Second Update
Technical Support Document for Total Maximum Daily Loads for Indicator Bacteria in Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek Watersheds

Segments: 1002, 1003, 1004 and 1004D

Assessment Units: 1002_06, 1003_01, 1003_02, 1003_03, 1004_01, 1004_02, and 1004D_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
C-CAP	Coastal Change Analysis Program
CCN	Certificate of Convenience and Necessity
DAR	Drainage Area Ratio
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
NDEP	Nevada Division of Environmental Protection
NEIWPCC	New England Interstate Water Pollution Control Commission
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OSSF	onsite sewage facility
SAB	service area boundary
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
TWRI	Texas Water Resources Institute
USDA	United State 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 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 West Fork San Jacinto River in 2002, and within East Fork San Jacinto River, Crystal Creek, and Lake Houston in 2006 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 7 total assessment units (AUs). The complete list of water bodies and their identifying segment_AU number are as follows:

1) Lake Houston 1002_06,
2) East Fork San Jacinto River 1003_01, 1003_02, 1003_03,
3) West Fork San Jacinto River 1004_01, 1004_02, and
4) Crystal Creek (unclassified water body) 1004D_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 (EPA) 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, 2010a).

1.3 Report Purpose and Organization

The Lake Houston, East Fork & West Fork San Jacinto, and Crystal 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 Lake Houston, East Fork & West Fork San Jacinto River, and Crystal 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, however, outside the area covered by previous TMDLs for indicator bacteria in watersheds upstream of Lake Houston (TCEQ, 2011a). Lake Houston (AU 1002_06) flows from the confluence with Spring Creek to the West Lake Houston Parkway crossing, directly draining approximately 24 mi^2 but having a much larger area if Spring Creek and the West Fork San Jacinto River are included. The East Fork San Jacinto (Segment 1003) flows from US 190 in southeast Walker County to the confluence with Caney Creek in northeastern Harris County and drains approximately 398 mi^2. The West Fork San Jacinto (Segment 1004) flows from the Conroe dam in Montgomery County to the confluence with Spring Creek at the Montgomery-Harris county line and drains approximately 480 mi^2, excluding the drainage area of Lake Conroe. Crystal Creek (Segment 1004D) flows southwesterly from the confluence of the East and West Forks of Crystal Creek to the confluence of the West Fork San Jacinto River and drains approximately 48 mi^2. With the exception of the East Fork San Jacinto River and Lake Houston, the TMDL segments are located entirely within Montgomery County. Much of the East Fork San Jacinto River's northern watershed is located inside the Sam Houston National Forest.

This study incorporates a watershed approach where the drainage area of the entire water body 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 1002 (Lake Houston) – From Lake Houston Dam in Harris County to the confluence of Spring Creek on the West Fork San Jacinto Arm in Harris/Montgomery County and to the confluence of Caney Creek on the East Fork San Jacinto Arm in Harris County, up to normal pool elevation of 44.5 feet (impounds San Jacinto River).
    - 1002_06 – From the confluence with Spring Creek to West Lake Houston Pkwy.
- Segment 1003 (East Fork San Jacinto River) – From the confluence of Caney Creek in Harris County to US 190 in Walker County.
    - 1003_01 – From the Caney Creek confluence upstream to US 59.
    - 1003_02 – From US Hwy 59 to a point immediately downstream of State Hwy 150.
    - 1003_03 – From a point immediately downstream of State Hwy 150 to US 190 (upper segment boundary).
- Segment 1004 (West Fork San Jacinto River) – From the confluence of Spring Creek in Harris/Montgomery County to Conroe Dam in Montgomery County.
    - 1004_01 – From the Spring Creek confluence upstream to the Stewart Creek confluence.
    - 1004_02 – From the Stewart Creek confluence upstream to the Lake Conroe Dam.
- Segment 1004D (Crystal Creek) – From the West Fork of the San Jacinto River confluence to the confluence of the East and West Forks of Crystal Creek.
    - 1004D_01 – From the confluence with West Fork San Jacinto River upstream to confluence of the East and West Forks of Crystal Creek.

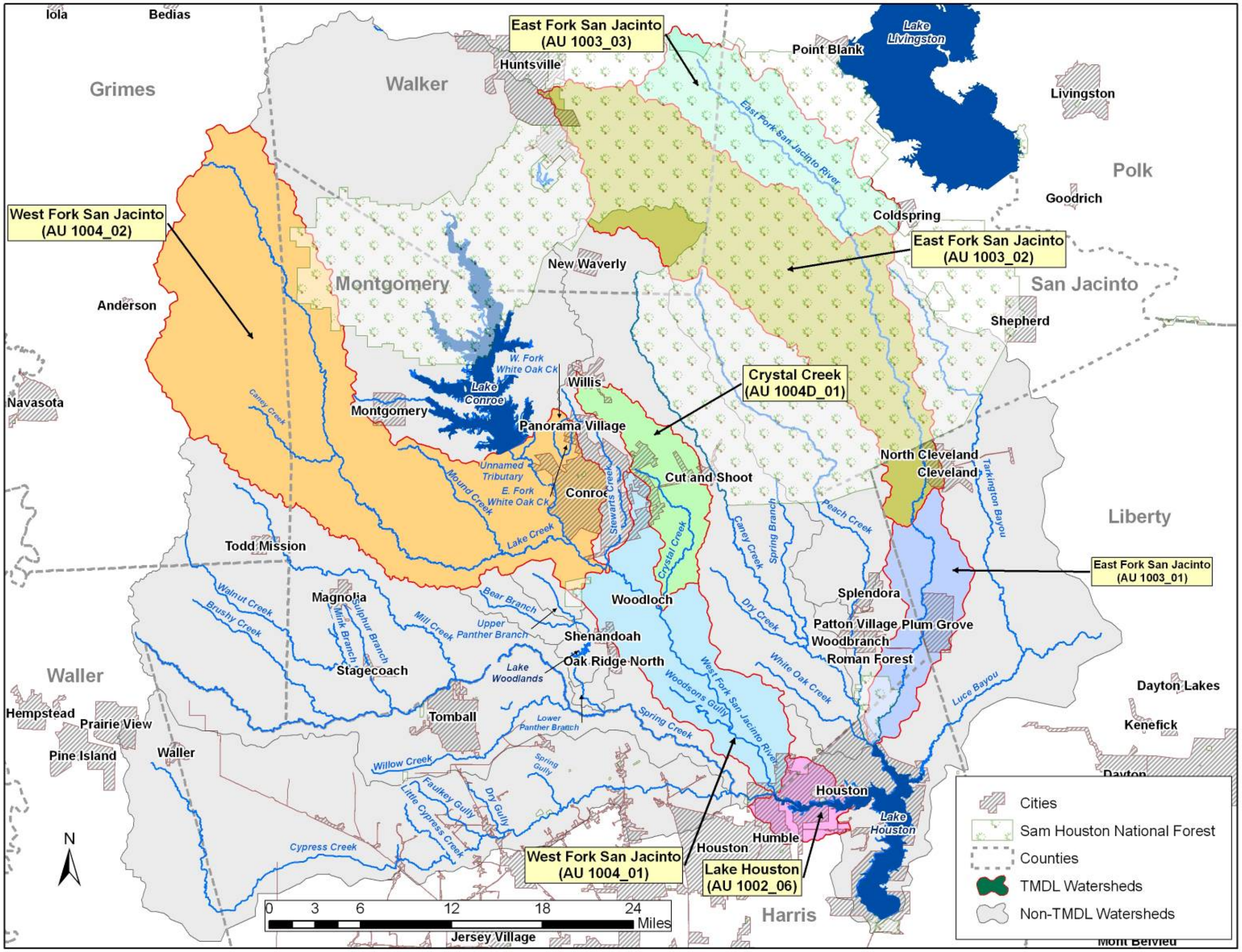

Figure 1 Total contributing drainage area for the study, including Segments 1002, 1003, 1004, and 1004D.

The 7 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 7 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 boundaries for the two AUs of West Fork San Jacinto River changed with the 2008 and 2010 editions of the *Texas Water Quality Integrated Report*. The AU definition used in the 2008 Texas Water Quality Integrated Report for 1004_01 of the West Fork San Jacinto describes the boundaries as being from the Lake Conroe Dam to IH45 and the boundary for 1004_02 as being from IH45 to the Spring Creek confluence. The AU boundary for 1004_01 used in the 2010 and 2012 Texas Water Quality Integrated Reports is from the Spring Creek confluence to the Stewart Creek confluence and for 1004_02 is from the Stewart Creek confluence upstream to the Lake Conroe Dam.

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 Grimes, Harris, Liberty, and Walker 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 precipitation data (1997-2006) for key weather stations is provided in Table 1. These data were obtained through the EPA 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. The warmest temperatures occur during the month of August when high temperatures typically average 95°F while the coolest low temperatures typically occur during the month of January with average low temperatures of 43°F. Maximum precipitation occurs in the late spring and autumn. It is not unusual for hurricanes to affect rainfall in the early autumn.

2.3 Review of Routine Monitoring Data for TMDL 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 1002_06, 1003_01, 1003_02, 1003_03, 1004_01, 1004_02, and 1004B_01 has occurred at numerous TCEQ monitoring stations (Figure 2). *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 *2012 Texas Integrated Report* (TCEQ, 2013) and as summarized in Table 2. For the purposes of this study, the current AU boundary definitions in Segments 1003 and 1004 were used.

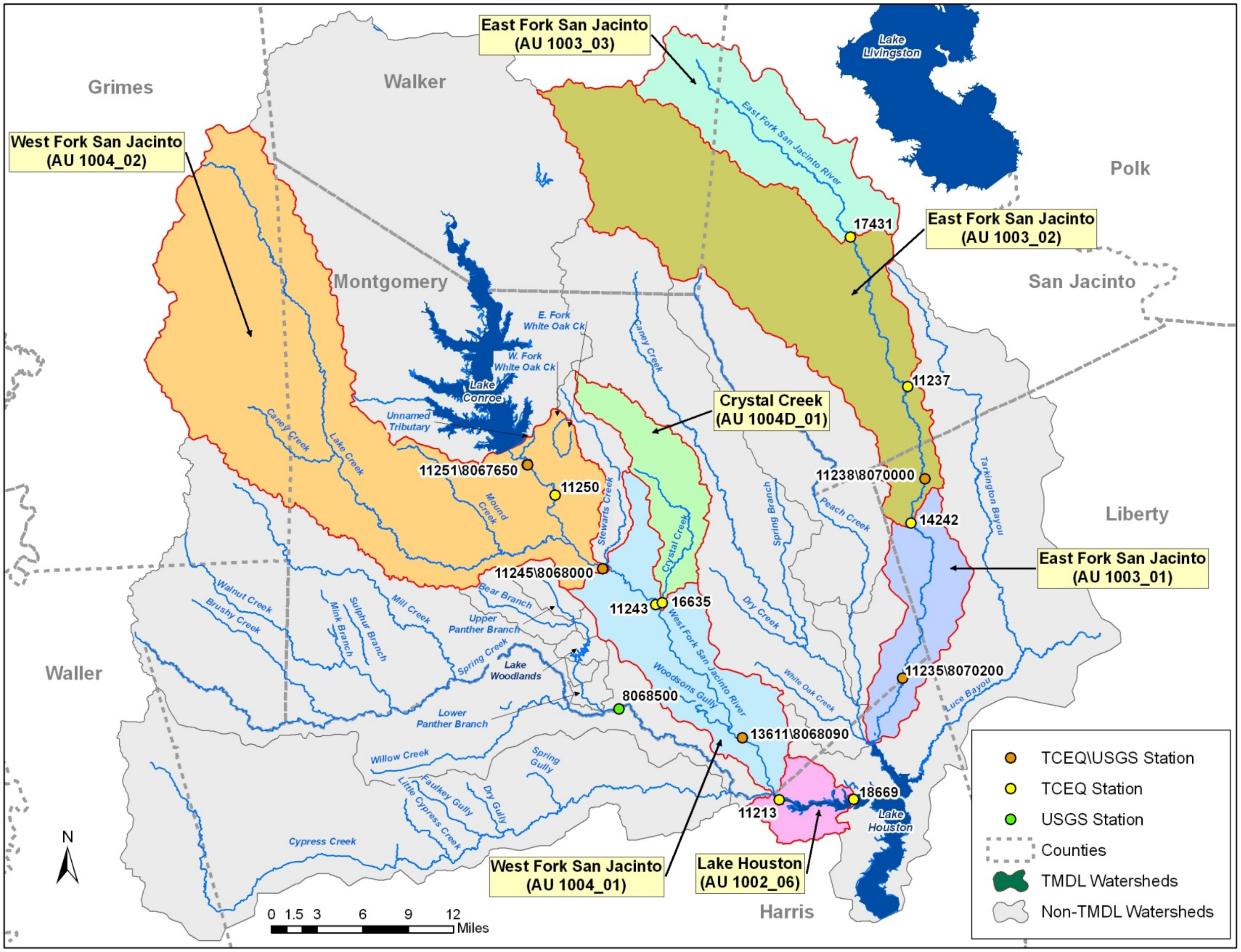

Figure 2 Lake Houston watershed showing SWQM monitoring stations and USGS gauging stations.

Table 2 2012 Integrated Report Summary for the watersheds of Lake Houston, East and West Fork San Jacinto River, and Crystal Creek. (Source: TCEQ, 2013)

Water Body	Assessment Unit (AU)	Data Date Range	No. of Samples in AU	AU Geometric Mean (MPN/100 mL)
Lake Houston	1002_06	2003—2010	218	255
East Fork San Jacinto	1003_01	2003 – 2010	84	193
	1003_02	2003 – 2010	37	158
	1003_03	2002 – 2010	11	197
West Fork San Jacinto	1004_01	2003 – 2010	24	179
	1004_02	2003 – 2010	59	170
Crystal Creek	1004D_01	2003 – 2010	24	338

2.4 Land Use

The land use/land cover data presented in this report are from the National Oceanic and Atmospheric Association (NOAA) Coastal Change Analysis Program (C-CAP) as obtained from the Houston-Galveston Area Council (H-GAC) and indicated to be for the year 2011 (NOAA, 2011). The land use/ land cover is represented by the following categories and definitions:

- **Developed (High Intensity)** – High intensity includes heavily built up urban centers and large constructed surfaces in suburban and rural areas. Constructed surfaces account for 80% to 100% of the total cover.
- **Developed (Medium Intensity)** – Medium intensity developed areas most commonly include multi- and single-family housing areas. Constructed surfaces account for 50% to 79% of the total cover.
- **Developed (Low Intensity)** – Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. These areas most commonly include single-family housing units. Constructed surfaces account for 20% to 49% percent of total cover.
- **Developed (Open Space)** – Areas with a mixture of constructed materials and vegetation. Constructed 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.
- **Cultivated** – Areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
- **Grassland/Scrub/Shrub** – A combined category composed of grassland and scrub/shrub. Grassland areas are dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. Scrub/shrub areas are dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

- **Forest** – Areas characterized by tree cover greater than 5 meters tall and tree canopy accounting for greater than 20% of the cover. The forest category includes deciduous, evergreen and mixed forests.
- **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, or 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.
- **Pasture/Hay** – Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation
- **Bare Land** – Areas of bedrock, scarps, talus, slides, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 10% of total cover.
- **Water and Unconsolidated Shore** – Areas of open water, generally with less than 25% cover of vegetation or soil, and unconsolidated shore comprised of silt, sand, and gravel that is subject to inundation and redistribution due to the action of water.

In reference to the broader Lake Houston watershed, the western portion is pasture and hay lands whereas forest and wetlands dominate the northern and eastern portions of the watershed (Figure 3). The south-central portions of the watershed are more heavily developed and urbanized. Among the 4 TMDL segments, only Lake Houston (1002_06) had a much of its land use classified as developed (approximately 44%), though forest is the largest single category (Table 3). The remaining segments were dominated by forest, grassland/scrub/shrub, and wetlands (Tables 4-6).

Table 3 Land use / land cover, Segment_AU 1002_06 (Source: NOAA, 2011)

Segment	**1002_06**	
AU	**Acres**	**%**
Bare Land	80.0	0.5%
Cultivated	1.9	0.0%
Forest	5,250.0	33.9%
Grassland/Scrub/Shrub	804.7	5.2%
Developed Open Space	1,651.7	10.7%
High Intensity Developed	882.0	5.7%
Low Intensity Developed	2,298.2	14.8%
Medium Intensity Developed	2,025.4	13.1%
Pasture/Hay	238.1	1.5%
Water & Unconsolidated Shore	879.1	5.7%
Wetland	1,384.3	8.9%
Total Acres	***15,495.5***	

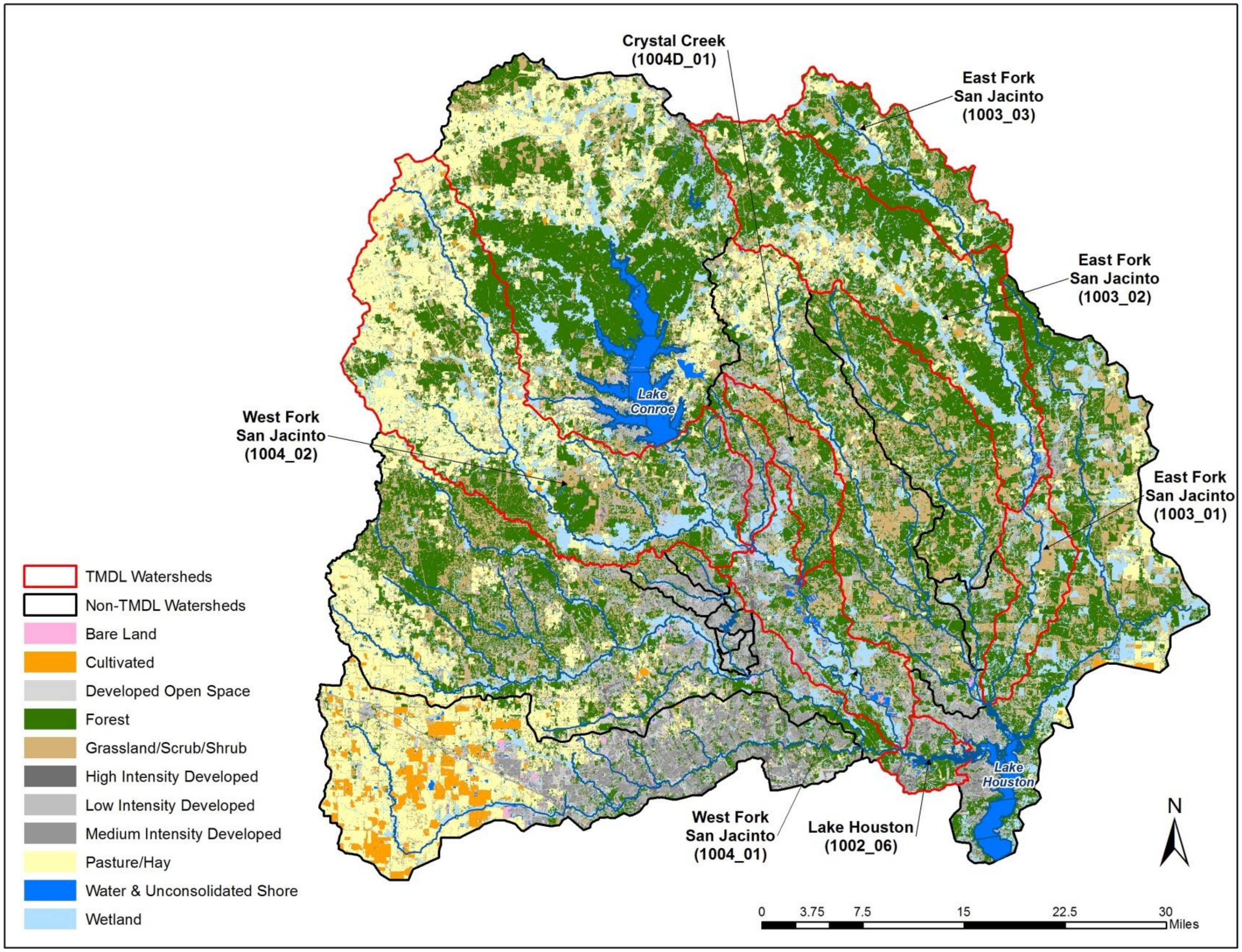

Figure 3 Land use / land cover in the Lake Houston watershed (Source: NOAA, 2011)

Table 4 Land use / land cover, Segment 1003 (Source: NOAA, 2011)

Segment	1003_01		1003_02		1003_03		1003 TOTAL	
AU	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Bare Land	62.0	0.2%	306.1	0.2%	66.3	0.1%	434.4	0.2%
Cultivated	0.0	0.0%	796.0	0.5%	66.7	0.1%	862.7	0.3%
Forest	14,256.8	38.1%	77,669.1	49.0%	29,811.0	50.7%	121,736.9	47.8%
Grassland/Scrub/Shrub	10,349.3	27.6%	25,058.2	15.8%	11,012.1	18.7%	46,419.6	18.2%
Developed Open Space	438.8	1.2%	404.2	0.3%	52.6	0.1%	895.6	0.4%
High Intensity Developed	108.0	0.3%	350.9	0.2%	8.3	0.0%	467.1	0.2%
Low Intensity Developed	1,513.0	4.0%	2,279.3	1.4%	581.5	1.0%	4,373.8	1.7%
Medium Intensity Developed	291.9	0.8%	430.5	0.3%	26.1	0.0%	748.5	0.3%
Pasture/Hay	999.7	2.7%	20,462.2	12.9%	6,387.0	10.9%	27,848.9	10.9%
Water & Unconsolidated Shore	231.0	0.6%	1,454.6	0.9%	142.8	0.2%	1,828.4	0.7%
Wetland	9,199.3	24.6%	29,152.7	18.4%	10,691.5	18.2%	49,043.5	19.3%
Total Acres	***37,449.6***		***158,363.8***		***58,845.9***		***254,659.3***	

Table 5 Land use / land cover, Segment 1004 (Source: NOAA, 2011)

Segment	1004_01		1004_02		1004 TOTAL	
AU	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Bare Land	899.8	1.4%	1,200.3	0.5%	2,100.1	0.7%
Cultivated	43.2	0.1%	1,648.4	0.7%	1,691.6	0.6%
Forest	18,457.1	28.8%	66,892.2	27.5%	85,349.3	27.8%
Grassland/Scrub/Shrub	10,030.0	15.7%	35,137.7	14.4%	45,167.6	14.7%
Developed Open Space	2,207.7	3.4%	1,744.8	0.7%	3,952.5	1.3%
High Intensity Developed	1,508.4	2.4%	1,348.6	0.6%	2,856.9	0.9%
Low Intensity Developed	9,079.9	14.2%	10,797.8	4.4%	19,877.6	6.5%
Medium Intensity Developed	3,136.4	4.9%	2,020.1	0.8%	5,156.6	1.7%
Pasture/Hay	889.9	1.4%	83,398.4	34.3%	84,288.3	27.4%
Water & Unconsolidated Shore	2,734.2	4.3%	1,964.4	0.8%	4,698.6	1.5%
Wetland	15,029.2	23.5%	37,289.4	15.3%	52,318.6	17.0%
Total Acres	***64,015.8***		***243,442.1***		**307,457.9**	

Table 6 Land use / land cover, Segment 1004D (Source: NOAA, 2011)

Segment	**1004D_01**	
AU	**Acres**	**%**
Bare Land	131.5	0.4%
Cultivated	0.0	0.0%
Forest	13,338.6	43.1%
Grassland/Scrub/Shrub	8,638.7	27.9%
Developed Open Space	1,176.5	3.8%
High Intensity Developed	584.2	1.9%
Low Intensity Developed	3,191.4	10.3%
Medium Intensity Developed	750.7	2.4%
Pasture/Hay	806.4	2.6%
Water & Unconsolidated Shore	129.0	0.4%
Wetland	2,182.6	7.1%
Total Acres	**30,929.7**	

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 TMDL watersheds

2.5.1.1 Domestic and Industrial Wastewater Treatment Facility Discharges

There are 60 regulated discharge facility outfalls located in the TMDL watersheds of which 53 are authorized to treat and discharge wastewater that contains a human waste component (Table 7, Figure 4). The remaining seven permitted outfalls are not considered to be potential sources of bacteria due to the absence of a human waste component within the wastewater discharge.

Table 7 Permitted wastewater operations in Lake Houston, East Fork & West Fork San Jacinto Rivers, and Crystal Creek watersheds.

Actual discharge values based on available monthly discharge monitoring reports within the 1999-2012 period.

Reference No. for Figure 7	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
01	WQ11658-001	TX0063461	San Jacinto River Authority	Vince Tract Development WWTF	1004_01	0.900	0.474
02	WQ11820-001	TX0069256	Lazy River Improvement District	Lazy River Improvement District WWTF	1004_01	0.100	0.048
03	WQ11844-001	TX0071765	Forest Glen Inc.	Forest Glen Christian Camp WWTF	1003_03	0.040	0.015
04	WQ15288-001	TX0135682	Montgomery County MUD 96	Montgomery County MUD 96 WWTF	1004_01	0.4	—[f]
05	WQ04249-000[a]	TX0123421	Steely Lumber Co. Inc.	Steely Lumber WWTF	1003_02	Report Only	Report Only
06	WQ14755-001	TX0129160	Quadvest LP	Benders Landing WWTF	1004_01	0.900	0.003
07	WQ10008-002	TX0022268	City of Conroe	City of Conroe Southwest Regional WWTF	1004_02	10.0	5.83
08	WQ12212-002	TX0093564	City of Shenandoah	City of Shenandoah WWTF	1004_01	3.00	0.467
09	WQ12761-001	TX0093505	Karbalia, Laura Redow	Westmont MHP WWTF	1004_02	0.050	0.016
10	WQ15089-001	TX0134520	D R Horton-Texas LTD	Montgomery County MUD 139 WWTP	1015_01[c]	0.51	—[f]
11	WQ00584-000[a] (Outfall 002)	TX0005592	Huntsman Petrochemical Corp.	Conroe Chemical Plant	1004G_01[b]	Report Only	Report Only
12	WQ00584-000 Outfall 001	TX0005592	Huntsman Petrochemical Corp.	Huntsman Petrochemical Conroe Plant	1004G_01[b]	0.750	0.409
13	WQ10315-001	TX0068845	City of Willis	City of Willis WWTF	1004D_01	0.800	0.594
14	WQ13526-001	TX0105996	Kings Manor MUD	Kings Manor MUD WWTF	1002_06	0.400	0.222

Reference No. for Figure 7	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
15	WQ14996-001	TX0028169	Universal Forest Products Texas LLC	UFP New Waverly WWTF	1003_02	0.020	0.006
16	WQ15012-001	TX0133167	Utilities Investment Company Inc.	Plum Grove WWTF	1003_01	0.225	0.068
17	WQ13700-001	TX0090123	Chateau Woods MUD	Chateau Woods WWTF	1004_01	0.200	0.095
18	WQ13760-001	TX0089672	Montgomery County MUD 56	Montgomery County MUD 56 WWTF	1004_01	0.100	0.068
19	WQ10495-142	TX0088501	City of Houston	Kingwood West WWTF	1004_01	2.000	0.300
20	WQ10495-149	TX0115924	City of Houston	Forest Cove WWTF	1002_06	0.950	0.319
21	WQ13985-001	TX0117706	Montgomery County MUD 89	Rembert Tract WWTF	1004_01	0.500	0.193
22	WQ14414-001	TX0125601	242 LLC	Woodland Lakes Village WWTF	1004_01	0.450	0.319
23	WQ02475-000 Outfall 001	TX0087190	Chevron Phillips Chemical Co LP	Drilling Specialties Alamo Plant	1004G_01[b]	0.016	0.006
24	WQ02502-000[a]	TX0087793	Hanson Aggregates Central Inc.	Woodlands Plant	1004_01	0.350	0.000
25	WQ02642-000[a]	TX0093483	PWT Enterprises Inc.	King Kleen Car Wash	1002_06	0.003	0.001
26	WQ14114-001	TX0119504	Aqua Development Inc.	Aquasource Development Company WWTF	1004_02	0.600	0.009
27	WQ14091-001	TX0095630	North Park Business Center Ltd.	North Park Business Center Ltd. WWTF	1002_06	0.0048	0.001
28	WQ14671-001	TX0128431	Montgomery County MUD 112	Montgomery County MUD 112 WWTF	1004_02	0.500	0.015
29	WQ10766-001	TX0053473	City of Cleveland	West WWTF	1003_02	0.750	0.344
30	WQ14482-001	TX0126209	Montgomery County MUD 83	Montgomery County MUD 83 WWTF	1004_01	0.600	0.152
31	WQ14604-001	TX0127752	Montgomery County MUD 99	Montgomery County MUD 99 WWTF	1004_01	1.50	0.046
32	WQ10978-001	TX0025674	River Plantation MUD	River Plantation MUD WWTF	1004_01	0.600	0.365

Reference No. for Figure 7	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
33	WQ14523-001	TX0126713	Montgomery County MUD 88	Montgomery County MUD 88 WWTF	1004_01	0.600	0.005
34	WQ14531-001	TX0126799	JTM Housing Ltd. And Quadvest Inc.	Creekside WWTF	1004_01	0.600	0.054
35	WQ02365-000[a]	TX0034681	Maverice Tube Corp.	Tenaris Conroe	1004_01	0.1108	0.020
36	WQ02475-000[a] Outfall 002	TX0087190	Chevron Phillips Chemical Co LP	Drilling Specialties WWTF	1004G_01[b]	Stormwater Only	—
37	WQ11097-001	TX0020206	City of Panorama Village	City of Panorama Village WWTF	1004_02	0.400	0.250
38	WQ14586-001	TX0127400	LMV Management Co. Ltd.	ER Woodsons WWTF	1004_01	0.900	0.285
39	WQ14709-001	TX0102962	Stone Hedge Utility Co. Inc.	Stone Hedge WWTF	1004D_01	0.015	0.005
40	WQ11395-001	TX0022055	Montgomery County MUD 15	Gleneagles Sub-division WWTF	1004_01	0.900	0.146
41	WQ11580-001	TX0075680	Town of Woodloch	Town of Woodloch WWTF	1004_01	0.150	0.075
42	WQ14711-001	TX0128368	Quadvest LP	Mostyn Manor WWTF	1015_01[c]	0.500	0.006
43	WQ14989-001	TX0132845	The Cardon Group Inc.	Montgomery Co. MUD 125 WWTF	1015_01[c]	0.960	0.118
44	WQ14638-001	TX0128121	MSEC Enterprises Inc.	MSEC WWTF	1015A_01[d]	0.02	0.004
45	WQ12456-001	TX0088901	Crane Co.	Crane Energy Flow Solutions WWTF	1015A_01[d]	0.005	0.002
46	WQ13527-001	TX0106119	Richards ISD	Richards ISD WWTF	1015_01[c]	0.005	0.0004
47	WQ14166-001	TX0122327	Woodland Oaks Utility Co. Inc.	Woodland Oaks WWTF	1015_01[c]	0.498	0.134
48	WQ14305-001	TX0124486	SR Superior LLC	Skye Ranch WWTF	1015_01[c]	0.240	0.029
49	WQ14800-001	TX0129585	John David Hagerman and Martha Voss Byrd	Fair Oaks WWTF	1015_01[c]	0.700	0.086
50	WQ14814-001	TX0129674	Montgomery County MUD 113 C/O Allen Boone Humphries Robinson LLP	Woodforest Interim WWTF	1015_01[c]	0.945	0.116
51	WQ11437-001	TX0092649	Grimes County MUD 1	Grimes County MUD 1 WWTF	1015B_01[e]	0.025	0.003

Reference No. for Figure 7	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
52	WQ15317-001 Outfall 002	TX0136000	QUADVEST LP	Magnolia Lake Creek	1015_01[c]	See Below	—[f]
53	WQ15317-001 Outfall 001	TX0136000	QUADVEST LP	Magnolia Lake Creek	1015_01[c]	0.250 for both outfalls combined	—[f]
54	WQ15283-001	TX0135658	Bluejack Development CO LLC	Blaketree MUD 1of Montgomery County	1015_01[c]	0.200	—[f]
55	WQ15341-001	TX0136191	MSEC Enterprises Inc.	MSEC WWTP 2	1015A_02[d]	0.130	—[f]
56	WQ05111-000[a]	TX0135071	Tenaska Roans Prairie Partners LLC	Tenaska Roans Prairie Generating Station	1015_01[c]	0.105	—[f]
57	WQ15296-001	TX0135755	Woodlands Oaks Utility LP	Lost Creek WWTP	1004G_01[b]	0.250	—[f]
58	WQ15313-001	TX0135941	Montgomery County MUD 127	Montgomery County MUD 127 WWTP	1004_01	0.600	—[f]
59	WQ15192-001	TX0134996	QUADVEST LP	Grande San Jacinto WWTF	1003_01	0.900	—[f]
60	WQ15061-001	TX0133817	QUADVEST LP	Bella Vista WWTP	1003_01	0.480	—[f]

[a] Discharge from facility does not include a human waste component and thus was not considered a bacteria source.

[b] West Fork Crystal Creek (1004G_01) is not impaired, but is a tributary to impaired Crystal Creek (1004D_01).

[c] Lake Creek (1015_01) is not impaired, but is a tributary to impaired West Fork San Jacinto River AU 1004_02.

[d] Mound Creek (1015A_01 & 1015A_02) is not impaired, but as a tributary to Lake Creek, its watershed contributes to impaired West Fork San Jacinto AU 1004_02.

[e] Caney Creek (1015B_01) is not impaired, but as tributary to Lake Creek, its watershed contributes to impaired West Fork San Jacinto AU 1004_02.

[f] Recent permit, no discharge record within the period of 1999-2012.

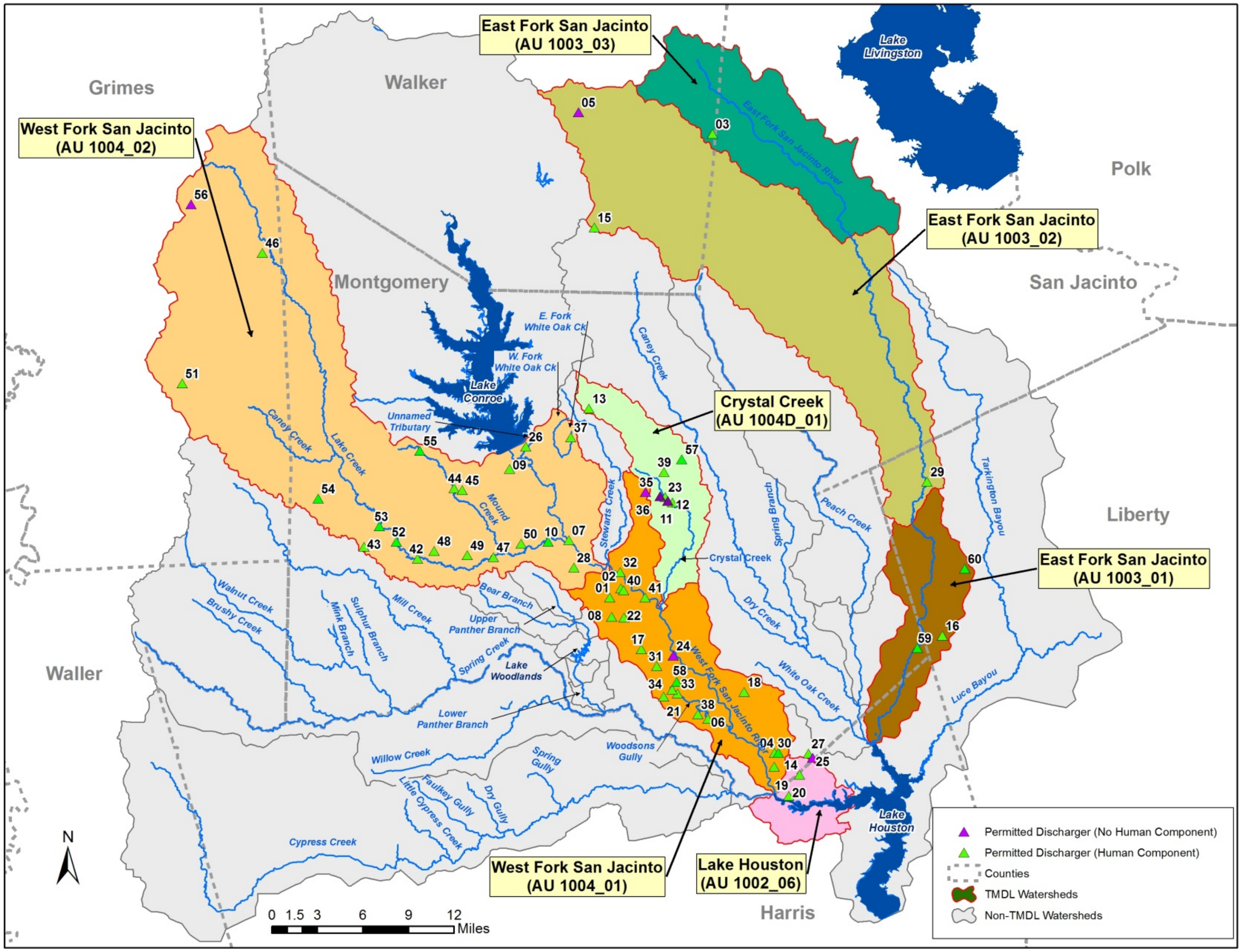

Figure 4 Permitted wastewater operations in Lake Houston, East Fork & West Fork San Jacinto Rivers, and Crystal Creek watersheds

Within East Fork San Jacinto (1003_03) there is one WWTF with a permitted discharge of 0.040 million gallons per day (MGD) and a human waste component. Within East Fork San Jacinto (1003_02) there are two WWTFs with a combined permitted discharge of 0.770 MGD that have a human waste component and one treatment facility that is authorized to discharge wet decking and other wastewater that does not contain human waste. Within East Fork San Jacinto (1003_01) there are three WWTFs with a combined permitted to discharge 1.605 MGD that have a human waste component.

The drainage area of West Fork San Jacinto (1004_02) includes the drainage areas of Lake Creek (1015_01), Mound Creek (1015A_01), and Caney Creek (1015B_01). Within the entire drainage area of West Fork San Jacinto (1004_02) there are 20 wastewater facilities with a combined permitted discharge of 16.538 MGD that have a human waste component. The Lake Creek watershed also includes one permitted outfall with a discharge of 0.105 MGD that is not considered to be a potential source of bacteria due to lack of a human waste component.

Within the West Fork San Jacinto (1004_01) there are 19 WWTFs with a combined permitted discharge of 15.0 MGD that have a human waste component. West Fork San Jacinto (1004_01) also contains two facilities that are authorized to discharge 0.4608 MGD of wastewater and do not contain a human waste component.

The drainage area of Crystal Creek (1004D_01) includes the drainage area of West Fork Crystal Creek (1004G_01). Within the entire drainage area of Crystal Creek (1004D_01) there are five WWTFs with a combined permitted discharge of 1.831 MGD that have a human waste component. The watershed of Crystal Creek also contains two permitted outfalls that are not considered to be potential sources of bacteria due to a lack of a human waste component.

Within the watershed of Lake Houston (1002_06) there are three WWTFs with a combined permitted discharge of 1.3548 MGD that have a human waste component. The Lake Houston watershed also contains one facility that is authorized to discharge 0.003 MGD of wastewater that does not contain a human waste component.

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 September 2001 - January 2013 for permits in the Lake Houston, East Fork & West Fork San Jacinto Rivers, and Crystal Creek watersheds and is summarized in Table 8. It should be noted that data were only available at the segment level for the East and West Fork San Jacinto watersheds. The East Fork San Jacinto watershed had the lowest number of reported incidences while the West Fork San Jacinto had the highest number of incidences. The smaller median volume for Lake Houston, East and West Fork San Jacinto, and Crystal Creek indicates that most of the SSO events were relatively small.

Table 8 Summary of SSO incidences reported in the TMDL watershed from September 2001 through January 2013.

Volumes are presented in gallons which were estimated by the reporting entity.

Segment/AU	No. of Incidences	Total Volume (gallons)	Average Volume (gallons)	Median Volume (gallons)	Min Volume (gallons)	Max Volume (gallons)
1002_06	20	30,230	1,512	500	10	7,000
1003	5	5,050	1,010	1,000	250	2,500
1004	96	994,902	10,364	500	5	540,000
1004D_01	7	247,900	35,414	1,000	100	240,000

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 EPA-defined urbanized area that are regulated by a general permit. The purpose of a MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge detection and elimination;
- Construction site runoff control;

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

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

For the TMDL watersheds containing entities with Phase II general permits and Phase I individual permits, the areas included under these MS4 permits were used to estimate the areas under stormwater regulation for construction, industrial and MS4 permits (Figure 5). The regulated area for the Phase II permits was based on the 2010 Urbanized Area from the U.S. Bureau of Census. The entities regulated under MS4 permits for the TMDL watersheds are provided in Table 9. For AUs 1003_03 and 1003_02 of the East Fork San Jacinto River that have no areas under MS4 permits, the regulated stormwater area was estimated from the other AUs based on an empirical relationship developed between MS4 permitted area and the total developed land use area in each AU (Figure 6). The total developed land use was calculated as the sum of Developed Open Space, Low Intensity Developed, Medium Intensity Devloped and High Intensity Developed in Table 4. The percentage of land area under 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.

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.

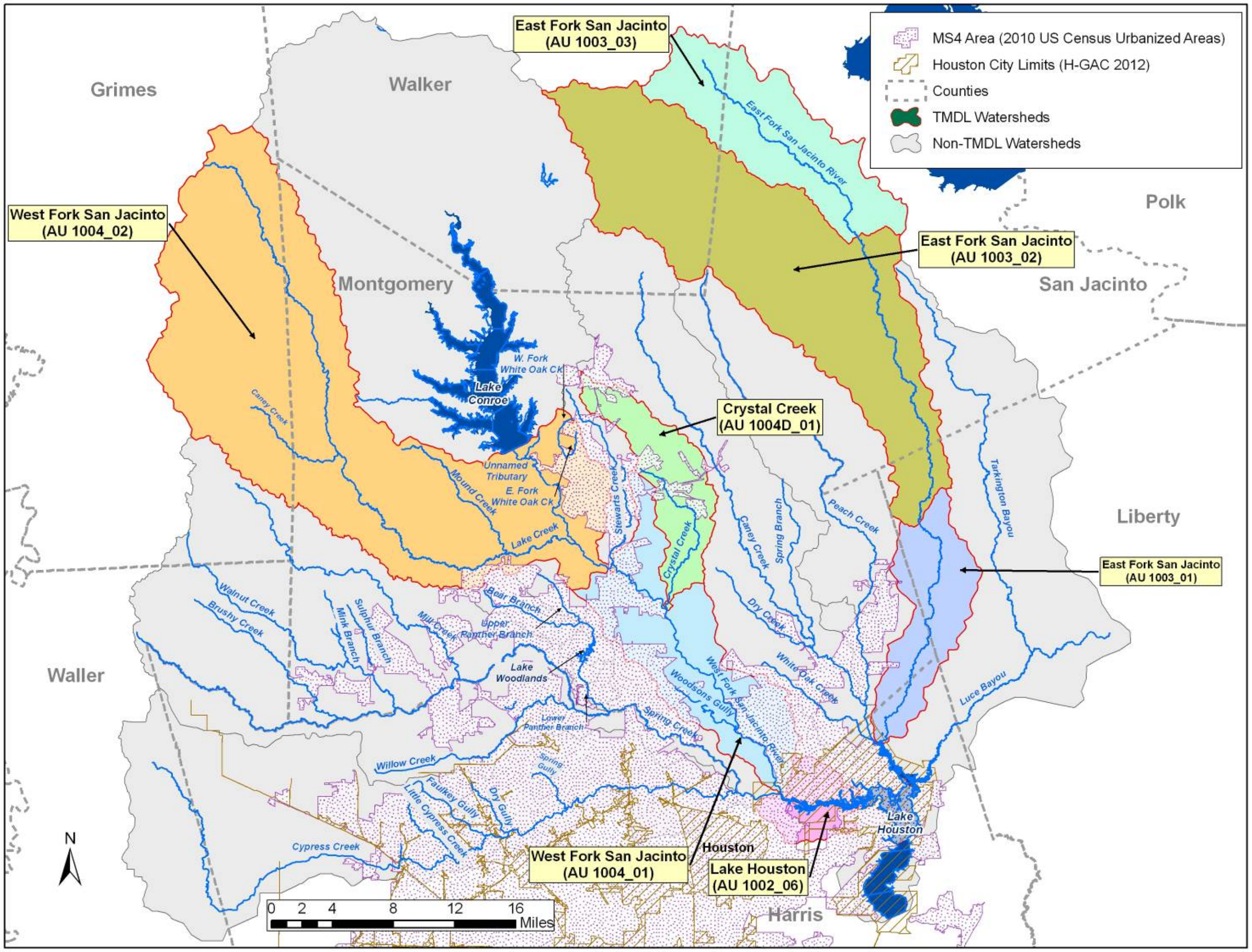

Figure 5 Lake Houston, East Fork & West Fork San Jacinto Rivers, and Crystal Creek watersheds showing MS4 permitted areas

Table 9 TPDES MS4-permits associated with TMDL area watersheds

Entity	Permit Number	AU
Kings Manor MUD MS4	TXR040387	1002_06
City of Humble MS4	TXR040251	1002_06
Texas Department of Transportation	TXR040191	1002_06, 1004_01
City of Houston, Harris County, Harris County Flood Control District, and Texas Department of Transportation	TXS001201	1002_06, 1003_01, 1004_01
Montgomery County MUD 15 MS4	TXR040382	1004_01
Rayford Road MUD MS4	TXR040147	1004_01
Spring Creek Utility District MS4	TXR040216	1004_01
City of Oak Ridge North MS4	TXR040273	1004_01
City of Shenandoah MS4	TXR040210	1004_01
Montgomery County Drainage District 6 MS4	TXR040121	1004_01
Montgomery County MS4	TXR040348	1004_01, 1004_02, 1004D_01
The Woodlands Joint Powers Agency MS4	TXR040256	1004_01, 1004_02

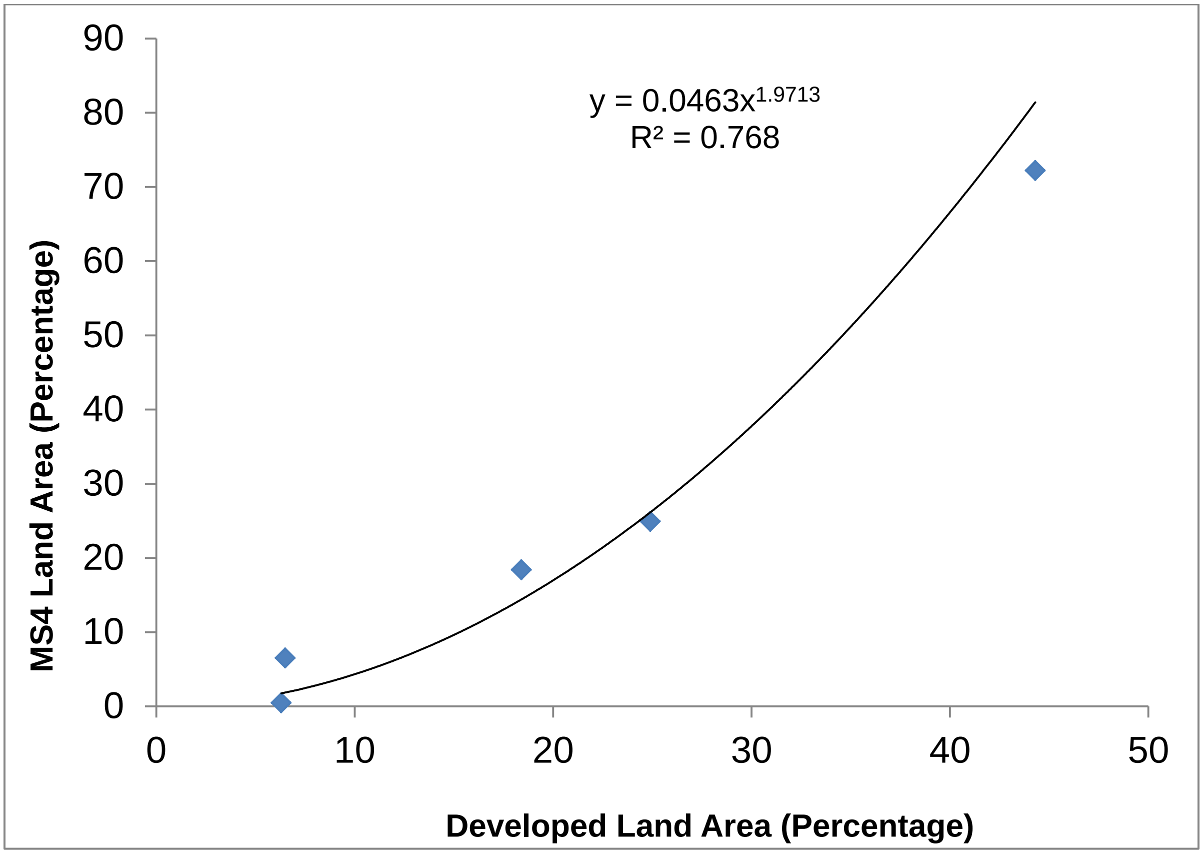

Figure 6 Relationship between MS4 permitted area and total developed land use area.

Table 10 Estimated area under stormwater permit regulations for TMDL watersheds

AU	Estimated areas under stormwater regulation (ac)	AU watershed area (ac)	Percentage of drainage area under stormwater regulation (%)
1002_06	11,195	15,495	72.2
1003_01	171	37,450	0.46
1003_02	347*	158,364	0.22
1003_03	33*	58,846	0.056
1004_01	27,307	64,016	42.7
1004_02	12,437	243,442	5.1
1004D_01	4,856	30,930	15.7

* Area calculated from the equation in Figure 6 and a total percentage of developed land uses of 2.2 for AU 1003_02 and 1.1 for AU 1003_03.

2.5.1.5 Review of Information on Permitted Sources

A review conducted March 21, 2013 of the EPA 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 Failing 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 Yanke (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 were 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 7, and an estimate of the number of OSSFs in each AU of the TMDL watersheds is provided in Table 11.

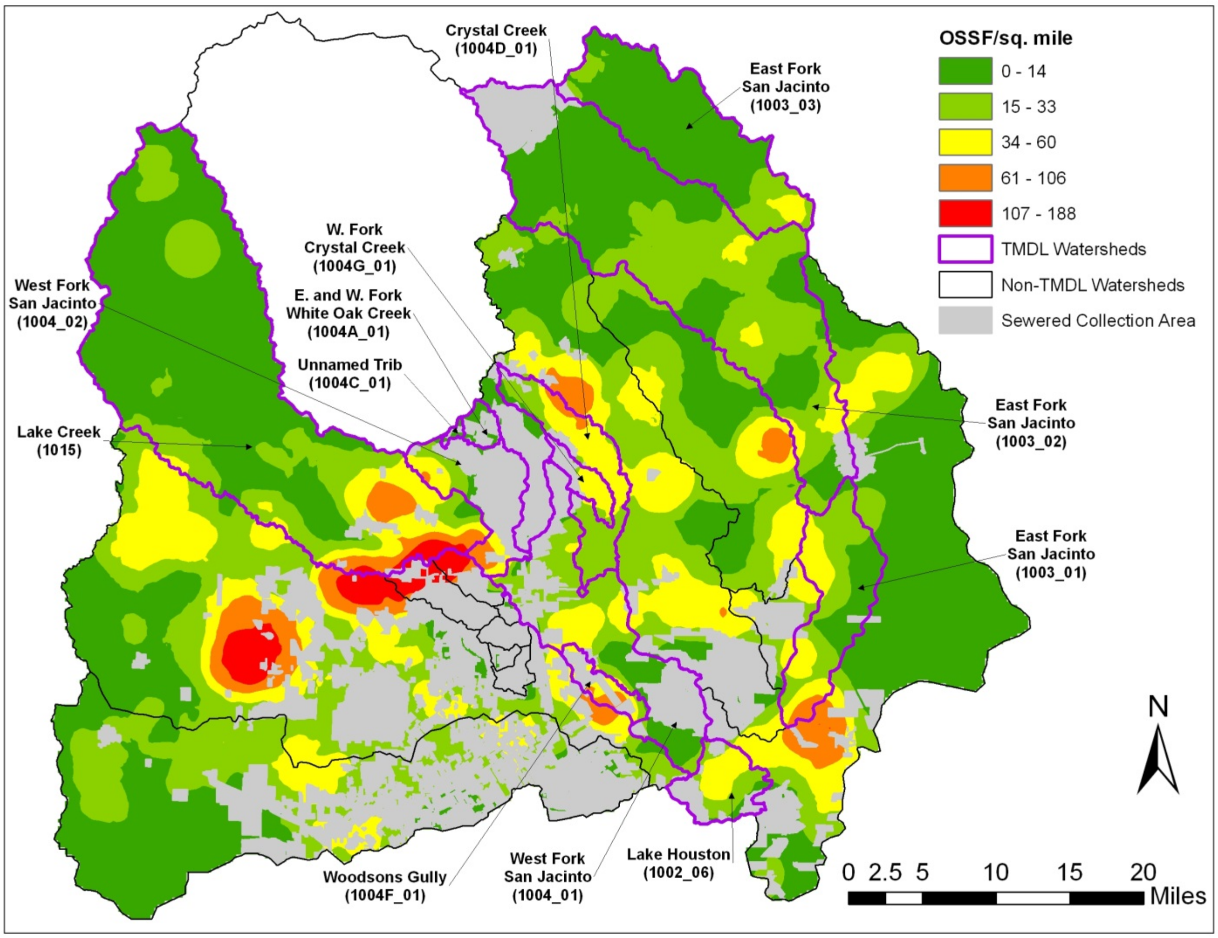

Figure 7 OSSFs densities within the Lake Houston watershed

Table 11 OSSF estimates for TMDL watersheds

AU	OSSFs
1002_06	687
1003_01	1,326
1003_02	3,570
1003_03	1,290
1004_01	2,165
1004_02	6,948
1004D_01	1,695

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 were 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 TMDL 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 TMDL 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. Only zip-code level population projections were available from H-GAC for the more rural northeastern part of East Fork San Jacinto River. The tract 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 East and West Fork San Jacinto, Lake Houston, and Crystal 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
1002_06	438	<10	71	<10	80	41
1003_01	2,433	31	355	27	328	172
1003_02	8,311	61	568	1,617	690	544
1003_03	2,972	27	226	463	252	216
1004_01	1,466	36	500	53	400	193
1004_02	678	17	231	24	185	89
1004D_01	1,018	25	347	37	278	134

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 (0.638) 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
1002_06	16,095	9,400	10,269
1003_01	6,948	4,057	4,433
1003_02	3,530	2,062	2,252
1003_03*	1,290	753	823
1004_01	18,480	10,792	11,790
1004_02	22,981	13,421	14,662
1004D_01	5,305	3,098	3,384

* OSSF data from Table 11 was used as an estimate of the number of households within AU 1003_03 due to suspected inaccuracies that resulted from the zip-code level data available for population projects for that AU.

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

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 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 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 six streamflow gauges within the Lake Houston Watershed (Table 14, Figure 2). USGS streamflow gauge 0807000 is located on the East Fork San Jacinto River and is the source for streamflow records for AUs 1003_01, 1003_02, and 1003_03. USGS streamflow gauge 08068090 is located on the West Fork San Jacinto River and is the source for streamflow records for AUs 1004_01 and 1004_02. USGS streamflow gauge 0867650 is also located on the West Fork San Jacinto River and is the source for determining streamflow as a result of releases from the Lake Conroe dam. Streamflow for Crystal Creek (1004D_01) were calculated based on the streamflow records at USGS gauge 08068090 which is located on the West Fork San Jacinto River. Streamflow for Lake Houston (1002_06) was determined using streamflow records from USGS gauges located on West Fork San Jacinto River (08068090) and USGS gauge 08068500 on Spring Creek (1008_04) which are the major tributaries of AU 1002_06.

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)
08070200	East Fork San Jacinto River near New Caney, TX	1003_01	388	May 1984 – present
08070000	East Fork San Jacinto River near Cleveland, TX	1003_02	325	May 1939 – present
08068090	West Fork San Jacinto River above Lake Houston near Porter, TX	1004_01	962	May 1984 – present
08067650	West Fork San Jacinto River below Lake Conroe near Conroe, TX	1004_02	451	Oct. 1973 – present
08068000	West Fork San Jacinto River near Conroe, TX	1004_02	828	May 1924 - present
08068500	Spring Creek near Spring, TX	1008_04	409	Apr. 1939 – present

Self-reporting data in the form of monthly discharge information were available for the 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.

Water Body	Assessment Unit (AU)	Station	Station Location	No. of Samples	Data Date Range
Lake Houston	1002_06	11213	US 59	263	2000-2012
	1002_06	18669	West Lake Houston Parkway	302	2001-2007
East Fork San Jacinto River	1003_01	11235	FM 1485	153	2000-2012
	1003_02	11237	FM 945	20	2007-2011
	1003_02	11238	SH 105	11	2010-2012
	1003_02	14242	US 59	55	2000-2010
	1003_03	17431	SH 150	17	2002-2012
West Fork San Jacinto River	1004_01	11243	SH 242	76*	2000-2012
	1004_02	11251	SH 105	66	2000-2012
	1004_02	11250	FM 2854	49	2004-2012
Crystal Creek	1004D_01	16635	SH 242	114	2000-2012

* The total number of samples for station 11243 includes samples collected from discontinued TCEQ sampling station 16624 which was located in close proximity to 11243.

3.1.3 Allocation Tool Selection

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

The load duration curve method is not typically applied to reservoir and lake situations, rather application is typically restricted to systems that experience flowing water, i.e., rivers and creeks. The decision was made, however, to apply this method to AU 1002_06 of Lake Houston, because of the riverine characteristics of this portion of Lake Houston. Assessment unit1002_06 is the uppermost AU on the western arm of Lake Houston (e.g., see Figure 2) and by physical location represents a transition zone from the strictly riverine characteristics of the West Fork San Jacinto River and Spring Creek to more lake-like or lacustrine characteristics of the main body of Lake

Houston nearer its dam. The anticipated strong and immediate interconnection of AU 1002_06 to upstream tributaries made it feasible to apply the load duration curve method to this AU.

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. 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

Sampling stations that currently and are scheduled to have *E. coli* data collected determined the stream locations for which flow and bacteria load duration curves would be developed. This determination of the status of current and scheduled sampling efforts was determined by utilizing the Clean Rivers Program Coordinated Monitoring Schedule which is available online at https://cms.lcra.org/. These stations were conveniently located within the impaired reaches of each AU.

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 7) 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.

The location of Lake Conroe above stations along the mainstem of the West Fork San Jacinto River necessitated a further modification to the application of the drainage area ratio (DAR) method. Since discharges from the Lake Conroe dam are largely independent of drainage areas those discharges were identified and removed from the appropriate USGS gauge streamflow record prior to applying the drainage area ratio for stations along the mainstem of the West Fork San Jacinto River. The Lake Conroe discharges were then added to the flows of the West Fork.

Spring Creek (1008_04) and the West Fork San Jacinto (1004_01) are the two main tributaries that enter Lake Houston (1002_06). To develop a streamflow record for Lake Houston, flows were developed at the outlet of each of these tributaries using the drainage ratio method. The combined flows of these two tributaries defined the inlet flows to AU 1002_06. The inlet flows were then multiplied by another drainage area ratio that was calculated based on the drainage area of each of the two sampling stations within AU 1002_06 and drainage area of the inlet to AU 1002_06.

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 the appropriate USGS gauge.

Table 16 DARs for locations within the TMDL watersheds

Assessment Unit	Sampling Station	USGS Gauge / Inlet	Station Drainage Area (ac)	USGS Gauge / Inlet Drainage Area (ac)	DAR
1002_06	11213	Inlet of 1002_06	837,753	837,221	1.00
1002_06	18669	Inlet of 1002_06	852,717	837,221	1.02
1003_01	11235	0807000	246,237	207,771	1.19
1003_02	11237	0807000	90,358	207,771	0.435
1003_02	11238	0807000	207,771	207,771	1.00
1003_02	14242	0807000	217,210	207,771	1.05
1003_03	17431	0807000	58,846	207,771	0.283
1004_01	11243	08068090	273,699	339,219	0.807
1004_01	outlet	08068090	353,098	339,219	1.04
1004_02	11251	08068090	4,394	339,219	0.013
1004_02	11250	08068090	13,100	339,219	0.039
1004D_01	16635	08068090	30,793	339,219	0.091
1012	outlet	08067650	288,785	292,323	0.988
1008_04	outlet	08068500	484,123	258,560	1.87

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 (2.44658×10^7), which gives a loading in units of MPN/day; and

§ plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of *E. coli*.

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

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

- plot on the LDC for each station the load for each measurement at the exceedance percentage for its corresponding streamflow.

The plots of the LDC with the measured loads (*E. coli* concentration 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 8 through 14). In addition FDCs were developed for the outlet of Lake Conroe (1012) that enters the West Fork San Jacinto (1004_02), and the outlets of Spring Creek (1008_04) and West Fork San Jacinto River which enter Lake Houston (1002_06). 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. The influences of releases from the Lake Conroe dam are apparent in the FDC for West Fork San Jacinto (1004_02) at flow exceedances 0-40% (Figure 13). 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.

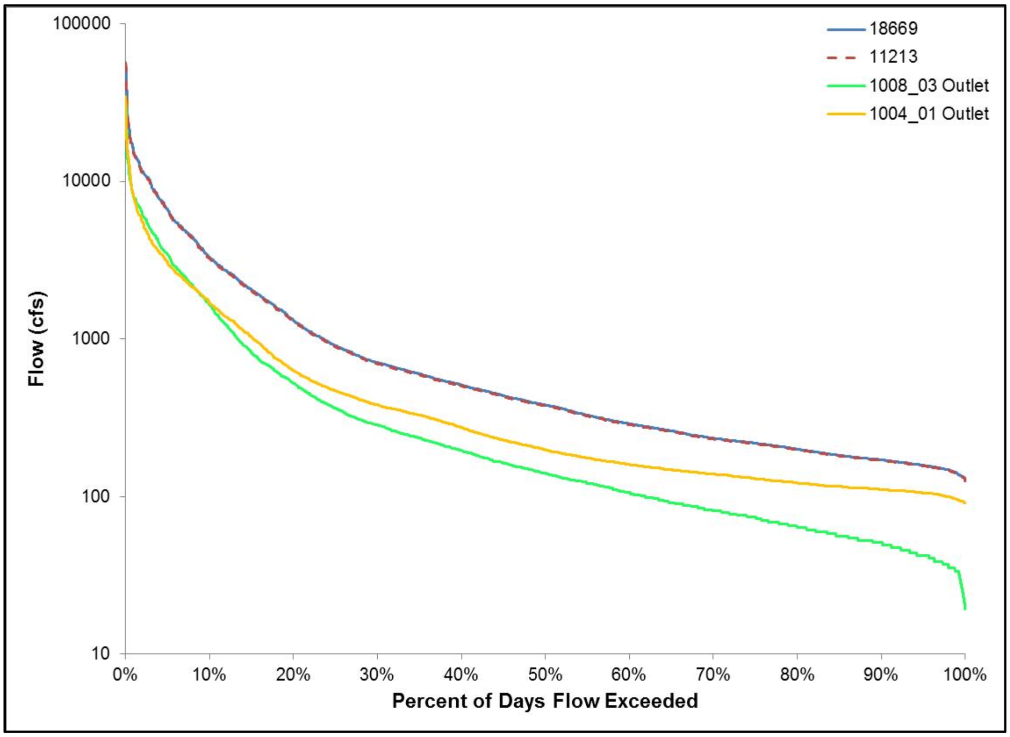

Figure 8 Flow duration curve at monitoring stations on Lake Houston (1002_06), and at the outlet of Spring Creek (1008_04) and West Fork San Jacinto River (1004_01).

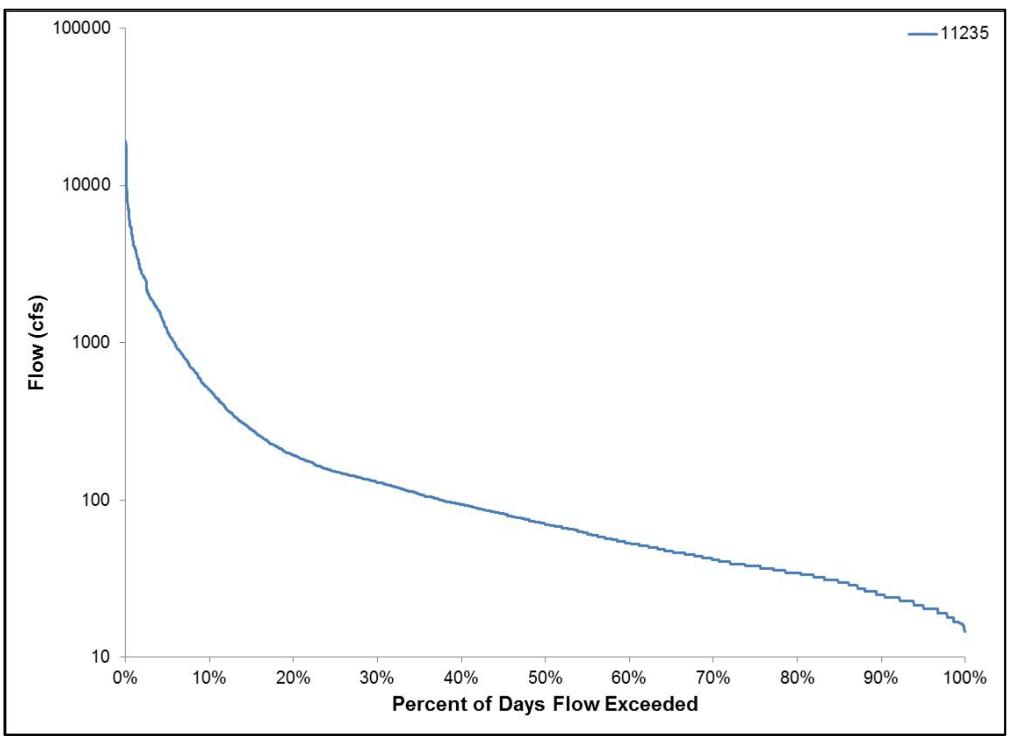

Figure 9 Flow duration curve at the monitoring station on the East Fork San Jacinto River (1003_01)

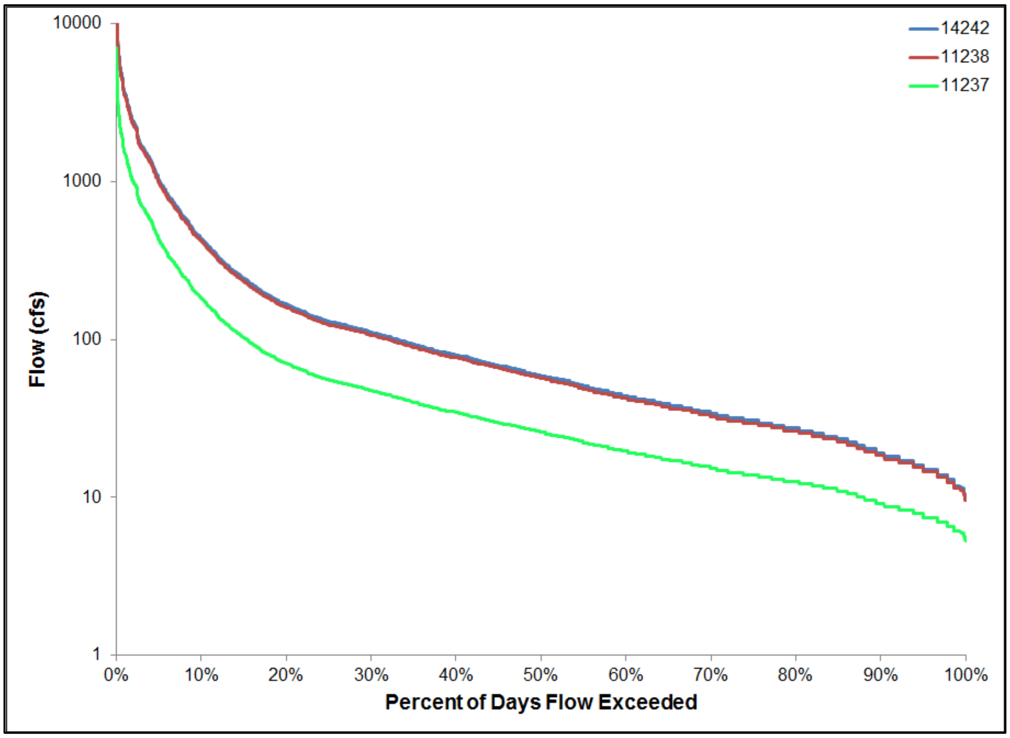

Figure 10 Flow duration curve at monitoring stations on the East Fork San Jacinto River (1003_02)

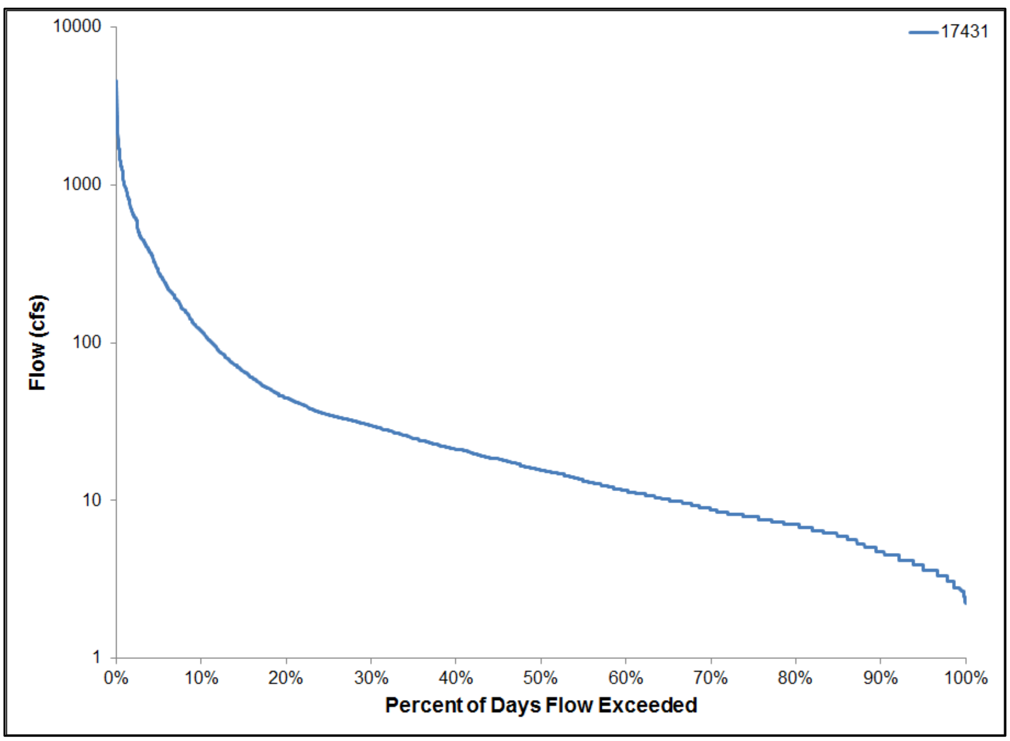

Figure 11 Flow duration curve at the monitoring station on the East Fork San Jacinto River (1003_03)

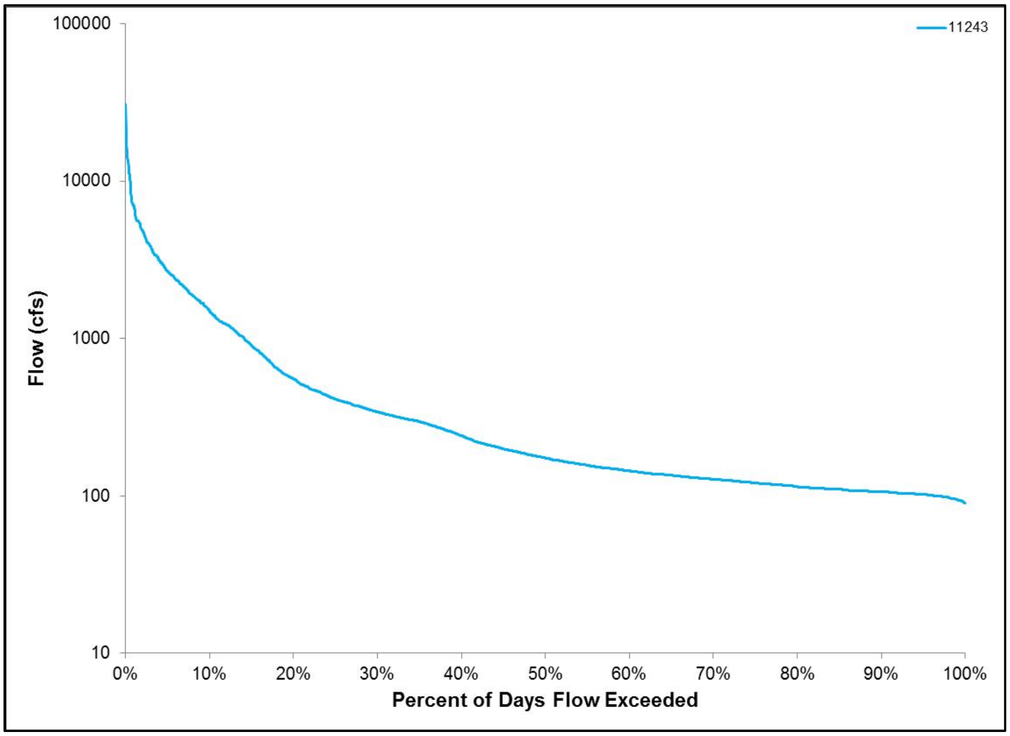

Figure 12 Flow duration curve at the monitoring station on the West Fork San Jacinto River (1004_01)

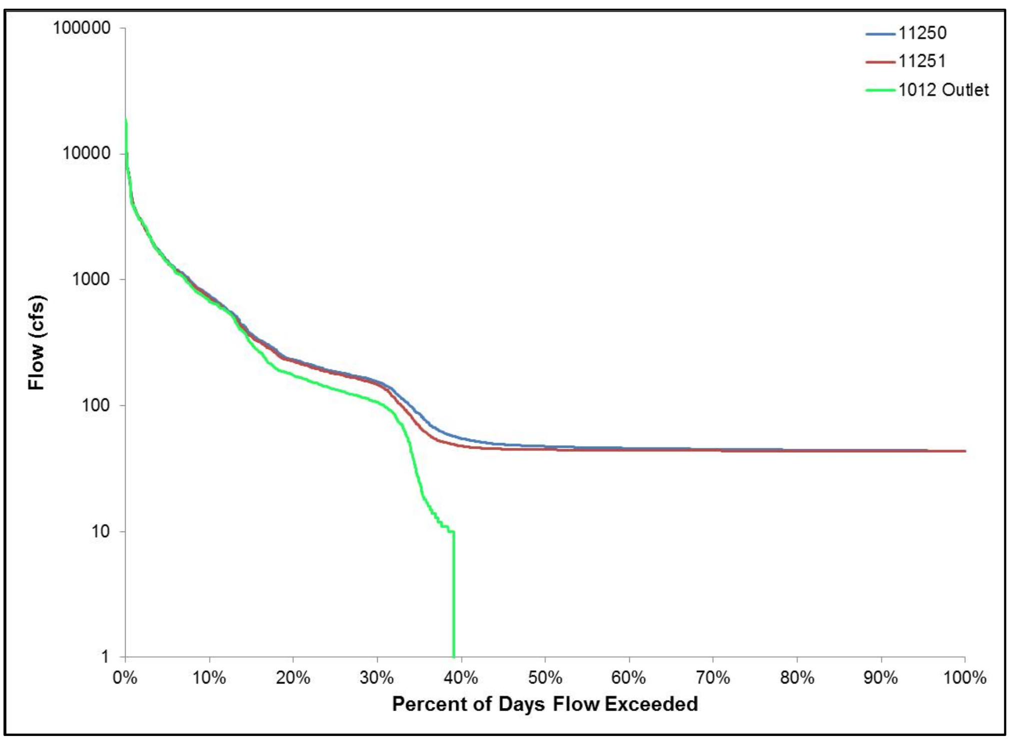

Figure13 Flow duration curve at monitoring stations on the West Fork San Jacinto River (1004_02)

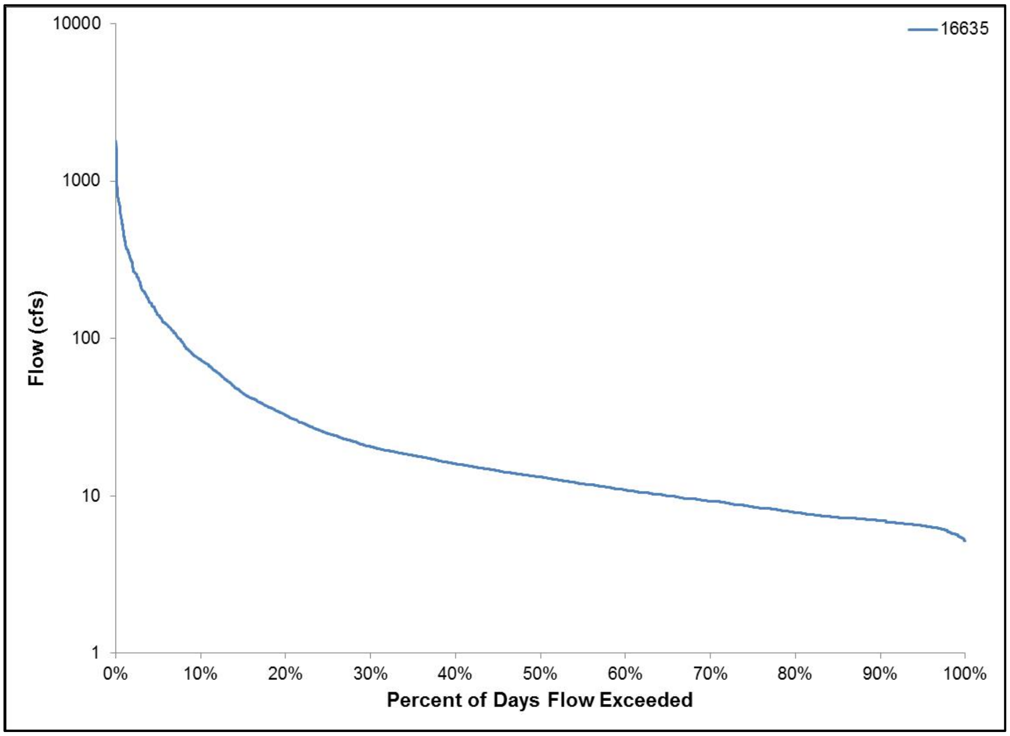

Figure 14 Flow duration curve at the monitoring station on Crystal Creek (1004D_01)

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 15 through 25, and were constructed for developing the TMDL allocation for each of the TMDL watersheds. Geometric mean loadings for the data points within each flow regime have also been distinguished on each figure to aid interpretation. The LDCs for the water quality monitoring stations provide a means of identifying the streamflow conditions under which exceedances in *E. co*li concentrations have occurred. The LDCs depict the allowable loadings at the stations under the geometric mean criterion (126 MPN/100 mL) and show that existing loadings often exceed the criterion. In addition, the LDCs also present the allowable loading at the stations under the single sample criterion (399 MPN/100 mL) 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.

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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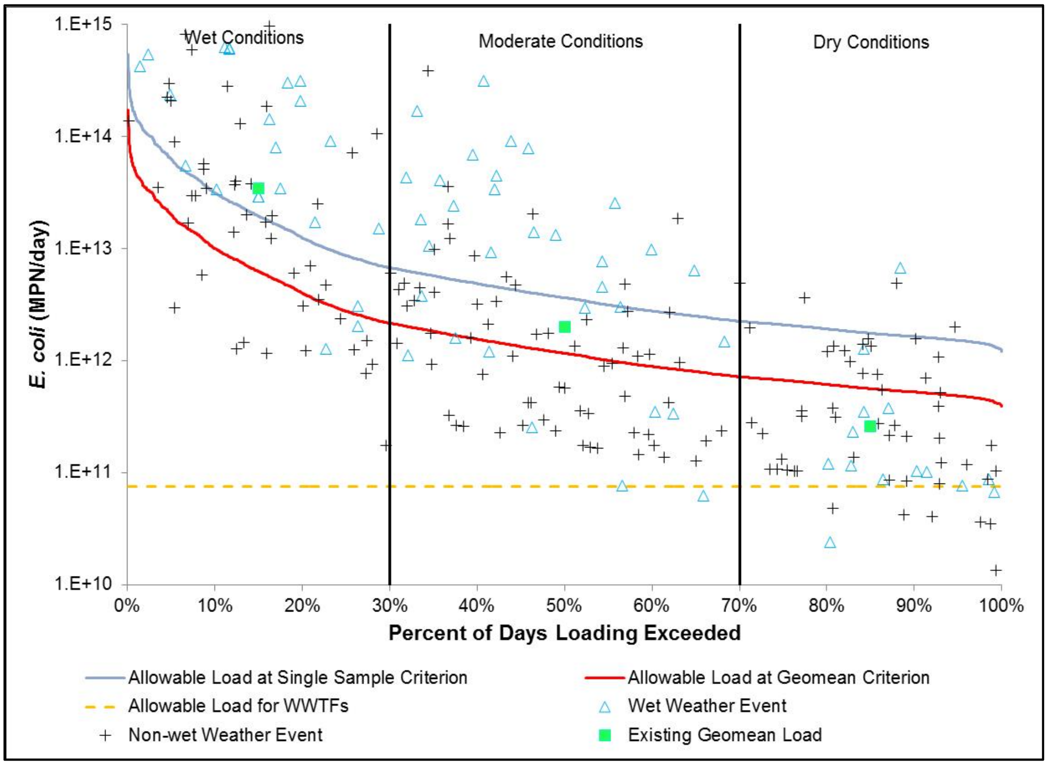

Figure 15 Load duration curve for station 11213, Lake Houston (1002_06).

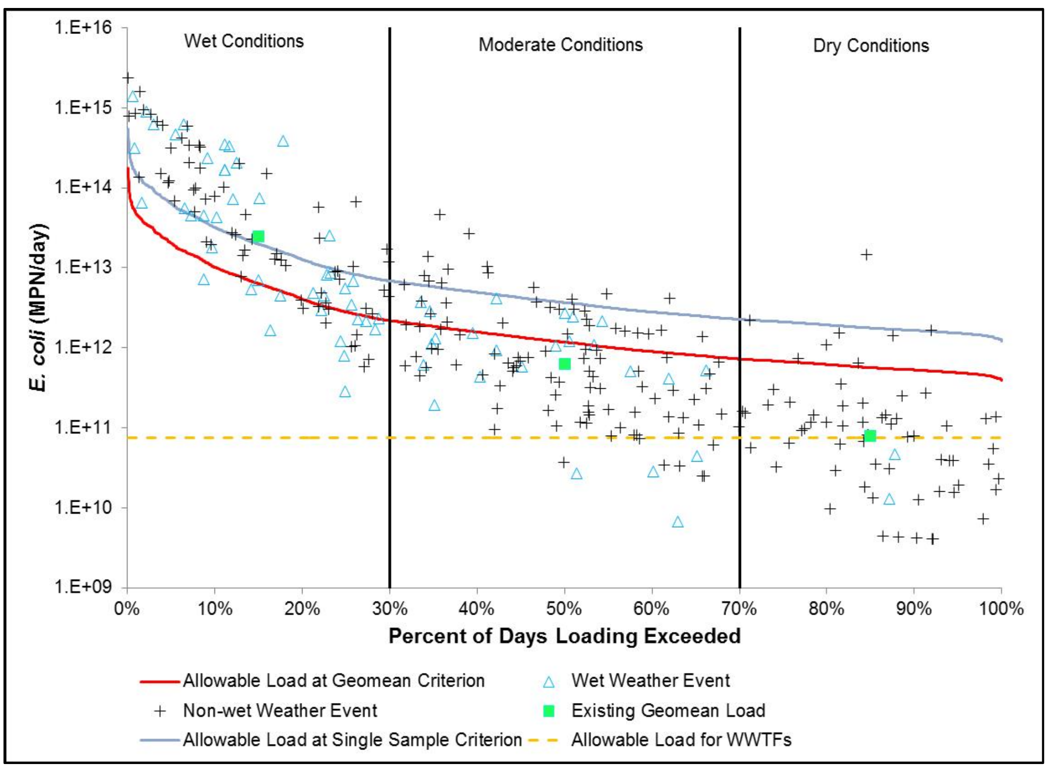

Figure 16 Load duration curve for station 18669, Lake Houston (1002_06).

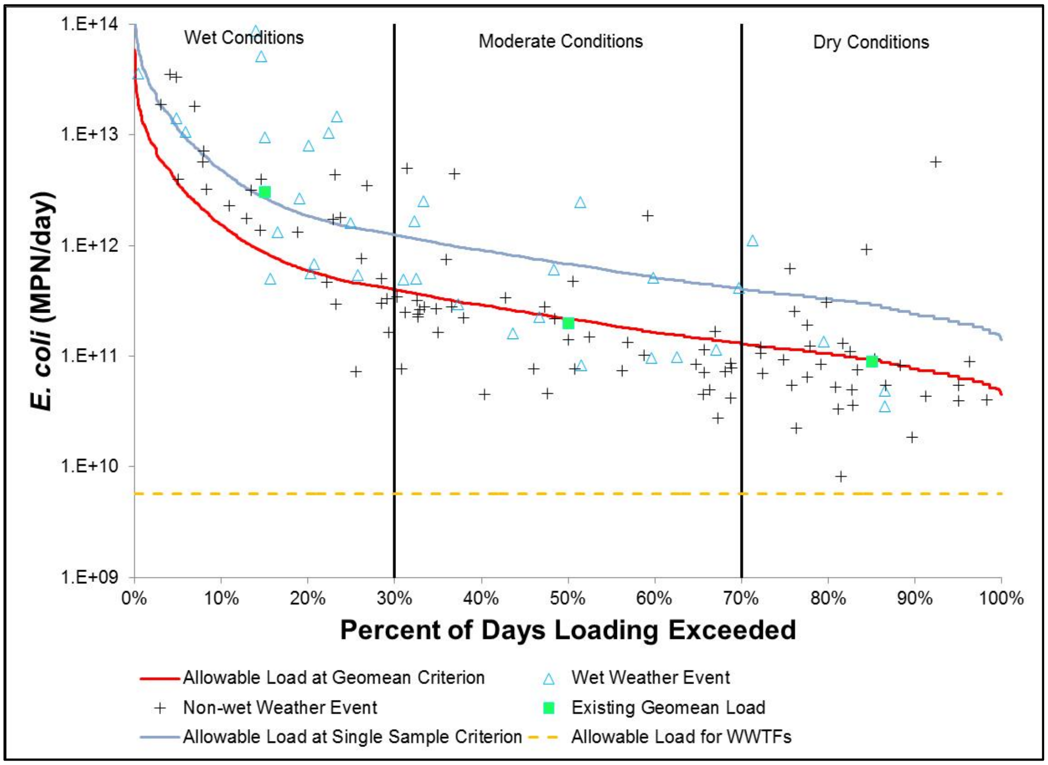

Figure 17 Load duration curve for station 11235, East Fork San Jacinto River (1003_01).

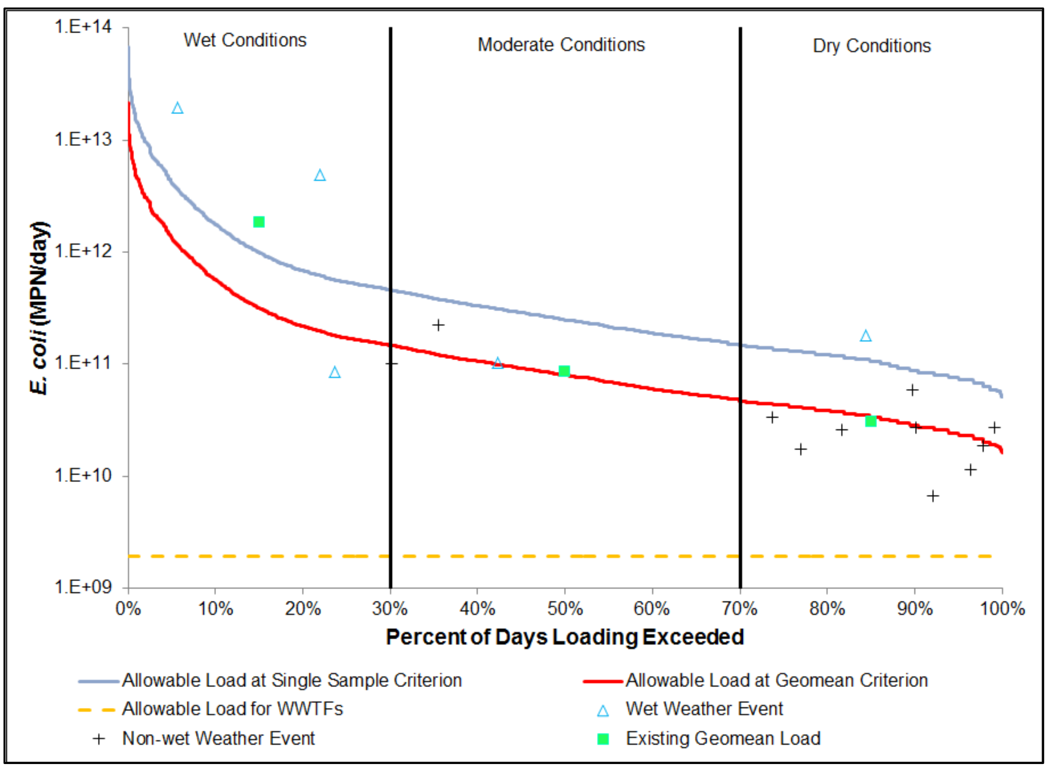

Figure 18 Load duration curve for station 11237, East Fork San Jacinto River (1003_02).

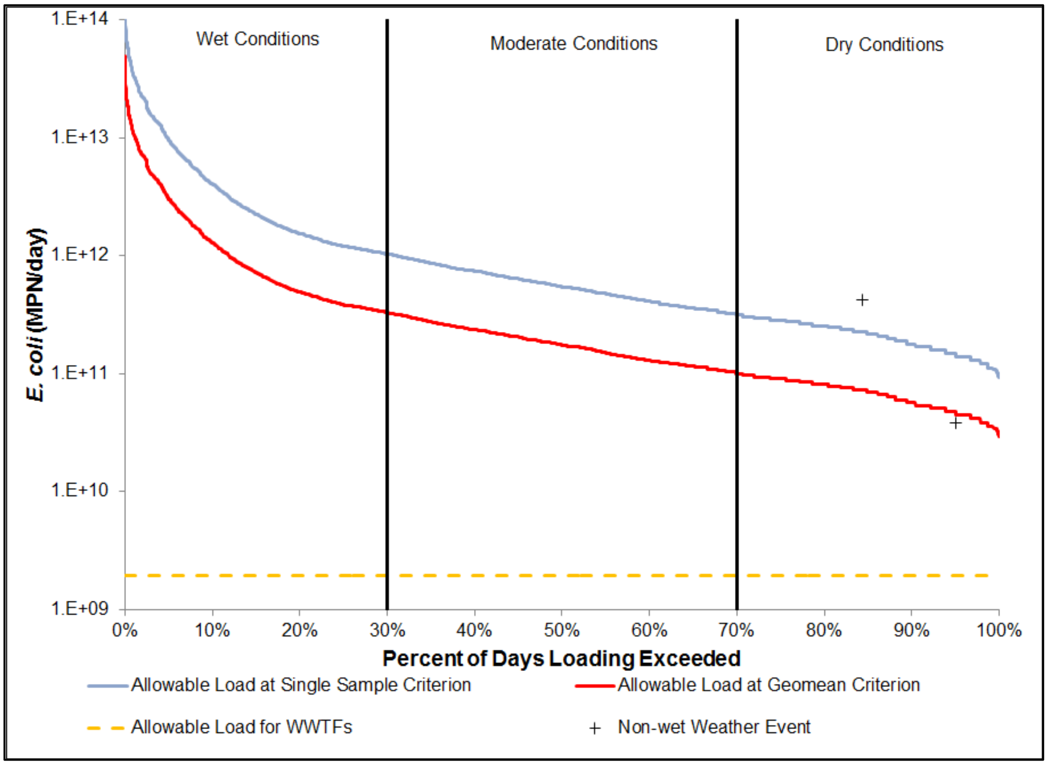

Figure 19 Load duration curve for station 11238, East Fork San Jacinto River (1003_02).

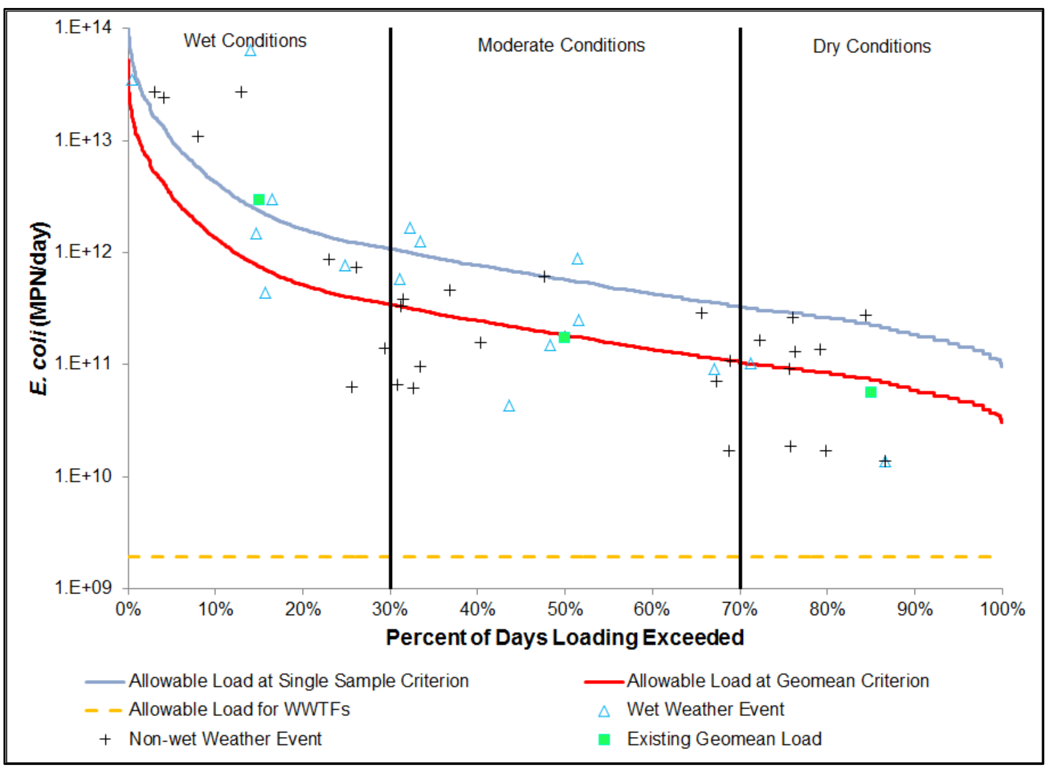

Figure 20 Load duration curve for station 14242, East Fork San Jacinto River (1003_02).

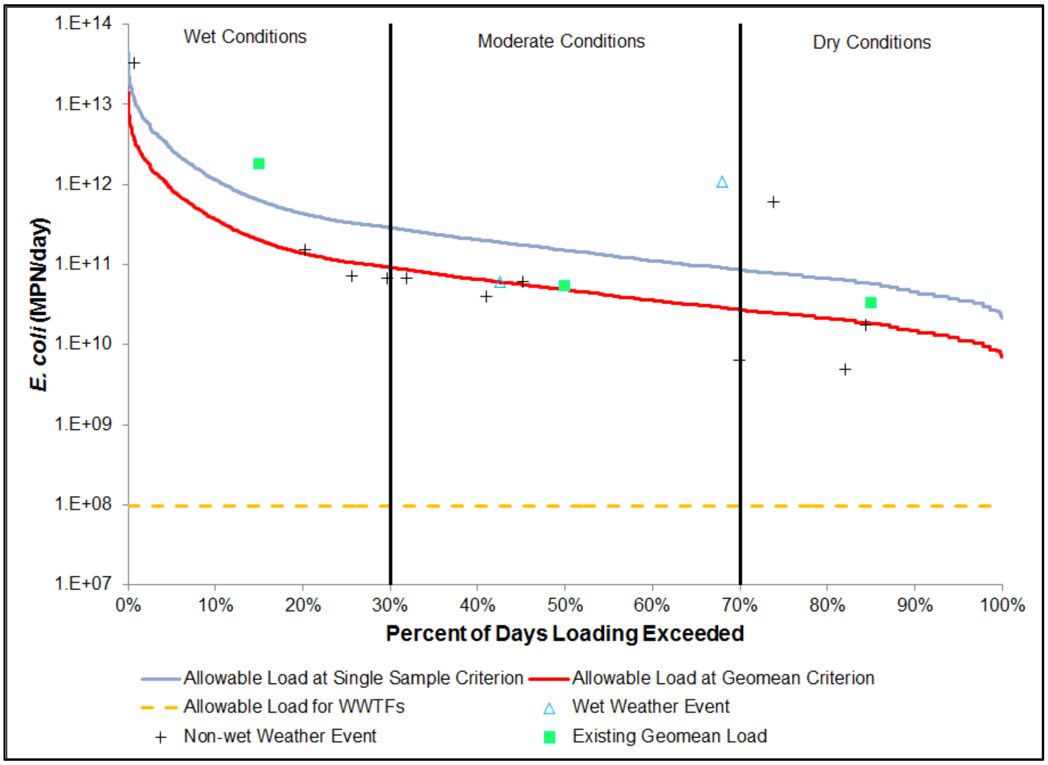

Figure 21 Load duration curve for station 17431, East Fork San Jacinto River (1003_03).

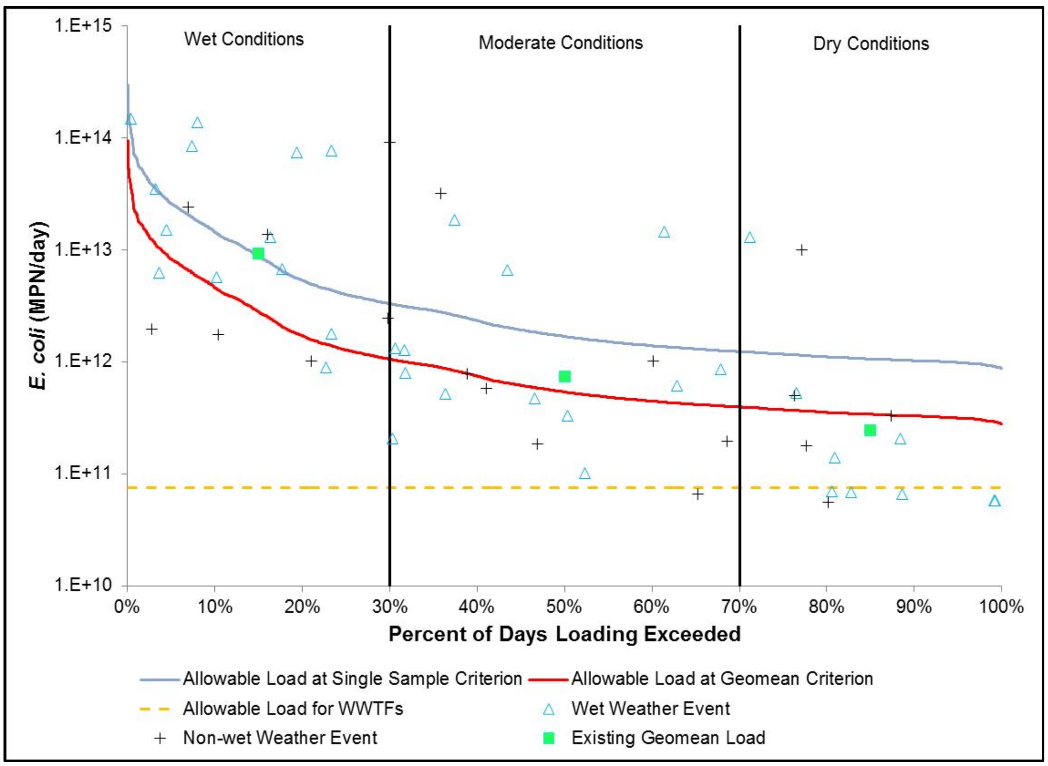

Figure 22 Load duration curve for station 11243, West Fork San Jacinto River (1004_01).

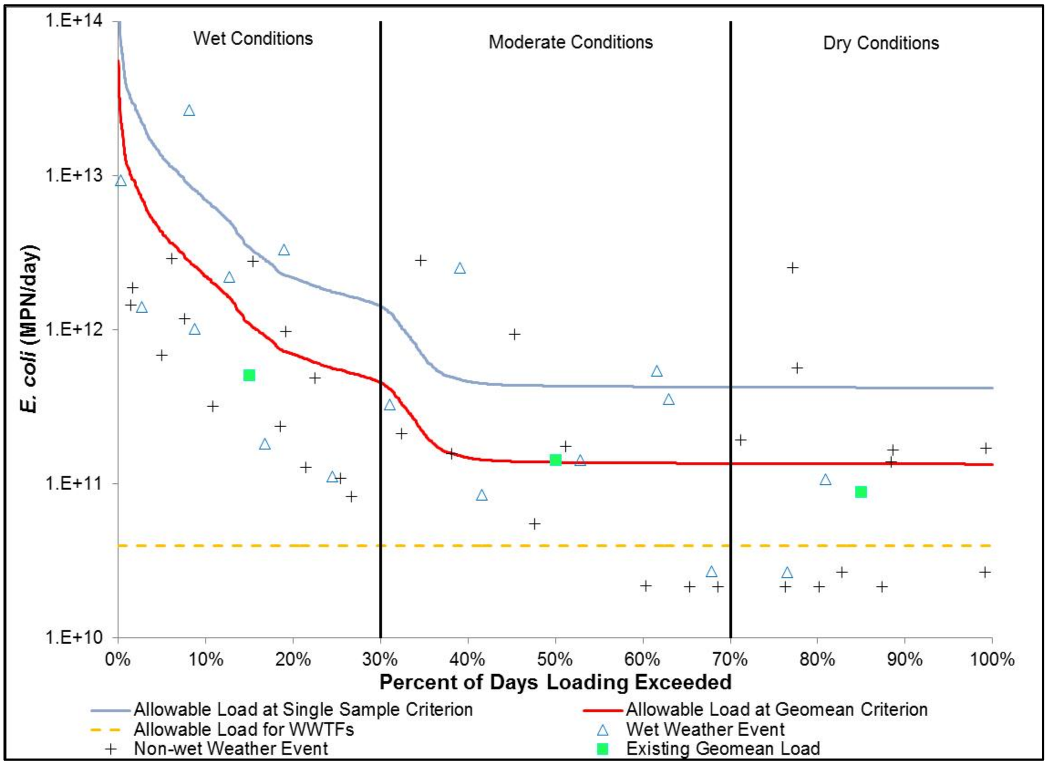

Figure 23 Load duration curve for station 11251, West Fork San Jacinto River (1004_02).

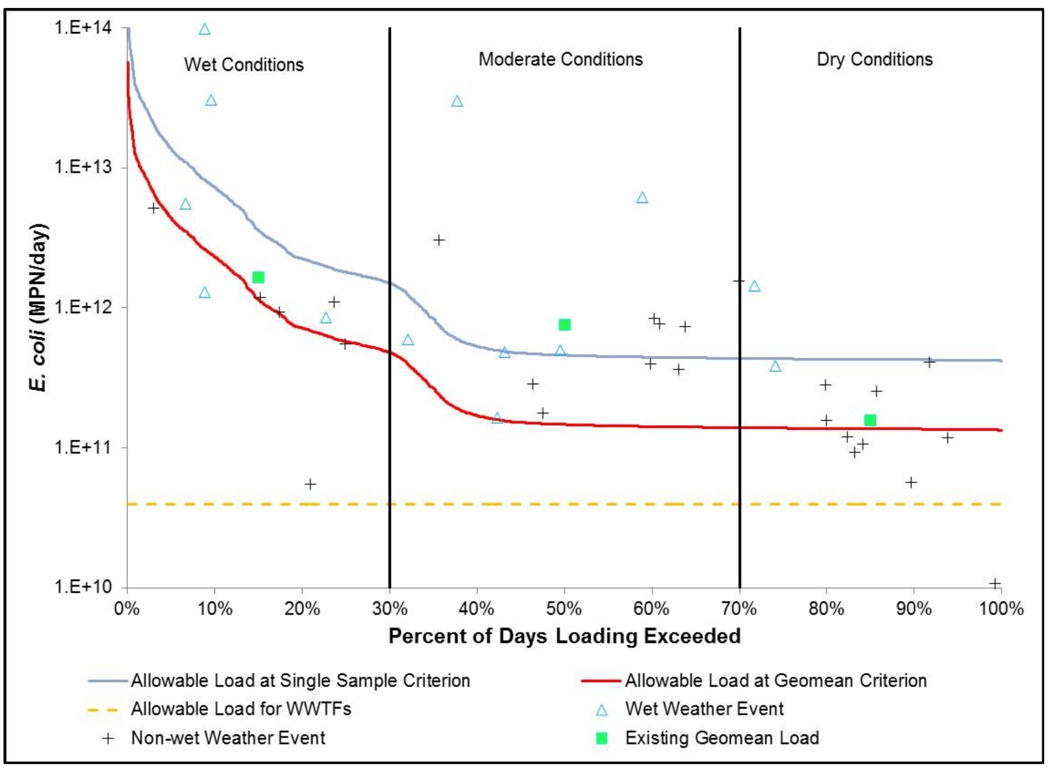

Figure 24 Load duration curve for station 11250, West Fork San Jacinto River (1004_02).

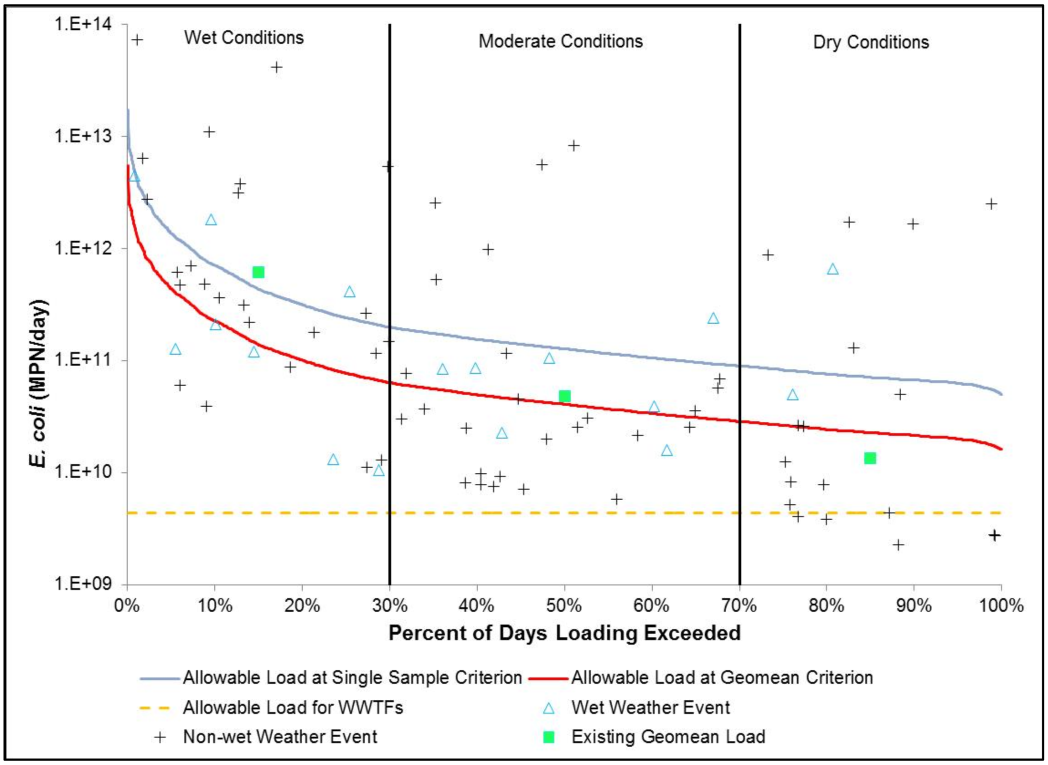

Figure 25 Load duration curve for station 16635, Crystal Creek (1004D_01).

SECTION 4
TMDL ALLOCATION ANALYSIS

Within this report section is presented the development of the bacteria TMDL allocation for the 7 TMDL watersheds, which are comprised of 4 water bodies and 7 AUs. 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 seven 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 gage for the reference flow record was employed to estimate the daily flow within the Lake Houston (1002_06), East Fork San Jacinto River (1003_01, 1003_02, and 1003_03), West Fork San Jacinto River (1004_01 and 1004_02), and Crystal Creek (1004D_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* criteria 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 7 AUs addressed by this TMDL. This endpoint is identical to the geometric mean criterion for primary contact recreation in the 2010 Surface Water Quality Standard (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 Lake Houston (1002_06), East Fork San Jacinto River (1003_02 and 1003_03), West Fork San Jacinto River (1004_02), and Crystal Creek (1004D_01) with the cool season having the higher concentrations. Seasonality was not detected in the remaining two 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 EPA 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 EPA guidance (USEPA 1991), the MOS can be incorporated into the TMDL using two methods:

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

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

The TMDLs covered by this report incorporate an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target for *E. coli* of 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 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 (Table 18).

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 very high flow regime, often at a value of 0 at the low flow regime, and in between in magnitude for the moderate 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
11213	1002_06	704	82%	218	42%	58	0%
18669	1002_06	499	75%	67	0%	17	0%
11235	1003_01	442	71%	116	0%	122	0%
11237	1003_02	—*	—*	—*	—*	—*	—*
11238	1003_02	—*	—*	—*	—*	—*	—*
14242	1003_02	488	74%	121	0%	99	0%
17431	1003_03	—*	—*	—*	—*	—*	—*
11243	1004_01	419	70%	173	27%	91	0%
13611	1004_01	—*	—*	—*	—*	—*	—*
11251	1004_02	58	0%	131	4%	83	0%
11250	1004_02	182	31%	646	80%	144	13%
11245	1004_02	—*	—*	—*	—*	—*	—*
16635	1004D_01	557	77%	150	16%	75	0%

* The minimum number of 24 samples was not available for calculation of required percent reduction.

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 4 TMDL watersheds were calculated using the following equation:

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

Where:

TMDL = total maximum daily load

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

LA = load allocation, the amount of pollutant allowed by 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.

While LDC analysis is typically applied only to riverine water bodies, this analysis tool was also applied to Lake Houston AU 1002_06. The Lake Houston AU is the most upstream AU in the western arm of the reservoir and as such represents a transition zone that shares riverine and lake-like characteristics. The decision to apply the LDC to this AU is based on its riverine characteristics of this AU and the consistency of the pattern of measured *E. coli* data on the LDC for station 18669 (Figure 16) to the LDCs of the other TMDL water bodies.

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 flow rate multiplied by one half the instream geometric criterion, One-half of the water quality criterion (63 MPN/100mL) is used as the WWTF target to provide instream and downstream load capacity. This is expressed in the following equation:

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

Where:

Target = 63 MPN/100 mL

Flow (MGD) = full permitted flow

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 under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

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

Where:

ΣWLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

ΣWLA_{WWTF} = sum of all WWTF loads

ΣLA_{TRIB} = sum of loading from tributaries of previously completed TMDLs (defined in Section 4.7.1.2)

LA_{RES} = loading from a significant upstream reservoir (defined in Section 4.7.1.2)

ΣFG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area estimated to be under stormwater permit regulation

4.7.1.2 Load Allocation

The load allocation is the sum of loads from unregulated sources. Complexities of the load allocation term occur as a result of 1) the pollutant load allocations from previously completed indicator bacteria TMDLs for watersheds upstream of Lake Houston (TCEQ, 2011a) and 2) Lake Conroe (Segment 1012) as a major non-impaired reservoir.

Of the 15 previously completed TMDLs, three are of relevance because they provide tributary loadings to TMDL watersheds of this study. Previously completed Stewarts Creek (AU 1004E_02) is a direct tributary into West Fork San Jacinto River AU 1004_01. Previously completed TMDLs for Spring Creek (AU 1008_04) and Cypress Creek (AU 1009_04) are direct tributaries in Lake Houston AU 1002_06. Geographical positioning of the watersheds of these three previous indicator bacteria TMDLs are provided in Figure 26. Because the pollutant load allocations for these three water bodies are already specified in TCEQ adopted and USEPA approved TMDLs (TCEQ, 2011a), their load allocations are designated as tributary load allocations (LA_{TRIB}) in this pollutant load allocation.

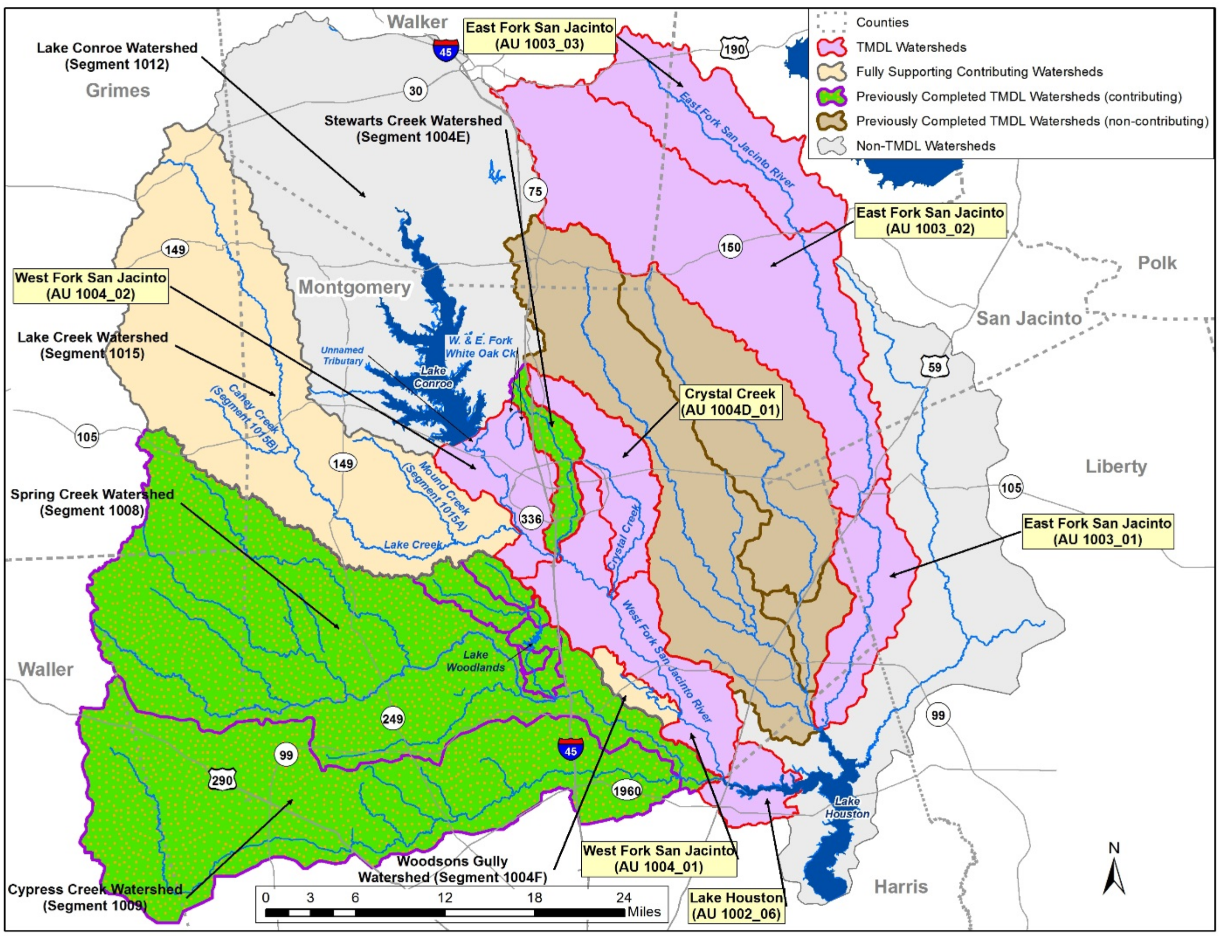

Figure 26 Lake Houston watershed showing the three previously completed indicator bacteria TMDLs for Stewarts Creek, Cypress Creek, and Spring Creek.

The second complexity is due to Lake Conroe. Large reservoirs, such as Lake Conroe, modify downstream hydrology by attenuating peak flows, reducing overall flow, and reducing 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 Conroe (Segment 1012). To accommodate the disruption in downstream bacteria loadings from a significant reservoir, the bacteria loadings associated with its releases are considered separately and defined as LA_{RES}. The calculation of LA_{RES} only applies to the AUs that are downstream of Lake Conroe, which are Lake Houston AU 1002_06 and the two AUs for the West Fork San Jacinto River (AUs 1004_01 and 1004_02).

The total load allocation (LA), therefore, becomes defined as the sum of tributary loadings from previously completed TMDL (LA_{TRIB}), 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 completed TMDLs or a significant reservoir. The LA term becomes full expressed as:

$$LA_{TOTAL} = LA_{AU} + \Sigma LA_{TRIB} + LA_{RES} \qquad \text{(Eq. 5)}$$

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

ΣLA_{TRIB} = sum of loading from tributaries of previously completed TMDLs

LA_{RES} = loading from a significant upstream reservoir

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

The LA_{TRIB} is calculated as:

$$LA_{TRIB} = \text{Criterion} * Q_{TRIB} * \text{conversion factor} \qquad \text{(Eq 6)}$$

Where:

Criterion = 126 MPN/100 mL

Q_{TRIB} = median value of the wet-conditions flow regime at the tributary or AU outlet(s) to an impaired AU from a previously completed TMDL (TCEQ, 2011a).

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

LA_{RES} is calculated as:

$$LA_{RES} = \text{Criterion} * Q_{RES} * \text{conversion factor} \qquad \text{(Eq 7)}$$

Criterion = 126 MPN/100 mL

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

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

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

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

Where:

LA_{AU} = allowable loads from unregulated sources within the AU

TMDL = total maximum daily load

ΣWLA_{WWTF} = sum of all WWTF loads

ΣWLA_{SW} = sum of all permitted stormwater loads

ΣLA_{TRIB} = sum of loading from tributaries of previously completed TMDLs

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:

$$TMDL = \Sigma WLA_{WWTF} + \Sigma WLA_{SW} + LA_{AU} + \Sigma LA_{TRIB} + LA_{RES} + \Sigma FG + MOS \qquad \text{(Eq 9)}$$

4.7.1.3 Computation of Margin of Safety

The margin of safety is only applied to the allowable loading for an AU and is not applied to the LA_{TRIB} or LA_{RES} that enters the segment as an external loading (i.e., originates outside the segment). Therefore the margin of safety is expressed mathematically as the following:

$$MOS = 0.05 * (TMDL - \Sigma LA_{TRIB} - LA_{RES}) \qquad \text{(Eq 10)}$$

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

ΣLA_{TRIB} = sum of loading from tributaries of previously completed TMDLs

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). The information obtained from the H-GAC included population projections based on census tracts that encompassed the watersheds of each AU, but only at the zip-code level for the low populated northeastern part of the TMDL watersheds. The tract and zip-code 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.

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:

$$FG = WWTF_{FP} * POP_{2008\text{-}2035} * \text{conversion factor} * \text{target} \qquad \text{(Eq. 11)}$$

Where:

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

$POP_{2008\text{-}2035}$ = 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 selected station of each AU (Table 19). Within the TMDL watershed are three impaired AUs that have approved TMDLs. These three watersheds are Stewarts Creek

(1004E_02) which is a tributary to West Fork San Jacinto River (1004_01), Spring Creek (1008_04), and Cypress Creek (1009_04) which are tributaries to Lake Houston (1002_06). The existing approved TMDL values for these three AUs are included in Table 19. A loading entering West Fork San Jacinto River (1004_01 and 1004_02) and Lake Houston (1002_06) from unimpaired Lake Conroe (1012) was also calculated (Table 19).

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

AU or LA Term	Segment Name	Sampling Station	Wet-Condition Median Flow (cfs)	LA_{TRIB} (Billion MPN/100 mL)	LA_{RES} (Billion MPN/100 mL)	TMDL (Billion MPN/100 mL)
1002_06	Lake Houston	11213	2010.2	3,106.9[a]	958.7	6,197
1003_01	East Fork San Jacinto River	11235	281.07	—	—	866.4
1003_02	East Fork San Jacinto River	11238	234.47	—	—	722.8
1003_03	East Fork San Jacinto River	17431	65.949	—	—	203.3
1004_01	West Fork San Jacinto River	11243	901.54	44.86[b]	958.7	2,779
1004_02	West Fork San Jacinto River	11250	370.06	—	958.7	1,141
1004D_01	Crystal Creek	16635	44.708	—	—	137.8
LA_{TRIB}	Stewarts Creek	16626	14.550	—	—	44.86
LA_{TRIB}	Spring Creek	11213	491.19	—	—	1,514
LA_{TRIB}	Cypress Creek	11324	502.18	—	—	1,548
LA_{RES}	Lake Conroe	outlet	311.00	—	—	958.7

[a] LA_{TRIB} to 1002_06 is the sum of the allowable loadings for Stewarts, Spring and Cypress Creeks

[b] LA_{TRIB} to 1004_01 is the Stewarts Creek allowable loading

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 10 (Table 20).

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

AU	MOS (Billion MPN/day)
1002_06	106.57
1003_01	43.32
1003_02	36.14
1003_03	10.170
1004_01	88.77
1004_02	9.12
1004D_01	6.89

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 11 (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 (Billion MPN/day)
1002_06 (indiv.)	39,729	65,376	64.55%	1.3548	0.8746	2.086
1002_06 (aggr.)[a]	170,221	384,066	125.6%	34.7238	49.5415	118.100
1003_01 (indiv.)	17,372	32,511	87.15%	1.6050	1.3987	3.336
1003_01 (aggr.)[b]	26,854	54,195	101.8%	2.4150	2.416	5.761
1003_02 (indiv.)	8,528	18,981	122.6%	0.7700	0.9438	2.251
1003_02 (aggr.)[c]	9,482	21,685	128.7%	0.8100	1.017	2.426
1003_03 (indiv.)	954	2,704	183.4%	0.0400	0.0734	0.1749
1004_01 (indiv.)	38,575	97,663	153.2%	15.000	22.977	54.800
1004_01 (aggr.)[d]	130,492	318,690	144.2%	33.369	48.669	116.100

AU (individual [indiv.] and aggregated [aggr.])	2008 Population	2035 Population	Growth (%)	Current Permitted Wastewater Discharge (MGD)	Additional Permitted Wastewater Discharge (MGD)	Future Growth (Billion MPN/day)
1004_02 (indiv.) [e]	79,711	189,735	138.0%	16.538	22.827	54.440
1004D_01 (indiv.) [f]	12,206	31,292	156.4%	1.8310	2.8632	6.828

[a] Future Growth for 1002_06(aggr.) is the sum or aggregation of AUs 1002_06, 1004D_01, 1004_01, and 1004_02

[b] Future Growth for 1003_01(aggr.) is the sum or aggregation of AUs 1003_01, 1003_02, and 1003_03

[c] Future Growth for 1003_02(aggr.) is the sum or aggregation of AUs 1003_02 & 1003_03

[d] Future Growth for 1004_01(aggr.) is the sum or aggregation of AUs 1004_01, 1004_02, and 1004D_01

[e] Future Growth for 1004_02 (indiv.) includes AUs 1004_02, 1015_01, 1015A_01, and 1015B_01

[d] Future Growth for 1004D_01 (indiv.) includes AUs 1004D_01 and 1004G_01

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, including WWTFs located in AUs that are not impaired, such as West Fork Crystal Creek (1004G_01), Lake Creek (1015_01), Mound Creek (1015A_01), and Caney Creek (1015B_01).

Table 22 Waste load allocations for TPDES-permitted facilities

TPDES Permit No.	NPDES Permit No.	Facility	AU	Final Permitted Discharge (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
WQ13526-001	TX0105996	Kings Manor MUD WWTF	1002_06	0.4	0.9539
WQ10495-149	TX0115924	Forest Cove WWTF	1002_06	0.95	2.266
WQ14091-001	TX0095630	North Park Business Center Ltd. WWTF	1002_06	0.0048	0.01145
WQ15012-001	TX0133167	Plum Grove WWTF	1003_01	0.225	0.5366
WQ15192-001	TX0134996	Grande San Jacinto	1003_01	0.9	2.146
WQ15061-001	TX0133817	Bella Vista WWTP	1003_01	0.48	1.145
WQ14996-001	TX0028169	UFP New Waverly WWTF	1003_02	0.02	0.04770

TPDES Permit No.	NPDES Permit No.	Facility	AU	Final Permitted Discharge (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
WQ10766-001	TX0053473	West WWTF	1003_02	0.75	1.789
WQ11844-001	TX0071765	Forest Glen Christian Camp WWTF	1003_03	0.04	0.09539
WQ11658-001	TX0063461	Vince Tract Development WWTF	1004_01	0.9	2.146
WQ11820-001	TX0069256	Lazy River Improvement District WWTF	1004_01	0.1	0.2385
WQ15288-001	TX0135682	Montgomery County MUD 96 WWTF	1004_01	0.4	0.9539
WQ14755-001	TX0129160	Benders Landing WWTF	1004_01	0.9	2.146
WQ12212-002	TX0093564	City of Shenandoah WWTF	1004_01	3.0	7.154
WQ13700-001	TX0090123	Chateau Woods WWTF	1004_01	0.2	0.4770
WQ13760-001	TX0089672	Montgomery County MUD 56 WWTF	1004_01	0.1	0.2385
WQ10495-142	TX0088501	Kingwood West WWTF	1004_01	2.0	4.770
WQ13985-001	TX0117706	Rembert Tract WWTF	1004_01	0.5	1.192
WQ14414-001	TX0125601	Woodland Lakes Village WWTF	1004_01	0.45	1.073
WQ14482-001	TX0126209	Montgomery County MUD 83 WWTF	1004_01	0.6	1.431
WQ14604-001	TX0127752	Montgomery County MUD 99 WWTF	1004_01	1.5	3.577
WQ10978-001	TX0025674	River Plantation MUD WWTF	1004_01	0.6	1.431
WQ14523-001	TX0126713	Montgomery County MUD 88 WWTF	1004_01	0.6	1.431
WQ14531-001	TX0126799	Creekside WWTF	1004_01	0.6	1.431
WQ14586-001	TX0127400	ER Woodsons WWTF	1004_01	0.9	2.146
WQ11395-001	TX0022055	Gleneagles Sub-division WWTF	1004_01	0.9	2.146
WQ11580-001	TX0075680	Town of Woodloch WWTF	1004_01	0.15	0.3577

TPDES Permit No.	NPDES Permit No.	Facility	AU	Final Permitted Discharge (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
WQ15313-001	TX0135941	Montgomery County MUD 127 WWTP	1004_01	0.6	1.431
WQ10008-002	TX0022268	City of Conroe Southwest Regional WWTF	1004_02	10.0	23.848
WQ12761-001	TX0093505	Westmont MHP WWTF	1004_02	0.05	0.1192
WQ14114-001	TX0119504	Aquasource Development Company WWTF	1004_02	0.6	1.431
WQ14671-001	TX0128431	Montgomery County MUD 112 WWTF	1004_02	0.5	1.192
WQ11097-001	TX0020206	City of Panorama Village WWTF	1004_02	0.4	0.9539
WQ10315-001	TX0068845	City of Willis WWTF	1004D_01	0.8	1.908
WQ14709-001	TX0102962	Stone Hedge WWTF	1004D_01	0.015	0.03577
WQ00584-000	TX0005592	Huntsman Petrochemical Conroe Plant	1004G_01[a]	0.75	1.789
WQ02475-000	TX0087190	Drilling Specialties Alamo Plant	1004G_01[a]	0.016	0.03816
WQ15296-001	TX0135755	Lost Creek WWTP	1004G_01	0.25	0.5962
WQ15089-001	TX0134520	Montgomery County MUD NO 139 WWTP	1015_01	0.51	1.216
WQ14711-001	TX0128368	Mostyn Manor WWTF	1015_01[b]	0.5	1.192
WQ14989-001	TX0132845	Montgomery Co. MUD 125 WWTF	1015_01[b]	0.96	2.289
WQ13527-001	TX0106119	Richards ISD WWTF	1015_01[b]	0.005	0.01192
WQ14166-001	TX0122327	Woodland Oaks WWTF	1015_01[b]	0.498	1.188
WQ14305-001	TX0124486	Skye Ranch WWTF	1015_01[b]	0.24	0.5724
WQ14800-001	TX0129585	Fair Oaks WWTF	1015_01[b]	0.7	1.669
WQ14814-001	TX0129674	Woodforest Interim WWTF	1015_01[b]	0.945	2.254

TPDES Permit No.	NPDES Permit No.	Facility	AU	Final Permitted Discharge (MGD)	*E. coli* WLA_{WWTF} (Billion MPN/day)
WQ15317-001 Outfall 001	TX0136000	Magnolia Lake Creek	1015_01[c]	0.25 (Combine Outfalls 1 & 2)	0.5962 (Combine Outfalls 1 & 2)
WQ15317-001 Outfall 002	TX0136000	Magnolia Lake Creek	1015_01[c]	See Above	See Above
WQ15283-001	TX0135658	Blaketree MUD 1of Montgomery County	1015_01[c]	0.2	0.4770
WQ14638-001	TX0128121	MSEC WWTF	1015A_01[c]	0.02	0.04770
WQ12456-001	TX0088901	Crane Energy Flow Solutions WWTF	1015A_01[c]	0.005	0.01192
WQ15341-001	TX0136191	MSEC WWTP 2	1015A_02[c]	0.13	0.3100
WQ11437-001	TX0092649	Grimes County MUD 1 WWTF	1015B_01[d]	0.025	0.05962

[a] West Fork Crystal Creek (1004G_01) is not impaired, but is a tributary to impaired Crystal Creek (1004D_01).

[b] Lake Creek (1015_01) is not impaired, but is a tributary to impaired West Fork San Jacinto River AU 1004_02.

[c] Mound Creek (1015A_01 & 1015A_02) is not impaired, but as a tributary to Lake Creek, its watershed contributes to impaired West Fork San Jacinto AU 1004_02.

[d] Caney Creek (1015B_01) is not impaired, but as tributary to Lake Creek, its watershed contributes to impaired West Fork San Jacinto AU 1004_02.

4.7.2.4 Regulated Stormwater Computation

With the exception of AUs 1003_03 and 1003_02, portions of each AU within the TMDL watersheds have areas regulated under MS4 Phase II general permits and Phase I individual permits, and these areas were used to estimate the areas under stormwater regulation for construction, industrial, and MS4 permits (Figure 5). The regulated stormwater area was estimated for AUs 1003_02 and 1003_03 based on an empirical relationship developed between MS4 permitted area and the total developed land use area in each AU (Figure 6). Table 23 summarizes the computation of term WLA_{SW} as calculated using Equation 4.

4.7.2.5 Unregulated Stormwater and Upstream Tributary and 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 watersheds that are not regulated by stormwater permits. The LA_{AU} for each TMDL watershed was computed using Equation 8 (Table 24).

The LA_{TRIB} represents the loading arising from upstream tributaries that have pre-existing approved TMDLs for bacteria. The LA_{TRIB} term defines the pre-existing TMDL loadings Spring Creek (1008_04) and Cypress Creek (1009_04), which are tributaries to Lake Houston (1002_06), and to Stewarts Creek (1004E_02) which is a tributary to the West Fork San Jacinto River (1004_01). The pre-existing TMDL for Spring, Cypress, and Stewarts Creeks represents the LA_{TRIB}.

The LA_{RES} represents the loading arising from a significant and immediately upstream reservoir. The LA_{RES} for this report applies to Lake Conroe (1012) which is immediately upstream of the West Fork San Jacinto River (1004_02). To calculate the loading entering West Fork San Jacinto (1004_01 and 1004_02) and Lake Houston (1002_06), a median flow value within the wet-conditions flow regime was determined at the outlet of Lake Conroe and the LA_{RES} was computed by using Equation 7 (Table 24).

Table 23 Regulated stormwater computation for TMDL watersheds

AU	TMDL (billion MPN/day)	WLA_{WWTF} (billion MPN/day)	Future Growth (billion MPN/day)	LA_{TRIB} (billion MPN/day)	LA_{RES} (billion MPN/day)	MOS (billion MPN/day)	FDA_{SWP}	WLA_{SW} (billion MPN/day)
1002_06	6,197	82.81	118.15	3106.9	958.7	106.57	0.158[a]	288.17
1003_01	866.4	5.76	5.76	—	—	43.32	0.00216[b]	1.75
1003_02	722.8	1.93	2.43	—	—	36.14	0.00175[c]	1.19
1003_03	203.3	0.095	0.175	—	—	10.17	0.000560	0.108
1004_01	2,779	79.58	116.06	44.86	958.7	88.77	0.132[d]	196.82
1004_02	1,141	39.44	54.44	—	958.7	9.12	0.0510	4.04
1004D_01	137.8	4.37	6.83	—	—	6.89	0.157	18.79

[a] FDA_{SWP} value based on the area of AU 1002_06 and upstream AUs 1004D_01, 1004_01 and 1004_02

[b] FDA_{SWP} value based on the area of AU 1003_01 and upstream AUs 1003_02 and 1003_03

[c] FDA_{SWP} value based on the area of AU 1003_02 and upstream AU 1003_03

[d] FDA_{SWP} value based on the area of AU 1004_01 and upstream AUs 1004_02 and 1004D_01

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

All loads expressed as billion MPN/day

AU	LA_{TRIB}	LA_{RES}	LA_{AU}
1002_06	3106.9	958.7	1535.70
1003_01	0.0	0.0	809.81
1003_02	0.0	0.0	681.11
1003_03	0.0	0.0	192.752
1004_01	44.86	958.7	1,294.21
1004_02	0.0	958.7	75.26
1004D_01	0.0	0.0	100.92

4.8 Summary of TMDL Calculations

Table 25 summarizes the TMDL calculations for the seven 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-7 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-7, 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}	LA_{TRIB}	LA_{RES}	LA_{TOTAL} [a]	Future Growth
1002_06	Lake Houston	6,197	106.57	82.81	288.17	1,535.70	3,106.9	958.7	5,601.30	118.15
1003_01	East Fork San Jacinto River	866.4	43.32	5.76	1.75	809.81	0	0	809.81	5.76
1003_02	East Fork San Jacinto River	722.8	36.14	1.93	1.19	681.11	0	0	681.11	2.43
1003_03	East Fork San Jacinto River	203.3	10.170	0.095	0.108	192.752	0	0	192.752	0.175
1004_01	West Fork San Jacinto River	2,779	88.77	79.58	196.82	1,294.21	44.86	958.7	2,297.77	116.06
1004_02	West Fork San Jacinto River	1,141	9.12	39.44	4.04	75.26	0	958.7	1,033.96	54.44
1004D_01	Crystal Creek	137.8	6.89	4.37	18.79	100.92	0	0	100.92	6.83

[a] $LA_{TOTAL} = LA_{AU} + LA_{TRIB} + LA_{RES}$

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_{TOTAL}	MOS
1002_06	6,197	200.96	288.17	5,601.30	106.57
1003_01	866.4	11.52	1.75	809.81	43.32
1003_02	722.8	4.36	1.19	681.11	36.14
1003_03	203.3	0.270	0.108	192.752	10.170
1004_01	2,779	195.64	196.82	2,297.77	88.77
1004_02	1,141	93.88	4.04	1,033.96	9.12
1004D_01	137.8	11.20	18.79	100.92	6.89

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

Section 5
References

Ashworth, J.,J. Hopkins. 1995. Report 345: Aquifers of Texas. Texas Water Development Board. Austin, Texas.

AVMA(American Veterinary Medical Association). 2012. *In:* U.S. Pet Ownership & Demographics Sourcebook (2012 Edition) <www.avma.org/KB/Resources/Statistics/Pages/Market-research-statistics-US-pet-ownership.aspx> Accessed May 23, 2013.

Cleland, B. 2003. TMDL Development from the “Bottom Up” — Part III: Duration Curves and Wet-Weather Assessments. <www.tmdls.net/tipstools/docs/TMDLsCleland.pdf> Accessed May 15, 2014.

H-GAC (Houston Galveston Area Council). 2005. 2035 Regional Growth Forecast < www.h-gac.com/community/socioeconomic/forecasts/archive/2035.aspx> Accessed April 23, 2013

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

NDEP (Nevada Division of Environmental Protection. 2003. Load Duration Curve for Assessment and TMDL Development. <ndep.nv.gov/bwqp/loadcurv.pdf> (accessed April 03, 2013)

NOAA (National Oceanic and Atmospheric Administration). 2011. Coastal Change Analysis Program 2011 Land Cover. Obtained from the H-GAC website. < www.h-gac.com/community/socioeconomic/land-use-data.aspx> (accessed December 16, 2013)

NWS (National Weather Service). 2008. *2007 – Year in Review.* National Weather Service Houston/Galveston TX. 3 Jan 2008. <www.srh.noaa.gov/hgx/?n=climate_summary> (accessed April 23, 2013)

Reed, Stowe, and Yanke. 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in Texas. Austin, TX.

TCEQ (Texas Commission on Environmental Quality). 2006. Preserving & Improving Water Quality – The Programs of the Texas Commission on Environmental Quality for Managing the Quality of Surface Waters. GI-315. Available online at < www.tceq.texas.gov/publications/gi/gi-351.html >. Accessed April 23, 2013.

TCEQ (Texas Commission on Environmental Quality). 2010. Texas Surface Water Quality Standards, 2010 Rule Amendment, 30 TAC 307. Available online at: <www.tceq.texas.gov/assets/public/permitting/waterquality/standards/docs/TSWQS2010/TSWQS2010_rule.pdf > Accessed April 23, 2013.

TCEQ (Texas Commission on Environmental Quality). 2011a. Fifteen Total Maximum Daily Loads for Indicator Bacteria in Watersheds Upstream of Lake Houston. Available online at: < www.tceq.texas.gov/assets/public/waterquality/tmdl/82lakehouston/82-lakehoustontmdl_adopted.pdf > Accessed May 3, 2013.

TCEQ (Texas Commission on Environmental Quality). 2011b. 2010 Texas Integrated Report for Sections 305(b) and 303(d). (Approved by USEPA on Nov. 18, 2011) Available online at: <www.tceq.texas.gov/waterquality/assessment/10twqi/10twqi > Accessed April 23, 2013.

TCEQ (Texas Commission on Environmental Quality). 2013. 2012 Texas Integrated Report for Sections 305(b) and 303(d). (Approved by USEPA on May 9, 2013). Available online at: <www.tceq.texas.gov/waterquality/assessment/waterquality/assessment/12twqi/twqi12 > Accessed June 20, 2013.

TWRI (Texas Water Resources Institute). 2007. Bacteria Total Maximum Daily Load Task Force Report, Fourth Draft, June 4, 2007. Prepared for Texas Commission on Environmental Quality and Texas State Soil and Water Conservation Board. Available online at <twri.tamu.edu/reports/2009/tr341.pdf>. Accessed April 26, 2012.

USDA (U.S. Department of Agriculture). 2007. *In:* 2007 Census of Agriculture Volume 1 County Level Data. < www.agcensus.usda.gov/Publications/2007/index.php > accessed March 30, 2013.

USEPA (U.S. Environmental Protection Agency). 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. <www.epa.gov/OWOW/tmdl/decisions/>. Accessed April 1, 2010.

USEPA (U.S. Environmental Protection Agency). 2007 Better Assessment Science Integrating Point and Nonpoint Sources. BASINS v4. EPA-823-C-07-001. Office of Water. Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2009. *In:* Drinking Water Contaminants available online at <http: //water.epa.gov/drink/contaminants/>. Accessed April 26, 2012

Weiskel, P.K., B.L. Howes, and G.R. Heufelder. 1996. Coliform Contamination of Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology. 30:1872-1881.

APPENDIX A
Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

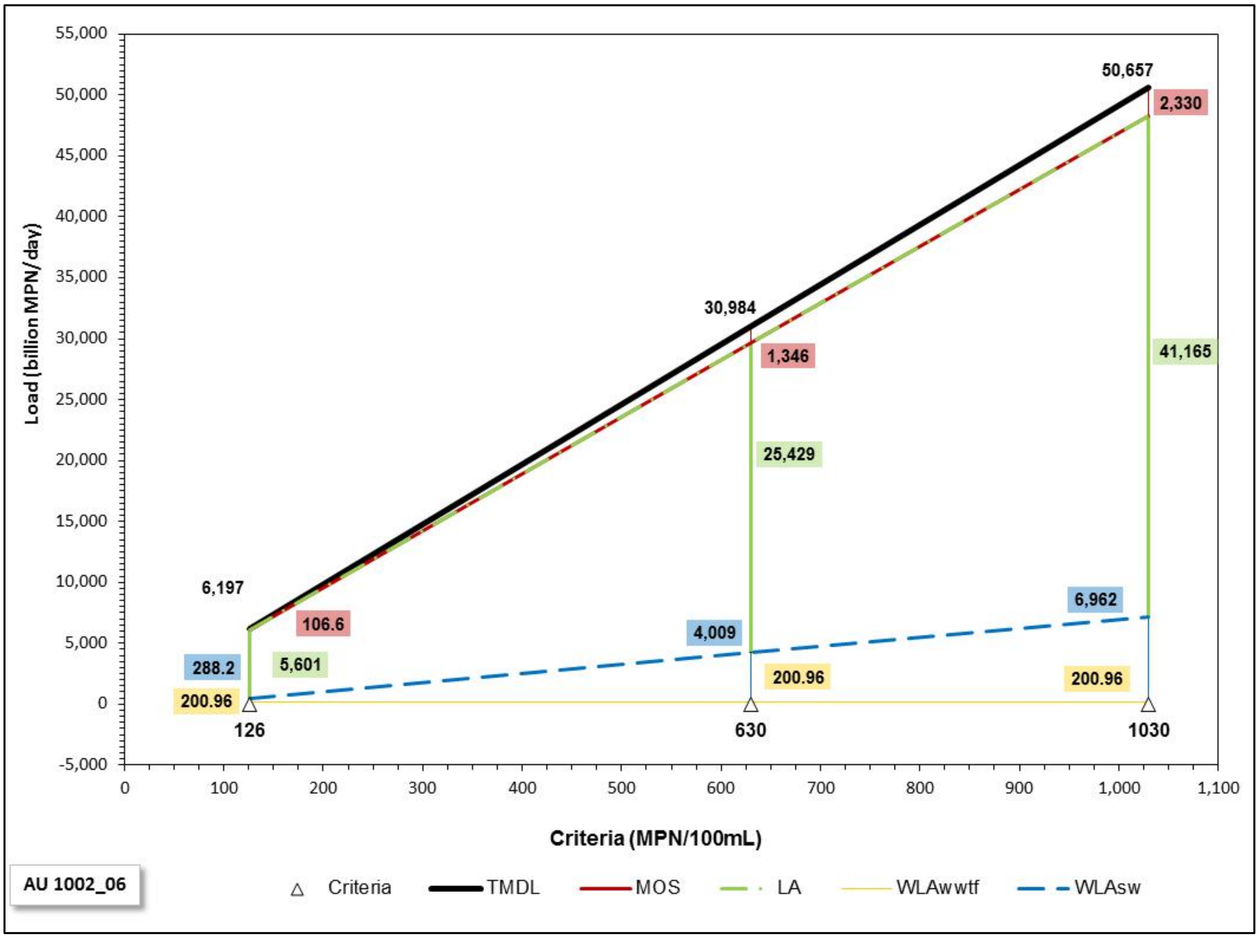

Figure A-1. Allocation loads for Lake Houston (1002_06) as a function of water quality criteria

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

$TMDL = 49.180966 * Std$
$WLA_{WWTF} = 200.96$
$WLA_{sw} = 7.382068 * Std – 641.97$
$LA = 39.339850 * Std + 644.46$
$MOS = 2.459049 * Std – 203.27$

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

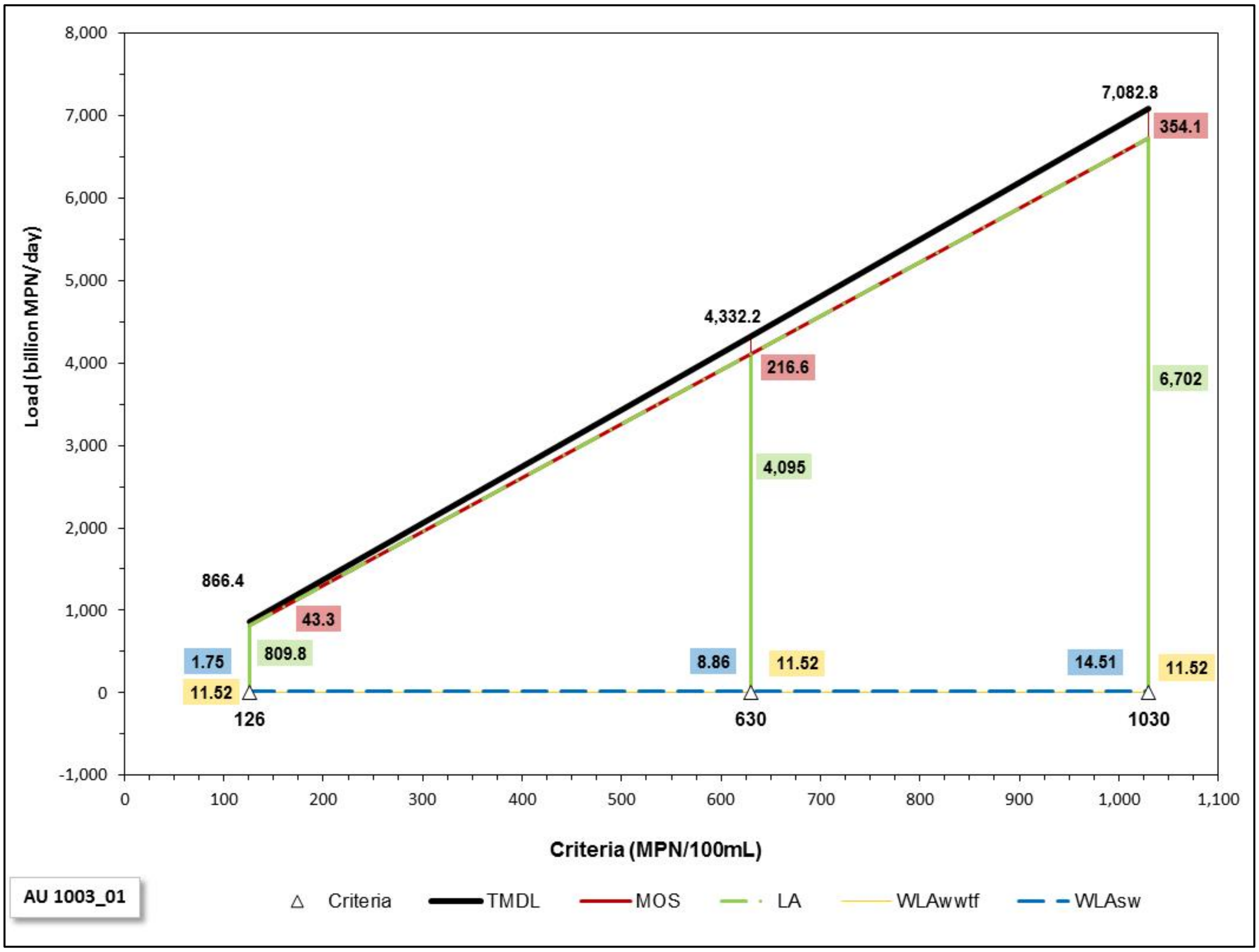

Figure A-2. Allocation loads for East Fork San Jacinto (1003_01) as a function of water quality criteria

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

TMDL = 6.876550 * Std
WLA_{WWTF} = 11.52
WLA_{sw} = 0.014115 * Std – 0.03
LA = 6.518607 * Std - 11.53
MOS = 0.343828 * 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

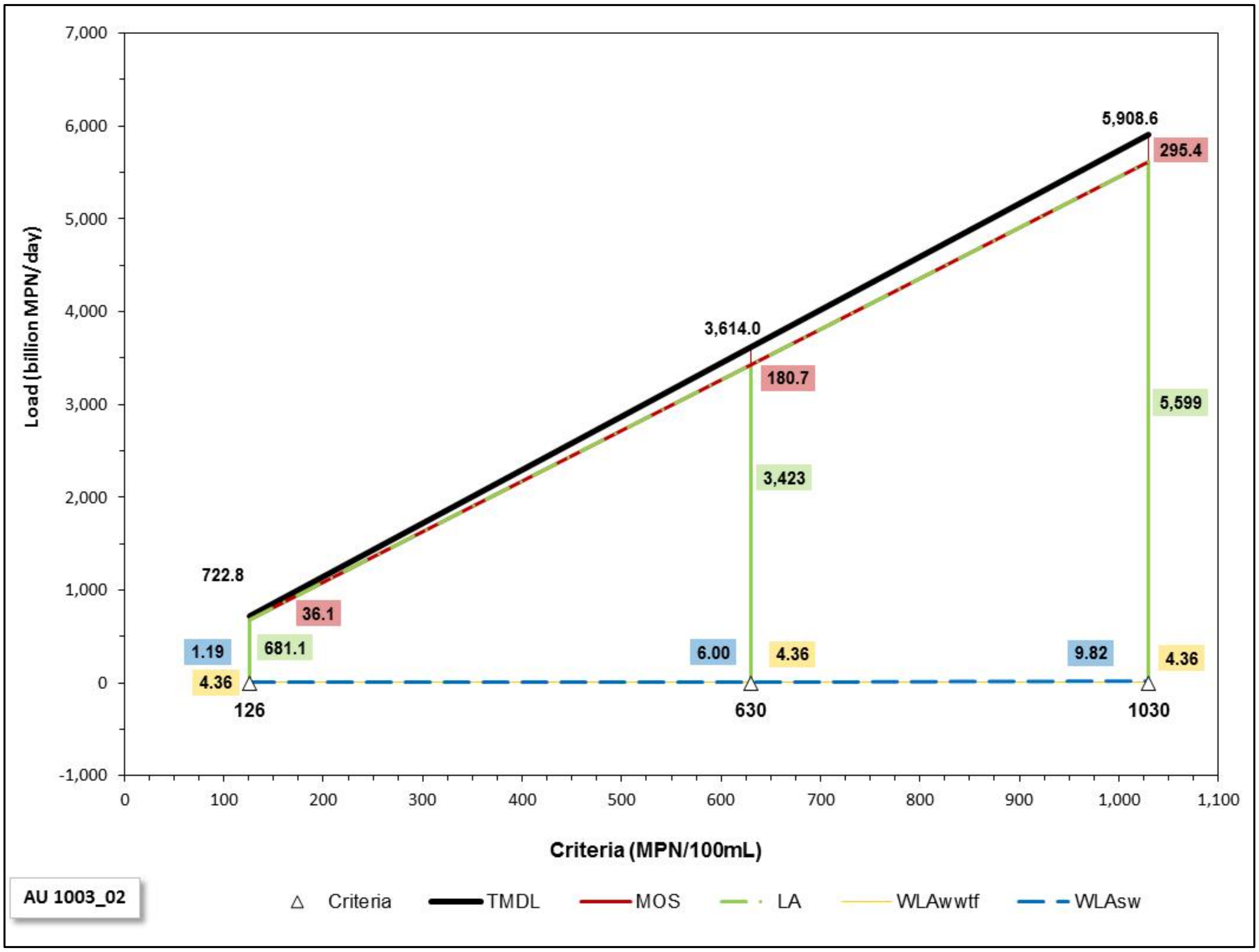

Figure A-3. Allocation loads for East Fork San Jacinto River (1003_02) as a function of water quality criteria

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

$TMDL = 5.736493 * Std$
$WLA_{WWTF} = 4.36$
$WLA_{sw} = 0.009546 * Std - 0.013$
$LA = 5.440132 * Std – 4.35$
$MOS = 0.286825 * Std$

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

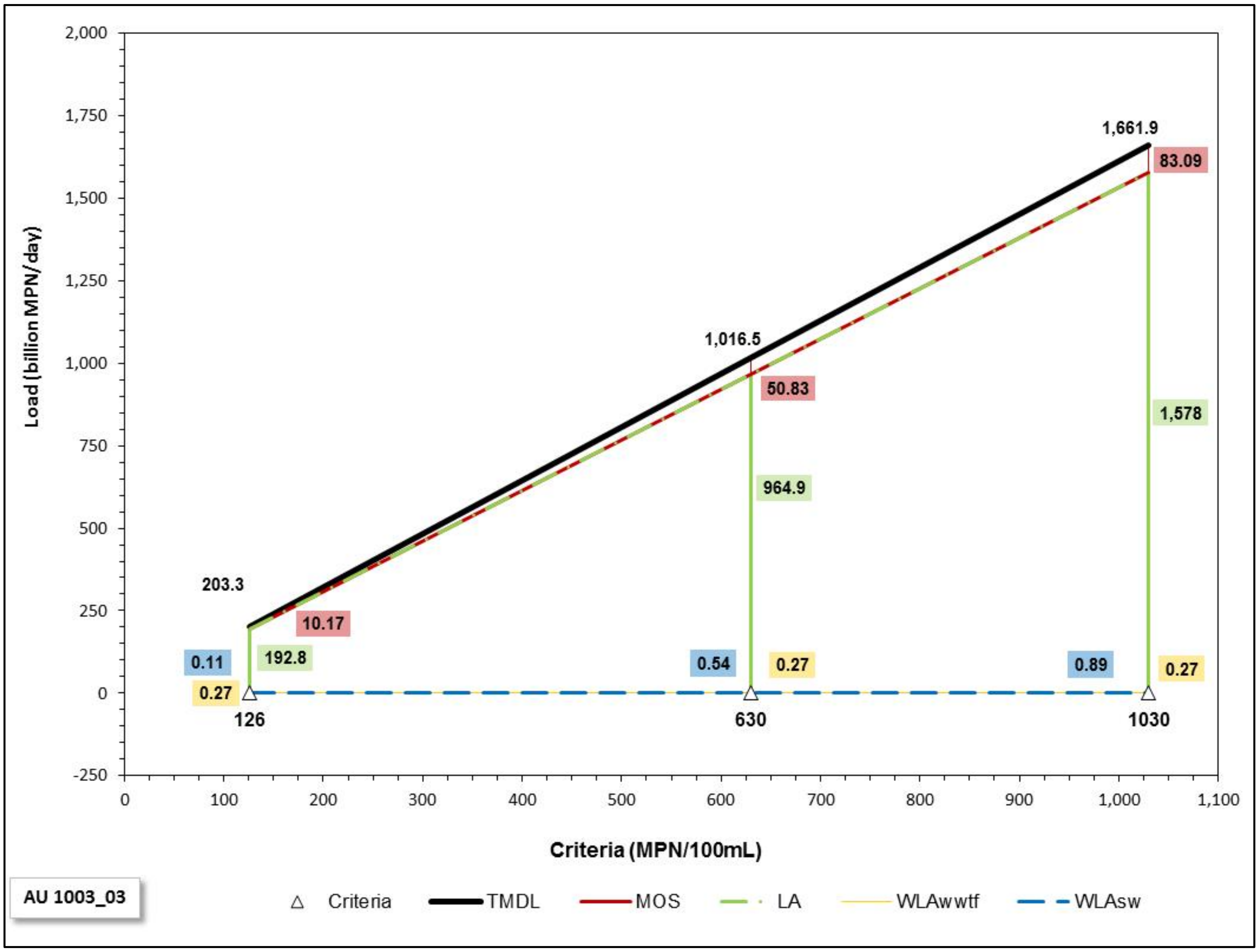

Figure A-4. Allocation loads for East Fork San Jacinto River (1003_03) as a function of water quality criteria

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

TMDL = 1.613479 * Std
WLA_{WWTF} = 0.270
WLA_{sw} = 0.000861 * Std
LA = 1.531950 * Std – 0.273
MOS = 0.080668 * Std + 0.005

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

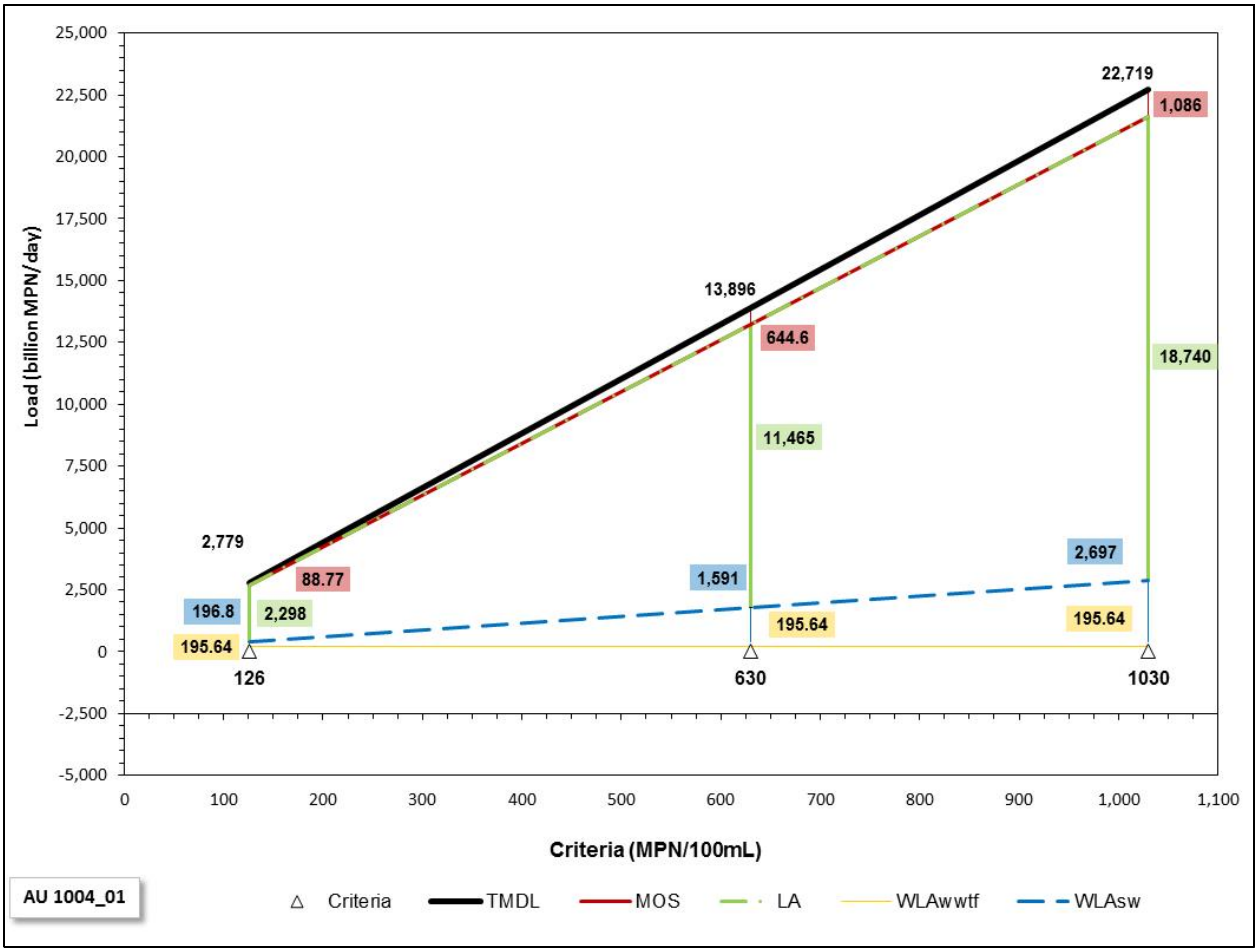

Figure A-5. Allocation loads for West Fork San Jacinto River (1004_01) as a function of water quality criteria

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

TMDL = 22.057008 * Std - 0.18
WLA_{WWTF} = 195.64
WLA_{sw} = 2.765941 * Std – 151.69
LA = 18.188213 * Std + 6.07
MOS = 1.102854 * Std – 50.19

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

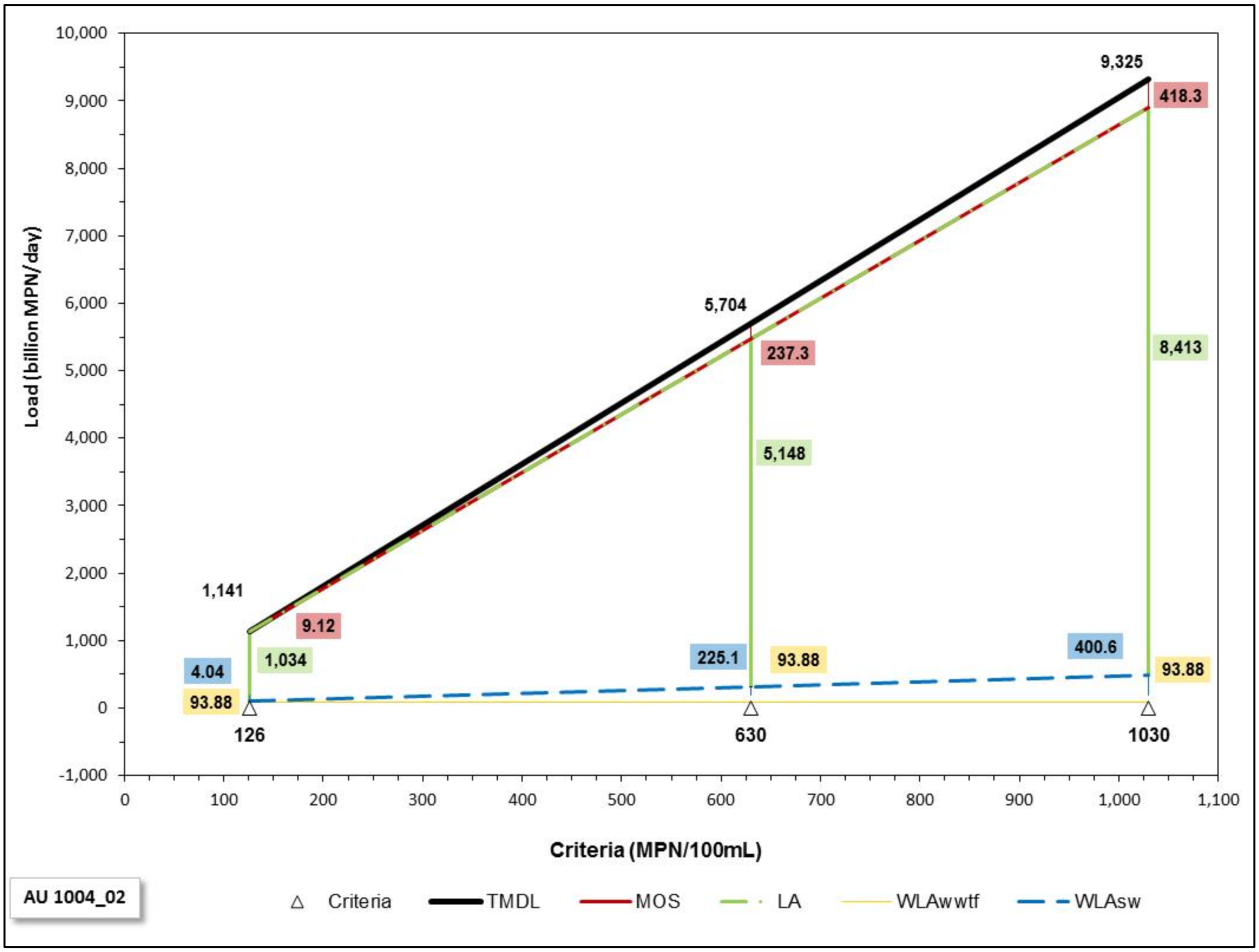

Figure A-6. Allocation loads for West Fork San Jacinto River (1004_02) as a function of water quality criteria

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

TMDL = 9.053587 * Std
WLA_{WWTF} = 93.88
WLA_{sw} = 0.438650 * Std – 51.23
LA = 8.162261 * Std + 5.49
MOS = 0.452676 * Std – 47.92

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

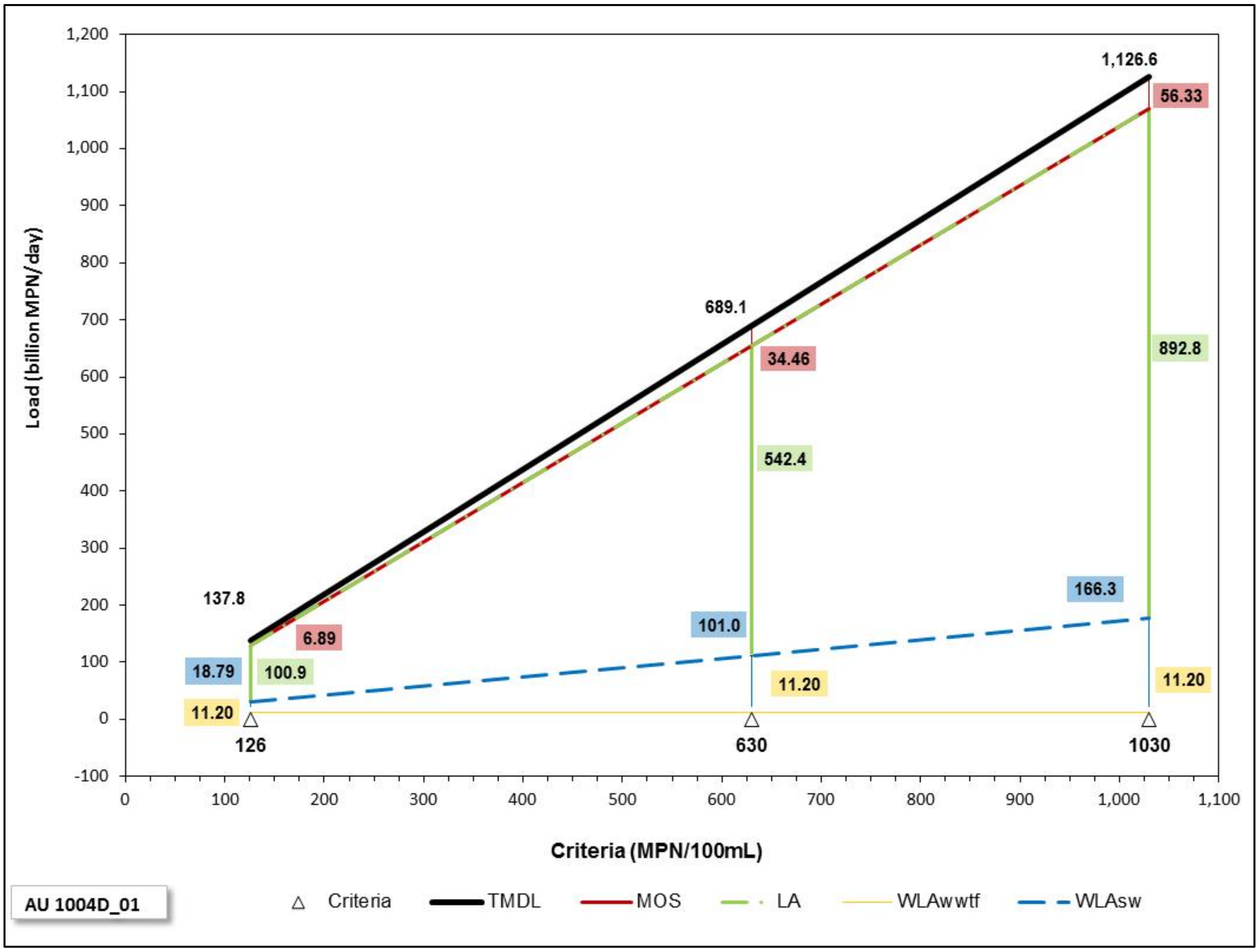

Figure A-7. Allocation loads for Crystal Creek (1004D_01) as a function of water quality criteria

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

TMDL = 1.093840 * Std
WLA_{WWTF} = 11.20
WLA_{sw} = 0.163153 * Std – 1.77
LA = 0.875996 *Std – 9.45
MOS = 0.054691 * 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