Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Upper & Lower Panther Branch, Bear Branch, and Peach Creek Watersheds

Segments: 1008B, 1008C, 1008E and 1011

Assessment Units: 1008B_01, 1008B_02, 1008C_01, 1008C_02, 1008E_01 and 1011_01

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List of Acronyms

AU	assessment unit
AVMA	American Veterinary Medical Association
BMP	best management practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
CCN	Certificate of Convenience and Necessity
DMR	Discharge Monitoring Report
DSLP	days since last precipitation
ECHO	Enforcement & Compliance History Online
E. coli	*Escherichia coli*
FDC	flow duration curve
FG	future growth
H-GAC	Houston-Galveston Area Council
ICIS	Integrated Compliance Information System
I/I	inflow and infiltration
I-Plan	implementation plan
LA	load allocation
LDC	load duration curve
mi	mile
mL	milliliter
MGD	million gallons per day
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
NEIWPCC	New England Interstate Water Pollution Control Commission
NPDES	National Pollutant Discharge Elimination System
OSSF	onsite sewage facility
SSO	sanitary sewer overflow
SWMP	Stormwater Management Program
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USEPA	United States Environmental Protection Agency
WLA	wasteload allocation
WQMP	Water Quality Management Plan
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 (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 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 Texas Commission on Environmental Quality (TCEQ) first identified the bacteria impairments within the Upper Panther Branch and Peach Creek segments in 2006, and within the Lower Panther Branch and Bear Branch segments in 2010 and 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*).

This document will consider bacteria impairments in 4 water bodies (segments) consisting of 6 total assessment units (AUs). The complete list of water bodies and their identifying segment_AU number are as follows:

1) Upper Panther Branch (unclassified water body) 1008B_01, 1008B_02,

2) Lower Panther Branch (unclassified water body) 1008C_01, 1008C_02,

3) Bear Branch (unclassified water body) 1008E_01, and

4) Peach Creek 1011_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 specifically protect appropriate uses for each segment (water body), and list appropriate limits for water quality indicators to assure water quality and attainment of uses. The TCEQ monitors and assesses water bodies based on the 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

Bacteria are indicators of the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Fecal coliforms are bacteria that originate from the wastes of warm-blooded animals. They usually live in human or animal intestinal tracts. *E. coli* (*Escherichia coli*) is a member of fecal coliform bacteria group (USEPA, 2009). The presence of these bacteria indicates that associated pathogens from the wastes may be reaching water bodies, because of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets in urban areas, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006).

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

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

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

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

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

1.3 Report Purpose and Organization

The Upper & Lower Panther Branch, Bear Branch, and Peach Creek Watersheds TMDL project was initiated through a contract between the TCEQ and Texas Institute for Applied Environmental Research (TIAER). The tasks of this project were to (1) 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 was to: (1) review the characteristics of the watershed and explore the potential sources of *E. coli* bacteria for the impaired segments; (2) develop an appropriate tool for development of bacteria TMDLs for the impaired segments; and (3) submit the draft and final technical support document for the impaired segments. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for the Upper & Lower Panther Branch, Bear Branch, and Peach Creek watersheds. 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.

Whenever it was feasible, the data development and computations for developing the load duration curves and pollutant load allocation were performed in a manner to remain consistent with the previously completed indicator bacteria TMDLs for watersheds upstream of Lake Houston (TCEQ, 2011a).

SECTION 2

HISTORICAL DATA REVIEW AND WATERSHED PROPERTIES

2.1 Description of Study Area

The water bodies included in this study are all within the Lake Houston watershed and are depicted in Figure 1. They are also within the area covered by a previous TMDL for indicator bacteria in watersheds upstream of Lake Houston (TCEQ, 2011a). Upper Panther Branch (Segment 1008B) begins at Old Conroe Road and continues to the confluence with Lake Woodlands, draining approximately 12 mi^2. Lower Panther Branch (Segment 1008C) flows in a south direction from Lake Woodlands Dam to the confluence with Spring Creek and drains approximately 8 mi^2. Bear Branch (Segment 1008E) lies to the west of Upper Panther Branch and flows southeasterly from FM 1488 to the confluence with Upper Panther Branch and drains approximately 16 mi^2. The above three segments are entirely located in Montgomery County, Texas. To the east, Peach Creek (Segment 1011) serves as the boundary between San Jacinto and Montgomery Counties. It flows southeasterly from SH 150 in Walker County to the confluence with Caney Creek in Montgomery County. Peach Creek drains approximately 135 mi^2 in Walker, San Jacinto, Montgomery, and Liberty Counties. Much of Peach Creek's northern half is located inside the Sam Houston National Forest.

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

The 2012 *Texas Water Quality Integrated Report* (TCEQ, 2013) provides the following segment and AU descriptions for the water bodies considered in this document:

- Segment 1008B (Upper Panther Branch (unclassified water body)) – From the normal pool elevation of 125 feet of Lake Woodlands upstream to Old Conroe Road.
  - 1008B_01 – From Old Conroe Road to a point 0.22 miles (0.35 km) upstream of the Bear Branch confluence.
  - 1008B_02 – From a point 0.22 miles (0.35 km) upstream of the Bear Branch confluence to the confluence of Lake Woodlands.
- Segment 1008C (Lower Panther Branch (unclassified water body)) – From the Spring Creek confluence upstream to the dam impounding Lake Woodlands in Montgomery County.
  - 1008C_01 – From Spring Creek confluence upstream to Saw Dust Road.
  - 1008C_02 – From Saw Dust Road to the Lake Woodlands Dam.
- Segment 1008E (Bear Branch (unclassified water body)) – From Upper Panther Branch confluence to south of FM1488.
- Segment 1011 (Peach Creek) – From the confluence with Caney Creek in Montgomery County to SH 150 in Walker County.
  - 1011_01 – Upper segment boundary to US Hwy 59.

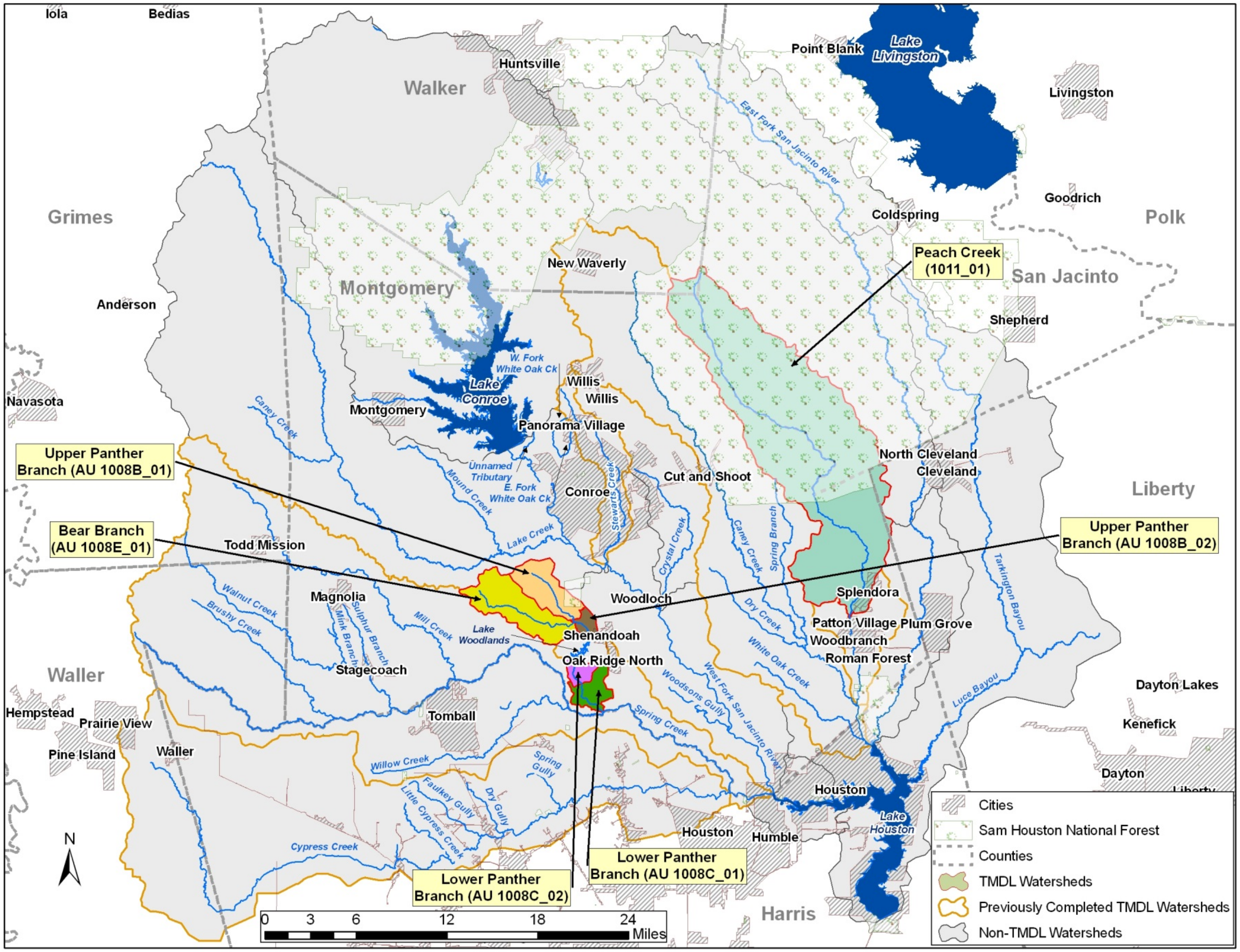

Figure 1 Lake Houston watershed, including Segments 1008B, 1008C, 1008E, and 1011

The 6 AUs listed above comprise the TMDL area addressed in this report. The phrase "TMDL watersheds" will be used when referring to the area of all 6 impaired AUs addressed in this report, and "Lake Houston watershed" will be used when referring to the combined TMDL and non-impaired watersheds comprising the watershed of Lake Houston in its entirety.

As an additional note, the boundary for the two AUs of Upper Panther Branch changed with the publication of the *2012 Texas Water Quality Integrated Report* (TCEQ, 2013). The wording from the 2010 *Texas Water Quality Integrated Report* (TCEQ, 2011b) indicated the two AUs met at the confluence of Bear Branch whereas the 2012 definition places the boundary 0.22 miles upstream of the confluence. In addition, the *2012 Texas Water Quality Integrated Report* reverses the geographic positions of the two AU numbers of Upper Panther Branch. Whereas the 2010 definition placed AU 1008B_02 upstream of 1008B_01, the 2010 definition places 1008B_02 downstream. The 2012 *Water Quality Integrated Report* provided definitions of the two AUs of Upper Panther Branch are used in this report.

2.2 Watershed Climate and Hydrology

The streams addressed by this project are located within the Lake Houston watershed of the San Jacinto River Basin. The southern part of the watershed includes portions of the City of Houston and its northern suburbs. The Woodlands and the City of Conroe are the largest municipalities located entirely within the watershed. Other smaller municipalities located in the watershed include Cut and Shoot, Magnolia, New Waverly, Pinehurst, Splendora, Tomball, and Waller. The northern part of the watershed is relatively rural, and includes portions of the Sam Houston National Forest.

The total drainage area for Lake Houston is 2,850 square miles. The TMDL watersheds are located primarily within Montgomery and San Jacinto Counties, but also include portions of Walker and Liberty Counties (Figure 1). Peach Creek forms the boundary between Montgomery and San Jacinto Counties.

The watershed is located within the Gulf Coastal Plain physiographic region. The southern portion of the watershed is relatively flat, and slopes toward the Gulf of Mexico. The northern portion of the watershed includes gently rolling hills where drainage patterns are more easily defined.

The watershed is also located entirely within the Gulf Coast Aquifer region. The aquifer consists of layers of clay, silt, sand, and gravel. The maximum total sand thickness of the aquifer is around 1,000 feet in the Houston area. Water extraction by pumping has resulted in significant decreases in aquifer levels and land-surface subsidence of up to nine feet in the Houston area (Ashworth, 1995).

The Lake Houston watershed is within the Upper Coast and East Texas climatic divisions. The Gulf of Mexico is the principal source of moisture that drives precipitation in the region. Annual average precipitation generally increases from west to east across the watershed. Annual average precipitation data (1997-2006) for key weather stations is provided in Table 1. These data were obtained through the USEPA BASINS program (USEPA, 2007). In 2007, the annual precipitation totals at Tomball, Conroe, and George Bush Intercontinental Airport were 53.2, 50.5, and 65.5 inches, respectively (NWS, 2008).

Table 1 Annual rainfall totals for Lake Houston Watershed (1997-2006)

Station ID	Location	Average (in.)
TX411810	Cleveland	57.2
TX411956	Conroe	51.1
TX412206	Cypress	50.2
TX414300	George Bush Intercontinental Airport	53.1
TX416024	Montgomery	47.7
TX416280	New Caney	55.4
TX419076	Tomball	51.3
	Overall Average	***52.3***

Temperature and precipitation in the study area vary throughout the year, with average temperatures in the low eighties in the summer to the low fifties in the winter. Maximum precipitation occurs in the late spring and autumn. It is not unusual for hurricanes and tropical storms to affect rainfall in the early autumn.

2.3 Review of Routine Monitoring Data for Upper and Lower Panther Branch, Bear Branch, and Peach Creek Watersheds

2.3.1 Data Acquisition

Ambient *E. coli* data were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS). The data represented the routine ambient *E. coli* and other water quality data collected in the project area. General assessment criteria methodologies established by TCEQ were used in data evaluations.

2.3.2 Analysis of Bacteria Data

Recent environmental monitoring within AUs 1008B_01, 1008B_02, 1008C_01, 1008C_02, 1008E_01, and 1011_01 has occurred at numerous TCEQ monitoring stations (Figures 2 and 3). *E. coli* data collected at these stations over the seven-year period of December 1, 2003 through November 30, 2010 were used in assessing attainment of the primary contact recreation use as reported in the *2012 Texas Integrated Report* (TCEQ, 2013). The 2012 assessment data indicate non-support of the primary contact recreation use because of geometric mean concentrations exceeding the geometric mean criterion of 126 MPN/100 mL for all assessed AUs within the Upper and Lower Panther Branch, Bear Branch, and Peach Creek study areas (Table 2).

Table 2 Integrated Report Summary for the watersheds of Upper and Lower Panther Branch, Bear Branch, and Peach Creek (Source: TCEQ, 2013)

Water Body	Assessment Unit (AU)	2012 Assessment No. of Samples	2012 Assessment Geometric Mean (MPN/100 mL)
Upper Panther Branch	1008B_01	28	158
Upper Panther Branch	1008B_02	28	246
Lower Panther Branch	1008C_01	28	198
Lower Panther Branch	1008C_02	28	157
Bear Branch	1008E_01	27	167
Peach Creek	1011_01	43	162

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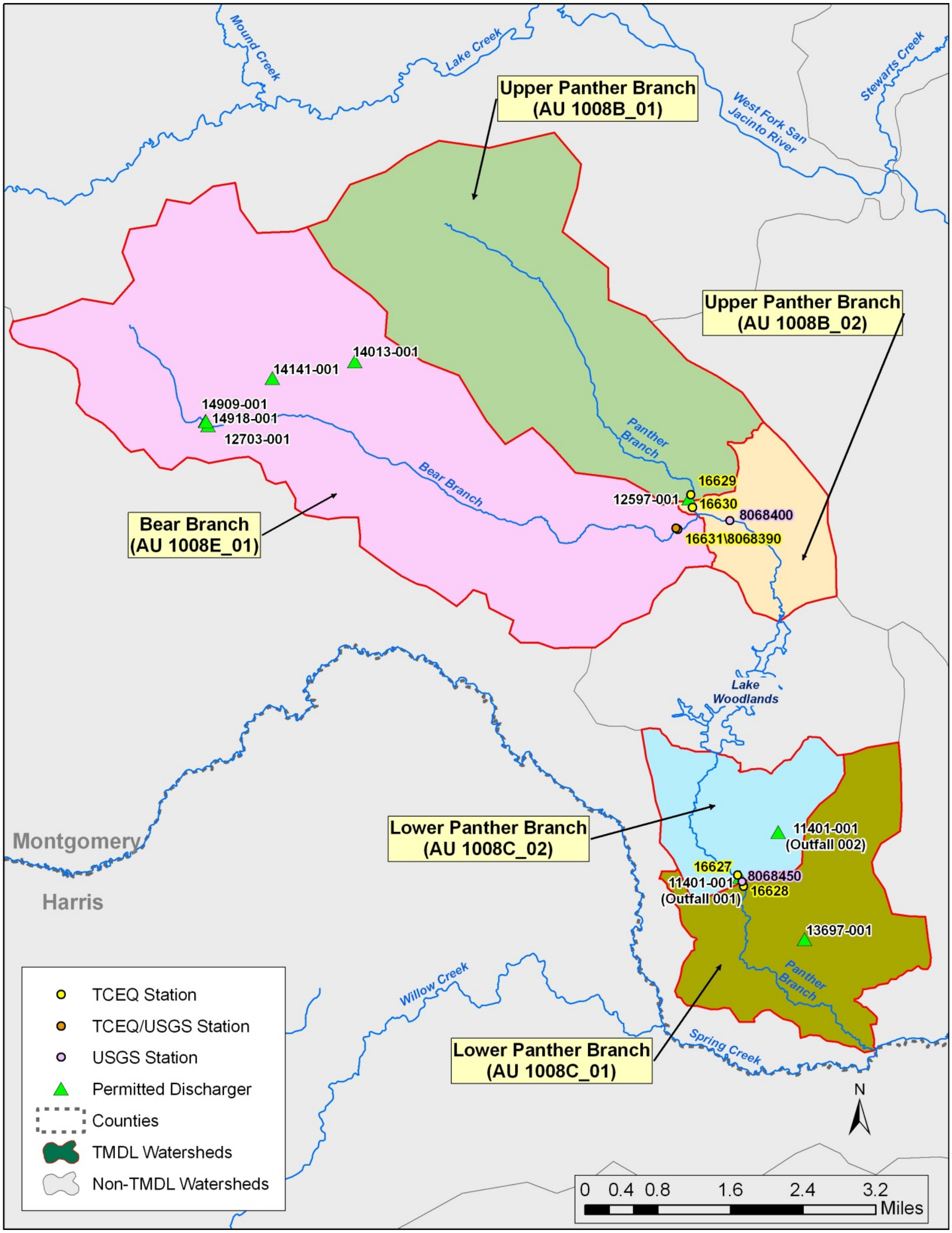

Figure 2 Upper and Lower Panther Branch, and Bear Branch watersheds showing permitted dischargers, SWQM monitoring stations

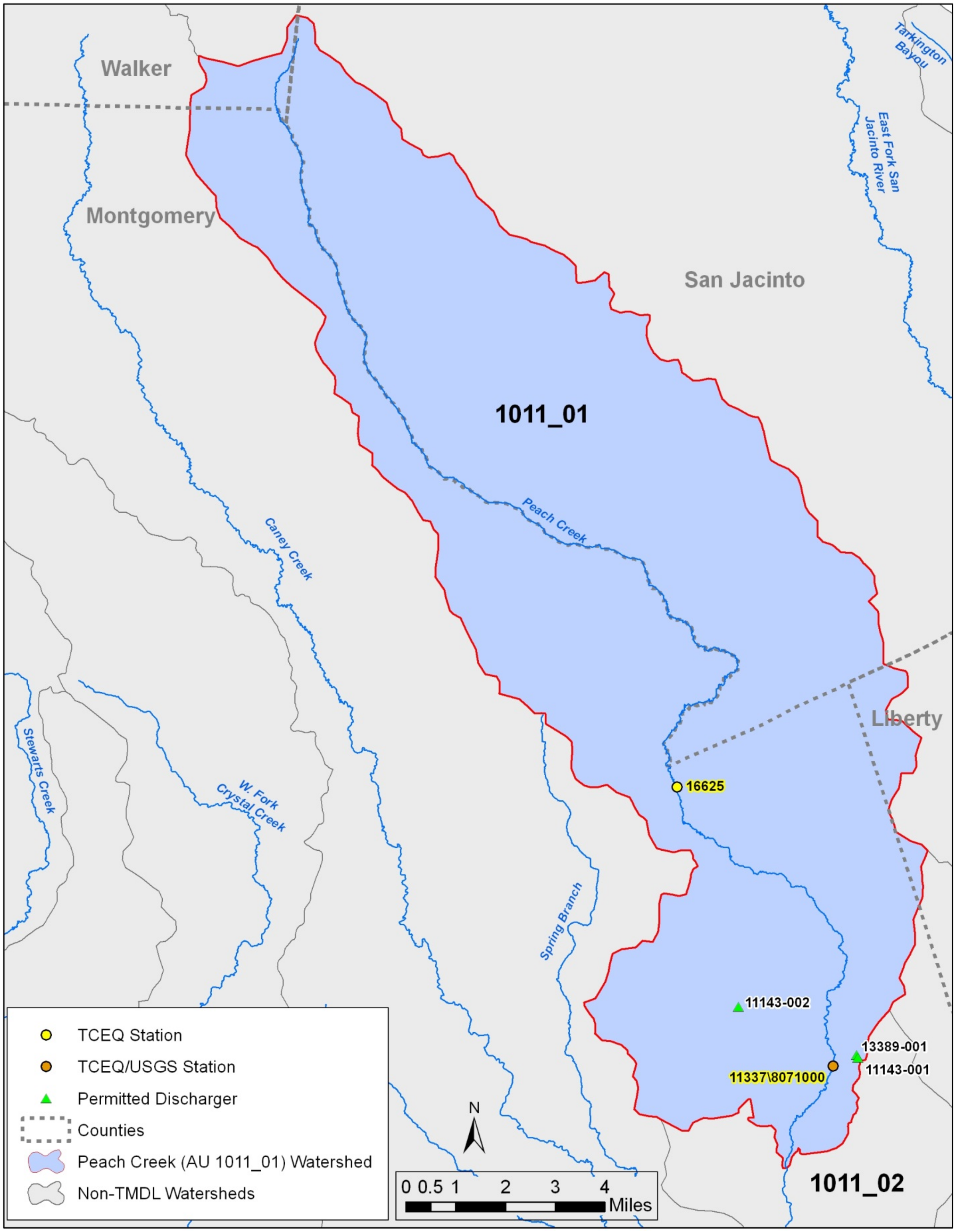

Figure 3 Peach Creek watershed showing permitted dischargers, SWQM monitoring stations and USGS streamflow gages

2.4 Land Use

The land use/land cover data presented in this report were obtained from the Houston-Galveston Area Council 2008 land cover dataset (H-GAC, 2008). The land use/ land cover is represented by the following categories and definitions:

- **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. 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 (Open 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.

- **Cultivated** – Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75% to 100% of the cover.

- **Grassland/Shrub** – Areas characterized by natural or semi-natural herbaceous and/or woody vegetation. Woody aerial stems are generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

- **Forest** – Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.

- **Woody Wetland** – 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.

- **Herbaceous Wetland** – 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.

- **Bare** – Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the green vegetated categories; lichen cover may be extensive.

- **Open Water** – Areas of open water, generally with less than 25% cover of vegetation or soil.

In reference to the broader Lake Houston watershed, the western portion is primarily cropland and pasture whereas forest and treed wetlands dominate the northern and eastern portions of the watershed (Figure 4, Table 3). The central and south-central portions of the watershed are more heavily developed and urbanized. Segments 1008B, 1008C and 1008E are primarily developed except for the northern half of 1008B_01 which is well forested (Tables 4 - 6). The upstream portion of Peach Creek watershed (1011_01) is largely parkland in the Sam Houston National Forest and thus contains only 7% developed or cultivated land while forest, shrubland, and wetlands, account for the remaining 93% of land cover (Table 7).

Table 3 Land use/land cover, entire Lake Houston watershed (Source: H-GAC, 2008)

Land Use	Lake Houston	
	Acres	%
Developed, High Intensity	110804.6	6.1%
Developed, Low Intensity	139043.4	7.7%
Developed, Open Space	12672.6	0.7%
Cultivated	327700.1	18.0%
Grassland/Shrub	295373.2	16.3%
Forest	607110.5	33.4%
Woody Wetland	252634.9	13.9%
Herbaceous Wetland	7797.2	0.4%
Bare	15901.5	0.9%
Open Water	46719.7	2.6%
Total Acres	***1815757.8***	

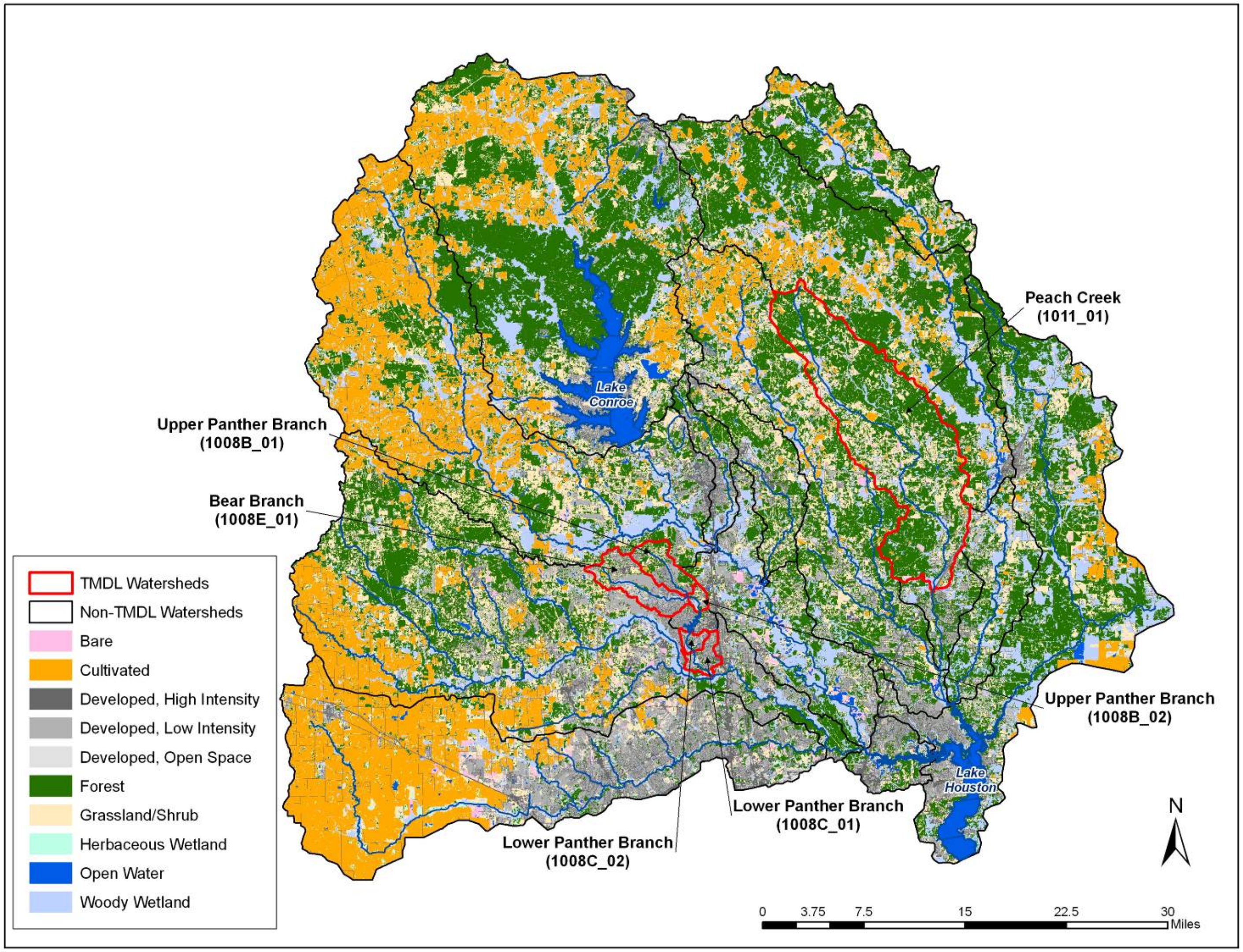

Figure 4 Land use/land cover in the Lake Houston Watershed (H-GAC, 2008)

Table 4 Land use/land cover, Segment 1008B (Source: H-GAC, 2008)

Land Use	1008B_01		1008B_02		1008B TOTAL	
	Acres	%	Acres	%	Acres	%
Developed, High Intensity	916.7	14.9%	309.4	19.1%	1226.1	15.8%
Developed, Low Intensity	1753.6	28.5%	437.3	27.0%	2190.8	28.2%
Developed, Open Space	3.7	0.1%	1.6	0.1%	5.3	0.1%
Cultivated	64.7	1.1%	0.0	0.0%	64.7	0.8%
Grassland/Shrub	1029.1	16.7%	326.8	20.2%	1355.9	17.4%
Forest	2107.0	34.2%	255.0	15.7%	2362.0	30.4%
Woody Wetland	224.7	3.6%	264.0	16.3%	488.6	6.3%
Herbaceous Wetland	3.8	0.1%	7.9	0.5%	11.7	0.2%
Bare	16.2	0.3%	0.0	0.0%	16.2	0.2%
Open Water	41.4	0.7%	19.6	1.2%	61.0	0.8%
Total Acres	***6160.9***		***1621.4***		***7782.3***	

Table 5 Land use/land cover, Segment 1008C (Source: H-GAC, 2008)

Land Use	1008C_01		1008C_02		1008C TOTAL	
	Acres	%	Acres	%	Acres	%
Developed, High Intensity	833.6	26.1%	376.5	23.3%	1210.1	25.2%
Developed, Low Intensity	1464.5	45.9%	771.8	47.8%	2236.3	46.6%
Developed, Open Space	75.9	2.4%	137.8	8.5%	213.6	4.4%
Cultivated	0.6	0.0%	0.0	0.0%	0.6	0.0%
Grassland/Shrub	163.1	5.1%	56.3	3.5%	219.4	4.6%
Forest	287.1	9.0%	113.4	7.0%	400.5	8.3%
Woody Wetland	330.5	10.4%	125.3	7.8%	455.8	9.5%
Herbaceous Wetland	0.8	0.0%	0.0	0.0%	0.8	0.0%
Bare	0.0	0.0%	0.0	0.0%	0.0	0.0%
Open Water	32.3	1.0%	32.4	2.0%	64.7	1.3%
Total Acres	***3188.5***		***1613.4***		***4801.9***	

Table 6 Land use/land cover, Segment 1008E (Source: H-GAC, 2008)

Land Use	1008E_01	
	Acres	%
Developed, High Intensity	1808.0	17.9%
Developed, Low Intensity	4522.8	44.8%
Developed, Open Space	291.3	2.9%
Cultivated	57.7	0.6%
Grassland/Shrub	1578.7	15.6%
Forest	1041.1	10.3%
Woody Wetland	647.6	6.4%
Herbaceous Wetland	12.3	0.1%
Bare	0.9	0.0%
Open Water	145.6	1.4%
Total Acres	***10106.0***	

Table 7 Land use/land cover, Segment 1011 (Source: H-GAC, 2008)

Land Use	1011_01	
	Acres	%
Developed, High Intensity	2400.0	2.8%
Developed, Low Intensity	2004.6	2.3%
Developed, Open Space	68.8	0.1%
Cultivated	1373.5	1.6%
Grassland/Shrub	20142.4	23.3%
Forest	48195.0	55.7%
Woody Wetland	10675.3	12.3%
Herbaceous Wetland	41.7	0.0%
Bare	1484.9	1.7%
Open Water	215.1	0.2%
Total Acres	***86601.4***	

2.5 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) and National Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities.

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

With the exception of WWTFs, which receive individual WLAs (report Section 4.7.2.3 - Regulated Wastewater Treatment Facility Computations), the regulated and unregulated sources in this section are presented to give a general account of the different sources of bacteria expected in the watershed. These are not meant to be interpreted as precise inventories and loadings.

2.5.1 Regulated Sources

Permitted sources are regulated by permit under the TPDES and the NPDES. WWTF outfalls and stormwater discharges from industries, construction, and MS4s represent the permitted sources in the Upper and Lower Panther Branch, Bear Branch, and Peach Creek watersheds.

2.5.1.1 Domestic and Industrial Wastewater Treatment Facility Discharges

All 11 regulated discharge facilities in the Upper and Lower Panther Branch, Bear Branch and Peach Creek watersheds treat domestic wastewater (Table 8; Figures 2 and 3). Within Lower Panther Branch (1008C_02) there is one WWTF with a permitted discharge of 7.8 million gallons per day (MGD). Within Lower Panther Branch (1008C_01) there is one WWTF with a permitted discharge of 0.003 MGD. There are five WWTFs that discharge into Bear Branch (1008E_01) with a total permitted discharge of 0.698 MGD. There is one WWTF that discharges into Upper Panther Branch (1008B_01) that has a permitted discharge of 7.8 MGD. Three WWTFs discharge into Peach Creek (1011_01) and have a combined permitted discharge of 0.38 MGD. No WWTFs are located within the watershed of the downstream AU of Upper Panther Branch (1008B_02).

Table 8 Permitted wastewater operations in Upper and Lower Panther Branch, Bear Branch, and Peach Creek watersheds

Actual Discharges are for the periods of record are generally 1999 – 2012, with significant exceptions noted.

TPDES Permit No.	NPDES Permit No.	Permittee	Facility	Effluent Type[a]	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
WQ0012597-001	TX0091715	San Jacinto River Authority	The Woodlands WWTP 2	WW	1008B_01	7.800	2.887
WQ0011401-001	TX0054186[b]	San Jacinto River Authority	Woodlands	WW	1008C_02	7.800	3.724
WQ0013697-001	TX0090000	Cedarstone One Investors Ltd.	Cedarstone WWTP	WW	1008C_01	0.003	0.001
WQ0014141-001	TX0120073	Aqua Texas Inc.	Old Egypt Regional Business Center	WW	1008E_01	0.450	0.067
WQ0014918-001	TX0131725[d]	Woodlands DB LP	Eaglestar WWTP	WW	1008E_01	0.100	0.019
WQ0014909-001	TX0131652[d]	Lincoln Manufacturing, Inc.	Lincoln Manufacturing	WW	1008E_01	0.050	0.010
WQ0014013-001	TX0118028[c]	AquaTexas Inc.	Greenfield Forest WWTP	WW	1008E_01	0.050	0.011
WQ0012703-001	TX0092843	Magnolia ISD	Bear Branch Plant	WW	1008E_01	0.048	0.010
WQ0013389-001	TX0102512	City of Splendora	City of Splendora WWTP	WW	1011_01	0.300	0.097
WQ0011143-001	TX0082511	Splendora ISD	Splendora Elementary School	WW	1011_01	0.040	0.022
WQ0011143-002	TX0117463	Splendora ISD	Splendora ISD WWTP	WW	1011_01	0.040	0.010

[a] WW = domestic wastewater treatment facility

[b] Represents the two outfalls at this facility. Pipe #2 in operation since Nov. 2007. (Both locations shown in southeast portion of Figure 2)

[c] Average measured discharge from Jul. 2005 through Nov. 2012.

[d] Average measured discharge from 2001 through 2010.

2.5.1.2 Sanitary Sewer Overflows

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

The TCEQ Region 12 Office maintains a database of SSO data reported by municipalities. This SSO data typically contains an estimate of the total gallons spilled, responsible entity, and a general location of the spill. The dataset covers late 2001 - January 2013 and no SSOs were reported for the areas covered by the permits in the Upper and Lower Panther Branch, Bear Branch, and Peach Creek watersheds. It is possible that SSOs are being under reported in these watersheds as some data would have been anticipated over the period covered in the dataset.

2.5.1.3 TPDES-Regulated Stormwater

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

1) stormwater subject to regulation, which is any stormwater originating from TPDES-regulated Phase I or Phase II MS4, stormwater discharges associated with industrial activities, and stormwater discharges from regulated construction activities; and

2) stormwater runoff not subject to regulation.

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

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge detection and elimination;

- Construction site runoff control;
- Post-construction runoff control; and
- Pollution prevention/good housekeeping.

The geographic region of the TMDL watersheds covered by Phase I and II MS4 permits is that portion of the area within the jurisdictional boundaries of the regulated entity. For Phase I permits the jurisdictional area is defined by the city limits, and for current Phase II permits the jurisdictional area is defined as the intersection or overlapping areas of the city limits and the 2000 Census Bureau Urbanized Area. The process for renewal of the Texas general permit for Phase II MS4s was ongoing at the time of this report. The proposed language for the general permit renewal bases the Phase II permittees jurisdictional areas on the larger of the 2000 and 2010 Urbanized Areas.

The 2010 Urbanized Area is used in these TMDLs to represent the areas under stormwater regulation for construction, industrial, and Phase II MS4 permits (Figure 5; USCB, 2010). The TMDL watersheds contain entities that are regulated under Phase II general permits and no Phase I entities (Table 9). Using the 2010 Urbanized Area as the basis of computation, the percentage of land area under the jurisdiction of stormwater permits for each of the TMDL watersheds is presented in Table 10.

2.5.1.4 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 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.

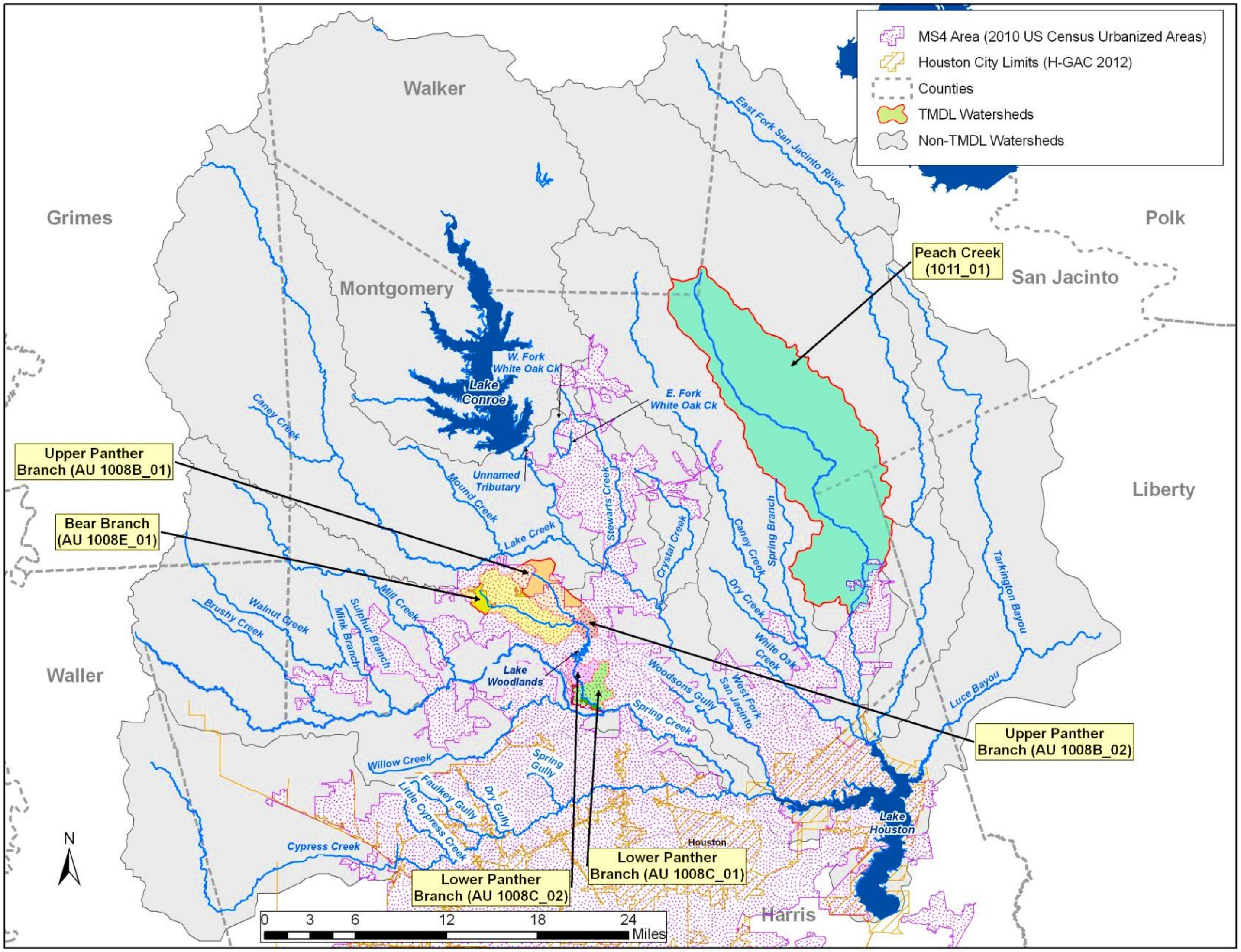

Figure 5 Upper and Lower Panther Branch, Bear Branch, and Peach Creek watersheds showing 2010 Urbanized Areas (Source: USCB, 2010 & H-GAC, 2012)

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.

Table 9 TPDES MS4 permits associated with TMDL area watersheds

Entity	Permit Number	AU
The Woodlands Joint Powers Agency MS4	TXR040256	1008B_01, 1008B_02, 1008C_01, 1008C_02, 1008E_01
Montgomery County MS4	TXR040348	1008B_01, 1008B_02, 1008C_01, 1008C_02, 1008E_01, 1011_01
City of Shenandoah MS4	TXR040210	1008B_02
City of Oak Ridge North MS4	TXR040273	1008C_01
Southern Montgomery County MUD MS4	TXR040122	1008C_01
Montgomery County MUD 19 MS4	TXR040123	1008C_01

Table 10 Estimated area under stormwater permit regulations for TMDL watersheds

AU	AU Area within 2010 Urbanized Areas (ha)	AU watershed area (ha)	Percentage of drainage area under stormwater regulation (%)
1008B_01	3,763	6,406	58.7
1008B_02	1,377	1,377	100
1008C_01	2,897	3,188	90.8
1008C_02	1,598	1,613	99.0
1008E_01	9,028	10,106	89.3
1011_01	1,312	86,601	1.51

2.5.1.5 Review of Information on Permitted Sources

A review conducted March 21, 2013, of the USEPA Enforcement & Compliance History Online (ECHO) did not reveal any non-compliance issues regarding *E. coli* permit limits for the WWTFs located in the TMDL watersheds.

2.5.2 Unregulated Sources

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

2.5.2.1 Wildlife and Unmanaged Animal Contributions

E. coli bacteria 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.

2.5.2.2 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 (Weiskel, 1996). Reed, Stowe, and Yank (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. The TMDL watersheds are located within two of geographic regions in this report; the east-central Texas area has a reported failure rate of about 12 percent and the far-east Texas failure rate is about 19 percent, which provide insight into expected failure rates in these watersheds.

Estimates of the number of OSSFs in the Lake Houston watershed were determined using H-GAC supplied data and 911-address information for Grimes and San Jacinto Counties, which are outside the 13-county region of the H-GAC. For Harris and Montgomery Counties, the H-GAC data included registered OSSFs since 1970, and for Walker, Waller, and Liberty Counties the registration of facilities began in 1989. Further, H-GAC supplied data included estimated OSSF locations that pre-dated registration requirements. For Grimes and San Jacinto Counties, the approach to estimate OSSFs was to obtain a GIS layer of the 911 addresses from each county, limit the area considered to that portion of each county in the Lake Houston watershed, and exclude all addresses that were not designated residential or business. The TCEQ GIS layer of Certificates of Convenience and Necessity (CCN) and the H-GAC Service Area Boundaries (SAB) layer for wastewater service was then overlain and all 911 addresses within a CCN or SAB service area were assumed to be on a centralized wastewater collection system. Each remaining 911 address was assumed to have an OSSF. Estimated densities of OSSFs are provided in Figure 6, and an estimate of the number of OSSFs in each AU of the TMDL watersheds is provided in Table 11.

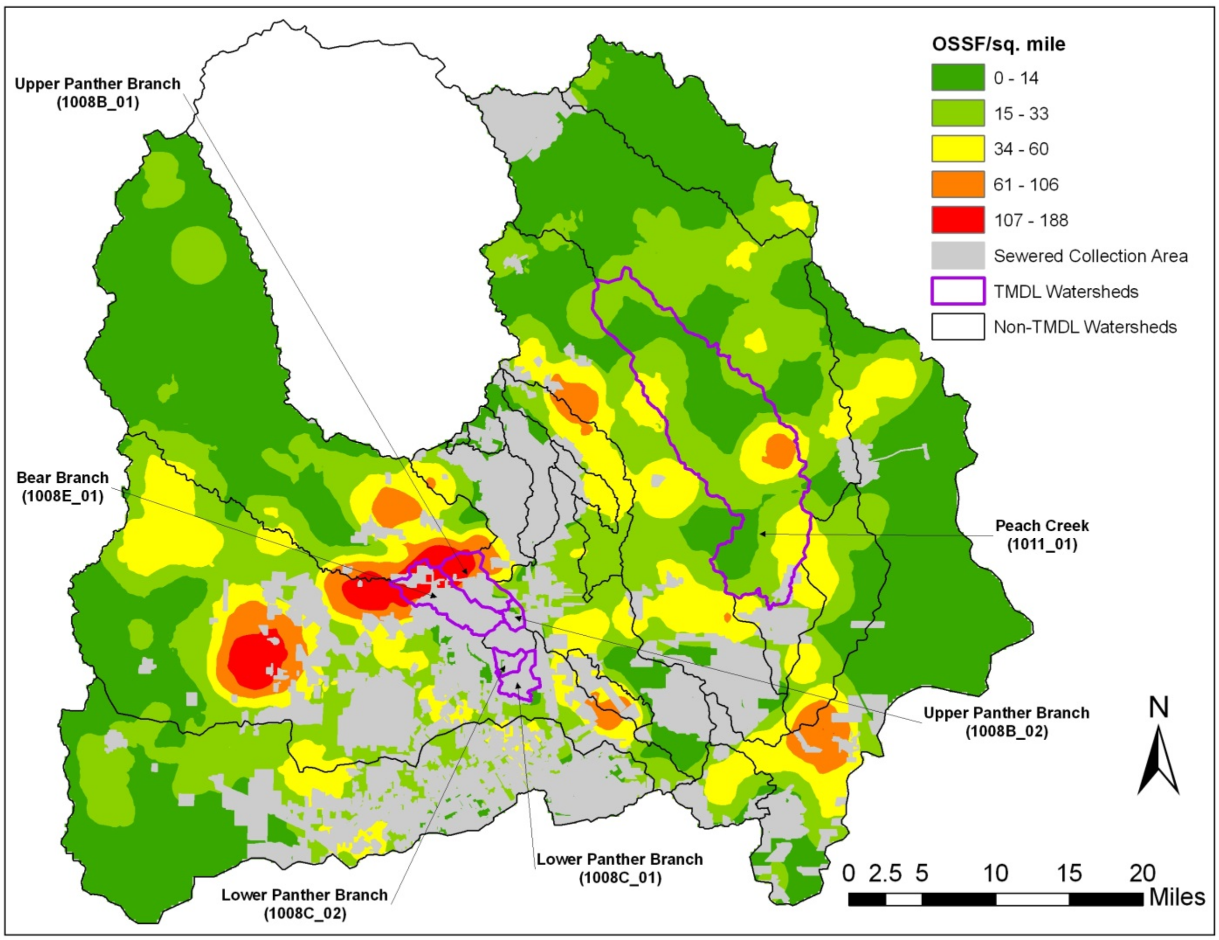

Figure 6 OSSF densities within the Lake Houston watershed

Table 11 OSSF estimates for TMDL watersheds

AU	OSSFs
1008B_01	785
1008B_02	86
1008C_01	6
1008C_02	22
1008E_01	1,474
1011_01	2,880

2.5.2.3 Non-Permitted Agricultural Activities and Domesticated Animals

The number of livestock that are found within the TMDL watersheds was estimated from county level data obtained from the 2007 Census of Agriculture (USDA, 2007). The County level data was refined to better reflect actual numbers within each impaired AU watershed. The refinement was performed by determining the total area of each County and each impaired AU that was designated as un-urbanized by the 2010 U.S. Census. A ratio was then developed by dividing the un-urbanized area of the AU that resides within a County by the total un-urbanized area of the County. This ratio was then applied to the County level data (Table 12). Activities, such as livestock grazing close to water bodies and farmers' use of manure as fertilizer, can contribute *E. coli* to nearby water bodies. The livestock numbers in Table 12 are provided to demonstrate that livestock are a potential source of bacteria in the watersheds of AU1008B_01 and AU 1011_01, but less likely a significant source in the other watersheds. These livestock numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

Pets can also be sources of *E. coli* bacteria, because storm runoff carries the animal wastes into streams (USEPA, 2009). The number of domestic pets in the Upper and Lower Panther Branch, Bear Branch, and Peach Creek watersheds was estimated based on human population and number of households for year 2013 obtained from the H-GAC regional growth forecast (H-GAC, 2005) The information obtained from the H-GAC included population and household projections based on the census for tracts that encompassed the watersheds of each AU. The tract level data were multiplied by the proportion of each census tract within the watershed to generate an estimate of the watershed's population and number of households. This estimation assumes that the population/households are uniformly distributed within the area of each census tract, which is the best estimate that can be made with the available data.

Table 12 Livestock statistics estimates for Upper and Lower Panther Branch, Bear Branch, and Peach Creek watersheds

(Estimated livestock numbers less than 10 reported as <10; estimates based on data from USDA, 2007)

AU	Cattles and Calves	Hogs and Pigs	Chickens	Other Poultry	Horses and Ponies	Sheep and Goats
1008B_01	399	10	136	14	109	53
1008B_02*	<10	<10	<10	<10	<10	<10
1008C_01+	10	<10	<10	<10	<10	<10
1008C_02	<10	<10	<10	<10	<10	<10
1008E_01	49	<10	17	<10	13	<10
1011_01	3911	106	572	64	160	157

* AU 1008B_02 is entirely within an area defined as Urbanized Area by the 2010 U.S. Census

+ The areas of AUs 1008C_01, 1008C_02, and 1008E_01 are mostly urbanized

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 13 summarizes the estimated number of dogs and cats for each segment of the TMDL watersheds. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.632) per household (AVMA, 2012). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the TMDL watersheds is unknown.

Table 13 Estimated households and pet populations within TMDL watersheds for the year 2013

AU	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
1008B_01	4,154	2,625	2,962
1008B_02	930	588	662
1008C_01	6,708	4,240	4,783
1008C_02	3,971	2,510	2,831
1008E_01	10,345	6,538	7,376
1011_01	6,397	4,043	4,561

2.5.2.4 Bacteria Survival and Die-off

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

SECTION 3

BACTERIA TOOL DEVELOPMENT

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

3.1 Model Selection

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

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 for representation of governing physical processes that determine the response of certain variables, such as streamflow and bacteria concentration such as precipitation. Under circumstances where the governing physical processes are acceptably quantifiable, the mechanistic model provides 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 load duration curve (LDC) method allows for estimation of existing and allowable loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, the load duration curve method allows for the determination of the hydrologic conditions under which impairments are typically occurring. This information can be used to identify broad categories of sources (point and nonpoint) that may be contributing to the impairment. The LDC method has found relatively broad acceptance among the regulatory community, primarily due to the simplicity of the approach and ease of application. The regulatory community recognizes the frequent information limitations with bacteria TMDLs that constrain use of the more powerful mechanistic models. Further, the bacteria task force appointed by the TCEQ and the Texas State Soil and Water Conservation Board (TSSWCB) supports application of the load duration curve method within their three-tiered approach to TMDL development (TWRI, 2007). The LDC method lacks the predictive capabilities to evaluate alternative allocation approaches to reach TMDL goals, nor can it be used to quantify specific source contributions and instream fate and transport processes. The method does, however, provide 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

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

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

While admittedly the hydrologic processes requiring simulation are complex, these processes are generally better understood and more readily simulated within needed levels of confidence by a mechanistic model than the bacterial processes. The hydrologic processes regarding response of the landscape to rainfall are well studied over many decades because of implications on transport of waterborne constituents, of which bacteria is only one of many. But even more importantly, these hydrologic processes are well investigated because of needs to design reservoirs and flood-control structures, define floodplains, and design the myriad of other structures required to direct and retain stormwater in both urban and rural situations. While each watershed is unique, the experienced hydrologist is able to readily and successfully apply these mechanistic models to most watersheds.

Mechanistic bacteria modeling has evolved 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, whether or not there are failed on-site treatment systems, such as septic systems, in a watershed rarely makes measurable differences to streamflow, but can dramatically impact *E. coli* concentrations present in the same streamflow. In the vast majority of circumstances, 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. Compounding implications of these data limitations, the bacteria concentrations and loadings predicted by the model, which potentially contain high uncertainty, will of necessity be used in direct comparison to the relevant numeric criteria that protect the contact recreation use.

3.1.2 Lake Houston Watershed Data Resources

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

Hydrologic data in the form of daily streamflow records are collected and made readily available by the U.S. Geological Survey (USGS), which operates four streamflow gauges in the watersheds of the impaired AUs (Table 14; Figures 2 and 3). USGS streamflow gauge 08068400 is located on Upper Panther Branch and serves as the primary source for streamflow records used in this document for AUs 1008B_01, 1008B_02, and 1008E_01. USGS streamflow gauge 08068450 is located on Lower Panther Branch and is the source for streamflow records for AUs 1008C_01 and 1008C_02. USGS streamflow gauge 08071000 is located on Peach Creek and serves as the source of streamflow records for AU 1011_01.

Table 14 Basic information on USGS streamflow gauges in project area

Gauge No.	Site Description	AU Location	Drainage Area (sq. mi.)	Daily Streamflow Record (beginning & end date)
08068400	Panther Branch at Gosling Rd., The Woodlands, TX	1008B_02	25.9	Aug. 1974 – Oct. 2012*
08068450	Panther Branch near Spring, TX	1008C_02	34.5	Apr. 1972 – present *
08068390	Bear Branch at Research Blvd., The Woodlands, TX	1008E_01	15.4	Jan. 1999 -- present
08071000	Peach Creek at Splendora, TX	1011_01	117	Oct. 1943 – present

* Streamflow available was not available from 1977 through 1998

Self-reporting data in the form of monthly discharge information were available for the 11 WWTFs located within the TMDL watersheds.

Ambient *E. coli* data used for the 2010 Texas Water Quality Inventory was provided by TCEQ. Additional historical ambient *E. coli* data used for development of LDCs was obtained through the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) and was used in developing LDCs for stations within the TMDL watersheds (Table 15).

Table 15 Summary of historical data set of *E. coli* concentrations

Only those stations with 24 or more E. coli data values are presented in the table.

Water Body	Assessment Unit (AU)	Station	Station Location	No. of Samples	Data Date Range
Upper Panther Branch	1008B_01	16629	80 m upstream of San Jacinto River Authority outfall (WQ12597-001)	40	2002-2012
	1008B_02	16630	170 m downstream of San Jacinto River Authority outfall (WQ12597-001)	40	2002-2012
Lower Panther Branch	1008C_01	16628	91 m downstream of Sawdust rd., 180 m downstream of San Jacinto River Authority WWTF outfall (WQ11401-001)	39	2002-2012
	1008C_02	16627	180 m upstream of Sawdust rd., 50 m upstream of San Jacinto River Authority WWTF outfall (WQ11401-001)	39	2002-2012
Bear Branch	1008E_01	16631	Research Forest Drive	40	2002-2012
Peach Creek	1011_01	16625	Old Hwy 105	67	2000-2012

3.1.3 Allocation Tool Selection

Based on good availability of historical daily streamflow records, discharge information for 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 load duration curve method as opposed to a mechanistic watershed loading and hydrologic/water quality model.

3.2 Methodology for Flow Duration & Load Duration Curve Development

To develop the flow duration curves (FDCs) and load duration curves (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 WWTF discharge monitoring report (DMR) 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. A significant amount of streamflow data was not available at USGS gauges located on Lower and Upper Panther Branch (08068400 and 08068450) from 1977 through 1998 while the USGS gauge located on Peach Creek (0807100) had a complete flow record that dated back to 1944.

Optimally the period of record to develop flow duration curves should include as much data as possible in order to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of conditions experienced when the *E. coli* data were collected. A 10-year period of record from January 2001 through December 2010 was selected. This 10-year period of record was 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

The stations for which adequate *E. coli* data were available (see Table 15) determined the stream locations for which flow and bacteria load duration curves would be developed. Stations with at least 24 *E. coli* data points were deemed as having an adequate amount of data for load duration curve development. These stations were located within the impaired reaches within each AU.

Even small lakes alter streamflow through detention and evaporation. The location of Lake Woodlands (Segment 1008F) between the lower boundary of Upper Panther Branch and upper boundary of Lower Panther Branch (Figure 2) sufficiently alters flow between these two unclassified segment to necessitate the development of flow and load duration curves at the outlet of this lake. Streamflow and loadings were determined for the outlet of Lake Woodlands and serve as an upstream loading entering Lower Panther Branch (1008C_02)

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 10-year 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 presence of WWTFs that discharge into the TMDL watersheds (Table 8) complicates the use of USGS streamflow records for developing flow and load duration curves: These facilities should be evaluated at their full permitted daily average discharge limits within the TMDL allocation process.

The method to develop the necessary streamflow record for each LDC location involved a modified drainage-area ratio approach. With this basic approach, each daily streamflow value at a USGS gauge is multiplied by a factor to estimate the flow at a station. The factor is determined by dividing the drainage area above the sampling station by the drainage area above the USGS gauge (Table 16). Further WWTFs are evaluated at their full permitted discharge as listed in Table 8, and their contributions to streamflow are accumulated in a downstream direction.

Because an assumption of the drainage area ratio approach is similarity of hydrologic response based on commonality of landscape features such as geology, soils, and land use/land cover, point source derived flows should first be removed from the flow record prior to application of the ratio. To address this complication within the TMDL watersheds, the discharges from WWTFs located above a USGS gauge were removed (subtracted) prior to applying the drainage area ratio. In practice this complication was addressed by determining the average discharge for each WWTF located above relevant USGS gauges. The average discharge for each needed WWTF was computed by averaging the data obtained from the TCEQ ICIS database and the USEPA Enforcement and Compliance History Online database (http://www.epa-echo.gov/echo/). The WWTF discharge data from these two sources included the period of 1999 – 2012. These two databases contain summaries of the discharge monitoring report data, which are a reporting requirement of all permitted discharge facilities under TPDES and NPDES. These computed discharge averages were subtracted from each daily record of a USGS gauge.

Table 16 DARs for locations within the TMDL watersheds

Assessment Unit	Sampling Station	USGS Gauge	Station Drainage Area(ac)	USGS Gauge Drainage Area (ac)	DAR
1008B_01	16629	08068400	6,158	16,662	0.370
1008B_02	16630	08068400	6,413	16,662	0.385
1008C_01	16628	08068450	22,925	22,921	1.00
1008C_02	16627	08068450	22,876	22,921	0.998
1008E_01	16631	08068400	9,929	16,662	0.596
1008F	Outlet	08068450	21,308	22,921	0.930
1011_01	16625	0871000	50,338	75,634	0.666

To account for WWTFs at their daily permitted discharge limit, as required in the TMDL, the drainage area ratio approach was applied at each FDC location and to that calculated streamflow record was added the summation of the full permitted daily average discharges from all upstream WWTFs.

3.2.4 Step 4: Flow Duration Curve and Load Duration Curve Methods

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

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

Further, when developing a LDC:

- multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 MPN/100 mL) and by a conversion factor ($2.44658x10^7$), which gives a loading in units of MPN/day; and
- plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of *E. coli*.

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

- using the unique data for each monitoring station, compute the daily loads for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding streamflow on that day and the conversion factor ($2.44658x10^7$); 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 times daily streamflow) display the frequency and magnitude that measured loads exceed the maximum allowable loadings for the geometric mean criterion. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

3.3 Flow Duration Curves for Sampling Stations within TMDL Watersheds

FDCs were developed for monitoring stations within the TMDL watersheds (Figures 7 through 12). In addition an FDC was developed for the outlet of un-impaired Lake Woodlands (1008F) that enters Lower Panther Branch (1008C_02. For this report, FDCs were developed by applying the DAR method and using the USGS gauges and period of record (2001-2010) described in the previous sections. Flow exceedances less than 30% typically represent streamflows influenced by storm run-off while higher flow exceedances represent nearly constant base flow conditions that are maintained as a result of WWTF discharges.

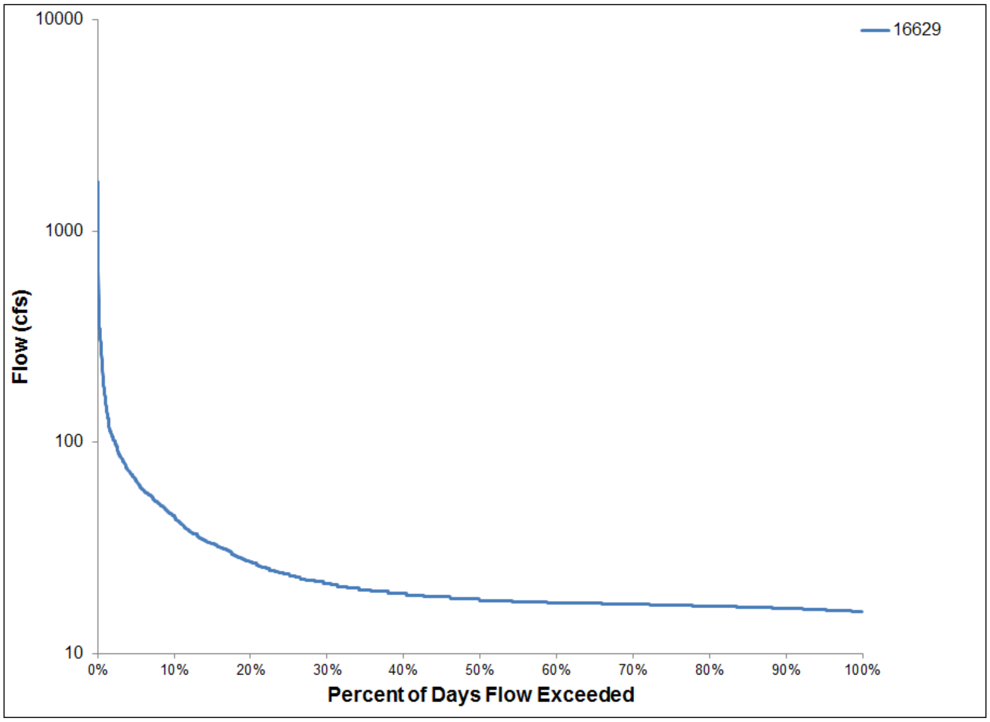

Figure 7 Flow duration curve at the monitoring station on Upper Panther Branch (1008B_01)

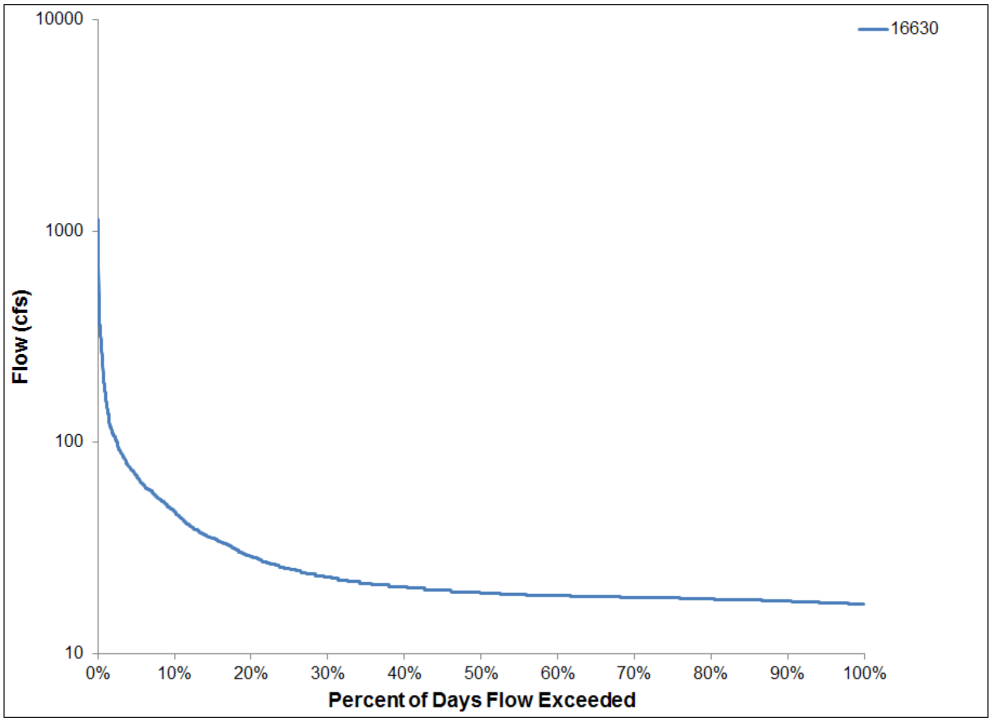

Figure 8 Flow duration curve at the monitoring station on Upper Panther Branch (1008B_02)

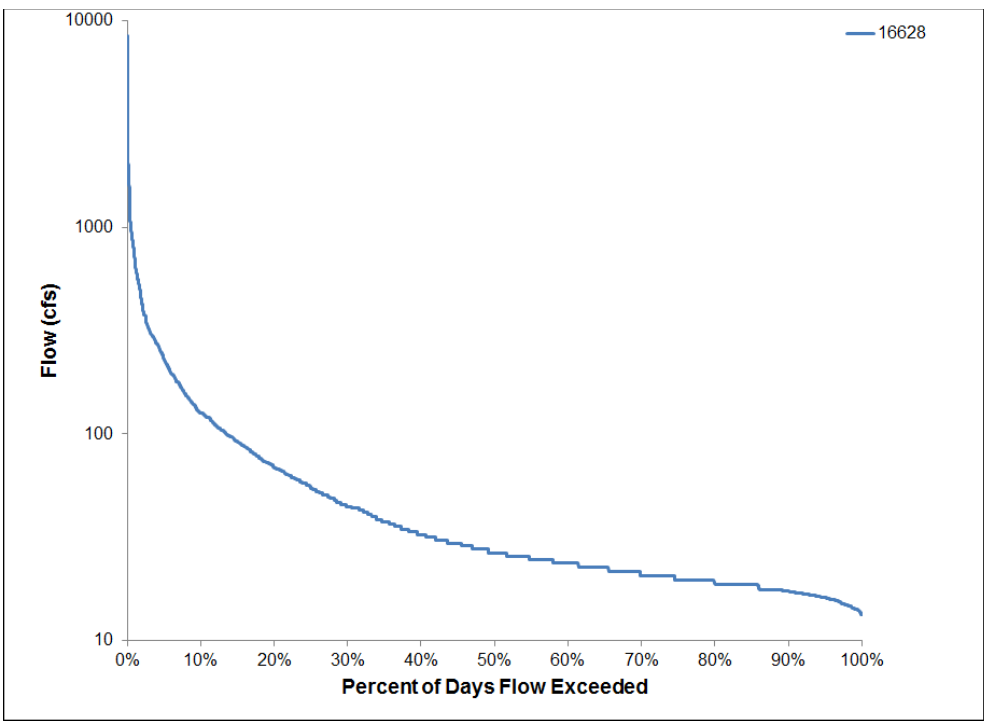

Figure 9 Flow duration curve at the monitoring station on Lower Panther Branch (1008C_01)

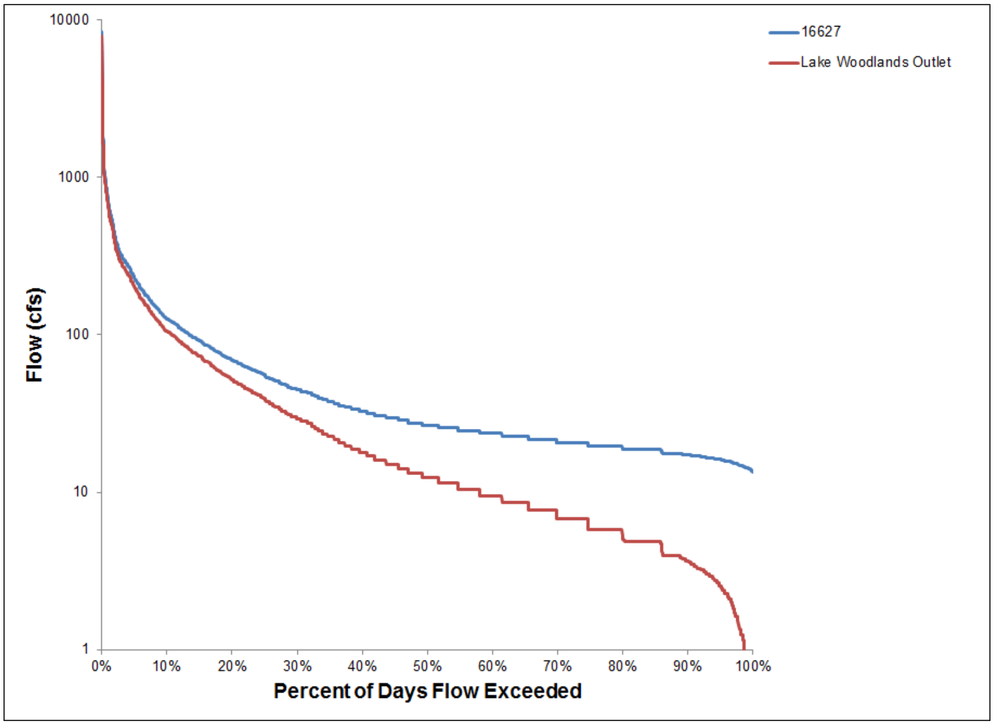

Figure 10 Flow duration curves at the monitoring station on Lower Panther Branch (1008C_02) and the outlet of Lake Woodlands (1008F)

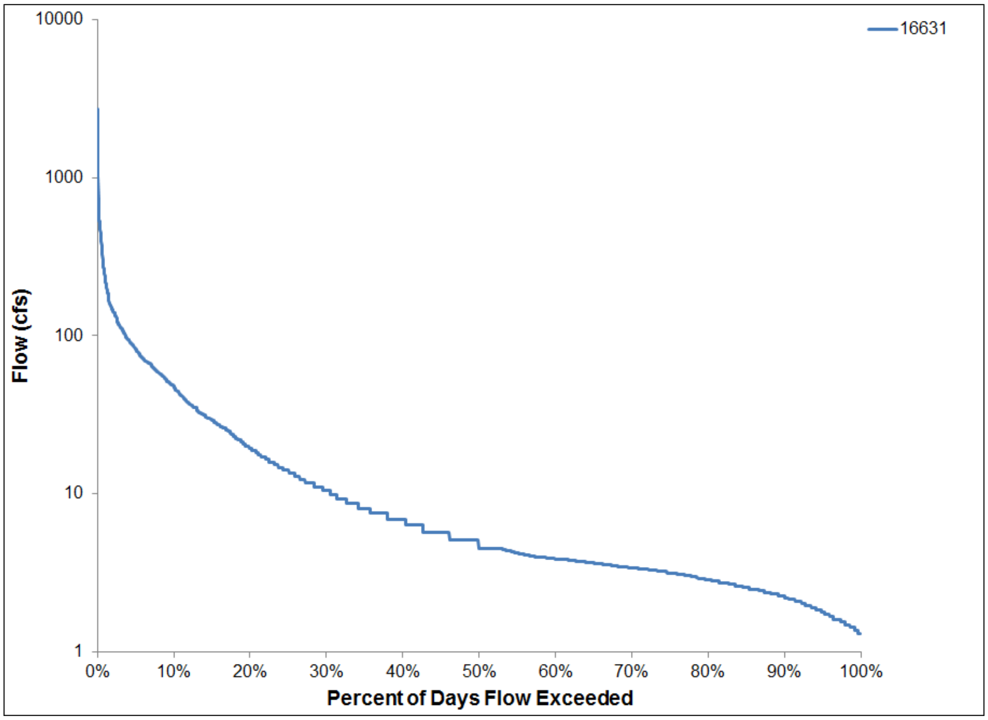

Figure 11 Flow duration curve at the monitoring station on Bear Branch (1008E_01)

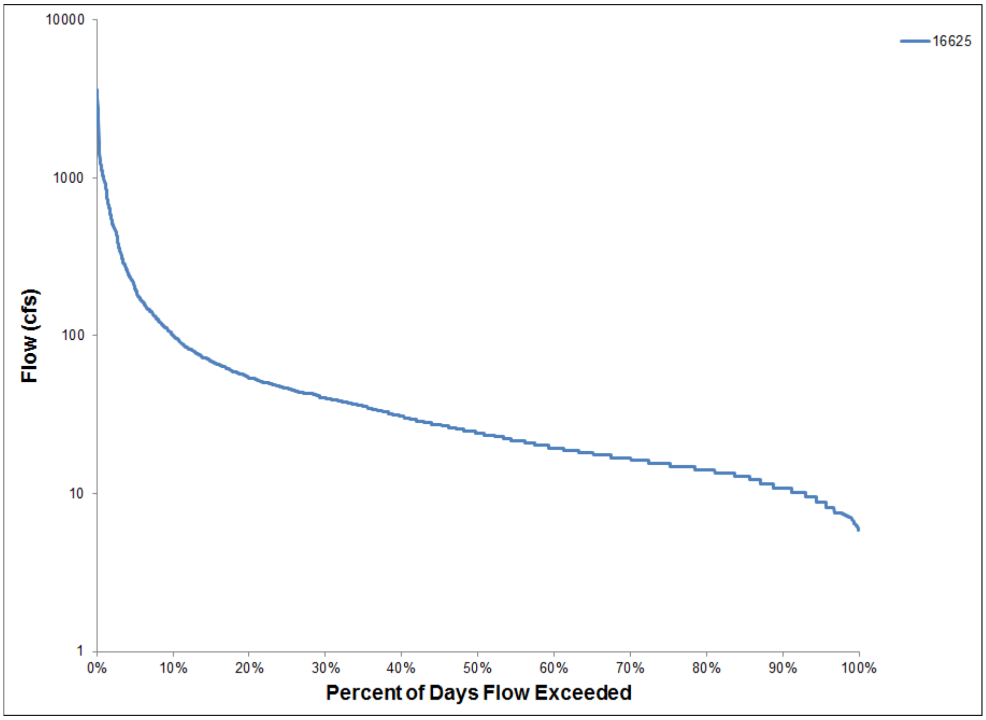

Figure 12 Flow duration curve at the monitoring station on Peach Creek (1011_01)

3.4 Load Duration Curves for Monitoring Stations within the TMDL Watersheds

LDCs were developed for each monitoring station within the TMDL watersheds. A useful refinement of the LDC approach is to divide the curve into flow-regime regions to analyze exceedance patterns in smaller portions of the duration curves. This approach can assist in determining streamflow conditions under which exceedances are occurring. Stream flow distribution has been divided into three flow regimes: Wet, Moderate, and Dry conditions. Wet conditions correspond to large storm-induced 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 17).

Table 17 Flow Regime Classifications

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

The load duration curves with these three flow regimes for water quality monitoring stations are provided in Figures 13 through 18, and were constructed for developing the TMDL allocation for each of the TMDL watersheds. Geometric mean loadings for the data points within each flow regime have also been distinguished on each figure to aid interpretation. The LDCs for the water quality monitoring stations provide a means of identifying the streamflow conditions under which exceedances in *E. co*li concentrations have occurred. The LDCs depict the allowable loadings at the stations under the geometric mean criterion (126 MPN/100 mL) and show that existing loadings often exceed the criterion. In addition, the LDCs also present the allowable loading at the stations under the single sample criterion (394 MPN/100 mL) and the allowable loading for WWTFs at one-half the geometric mean criterion (63 MPN/100 mL). For purposes of the pollutant load computations presented in Section 4.7, the hydrologic records for the FDCs and subsequent allowable loads from the LDCs are adjusted to reflect future capacity estimates that account for the probability that additional flows from WWTF discharges may occur as a result of future population increases in the TMDL watersheds. The measured *E. coli* concentrations and associated daily streamflow used to develop the loadings for measured data on each LDC are provided in Appendix A.

On each graph the measured *E. coli* data are presented as associated with a "wet weather event" or a "non-wet weather event." A sample was determined to be influenced by a wet weather event based on the reported "days since last precipitation" (DSLP) as noted on field data sheets associated with each sampling event. DSLP (TCEQ water quality parameter code 72053) is a field parameter that may be noted during a sampling event to inform of the general climatic conditions. A sample taken with a DSLP value of 2 or less 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.

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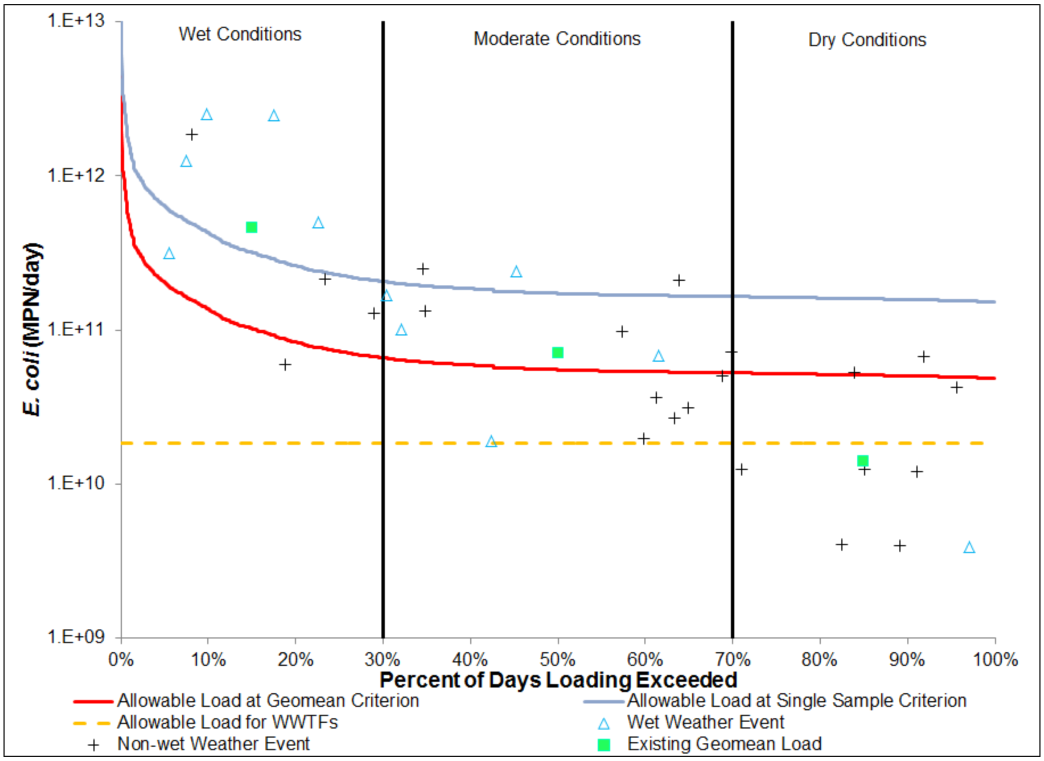

Figure 13 Load duration curve for station 16629, Upper Panther Branch (1008B_01)

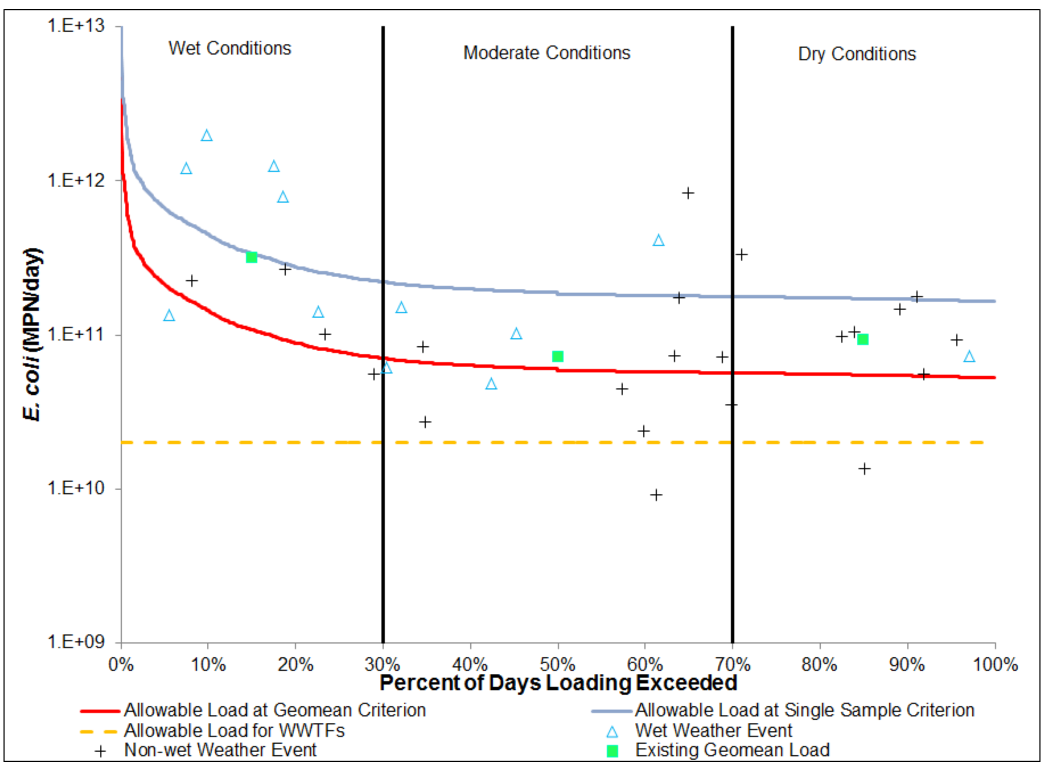

Figure 14 Load duration curve for station 16630, Upper Panther Branch (1008B_02)

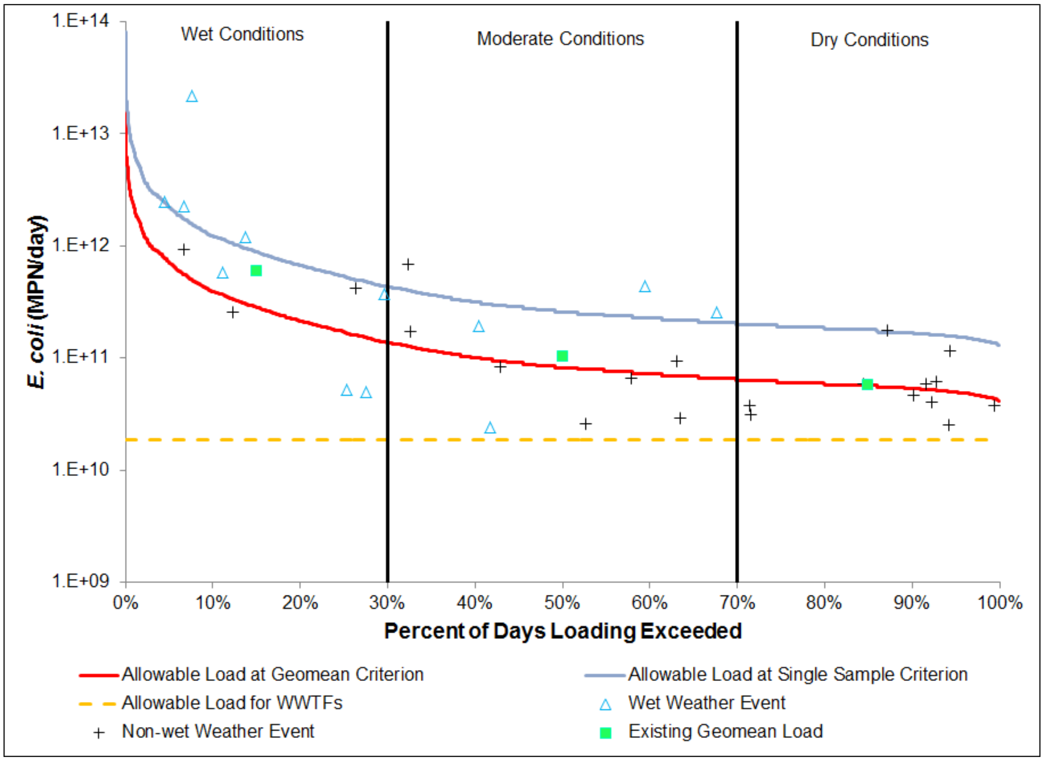

Figure 15 Load duration curve for station 16628, Lower Panther Branch (1008C_01)

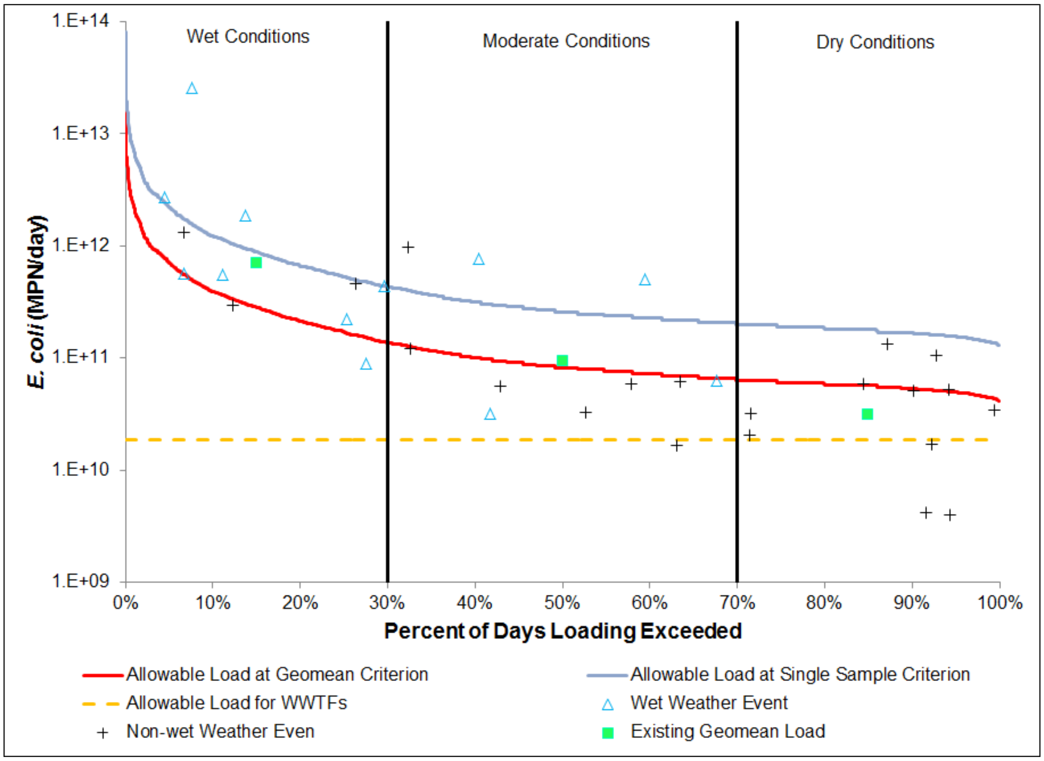

Figure 16 Load duration curve for station 16627, Lower Panther Branch (1008C_02)

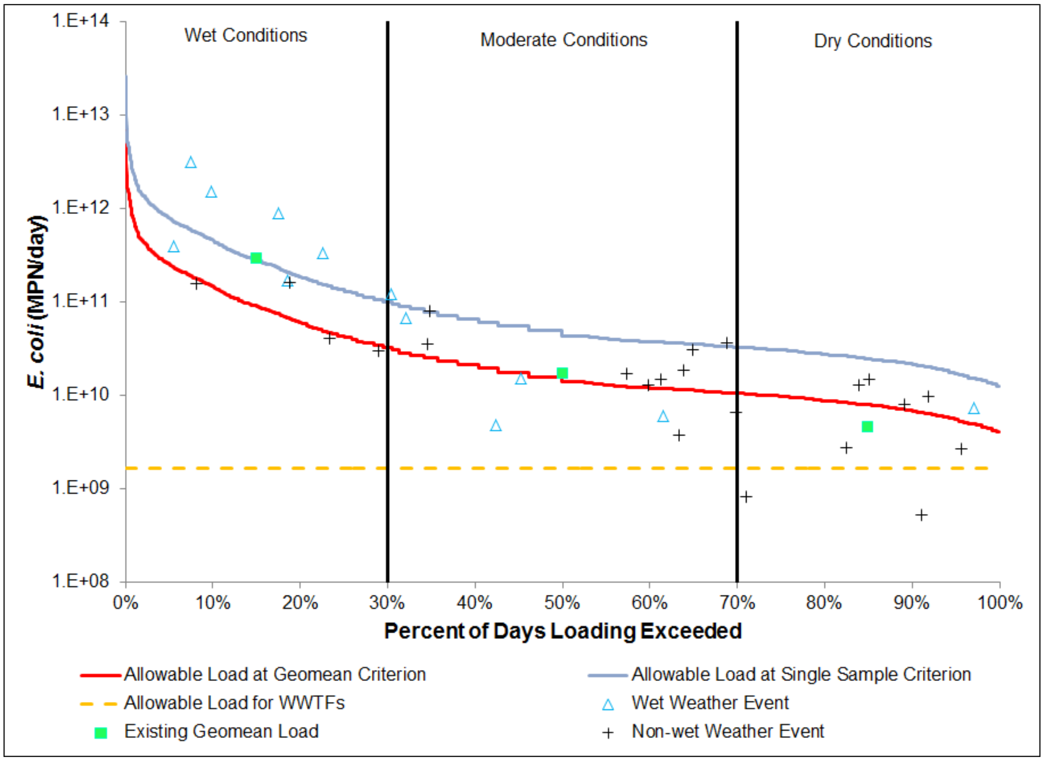

Figure 17 Load duration curve for station 16631, Bear Branch (1008E_01)

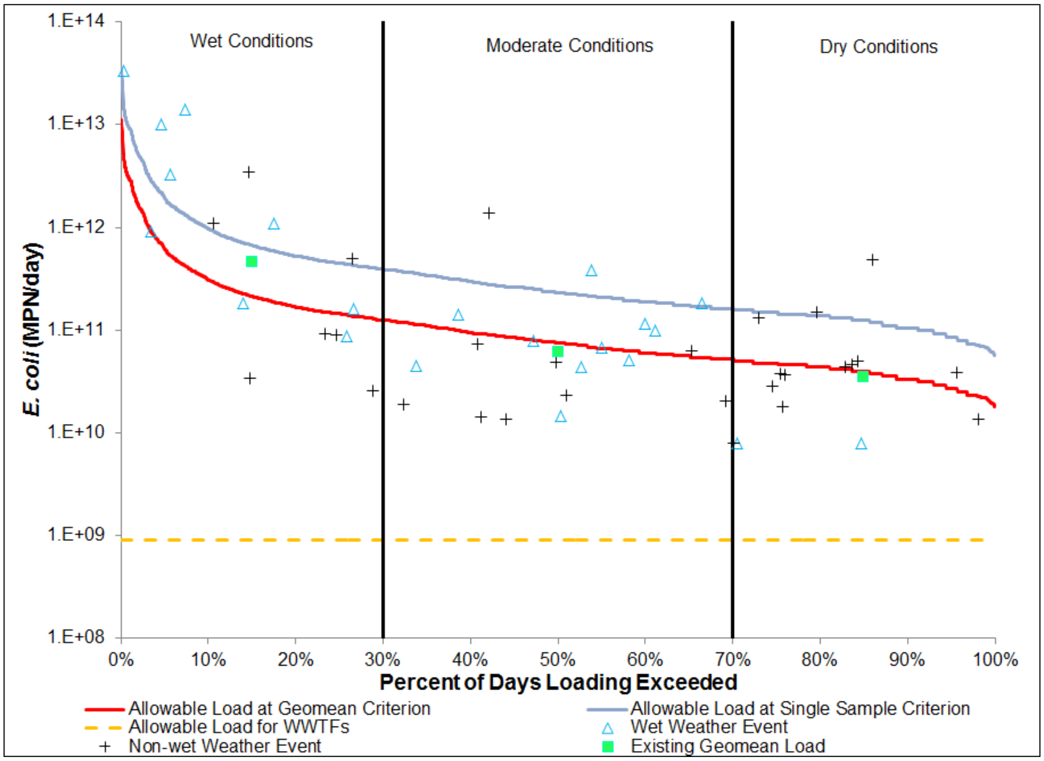

Figure 18 Load duration curve for station 16625, Peach Creek (1011_01)

SECTION 4

TMDL ALLOCATION ANALYSIS

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

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

For the purpose of this study, a drainage area ratio approach using a historical streamflow gauge for the reference flow record was employed to estimate the daily flow within Upper Panther Branch (1008B_01 and 1008B_02) , Lower Panther Branch (1008C_01 and 1008C_02), Bear Branch (1008E_01), and Peach Creek (1011_01) watersheds. Within the subsequent Implementation Plan, an adaptive approach will be used to bring the necessary spatial focus to improving water quality and restoring the primary contact recreation use.

4.1 Endpoint Identification

The water bodies within the TMDL watersheds have a use of primary contact recreation, which is protected by numeric criteria 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. *E. coli* criterion to protect freshwater contact recreation consist of a geometric mean concentration not to be exceeded of 126 MPN/100 mL (TCEQ, 2010). 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 endpoint for the TMDLs is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100 mL. This endpoint was applied to all six AUs addressed by this TMDL. This endpoint is identical to the geometric mean criterion for primary contact recreation in the 2010 Texas Surface Water Quality Standards (TCEQ, 2010).

4.2 Seasonality

Seasonal variations or seasonality occur 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. Seasonality was accounted for in these TMDL by considering more than 5 years of water quality and 10 years of streamflow data when estimating the flows used in flow exceedances.

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* concentrations obtained from routine monitoring collected in the warmer months (May – September) against those collected during the cooler months (November – March). The months of April and October were considered transitional between the warm and cool seasons and were excluded from the seasonal analysis. Only stations that had a minimum of six samples collected in each season were considered in the analysis. *E. coli* data were transformed using the natural log. Differences in *E. coli* concentrations obtained in warmer versus cooler months were then evaluated by performing a t-test on the natural log transformed dataset. This analysis of *E. coli* data indicated that there was a significant difference (α=0.05) in indicator bacteria between cool and warm weather seasons for Upper Panther Branch (1008B_01) and Peach Creek (1011_01) with the cool season having the higher concentrations. Seasonality was not detected in the remaining four impaired AUs.

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. During ambient flows, these constant 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 is typically diluted, and would therefore be a smaller part of the overall concentrations.

Bacteria load contributions from permitted and non-permitted stormwater sources are greatest during runoff events. Rainfall runoff, depending 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 reduce 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.

4.4 Load Duration Curve Analysis

Load duration curve (LDC) analyses were used to examine the relationship between instream water quality, the broad sources of indicator bacteria loads, and are the basis of the TMDL allocations. The strength of this TMDL is the use of the LDC method to determine the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders, and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The USEPA supports the use of this approach to characterize pollutant sources. In addition many other states are using this method to develop TMDLs.

The weaknesses of this method include the limited information it provides regarding the magnitude or specific origin of the various sources. Only limited information is gathered regarding point and nonpoint sources in the watershed. The general difficulty in analyzing and characterizing *E. coli* in the environment is also a weakness of this method.

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

4.5 Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis performed to develop the TMDL and thus provides a higher level of assurance that the goal of the TMDL will be met. According to 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 margin of safety is designed to account for any uncertainty that may arise in specifying water quality control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The TMDLs covered by this report incorporate an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target for *E. coli* of 120 MPN/100 mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.6 Load Reduction Analysis

While the TMDLs for the six TMDL watersheds will be developed using 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 stations within the impaired reaches. For simplicity of computation and presentation, the load reduction calculations were based on concentrations rather than loadings (concentration multiplied by flow), since the flow would be identical in both the existing and allowable loadings computations and, thus, the flow would effectively cancel out of the calculations. For each station and flow regime, the percent reduction required to achieve the geometric mean criterion was determined by calculating the difference in the existing (or measured) geometric mean concentration and the 126 MPN/100 mL criterion and dividing that difference by the existing geometric mean concentration .

The percent reduction for each monitoring station in a TMDL watershed with 24 or more *E. coli* data points was calculated (Table 18). Though not without exception, the general pattern observed in the percent reduction values is that they were highest for the wet-conditions flow regime, often at a value of 0 at the dry-conditions flow regime, and in between in magnitude for the moderate-conditions flow regime. An exception to this pattern was Upper Panther Branch (1008B_02) which indicated a higher required percent reduction for the dry conditions flow regime than for the moderate-conditions flow regime.

Table 18 Percent reduction calculations for stations within the water bodies of the TMDL watersheds

Station	AU	Wet Conditions (0-30%)		Moderate Conditions (30-70%)		Dry Conditions (70-100%)	
		Geometric Mean (MPN/100 mL)	Required Percent Reduction (%)	Geometric Mean (MPN/100 mL)	Required Percent Reduction	Geometric Mean (MPN/100 mL)	Required Percent Reduction (%)
16629	1008B_01	566	78	162	22	34	0
16630	1008B_02	367	66	154	18	211	40
16628	1008C_01	263	52	156	19	124	0
16627	1008C_02	317	60	145	13	69	0
16631	1008E_01	397	68	155	19	73	0
16625	1011_01	268	53	103	0	109	0

4.7 Pollutant Load Allocations

The bacteria TMDL for each of the TMDL watershed water bodies was developed as a pollutant load allocation based on information from the most downstream station within an impaired AU that is scheduled for future water quality monitoring. As discussed in more detail in Section 3, bacteria LDCs were developed by multiplying each streamflow value along the flow duration curves by the *E. coli* criterion (126 MPN/100 mL) and by the conversion factor to convert to loading in colonies per day. This effectively displays the LDC as the TMDL curve of maximum allowable loading:

TMDL (MPN/day) = criterion * flow (cfs) * conversion factor (Eq. 1)

Where:

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

Conversion factor (to MPN/day) = 24,465,756 100 mL/ft^3 * seconds/day

4.7.1 TMDL Definition

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

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

Where:

TMDL = total maximum daily load

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

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

FG = loadings associated with future growth from potential permitted facilities

MOS = margin of safety

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

The bacteria TMDLs for the six 303(d)-listed AUs as covered in this report were derived using the median flow (or 15% flow) within the wet conditions flow regime of the LDC developed for the selected sampling station of each AU.

4.7.1.1 Waste Load Allocation

TPDES-permitted wastewater treatment facilities are allocated a daily waste load (WLA_{WWTF}) calculated as their full permitted discharge multiplied by one half the instream geometric criterion, One-half of the water quality criterion (63 MPN/100mL) is used as the WWTF target to provide instream and downstream load capacity. This is expressed in the following equation:

$$WLA_{WWTF} = Target * Flow (MGD) * conversion factor \quad \text{(Eq. 3)}$$

Where:

Target = 63 MPN/100 mL

Flow (MGD) = full permitted discharge

Conversion factor = 37,854,000 100 mL / MGD

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 these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading. The percentage of each watershed that is categorized in the 2010 Census as Urbanized Area 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}.

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

$$\Sigma WLA_{SW} = (TMDL - \Sigma WLA_{WWTF} - LA_{RES} - \Sigma FG - MOS) * FDA_{SWP} \qquad \text{(Eq. 4)}$$

Where:

ΣWLA_{SW} = sum of all permitted stormwater loads

TMDL = total maximum daily load

ΣWLA_{WWTF} = sum of all WWTF loads

LA_{RES} = loading from a significant upstream reservoir

ΣFG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area categorized in the 2010 Census Urbanized Areas

4.7.1.2 Load Allocation

The load allocation is the sum of loads from unregulated sources. A complexity of the load allocation term occurs as a result of reservoirs because they 1) modify downstream hydrology by attenuating peak flows and reducing overall flow and 2) reduce bacteria concentrations by providing favorable conditions for their settling and die-off. If a reservoir is of sufficient size, it, therefore, represents a disruption of the downstream accumulation of bacteria loadings. For the pollutant load allocation computation, reservoirs that are designated by TCEQ as either a classified segment or an unclassified segment are considered significant enough in size to require being considered separately in the load allocation term. For water bodies associated with the Lake Houston watershed and associated with the TMDL watersheds, the only reservoir meeting this definition is Lake Woodlands (Segment 1008F). To accommodate the disruption in downstream bacteria loadings from a significant reservoir, the bacteria loadings associated with its releases are considered separately. The load allocation, therefore, becomes defined as the sum of the upstream loadings arising from a significant upstream reservoir that enters into an AU (LA_{RES}) and the remaining bacteria load that arises from unregulated sources within the AU and upstream AUs not associated with a significant reservoir (LA_{AU}). The calculation of LA_{RES} only applies to the two AUs that are downstream of Lake Woodlands, which are AUs 1008C_01 and 1008C_02. The full expression of the LA term, including loadings from an upstream reservoir, is the following:

$$LA = LA_{AU} + LA_{RES} \quad \text{(Eq. 5)}$$

Where:

LA = allowable load from unregulated sources (predominately nonpoint sources)

LA_{RES} = loading from a significant upstream reservoir

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

The LA_{RES} is calculated as:

$$LA_{RES} = Criterion * Q_{RES} \quad \text{(Eq. 6)}$$

Where:

Criterion = 126 MPN/100 mL

Q_{RES} = median value of the wet-conditions flow regime at the outlet of a significant upstream reservoir

The unregulated loading assigned to the AU (LA_{AU}) is calculated as:

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

Where:

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

TMDL = total maximum daily load

ΣWLA_{WWTF} = sum of all WWTF loads

ΣWLA_{SW} = sum of all permitted stormwater loads

LA_{RES} = loading from a significant upstream reservoir

ΣFG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

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

$$TMDL = \Sigma WLA_{WWTF} + \Sigma WLA_{SW} + LA_{AU} + LA_{RES} + \Sigma FG + MOS \qquad \text{(Eq. 8)}$$

4.7.1.3 Computation of Margin of Safety

The margin of safety is only applied to the allowable loading directly associated with an AU and is not applied to the LA_{RES} that enters the segment as an external loading from a significant reservoir. Therefore the margin of safety is expressed mathematically as the following:

$$MOS = 0.05 * (TMDL - LA_{RES}) \qquad \text{(Eq. 9)}$$

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

LA_{RES} = loading from a significant upstream reservoir

4.7.1.4 Future Growth

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

To account for the probability that new flows from WWTF discharges may occur in areas within the TMDL watersheds, a provision for future growth was included in the TMDL calculations based on population projections and current permitted wastewater dischargers. Recent and projected population data was acquired from the H-GAC 2035 regional growth forecast (H-GAC, 2005). Projected population growth for each watershed was calculated between 2008 and 2035. The year 2008 was used as the base year to maintain consistency with the previous TMDLS adopted in the Lake Houston Watershed (TCEQ, 2011a). The projected population percentage increase of each 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 2008 and 2035 to determine the estimated future flows.

Thus, the future growth (FG) is calculated as follows:

$$FG = WWTF_{FP} * POP_{2008\text{-}2035} * \text{conversion factor} * \text{target} \qquad \text{(Eq. 10)}$$

Where:

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

$POP_{2008-2035}$ = estimated percent increase in population between 2008 and 2035

Conversion factor = 37,854,000 100mL/MGD

Target = 63 MPN/100 mL

4.7.2 AU-Level TMDL Calculations

The allowable loading of *E. coli* that the impaired AUs within the TMDL watersheds can receive on a daily basis was determined using Equation 1 based on the median value within the wet-conditions flow regime of the FDC (or 15% flow exceedance value) for the most downstream station of each AU (Table 19). A loading entering Upper Panther Branch (1008C_01 and 1008C_02) from unimpaired Lake Woodlands (1008F) was also calculated and serves as a significant reservoir loading entering AU 1008C_02 (Table 19).

Table 19 Summary of allowable loading calculations for AUs within the TMDL watersheds

AU	Segment Name	Sampling Station	Wet-Condition Median Flow (cfs)	LA_{RES} (MPN/100 mL)	TMDL (MPN/100 mL)
1008B_01	Upper Panther Branch	16629	33.322	—	1.027E+11
1008B_02	Upper Panther Branch	16630	35.345	—	1.090E+11
1008C_01	Lower Panther Branch	16628	91.643	—	2.825E+11
1008C_02	Lower Panther Branch	16627	91.467	—	2.820E+11
1008F_03	Lake Woodlands	NA	72.732	2.242E+11	—
1008E_01	Bear Branch	16631	29.551	—	9.110E+10
1011_01	Peach Creek	16625	69.438	—	2.141E+11

4.7.2.1 Margin of Safety Computations

Using the values of TMDL for each AU provided in Table 19, the margin of safety may be readily computed by proper substitution into Equation 9 (Table 20).

Table 20 Computed margin of safety for impaired AUs within the TMDL Watersheds

AU	MOS (MPN/day)
1008B_01	5.136E+09
1008B_02	5.448E+09
1008C_01	2.914E+09
1008C_02	2.888E+09
1008E_01	4.555E+09
1011_01	1.070E+10

4.7.2.2 Future Growth Computations

The future growth allocations for AUs within the TMDL watersheds were calculated based on population projections and full permitted wastewater discharges by applying Equation 10 (Table 21). The resulting future wastewater flow was then converted into a loading (see Equation 3).

Table 21 Future Growth computations for the TMDL Watersheds

AU (individual [indiv.] and aggregated [aggr.])	2008 Population	2035 Population	Growth (%)	Current Permitted Wastewater Discharge (MGD)	Additional Permitted Wastewater Discharge (MGD)	Future Growth (MPN/day)
1008B_01 (indiv.)	9,870	15,972	61.82%	7.800	4.822	1.150E+10
1008B_02 (indiv.)	2,336	4,234	81%	0.000	0.000	0.0
1008B_02 (aggr.) [a]	—	—	—	8.498	5.103	1.217E+10
1008C_01 (indiv.)	17,324	21,355	23.26%	0.003	0.0007	1.664E+06
1008C_01 (aggr.) [b]	—	—	—	7.803	1.7009	4.056E+09
1008C_02 (indiv.)	10,359	12,617	21.80%	7.800	1.700	4.055E+09
1008E_01 (indiv.)	25,755	36,113	40.22%	0.698	0.2807	6.695E+08
1011_01 (indiv.)	14,827	36,590	146.78 %	0.380	0.5577	1.330E+09

[a] Future Growth for 1008B_02(aggr.) is the sum or aggregation of AUs 1008B_01, 1008B_02 and 1008E_01
[b] Future Growth for 1008C_01(aggr.) is the sum or aggregation of AUs 1008C_01 and 1008C-02

4.7.2.3 Regulated Wastewater Treatment Facility Computations

The daily allowable loading of *E. coli* assigned to WLA_{WWTF} was determined based on the full permitted flow of the WWTFs located in the TMDL watersheds using Equation 3. Table 22 presents the waste load allocations for each individual WWTF located within the TMDL watersheds. The WLA_{WWTF} for each AU includes the sum of the WWTF allocations for all upstream AUs.

Table 22 Waste load allocations for TPDES-permitted facilities

AU	TPDES Number	NPDES Number	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (MPN/day)
1008B_01	WQ0012597-001	TX0091715	The Woodlands WWTP 2	7.800	1.860E+10
1008C_02	WQ0011401-001	TX0054186	Woodlands	7.800 [a]	1.860E+10
1008C_01	WQ0013697-001	TX0090000	Cedarstone WWTP	0.003	7.154E+06
1008E_01	WQ0014141-001	TX0120073	Old Egypt Regional Business Center	0.450	1.073E+09
1008E_01	WQ0014918-001	TX0131725	Eaglestar WWTP	0.100	2.385E+08
1008E_01	WQ0014909-001	TX0131652	Lincoln Manufacturing	0.050	1.192E+08
1008E_01	WQ0014013-001	TX0118028	Greenfield Forest WWTP	0.050	1.192E+08
1008E_01	WQ0012703-001	TX0092843	Bear Branch Plant	0.048	1.145E+08
1011_01	WQ0013389-001	TX0102512	City of Splendora WWTP	0.300	7.154E+08
1011_01	WQ0011143-001	TX0082511	Splendora Elementary School	0.040	9.539E+07
1011_01	WQ0011143-002	TX0117463	Splendora ISD WWTF	0.040	9.539E+07

[a] San Jacinto River Authority WQ0011401-001 has two permitted outfalls and their combined full permitted flow is 7.8 MGD.

4.7.2.4 Regulated Stormwater Computation

Based on the 2010 Census Urbanized Area (Figure 5) portions of each AU within the TMDL watersheds have areas that fall within the jurisdiction regulated by stormwater permits. Table 23 summarizes the computation of term WLA_{SW} as calculated using Equation 4.

Table 23 Regulated stormwater computation for TMDL Watersheds

AU	TMDL (MPN/day)	WLA_{WWTF} (MPN/day)	Future Growth (MPN/day)	LA_{RES} (MPN/day)	MOS (MPN/day)	FDA_{SWP}	WLA_{SW} (MPN/day)
1008B 01	1.027E+11	1.860E+10	1.150E+10	0	5.136E+09	0.587	3.964E+10
1008B_02	1.090E+11	2.027E+10	1.217E+10	0	5.448E+09	0.792[a]	5.629E+10
1008C_01	2.825E+11	1.861E+10	4.056E+09	2.242E+11	2.914E+09	0.936[b]	3.062E+10
1008C_02	2.820E+11	1.860E+10	4.055E+09	2.242E+11	2.888E+09	0.990	3.190E+10
1008E_01	9.110E+10	1.665E+09	6.695E+08	0	4.555E+09	0.893	7.522E+10
1011_01	2.141E+11	9.062E+08	1.330E+09	0	1.070E+10	0.015	3.046E+09

[a] FDA_{SWP} value based on the area of AU 1008B_02 and upstream AUs 1008B_01 and 1008E_01
[b] FDA_{SWP} value based on the area of AU 1008C_01 and upstream AU 1008C_02

4.7.2.5 Unregulated Stormwater and Upstream Reservoir Bacteria Load Computation

The LA_{AU} is the allowable bacteria loading assigned to unregulated sources within each TMDL watershed. All AUs within the TMDL watersheds have at least some portion of their immediate watershed that are not regulated by stormwater permits. The LA_{AU} for each TMDL watershed was computed using Equation 7 (Table 24).

The LA_{RES} represents the loading arising from a significant and immediately upstream reservoir. Lower Panther Branch 1008C_01 and 1008C_02 are the two impaired AUs that required the calculation of LA_{RES} due to the upstream location of Lake Woodlands (segment 1008F). To calculate the loading entering Lower Panther Branch from Lake Woodlands, a median flow value within the wet-conditions flow regime was determined at the outlet of Lake Woodlands and the LA_{RES} was computed by using Equation 6 (Table 24).

Table 24 Computed unregulated stormwater terms for AUs within the TMDL watersheds

AU	LA_{RES} (MPN/day)	LA_{AU} (MPN/day) [a]
1008B_01	0	2.784E+10
1008B_02	0	1.478E+10
1008C_01	2.242E+11	2.096E+09
1008C_02	2.242E+11	3.166E+08
1008E_01	0	8.983E+09
1011_01	0	1.981E+11

[a] Note that the number of significant digits provided in the TMDL computation tables will not allow each of these values to be exactly calculated.

4.8 Summary of TMDL Calculations

Table 25 summarizes the TMDL calculations for the six impaired AUs comprising the TMDL watersheds. Each of the TMDLs was calculated based on the median flow in the 0-30 percentile range (wet-conditions flow regime) for flow exceedance from the LDC developed for the most downstream station of each AU that is currently scheduled to be monitored. Allocations are based on the current geometric mean criterion for *E. coli* in freshwater of 126 counts/100 mL for each component of the TMDL.

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 include the future growth component within the WLA_{WWTF} while allocations to permitted MS4 entities and permitted construction and industrial activities are designated as WLA_{sw} (Table 26). The WLA_{WWTF} for each AU includes the sum of the WWTF allocations for that AU and all upstream AUs. Similarly the WLA_{SW} for each AU includes the sum of all stormwater regulated areas for that AU and all upstream AUs. The LA component of the final TMDL allocations is comprised of the sum loadings arising from within each AU and all upstream AUs that are associated with non-permitted sources.

In the event that the criterion changes due to a change in the designated recreational use, Appendix B provides guidance for recalculating the allocations in Table 25. Figures B-1 through B-6 of Appendix B were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to the *E. coli* criteria for primary contact recreational use, secondary contact recreation 1 use, and secondary contact recreation 2 use. The equations provided, along with Figures B-1 through B-6, allow calculation of new TMDLs and pollutant load allocations based on these three categories of recreational use criterion for *E. coli*.

Table 25 TMDL allocation summary for impaired AUs of the TMDL Watersheds

All loads expressed as billion MPN/day

AU	Stream Name	TMDL	MOS	WLA_{WWTF}	WLA_{SW}	LA_{AU} [a]	LA_{RES}	LA Total	Future Growth
1008B_01	Upper Panther Branch	102.7	5.14	18.60	39.64	27.84	0	27.84	11.50
1008B_02	Upper Panther Branch	109.0	5.45	20.27	56.29	14.78	0	14.78	12.17
1008C_01	Lower Panther Branch	282.5	2.91	18.61	30.62	2.10	224.2	226.3	4.06
1008C_02	Lower Panther Branch	282.0	2.89	18.60	31.90	0.32	224.2	224.5	4.06
1008E_01	Bear Branch	91.10	4.56	1.66	75.22	8.98	0	8.98	0.67
1011_01	Peach Creek	214.1	10.70	0.91	3.05	198.1	0	198.1	1.33

[a] Note that the number of significant digits provided in the TMDL computation tables will not allow each of these values to be exactly calculated.

Table 26 Final TMDL allocations for impaired AUs of the TMDL Watersheds

All loads expressed as billion MPN/day

AU	TMDL	WLA_{WWTF}*	WLA_{SW}	LA	MOS
1008B_01	102.7	30.10	39.64	27.84	5.14
1008B_02	109.0	32.44	56.29	14.78	5.45
1008C_01	282.5	22.66	30.62	226.3	2.91
1008C_02	282.0	22.66	31.90	224.5	2.89
1008E_01	91.10	2.33	75.22	8.98	4.56
1011_01	214.1	2.24	3.05	198.1	10.70

*WLA_{WWTF} includes the future potential allocation to wastewater treatment facilities

Section 5

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APPENDIX A

BACTERIA DATA USED IN DEVELOPING LOAD DURATION CURVES

Table A-1 Measured *E. coli* concentration and estimated streamflow at station 16629, Upper Panther Branch, Segment 1008B_01.

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
31-Oct-02	211	61.41
28-Jan-03	828	24.82
28-Apr-03	86	17.39
22-Jul-03	46	17.42
23-Oct-03	74	17.28
22-Jan-04	510	20.01
22-Apr-04	109	16.06
22-Jul-04	360	24.45
27-Oct-04	10	15.99
25-Jan-05	170	16.28
21-Apr-05	160	17.39
21-Jul-05	230	28.51
26-Oct-05	500	17.31
26-Jan-06	270	20.01
20-Apr-06	30	17.06
20-Jul-06	30	16.32
25-Oct-06	240	21.86
25-Jan-07	2300	45.15
19-Apr-07	200	20.75
19-Jul-07	1500	51.06
18-Oct-07	320	21.49
7-Nov-07	171	17.09

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
17-Jan-08	3400	29.99
17-Apr-08	120	17.13
17-Jul-08	130	16.61
23-Oct-08	530	18.54
15-Jan-09	63	17.32
22-Apr-09	86	28.51
29-Jul-09	10	16.43
28-Oct-09	960	53.28
21-Jan-10	41	18.91
22-Apr-10	230	17.50
15-Jul-10	31	16.58
21-Oct-10	10	16.69

Table A-2 Measured *E. coli* concentration and estimated streamflow at station 16630, Upper Panther Branch, Segment 1008B_02.

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
31-Oct-02	85	64.60
28-Jan-03	218	26.49
28-Apr-03	20	18.75
22-Jul-03	52	18.79
23-Oct-03	1830	18.63
22-Jan-04	160	21.49
22-Apr-04	218	17.37
22-Jul-04	158	26.10

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
27-Oct-04	173	17.29
25-Jan-05	130	17.60
21-Apr-05	910	18.75
21-Jul-05	1060	30.34
26-Oct-05	380	18.67
26-Jan-06	52	21.49
20-Apr-06	740	18.41
20-Jul-06	410	17.64
25-Oct-06	97	23.41
25-Jan-07	1700	47.66
19-Apr-07	280	22.26
19-Jul-07	170	53.82
18-Oct-07	110	23.03
7-Nov-07	78	18.45
17-Jan-08	1600	31.88
17-Apr-08	160	18.48
17-Jul-08	240	17.95
23-Oct-08	210	19.95
15-Jan-09	160	18.68
22-Apr-09	360	30.34
29-Jul-09	340	17.75
28-Oct-09	880	56.13
21-Jan-10	98	20.33

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
22-Apr-10	97	18.87
15-Jul-10	31	17.91
21-Oct-10	220	18.02

Table A-3 Measured *E. coli* concentration and estimated streamflow at station 16628, Lower Panther Branch, Segment 1008C_01.

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
31-Oct-02	399	253.67
28-Jan-03	40	53.63
28-Apr-03	74	20.63
22-Jul-03	41	25.63
23-Oct-03	62	20.63
22-Jan-04	680	41.63
22-Apr-04	171	22.63
22-Jul-04	332	51.63
27-Oct-04	754	23.63
25-Jan-05	52	22.63
21-Apr-05	480	21.63
21-Jul-05	500	98.64
26-Oct-05	110	14.13
26-Jan-06	110	30.63
20-Apr-06	410	17.63
20-Jul-06	140	16.93
25-Oct-06	170	41.63

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
25-Jan-07	520	179.66
19-Apr-07	41	49.63
19-Jul-07	210	179.66
18-Oct-07	330	45.63
17-Jan-08	200	119.65
17-Apr-08	63	16.33
17-Jul-08	98	16.83
23-Oct-08	240	32.63
15-Jan-09	130	18.63
22-Apr-09	96	109.64
29-Jul-09	290	16.33
28-Oct-09	5500	162.65
21-Jan-10	31	31.63
22-Apr-10	110	24.63
15-Jul-10	150	16.73
21-Oct-10	110	17.33

Table A-4 Measured *E. coli* concentration and estimated streamflow at station 16627, Lower Panther Branch, Segment 1008C_02.

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
31-Oct-02	441	254.58
28-Jan-03	169	54.97
28-Apr-03	41	22.04
22-Jul-03	52	27.03

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
23-Oct-03	63	22.04
22-Jan-04	960	43.00
22-Apr-04	30	24.03
22-Jul-04	364	52.98
27-Oct-04	871	25.03
25-Jan-05	110	24.03
21-Apr-05	120	23.04
21-Jul-05	780	99.88
26-Oct-05	100	15.55
26-Jan-06	74	32.02
20-Apr-06	310	19.04
20-Jul-06	10	18.35
25-Oct-06	120	43.00
25-Jan-07	130	180.72
19-Apr-07	74	50.98
19-Jul-07	300	180.72
18-Oct-07	390	46.99
17-Jan-08	190	120.84
17-Apr-08	130	17.75
17-Jul-08	41	18.25
23-Oct-08	960	34.02
15-Jan-09	130	20.04
22-Apr-09	110	110.86

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
29-Jul-09	10	17.75
28-Oct-09	6500	163.76
21-Jan-10	41	33.02
22-Apr-10	97	26.03
15-Jul-10	260	18.15
21-Oct-10	120	18.75

Table A-5 Measured *E. coli* concentration and estimated streamflow at station 16631, Bear Branch, Segment 1008E_01.

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
31-Oct-02	218	74.84
28-Jan-03	857	15.84
28-Apr-03	158	3.86
22-Jul-03	135	3.92
23-Oct-03	341	3.68
22-Jan-04	180	8.10
22-Apr-04	63	1.72
22-Jul-04	109	15.25
27-Oct-04	189	1.60
25-Jan-05	190	2.08
21-Apr-05	63	3.86
21-Jul-05	320	21.80
26-Oct-05	200	3.74
26-Jan-06	400	8.10

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
20-Apr-06	10	3.33
20-Jul-06	10	2.14
25-Oct-06	110	11.08
25-Jan-07	1300	48.62
19-Apr-07	300	9.29
19-Jul-07	110	58.15
18-Oct-07	470	10.48
7-Nov-07	79	3.39
17-Jan-08	1500	24.19
17-Apr-08	430	3.45
17-Jul-08	200	2.61
23-Oct-08	110	5.71
15-Jan-09	41	3.75
22-Apr-09	300	21.80
29-Jul-09	140	2.32
28-Oct-09	2100	61.73
21-Jan-10	31	6.31
22-Apr-10	170	4.05
15-Jul-10	240	2.56
21-Oct-10	41	2.73

Table A-6 Measured *E. coli* concentration and estimated streamflow at station 16625, Peach Creek, Segment 1011_01.

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
30-Jan-01	1824	223.85
27-Feb-01	126	25.51
27-Mar-01	20	70.10
24-Apr-01	463	44.15
22-May-01	20	16.19
26-Jun-01	25	41.48
24-Jul-01	148	17.52
28-Aug-01	148	12.87
25-Sep-01	40	23.51
23-Oct-01	20	27.51
27-Nov-01	1928	28.84
19-Dec-01	786	171.93
29-Jan-02	20	38.16
27-Feb-02	20	29.50
27-Mar-02	148	44.15
24-Apr-02	82	24.18
29-May-02	342	15.53
26-Jun-02	20	16.19
24-Jul-02	104	14.86
16-Sep-02	1602	12.20
22-Jan-03	78	46.81
19-Mar-03	4125	137.99

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
21-May-03	50	14.86
23-Jul-03	100	14.86
17-Sep-03	130	21.52
19-Nov-03	840	1644.81
21-Jan-04	460	96.06
19-May-04	103	72.77
21-Jul-04	78	22.85
16-Sep-04	103	20.19
16-Nov-04	423	17.52
19-Jan-05	78	48.81
16-Mar-05	78	45.48
19-Apr-05	180	32.17
15-Jun-05	160	12.87
17-Aug-05	240	19.52
19-Oct-05	430	14.20
14-Dec-05	50	36.83
18-Jan-06	700	22.18
15-Mar-06	50	16.86
16-May-06	25	12.87
19-Jul-06	75	7.34
20-Sep-06	75	15.53
17-Nov-06	100	30.17
17-Jan-07	130	288.41

Sample Date	*E. coli* (MPN/100 mL)	Estimated Daily Flow on Sampling Date (cfs)
28-Mar-07	2000	70.77
16-May-07	25	24.18
18-Jul-07	730	60.79
2-Nov-07	132	13.53
15-Sep-10	210	19.52
10-Nov-10	180	8.87

APPENDIX B

EQUATIONS FOR CALCULATING TMDL ALLOCATIONS FOR CHANGED CONTACT RECREATION STANDARD

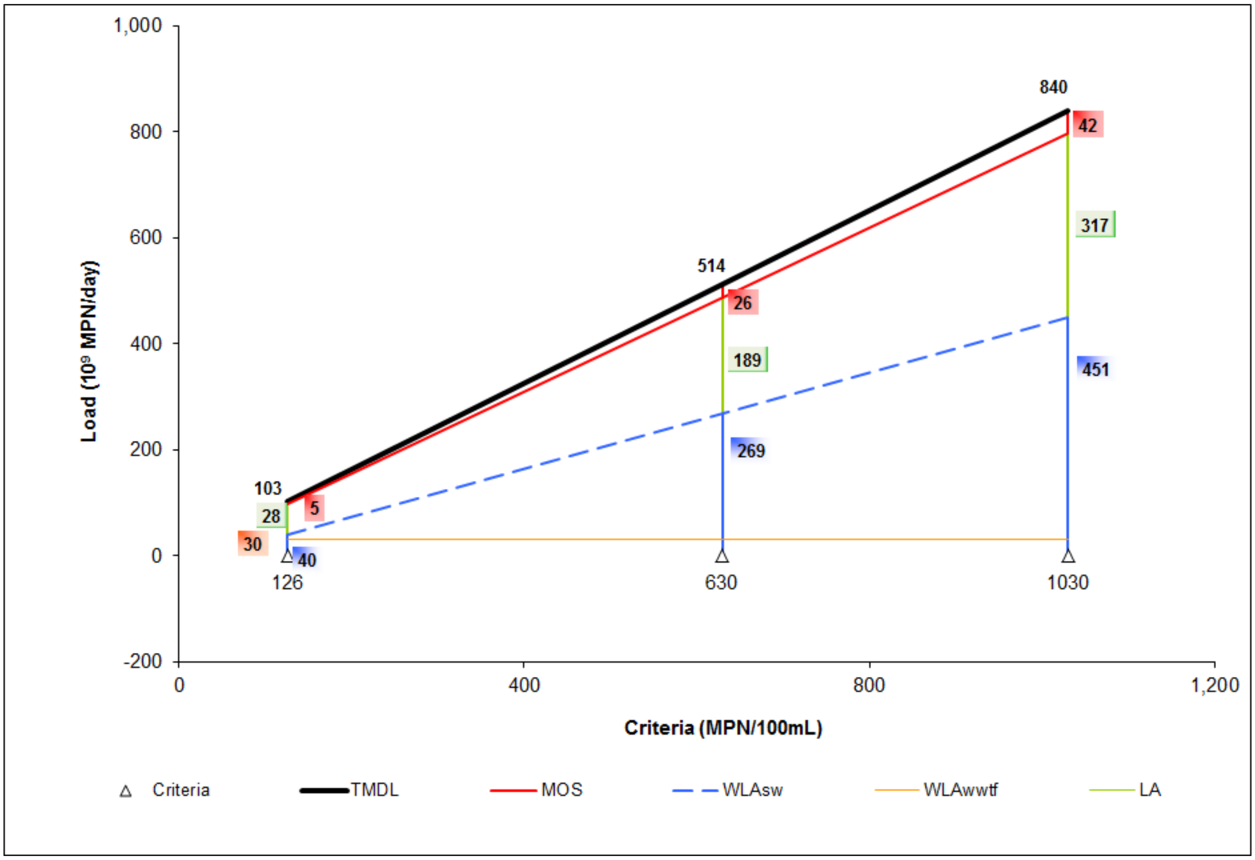

Figure B-1. Allocation loads for Upper Panther Branch (1008B_01) as a function of water quality criteria

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

TMDL = 0.81519 * Std

WLA_{WWTF} = 30.10

WLA_{sw} = 0.45494 * Std – 17.68

LA = 0.31949 * Std –12.42

MOS = 0.04076 * Std

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Waste load allocation (permitted stormwater)

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

MOS = Margin of Safety

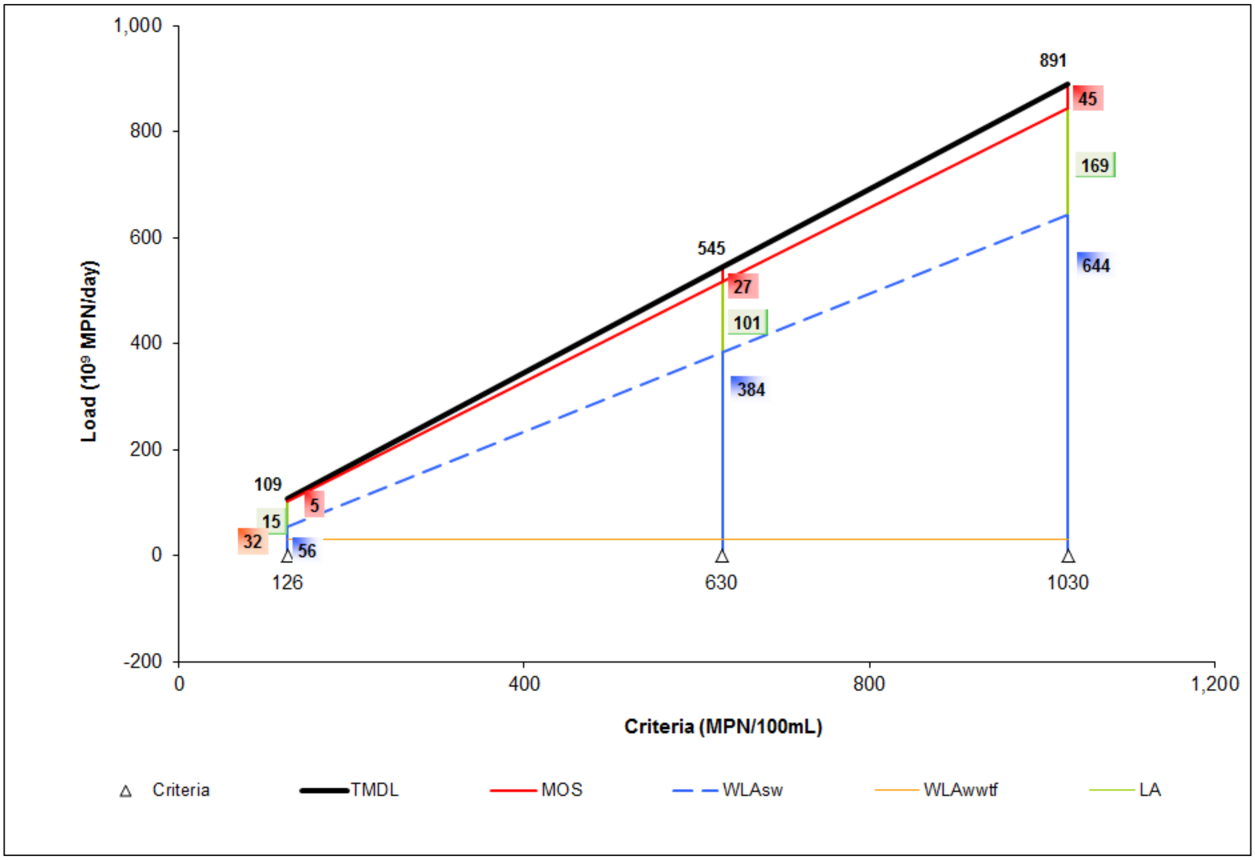

Figure B-2. Allocation loads for Upper Panther Branch (1008B_02) as a function of water quality criteria

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

TMDL = 0.86469 * Std

WLA_{WWTF} = 32.44

WLA_{sw} = 0.65059 * Std – 25.69

LA = 0.17086 * Std – 6.75

MOS = 0.04323 * Std

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Waste load allocation (permitted stormwater)

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

MOS = Margin of Safety

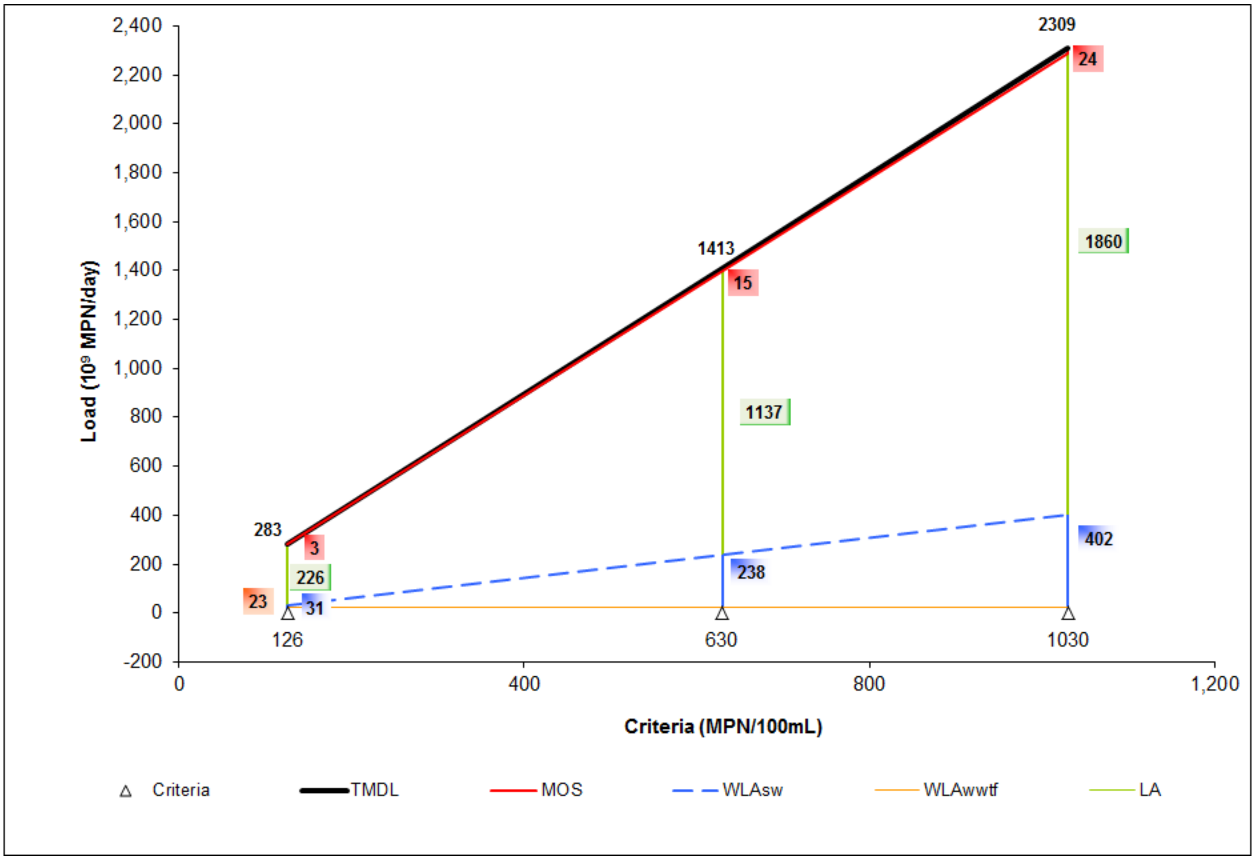

Figure B-3. Allocation loads for Lower Panther Branch (1008C_01) as a function of water quality criteria

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

$TMDL = 2.24211 * Std$

$WLA_{WWTF} = 22.66$

$WLA_{sw} = 0.41136 * Std - 21.21$

$LA = 1.80761 * Std - 1.45$

$MOS = 0.02313 * Std$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Waste load allocation (permitted stormwater)

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

MOS = Margin of Safety

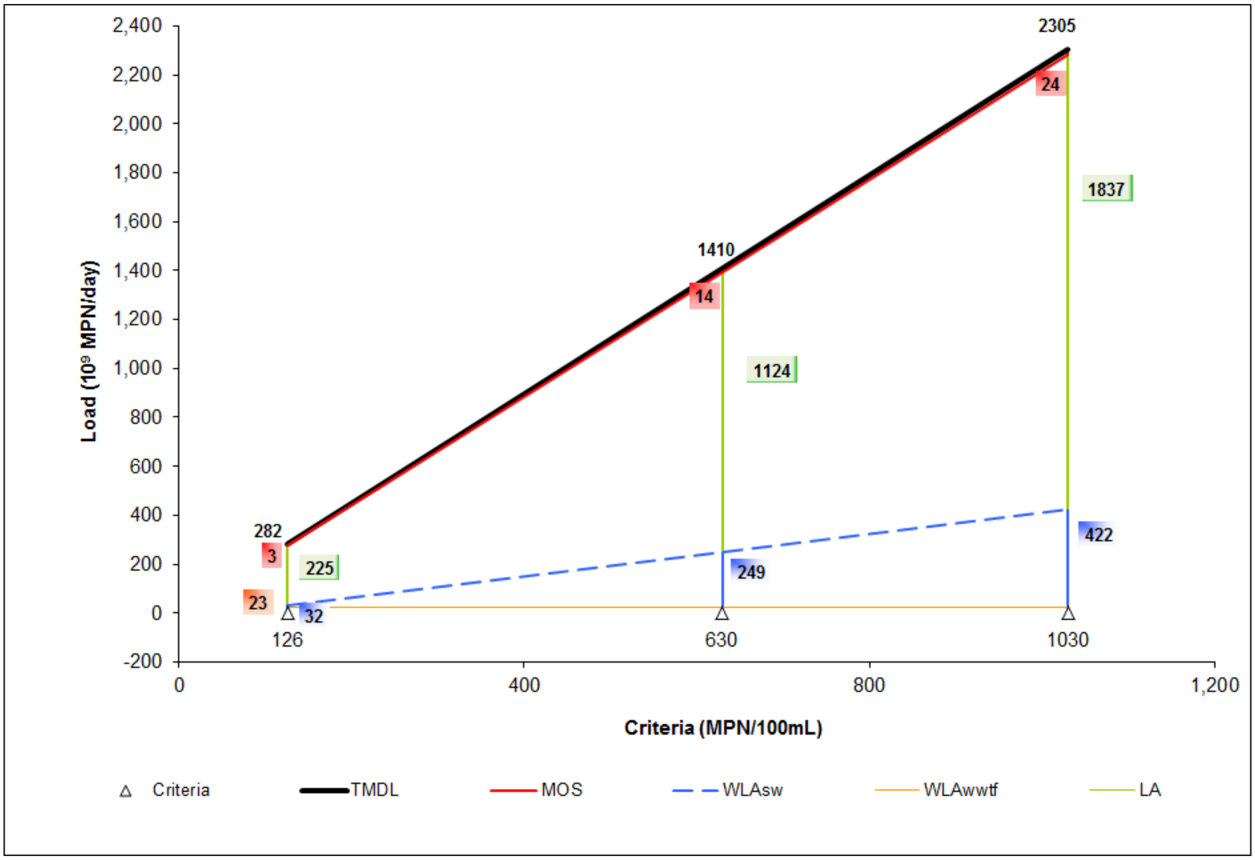

Figure B-4. Allocation loads for Lower Panther Branch (1008C_02) as a function of water quality criteria

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

TMDL = 2.23777 * Std

WLA_{WWTF} = 22.66

WLA_{sw} = 0.43113 * Std – 22.43

LA = 1.78372 * Std – 0.22

MOS = 0.02292 * Std

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Waste load allocation (permitted stormwater)

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

MOS = Margin of Safety

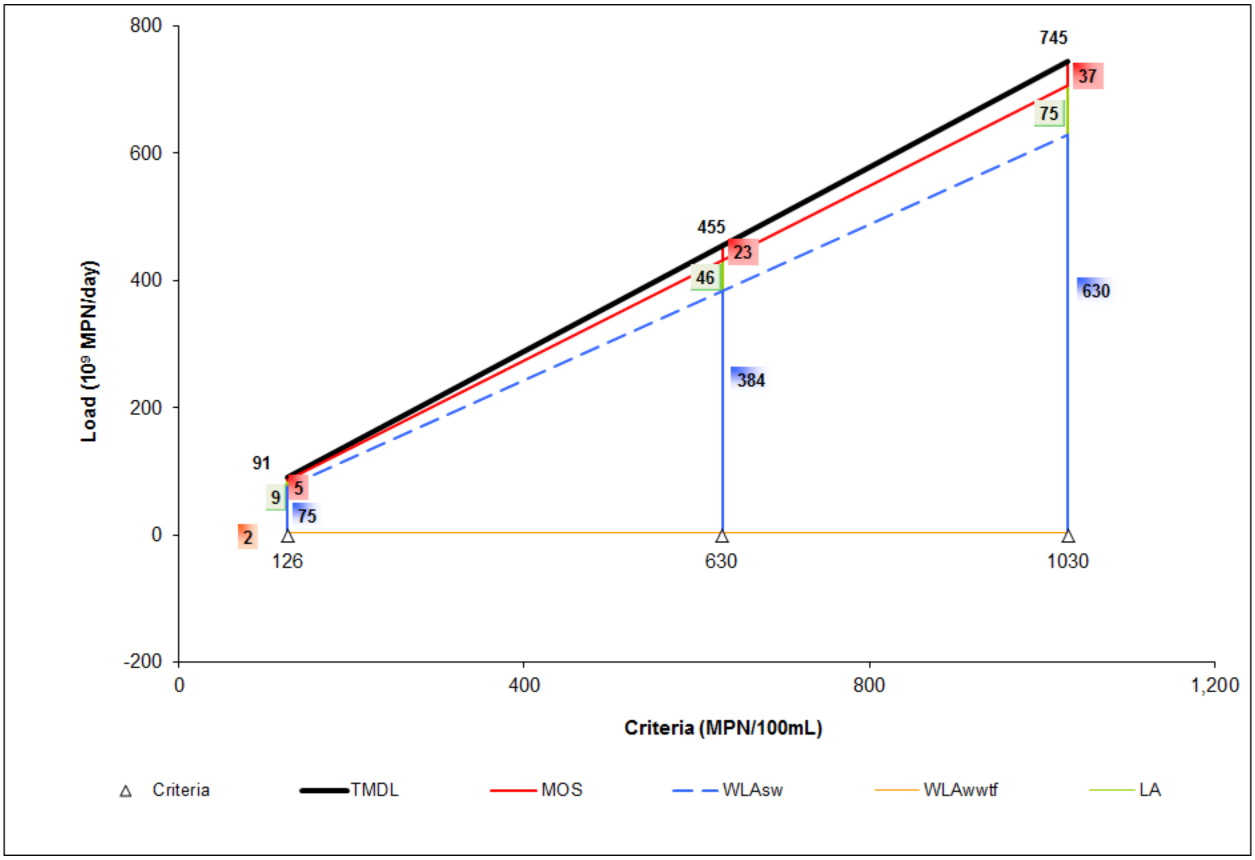

Figure B-5. Allocation loads for Bear Branch (1008E_01) as a function of water quality criteria

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

TMDL = 0.72298 * Std

WLA_{WWTF} = 2.33

WLA_{sw} = 0.61356 * Std – 2.09

LA = 0.07327 * Std – 0.25

MOS = 0.03615 * Std

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Waste load allocation (permitted stormwater)

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

MOS = Margin of Safety

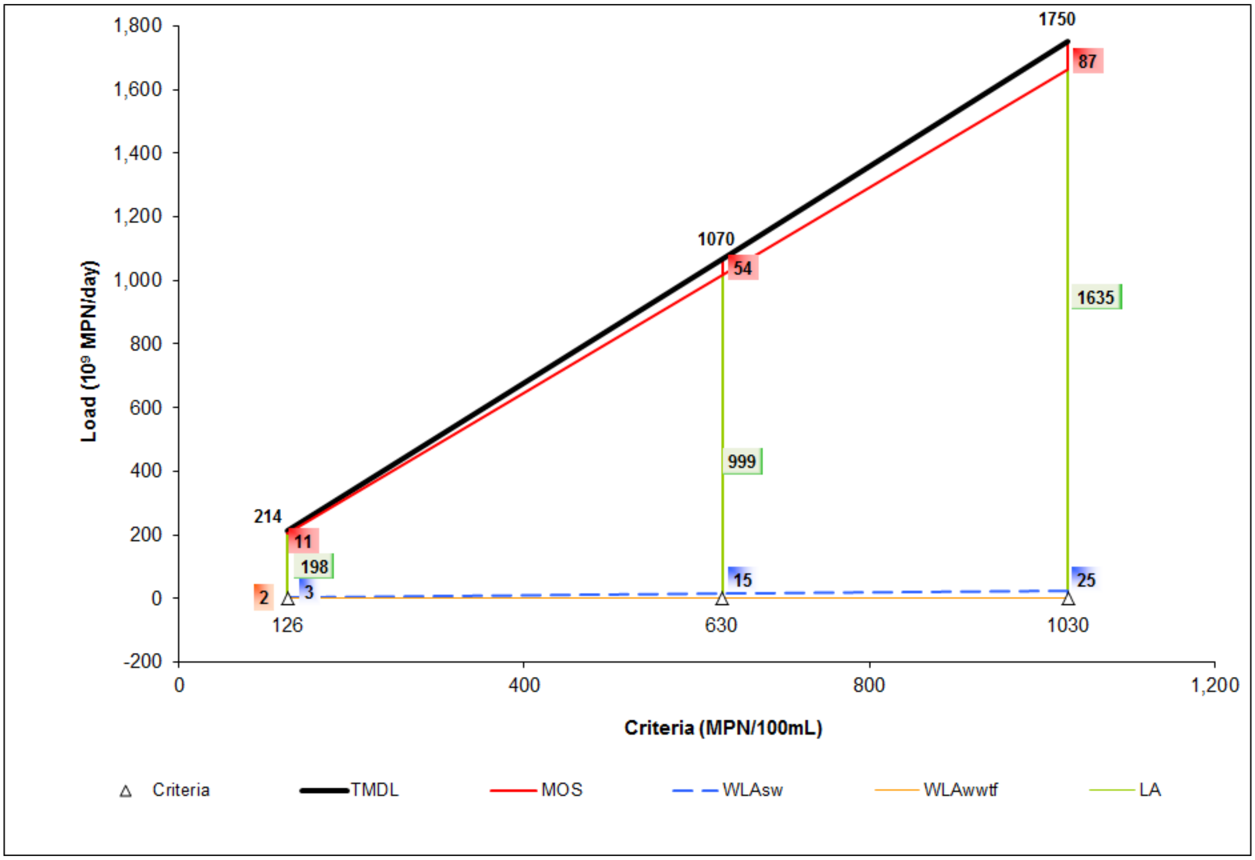

Figure B-6. Allocation loads for Peach Creek (1011_01) as a function of water quality criteria

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

$TMDL = 1.69886 * Std$

$WLA_{WWTF} = 2.24$

$WLA_{sw} = 0.02445 * Std – 0.03$

$LA = 1.58947 * Std – 2.20$

$MOS = 0.08494 * Std$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Waste load allocation (permitted stormwater)

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

MOS = Margin of Safety