasons for Walnut Creek AU 1008I_01 ($p=0.3308$).

4.3 Linkage Analysis

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

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

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

LDCs 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 LDC Analysis and Results

An LDC method was used to examine the relationship between instream water quality and the broad sources of indicator bacteria load and is the basis of the TMDL allocation. The strength of this TMDL is the use of the LDC method to determine the TMDL allocation. 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 load was based on the median flow within the Wet Conditions flow regime (or 15% flow), where exceedances to the PCR1 criteria are most pronounced.

The LDC method allows for estimation of existing and allowable 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 LDC used in the pollutant load allocation process with historical *E. coli* data added to the graph (Figure 13) and Section 2.7 (Potential Sources of FIB), the following broad linkage statements can be made. For the TMDL watershed, the historical *E. coli* data indicate that elevated bacteria loadings occur under all three flow regimes, especially during high flows. There is some moderation of the elevated loadings under moderate and dry conditions for the Walnut Creek watershed. On Figure 13, the geometric means of the measured data for each flow regime generally support the observation of decreasing concentration with decreasing flow, and under dry conditions the data indicate the geometric mean is below the geometric mean criterion (126 cfu/100 mL).

4.5 MOS

The 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 USEPA 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 a MOS. The TMDL in this report incorporate an explicit MOS of 5%.

4.6 Load Reduction Analysis

While the TMDL for the Walnut Creek watershed was developed using an LDC and associated load allocations, additional insight may, in certain situations, be gained through a load reduction analysis. A single percent load reduction required to meet the allowable loading for each of the three flow regimes was determined using the historical *E. coli* data obtained from the monitoring station within the impaired water body.

For each flow regime the percent reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean concentration and the 126 cfu/100 mL criterion and dividing that difference by the existing geometric mean concentration (Table 12).

Table 12. Percent reduction calculations for Walnut Creek SWQM station 20462

Flow Regime	Number of Samples	Geometric Mean by Flow Regime (cfu/100mL)	Required Percent Reduction by Flow Regime
Wet Conditions (0-30%)	10	746	83.1%
Moderate Conditions (30-70%)	12	133	5.3%
Dry Conditions (70-100%)	14	114	0%

4.7 Pollutant Load Allocation

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

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

Where:

TMDL = total maximum daily load

WLA = wasteload allocation, the amount of pollutant allowed by regulated dischargers

LA = load allocation, the amount of pollutant allowed by unregulated sources

FG = loadings associated with future growth from potential regulated facilities

MOS = margin of safety load

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

4.7.1 AU-Level TMDL Calculations

The bacteria TMDL for the TMDL water body was developed as a pollutant load allocation based on information from the LDC for the monitoring station located within the TMDL watershed (Figure 13). As discussed in more detail in Section 3, the bacteria LDC was developed by multiplying each flow value along the FDC by the *E. coli* criterion (126 cfu/100 mL) and by the conversion factor used to represent maximum loading in cfu/day. Effectively, the "Allowable Load" displayed in the LDC at 15% exceedance (the median value of the wet conditions-flow regime) is the TMDL:

TMDL (cfu/day) = criterion * flow (cfs) * conversion factor (Eq. 2)

Where:

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

Conversion Factor (to billion cfu/day) = (283.1685 100 mL/ft^3 * 86,400 sec/day)/1.0E+9

The allowable loading of *E. coli* that the impaired watershed can receive on a daily basis was determined using Equation 2 based on the median value within the high flows regime of the FDC (or 15% flow exceedance value) for the monitoring station (Table 13).

Table 13. Summary of allowable loading calculation for Walnut Creek

Water Body	AU	15% Exceedance Flow (cfs)	15% Exceedance Load (Billion cfu/day)	TMDL (Billion cfu/day)
Walnut Creek	1008I_01	108.990	335.982	335.982

4.7.2 MOS

The 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 daily load

Using the value of TMDL for the AU provided in Table 13, the MOS may be readily computed by proper substitution into Equation 3 (Table 14).

Table 14. MOS calculations for Walnut Creek

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

Water Body	AU	TMDL[a]	MOS
Walnut Creek	1008I_01	335.982	16.799

[a] TMDL from Table 13.

4.7.3 WLA

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

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

TPDES-permitted WWTFs are allocated a daily wasteload (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by one-half the instream geometric criterion. One-half of the water quality criterion (63 cfu/100mL) is used as the WWTF target to provide instream and downstream load capacity, and to be consistent with previously developed TMDLs. Thus, WLA_{WWTF} is expressed in the following equation:

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

Where:

Target= 63 cfu/100 mL

Flow = full permitted flow (MGD)

Conversion Factor (to billion cfu/day) = 37,854,000 mL/MGD

The daily allowable loading of *E. coli* assigned to WLA_{WWTF} was determined based on the combined full permitted flow of the permitted WWTFs within the TMDL watershed, using equation 5. Table 15 presents the WLA for each WWTF and the resulting total allocation for the AU within the TMDL watershed.

Stormwater discharges from MS4, industrial, and construction areas are 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 this TMDL 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 the TMDL 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 15. WLAs for TPDES-permitted facilities in the Walnut Creek watershed

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

Watershed (AU)	TPDES Permit No.	NPDES Permit No.	Permittee	Full Permitted Flow (MGD)[a]	*E. coli* WLA_{WWTF}
Walnut Creek (AU 1008I_01)	WQ0013653001	TX0110663	Magnolia ISD	0.015	0.036
Walnut Creek (AU 1008I_01)	WQ0014133001	TX0119857	Utilities Investment Company Inc.	0.49	1.169
Walnut Creek (AU 1008I_01)	WQ0014542001	TX0126934	Quadvest L.P.	0.15	0.358
Walnut Creek (AU 1008I_01)	WQ0014903001	TX0072702	City of Magnolia	2	4.770
Walnut Creek (AU 1008I_01)	WQ0014907001	TX0097969	Clovercreek MUD	0.12	0.286
Walnut Creek (AU 1008I_01)	WQ0015829001	TX0139637	Woodhaven Interests, LLC	0.45	1.073
Walnut Creek (AU 1008I_01)	WQ0015841001	TX0139751	South Central Water Company	0.10	0.238
Total				3.325	7.930

[a] Full Permitted Flow from Table 4.

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

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

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 regulated 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 presented in Table 16.

A portion of the Walnut Creek watershed lies within the jurisdiction of one MS4 phase II permit. Three MSGPs, eight construction permits, and three concrete production facilities exist within the Walnut Creek watershed. For this TMDL, the acreage associated with the three MSGP permits and the three concrete production facilities was estimated by importing the location information associated with the facilities into a geographic information system (GIS), and measuring the estimated disturbed area based on the most recently available aerial imagery. Additionally, the areas disturbed associated with each of the eight construction permits within the Walnut Creek watershed were summed. The area associated with the 2010 Houston urbanized area along with the areas associated with the MSGPs, concrete production facilities, and construction permits located within the Walnut Creek watershed provide stormwater coverage for Walnut Creek.

Table 16. Stormwater general permit areas and calculation of the FDA_{SWP} term for the Walnut Creek watershed (AU 1008I_01)

Water Body	AU	MS4 General Permit (acres)	MSGP (acres)	Construction Activities (acres)	Concrete Production Facilities (acres)	Petroleum Bulk Stations (acres)	Total Area of Permits (acres)	Watershed Area (acres)	FDA_{SWP}
Walnut Creek	1008I_01	3,538	26	3,178	27	-	6,769	48,987	0.1382

The daily allowable loading of *E. coli* assigned to WLA_{SW} was determined based on the combined area under regulated stormwater permits. In order to calculate the WLA_{SW} (Eq. 6), the 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 17 provides the information needed to compute WLA_{SW}.

Table 17. Regulated stormwater calculations for Walnut Creek

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

Water Body	AU	TMDL[a]	WLA_{WWTF}[b]	FG[c]	MOS[d]	FDA_{SWP}[e]	WLA_{SW}[f]
Walnut Creek	1008I_01	335.982	7.930	15.702	16.799	0.1382	40.845

[a] TMDL from Table 13

[b] WLA_{WWTF} from Table 15

[c] FG from Table 18

[d] MOS from Table 14

[e] FDA_{SWP} from Table 16

[f] $WLA_{SW} = (TMDL – WLA_{WWTF} – FG - MOS) * FDA_{SWP}$ (Eq. 6)

4.7.4 FG

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

The allowance for FG will result in protection of existing water quality uses and conform to Texas's antidegradation policy.

While the FG allowance is often computed for bacteria TMDLs using information from existing WWTF permits, it is not intended to restrict any future assignments of the allocation solely to expansions at these facilities. Rather, the FG allocation is purposed for any new facilities that may occur and expansions of existing facilities. This definition of FG is relevant as one WWTF (Fair Oaks WWTF) has been proposed for development within the Walnut Creek watershed and another WWTF (Woodhaven WWTF) is active but not operational. The proposed facility was still in the permit application/review phase of the permitting process at the time of this report with limited information available; however, full permitted flow data were available. Thus, both WWTFs were considered as currently permitted and operating.

The FG component of the TMDL watershed was based on population projections and current permitted wastewater dischargers for the entire TMDL watershed. Recent population and projected population growth between 2010 and 2070 for the TMDL watershed are provided in Table 1. The projected population percentage increase within the watershed was multiplied by the corresponding WLA_{WWTF} to calculate future WLA_{WWTF}. The permitted flows were increased by the expected population growth per AU between 2020 and 2070 to determine the estimated future flows.

Thus, the FG is calculated as follows:

$$FG = WWTF_{FP} * POP_{2020\text{-}2070} * \text{conversion factor} * \text{target} \qquad \text{(Eq. 7)}$$

Where:

$WWTF_{FP}$ = full permitted WWTF discharge (MGD)

$POP_{2020\text{-}2070}$ = estimated percent increase in population between 2020 and 2070

Conversion factor = (37,854,000 100mL/MGD)/1.0E+9

Target = 63 cfu/100 mL

The calculation results for the impaired TMDL watershed are shown in Table 18.

Table 18. FG calculation for Walnut Creek

Water Body	AU	Full Permitted Flow (MGD)	% Population Increase (2020-2070)	FG (MGD)	FG (*E. coli* Billion cfu/Day)[a]
Walnut Creek	1008I_01	3.325	198.0%	6.584	15.702

[a] $FG = WWTF_{FP} * POP_{2020\text{-}2070}$ * conversion factor * target (Eq. 7)

4.7.5 LA

The load allocation (LA) is the load 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 regulated facilities

MOS = margin of safety load

The calculation results are shown in Table 19.

Table 19. LA calculation for Walnut Creek

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

Water Body	AU	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	FG[d]	MOS[e]	LA[f]
Walnut Creek	1008I_01	335.982	7.930	40.845	15.702	16.799	254.706

[a] TMDL from Table 13

[b] WLA_{WWTF} from Table 15

[c] WLA_{SW} from Table 17

[d] FG from Table 18

[e] MOS from Table 14

[f] $LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS$ (Eq. 8)

4.8 Summary of TMDL Calculations

Table 20 summarizes the TMDL calculation for the TMDL watershed. The TMDL was calculated based on the median flow in the 0-30 percentile range (15% exceedance, Wet Conditions flow regime) for flow exceedance from the LDC developed for the SWQM station 20462. Allocations are based on the current geometric mean criterion for *E. coli* of 126 cfu/100 mL for each component of the TMDL.

Table 20. TMDL allocation summary for Walnut Creek

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

Water Body	AU	TMDL[a]	WLA_{WWTF}[b]	WLA_{SW}[c]	LA[d]	FG[e]	MOS[f]
Walnut Creek	1008I_01	335.982	7.930	40.845	254.706	15.702	16.799

[a] TMDL from Table 13
[b] WLA_{WWTF} from Table 15
[c] WLA_{SW} from Table 17
[d] LA from Table 19
[e] FG from Table 18
[f] MOS from Table 14

The final TMDL allocation (Table 21) needed to comply with the requirements of 40 CFR 130.7 include the FG component within the WLA_{WWTF}.

Table 21. Final TMDL allocation for Walnut Creek

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

Water Body	AU	TMDL	WLA_{WWTF}[a]	WLA_{SW}	LA	MOS
Walnut Creek	1008I_01	335.982	23.632	40.845	254.706	16.799

[a] WLA_{WWTF} includes the FG component

Section 5
REFERENCES

AVMA (American Veterinary Medical Association). 2018. 2017-2018 U.S. Pet Ownership Statistics, retrieved June 17, 2020, from website: <www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics>

Cleland, B. 2003. *TMDL Development From the "Bottom Up" - Part III: Duration Curves and Wet-Weather Assessments*. Retrieved June 18, 2010, from <engineering.purdue.edu/mapserve/ldc/pldc/help/TMDL_Development_from_the_Bottom_UP_PartIV.pdf>

eBird. 2020. eBird: An online database of bird distribution and abundance [web application]. Ithaca, NY. Retrieved June 16, 2020 from <www.ebird.org>

IRNR. 2013. Feral hog statewide population growth and density. Retrieved June 2, 2020 from <feralhogs.tamu.edu/files/2011/05/FeralHogFactSheet.pdf>

Jones, C. A., Wagner, K., Di Giovanni, G., Hauck, L., Mott, J., Rifai, H., Srinivasan, R., Ward, G., Wythe, K. 2009. *Bacteria Total Maximum Daily Load Task Force Final Report* (No. TR-341). TWRI. Retrieved June 18, 2020, from <www.researchgate.net/publication/26903717_Bacteria_Total_Maximum_Daily_Load_Task_Force_Report>

Larkin, Thomas J., G. Bomar. 1983. *Climatic Atlas of Texas*. LP-192. Texas Department of Water Resources. Retreived June 18, 2020 from <www.twdb.texas.gov/publications/reports/limited_printing/doc/LP192.pdf>

NEIWPCC (New England Interstate Water Pollution Control Commission). 2003. *Illicit Discharge Detection and Elimination Manual.*

NDEP (Nevada Division of Environmental Protection). 2003. *Load Duration Curve Methodology for Assessment and TMDL Development*. Retrieved June 18, 2020, from <ndep.nv.gov/uploads/water-tmdl-docs/LOADCURV.PDF>

NOAA (National Oceanic and Atmospheric Administration). 2020. *Station USW00053902, Conroe North Houston Regional Airport TX, US* Retrieved June 9, 2020, from National Climatic Data Center: <www.ncdc.noaa.gov/cdo-web/search>

NRCS. 2019. Gridded Soil Survey Geographic Database for Grimes, Montgomery, and Waller Counties. Retrieved March 25, 2020 from <datagateway.nrcs.usda.gov/>

Reed, Stowe, and Yanke, LLC. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-site Sewage Facility Systems in Texas. Retrieved June 18, 2020, from <www.tceq.texas.gov/assets/public/compliance/compliance_support/regulatory/ossf/StudyToDetermine.pdf>

TCEQ. 2006. *Preserving & Improving Water Quality – The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters*. Retrieved June 18, 2020, from <www.tceq.texas.gov/assets/public/comm_exec/pubs/gi/gi-351.pdf>

TCEQ. 2011. *Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston*. Available online at: <www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-lakehoustontmdl_adopted.pdf> Accessed June 18, 2020.

TCEQ. 2013. *Addendum One to Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston: Six Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston*. Available online at: <www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82A-LakeHoustonAddendum1.pdf> Accessed June 18, 2020.

TCEQ. 2014. *2014 Texas Surface Water Quality Standards*. 2014 Chapter 307 Rule Amendment. Retrieved, July 7, 2020. <www.tceq.texas.gov/waterquality/standards/2018-surface-water-quality-standards#fifthAnchor>

TCEQ. 2018. *2018 Texas Surface Water Quality Standards*. 2018 Chapter 307 Rule Amendment. Retrieved, June 22, 2020. <www.tceq.texas.gov/waterquality/standards/2018-surface-water-quality-standards#fifthAnchor>

TCEQ. 2019. *Addendum Two to Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston: Two Total Maximum Daily Loads for Indicator Bacteria in Brushy Creek and Spring Branch*. Available online at: <www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-brushy-spring-addendum-oct2019.pdf> Accessed July 7, 2020.

TCEQ. 2020a. *2020 Texas Integrated Report of Surface Water Quality for the Clean Water Act Sections 305(b) and 303(d)*. Retrieved June 18, 2020. <www.tceq.texas.gov/waterquality/assessment/20twqi/20txir>

TCEQ. 2020b. *Central Registry Query*. Retrieved May 20, 2020, from <www15.tceq.texas.gov/crpub/index.cfm?fuseaction=home.welcome>

TCEQ. 2020c. *Water Rights Analysis Package Input files and GIS files by River Basin*. Spatial dataset. Retrieved June 17, 2020 from: <www.tceq.texas.gov/permitting/water_rights/wr_technical-resources/wam.html>

TPWD. 2020. White-tailed Deer (WTD) Federal Aid Report 2020 Charts and Tables. Personal communication received June 18, 2020.

TSSWCB. 2020. Cattle and Calves Population Estimates for Walnut Creek Watershed. Personal communication received July 31, 2020.

TWDB. 2015. 2016 Texas Water Development Board Regional Water Plan (Regions G & H). Retrieved April 13, 2020 from <www.twdb.texas.gov/waterplanning/rwp/plans/2016/index.asp>

USCB (United States Census Bureau). 2010. 2010 *Census Block Shapefiles*. Retrieved March 19, 2020: <www.census.gov/cgi-bin/geo/shapefiles2010/main>; Tabular data from: *2010 Census Block Households and Families*. Retrieved March 19, 2020, from American FactFinder: <data.census.gov/cedsci/>

USDA NASS (National Agricultural Statistics Service). 2019. State and County Data, Volume 1, Part43A, Inventory and Sales (2017 Census). Retrieved June 17, 2020, from <www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Census_by_State/index.php>

USEPA. 1991. *Guidance for Water Quality-Based Decisions: The TMDL Process*. Retrieved June 18, 2020, from Office of Water: Total Maximum Daily Loads (303d): <www.epa.gov/sites/production/files/2018-10/documents/guidance-water-tmdl-process.pdf>

USEPA. 2020. *Enforcement and Compliance History Online (ECHO)*. Retrieved June 22, 2020 from <echo.epa.gov/>

USGS. 2019. National Land Cover Database 2016 Land Cover Conterminous United States, Retrieved March 26, 2020, from <www.mrlc.gov/data/nlcd-2016-land-cover-conus>

USGS. 2020. *USGS Streamflow Data for Station 08068390, Bear Branch at The Woodlands, TX*. Retrieved May 22, 2020, from <waterdata.usgs.gov/tx/nwis/current/?type=flow>

Weiskel, P., Howes, B., & Heufelder, G. 1996. Coliform Contamination of a Coastal Embayment: Sources and Transport Pathways. *Environmental Science and Technology, 30,* 1872-1881. Retrieved June 18, 2020, from <pubs.acs.org/doi/pdf/10.1021/es950466v>