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Seven 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

Water Quality Planning Division, Office of Water

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

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Abbreviations

AU	assessment unit
BIG	Bacteria Implementation Group
BMP	best management practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
CCN	Certificates of Convenience and Necessity
DMR	discharge monitoring report
DSLP	days since last precipitation
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency (U.S.)
FDA	fractional proportion of drainage area
FDC	flow duration curve
FG	future growth
GIS	geographic information system
H-GAC	Houston-Galveston Area Council
I/I	inflow and infiltration
I-Plan	implementation plan
LA	load allocation
LDC	load duration curve
mi^2	square miles
mL	milliliter
MGD	million gallons per day
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer system
MUD	municipal utility district
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	on-site sewage facility
SAB	service area boundaries

SSO	sanitary sewer overflow
SWMP	stormwater management program
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TMDL	total maximum daily load
TPDES	Texas Pollutant Discharge Elimination System
TSSWCB	Texas State Soil and Water Conservation Board
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	wasteload allocation
WQMP	Water Quality Management Plan
WWTF	wastewater treatment facility

Seven TMDLs for Indicator Bacteria in Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek Watersheds

Executive Summary

This document describes total maximum daily loads (TMDLs) for Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek where concentrations of indicator bacteria exceed the criteria used to evaluate attainment of the contact recreation use. The Texas Commission on Environmental Quality (TCEQ) first identified the impairments to the West Fork San Jacinto River in the *2002 State of Texas Clean Water Action Section 303(d) List* (TCEQ, 2002). The East Fork San Jacinto River, Crystal Creek, and Lake Houston were first listed in the *2006 Texas Water Quality Inventory and 303(d) List* (TCEQ, 2007). The impaired segments and corresponding assessment units (AUs) are:

- Lake Houston: 1002_06;
- East Fork San Jacinto River: 1003_01, 1003_02, 1003_03;
- West Fork San Jacinto River: 1004_01, 1004_02;, and
- Crystal Creek (unclassified water body): 1004D_01.

The water bodies included in this study are all within the Lake Houston watershed. They are, however, outside the area covered by previous TMDLs for indicator bacteria in watersheds upstream of Lake Houston (TCEQ, 2011). Lake Houston AU 1002_06 is defined as the portion of the lake from the confluence with Spring Creek to the West Lake Houston Parkway crossing. 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. The West Fork San Jacinto (Segment 1004) flows from the Lake Conroe dam in Montgomery County to the confluence with Spring Creek at the Montgomery-Harris county line. 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. With the exception of the East Fork San Jacinto River and Lake Houston, the TMDL segments are located entirely within Montgomery County.

There are 60 regulated discharging wastewater treatment facility (WWTF) outfalls located in the TMDL watersheds of which 53 are authorized to treat and discharge domestic wastewater. 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.

For the TMDL watersheds containing entities that are regulated under municipal separate storm sewer system (MS4) Phase II general permits and Phase I

individual permits, the area included within these permits was used to estimate the areas under stormwater regulation for construction, industrial, and MS4 permits. 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 between the MS4 permitted area and the total developed land use area in each AU.

The discharges authorized by the industrial wastewater and stormwater permits are considered intermittent and variable (subject to precipitation and runoff), and no flow limit is specified in the permits. Given the circumstances of the permits, these outfalls will be treated as part of the regulated stormwater discharge in the load allocations.

Escherichia coli (*E. coli*) are the preferred indicator bacteria for assessing the contact recreation use in freshwater, and were used for development of the TMDLs. The criteria for assessing attainment of the contact recreation use are expressed as the number (or "counts") of *E. coli* bacteria, typically given as the most probable number (MPN). The primary contact recreation use is not supported when the geometric mean of ambient *E. coli* samples exceeds 126 MPN per 100 milliliters (mL).

Historical ambient water quality data for indicator bacteria were evaluated at the AU level for the TCEQ water quality monitoring stations of Lake Houston, East Fork San Jacinto, West Fork San Jacinto, and Crystal Creek. For these seven AUs with impairments due to elevated indicator bacteria concentrations, the geometric means of *E. coli* ranged from 170 MPN/100 mL for West Fork San Jacinto AU 1004_02 to 338 MPN/100 mL for Crystal Creek AU 1004D_01. For these seven AUs, the geometric mean of the combined samples for all stations within each water body exceeded 126 MPN/100 mL, indicating non-support of primary contact recreation.

A load duration curve (LDC) analysis was used to quantify allowable pollutant loads and specific TMDL allocations for point and nonpoint sources of indicator bacteria.

The wasteload allocation for WWTFs was established as the permitted flow multiplied by one-half the geometric mean criterion for the indicator bacteria.

Future growth of existing or new domestic point sources was determined using population projections. The TMDL calculations in this report will guide determination of the assimilative capacity of each water body under changing conditions, including future growth. Wastewater discharge facilities will be evaluated case by case.

Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the geometric mean criterion of 126 MPN/100 mL.

Introduction

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.

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.

This TMDL addresses impairments to the contact recreation use due to exceeding indicator bacteria criteria in Lake Houston, East Fork San Jacinto, West Fork San Jacinto, and Crystal Creek. This TMDL project takes a watershed approach to addressing the bacteria impairments. While TMDL allocations are only being developed for the AUs that appear on the 303(d) list, the entire contributing watershed of each impaired AU, including all WWTFs that discharge within it, are included within the scope of this project.

Section 303(d) of the Clean Water Act and the implementing regulations of the U.S. Environmental Protection Agency (EPA) in Title 40 of the Code of Federal Regulations (CFR), Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

The TCEQ must consider certain elements in developing a TMDL. They are described in the following sections of this report:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Margin of Safety
- Pollutant Load Allocation
- Seasonal Variation

- Public Participation
- Implementation and Reasonable Assurance

Upon adoption of the TMDL report by the TCEQ and subsequent EPA approval, these TMDLs will become an update to the state's Water Quality Management Plan (WQMP).

Problem Definition

The TCEQ first identified bacteria impairments within AUs of the West Fork San Jacinto River in 2002, and within AUs of the East Fork San Jacinto River, Crystal Creek, and Lake Houston in 2006. The AUs have been identified for bacteria impairments in each subsequent edition through 2012 of the *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*) (TCEQ, 2012).

The water bodies 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 total drainage area for Lake Houston is 2,850 square miles (mi^2). The TMDL watersheds are located primarily within Montgomery and San Jacinto counties, but also include portions of Grimes, Harris, Liberty, and Walker counties.

This report will consider bacteria impairments in all or part of four water bodies (segments) consisting of seven total AUs (Figure 1). An AU is the smallest geographic area of use support reported in the TCEQ assessment of surface water quality. The complete list of water bodies and their identifying combined segment and AU numbers are as follows:

- Lake Houston: 1002_06;
- East Fork San Jacinto River: 1003_01, 1003_02, 1003_03;
- West Fork San Jacinto River: 1004_01, 1004_02; and
- Crystal Creek (unclassified water body): 1004D_01.

Because this TMDL project takes a watershed approach to addressing the bacteria impairments, the entire contributing drainage area defines the watershed of each of the seven impaired AUs within the four water bodies.

Complexities to the definition of the contributing drainage area occur as a result of:

- Water bodies that have not been evaluated for use support due to lack of data within the contributing drainage area of the seven impaired AUs;
- Water bodies fully supporting the contact recreation use exist within the contributing drainage area of the seven impaired AUs;

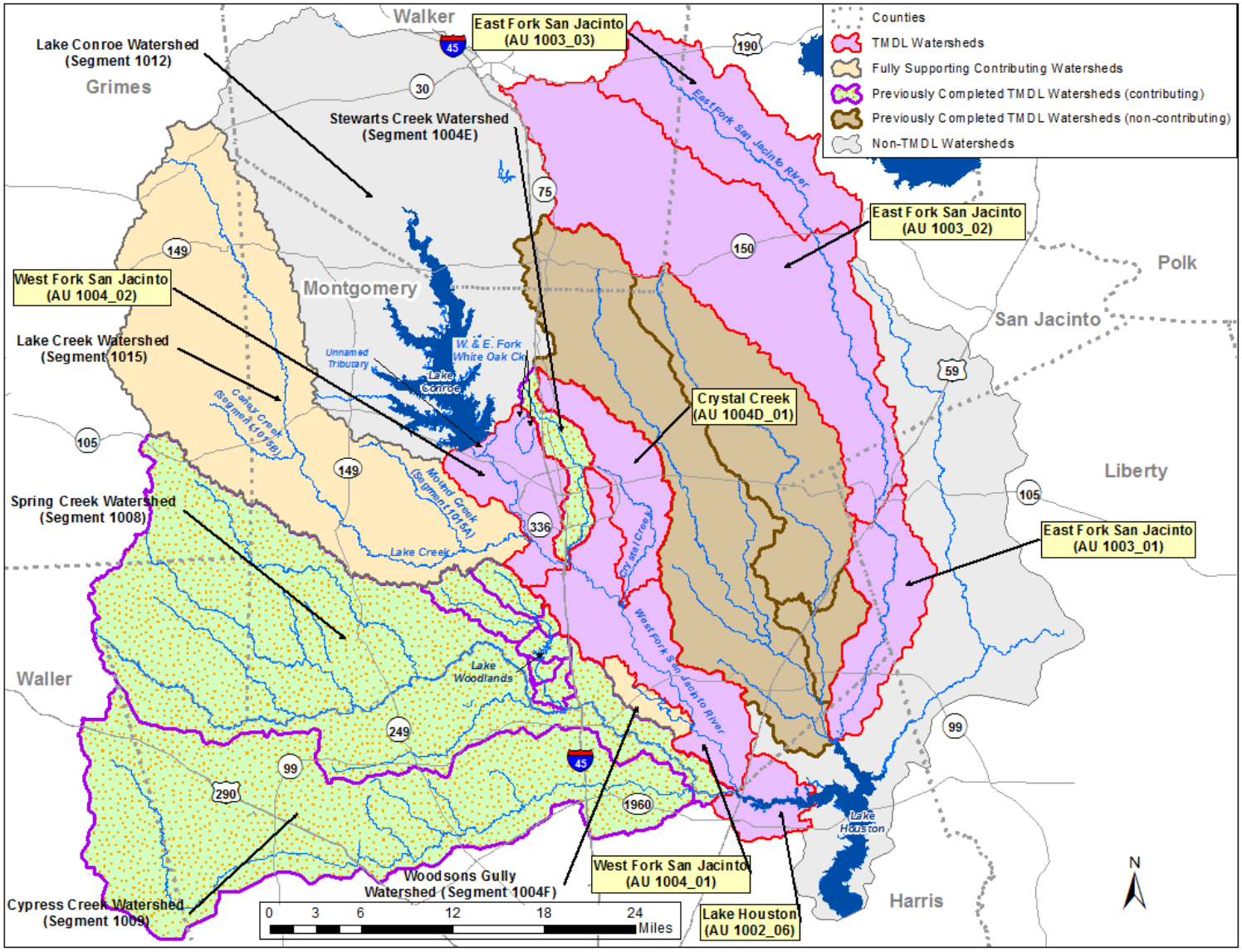

Figure 1. Total contributing drainage area for the Lake Houston watershed, including Segments 1002, 1003, 1004, and 1004D

- Previously completed indicator bacteria TMDLs for watersheds upstream of Lake Houston (TCEQ, 2011) occur within the drainage area of some of the seven impaired AUs; and
- Lake Conroe (Segment 1012)—a major non-impaired reservoir—occurs at the upstream end of the West Fork San Jacinto River (Segment 1004).

Those water bodies that have not been evaluated for contact recreation use support due to lack of data are considered part of the segment that receives their discharge.

For the second complexity, TMDLs were not explicitly developed for those water bodies fully supporting the contact recreation use in 2012. Those water bodies, however, are considered to be part of the AU of an impaired segment that receives their discharge. As a result of this consideration, unimpaired Lake Creek (Segment 1015), Mound Creek (Segment 1015A), and Caney Creek (Segment 1015B) are included in the drainage area for AU 1004_02 of the West Fork San Jacinto River, and Woodson Gully (Segment 1004F) is included in the drainage area of AU 1004_01 of the West Fork San Jacinto River. These water bodies and their stream networks are depicted in Figure 1 with the map legend designation of "Fully Supporting Contributing Watersheds." Also, any WWTF discharges from these unimpaired water bodies are included as point sources in the pollutant load allocations in this report.

The third complexity results from previously completed TMDLs. Of the 15 previously completed TMDLs, three watersheds are of relevance because they provide tributary loadings to the TMDL watersheds in this report. Previously completed Stewarts Creek (Segment 1004E) is a direct tributary into West Fork San Jacinto River AU 1004_01. Previously completed TMDLs for Spring Creek (Segment 1008) and Cypress Creek (Segment 1009) are direct tributaries into Lake Houston AU 1002_06. Geographical positioning of the watersheds of these three previous indicator bacteria TMDLs are provided in Figure 1 with the map legend designation of "Previously Completed TMDL Watersheds (Contributing)." Because the pollutant load allocations for these three water bodies are already specified in TCEQ-adopted and EPA-approved TMDLs (TCEQ, 2011), their load allocations are designated as tributary load allocations in this report.

The fourth 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 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 pollutant load allocation process. 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) as shown in Figure 1. To accommodate the disruption in downstream bacteria loadings from Segment

1012, the bacteria loadings associated with its releases are considered separately within the impaired AUs that are downstream of Lake Conroe. These AUs are Lake Houston AU 1002_06 and the two AUs for the West Fork San Jacinto River (AUs 1004_01 and 1004_02).

This report includes TMDLs for those seven AUs determined to be impaired, based on the 2012 Texas Integrated Report data. The TMDLs for each AU are based on a watershed-based approach that takes into account the contributing drainage area of each AU as well as the complexities discussed above. Subsequent maps of the Lake Houston watershed will contain delineations of the watersheds of the seven impaired AUs that include the drainage areas of any segments fully supporting the contact recreation use and flowing into the impaired AUs.

Ambient Indicator Bacteria Concentrations

Recent environmental monitoring within AUs 1002_06, 1003_01, 1003_02, 1003_03, 1004_01, 1004_02, and 1004D_01 has occurred at several 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, 2012). The 2012 assessment data indicate non-support of the primary contact recreation use. Concentrations exceed the geometric mean criterion of 126 MPN/100 mL for all seven assessed AUs within the 2012 Texas Integrated Report (TCEQ, 2012) and as summarized in Table 1. For the purposes of this report, the 2012 AU boundary definitions in Segments 1002, 1003, 1004, and 1004D were used.

Table 1. 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	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

Watershed Overview

The water bodies included in this study are all within the Lake Houston watershed and are depicted in Figure 2. They are, however, outside the area covered by previous TMDLs for indicator bacteria in watersheds upstream of Lake Houston (TCEQ, 2011). 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 Lake 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.

The 2012 Texas Integrated Report (TCEQ, 2012) 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.

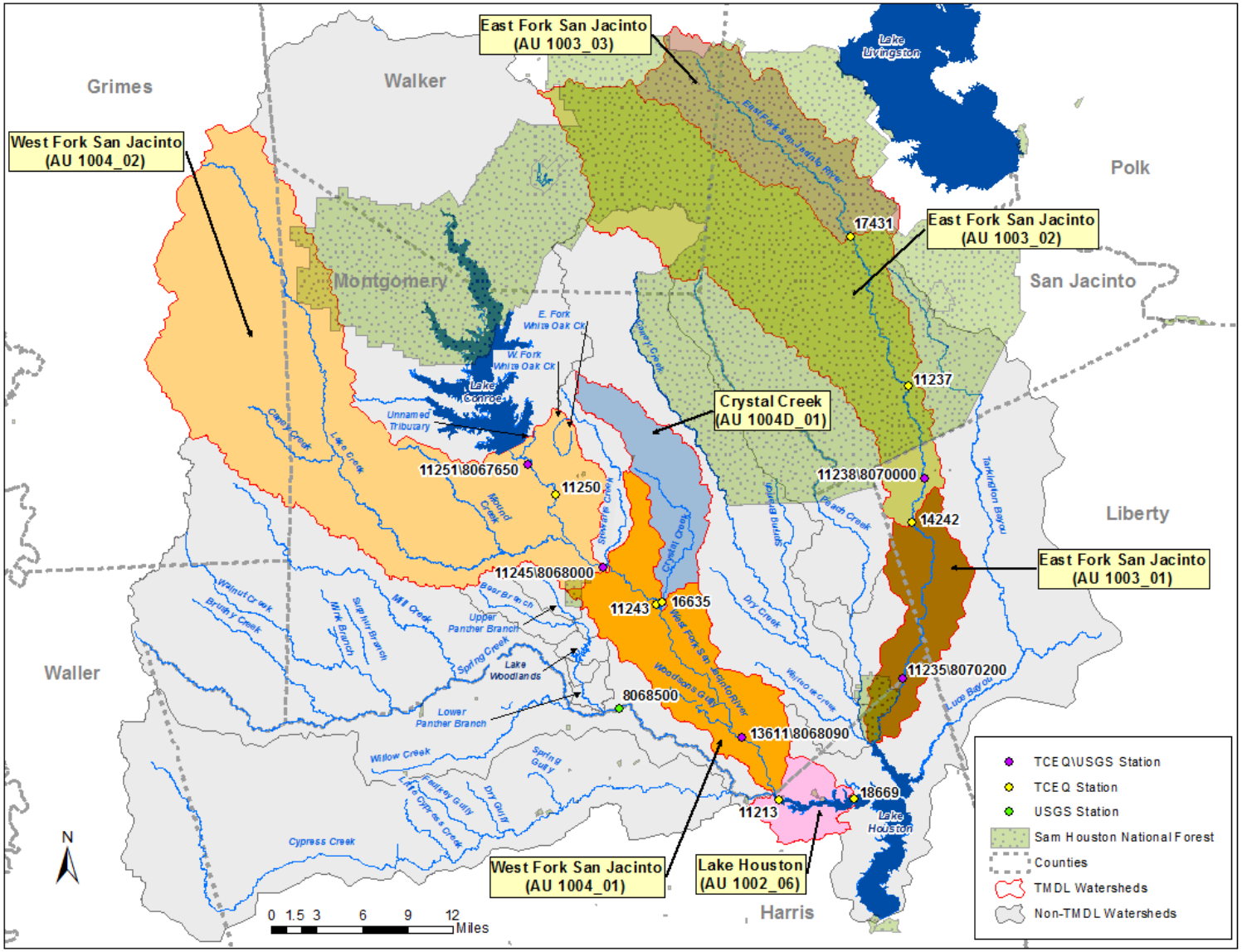

Figure 2. Lake Houston watershed showing SWQM monitoring stations and USGS gauging stations

- 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.

The phrase "TMDL watersheds" will be used when referring to the area of all seven 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.

The southern part of the Lake Houston 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 Lake Houston 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 Lake Houston 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 approximately 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 Lake Houston watershed. Annual precipitation data (1997-2006) for key weather stations are provided in Table 2. These data were obtained through the EPA BASINS program (EPA, 2007).

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 95^0F while the coolest low temperatures typically occur during the month of January with average low temperatures of 43^0F. Maximum precipitation occurs in the late spring and autumn. It is not unusual for hurricanes to affect rainfall in the early autumn.

Table 2. Annual rainfall totals for Lake Houston watershed (1997 – 2006)

NOAA 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***

The land use/land cover data presented in this report are from the National Oceanic and Atmospheric Association (NOAA) Coastal Change Analysis Program as obtained from the Houston-Galveston Area Council (H-GAC) (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 percent to 100 percent 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 percent to 79 percent 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 percent 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 percent 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 percent 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 graminoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. Scrub/shrub areas are dominated by shrubs less than five meters tall

with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

- **Forest** – Areas characterized by tree cover greater than five meters tall and tree canopy accounting for greater than 20 percent of the cover. The forest category includes deciduous, evergreen, and mixed forests.
- **Wetland** – Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water, or areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
- **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 percent 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 percent of total cover.
- **Water and Unconsolidated Shore** – Areas of open water, generally with less than 25 percent 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 four TMDL segment watersheds, only Lake Houston (1002_06) had a large portion of its land use classified as developed, though forest is the largest single category (Table 3). The remaining segment watersheds were dominated by forest, grassland/scrub/shrub, and wetlands (Table 3).

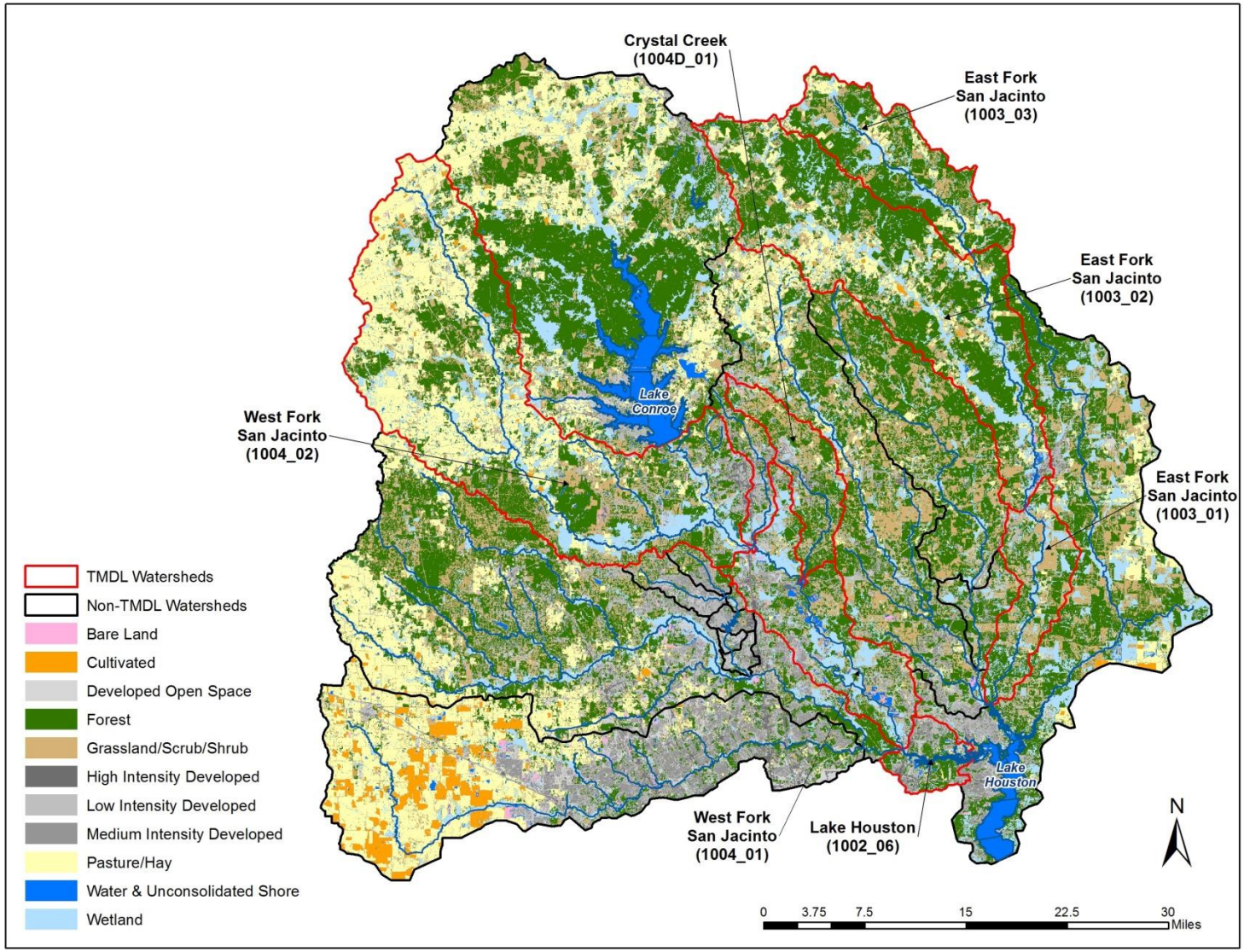

Figure 3. Land use / land cover in the Lake Houston watershed

Source: NOAA (2011)

Table 3. Aggregated land use summaries by impaired AUs

Source: NOAA (2011)

Land Use Category	1002_06	1003_01	1003_02	1003_03	1004_01	1004_02	1004D_01
Acres Bare Land	80.0	62.0	306.1	66.3	899.8	1,200.3	131.5
Acres Cultivated	1.9	0.0	796.0	66.7	43.2	1,648.4	0.0
Acres Forest	5,250.0	14,256.8	77,669.1	29,811.0	18,457.1	66,892.2	13,338.6
Acres Grassland/Scrub/Shrub	804.7	10,349.3	25,058.2	11,012.1	10,030.0	35,137.7	8,638.7
Acres Developed Open Space	1,651.7	438.8	404.2	52.6	2,207.7	1,744.8	1,176.5
Acres High Intensity Developed	882.0	108.0	350.9	8.3	1,508.4	1,348.6	584.2
Acres Low Intensity Developed	2,298.2	1,513.0	2,279.3	581.5	9,079.9	10,797.8	3,191.4
Acres Medium Intensity Developed	2,025.4	291.9	430.5	26.1	3,136.4	2,020.1	750.7
Acres Pasture/Hay	238.1	999.7	20,462.2	6,387.0	889.9	83,398.4	806.4
Acres Water & Unconsolidated Shore	879.1	231.0	1,454.6	142.8	2,734.2	1,964.4	129.0
Acres Wetland	1,384.3	9,199.3	29,152.7	10,691.5	15,029.2	37,289.4	2,182.6
Watershed Area (acres)	***15,495.5***	***37,449.6***	***158,363.8***	***58,845.9***	***64,015.8***	***243,442.1***	**30,929.7**
Percent Bare Land	0.5%	0.2%	0.2%	0.1%	1.4%	0.5%	0.4%
Percent Cultivated	0.0%	0.0%	0.5%	0.1%	0.1%	0.7%	0.0%
Percent Forest	33.9%	38.1%	49.0%	50.7%	28.8%	27.5%	43.1%
Percent Grassland/Scrub/Shrub	5.2%	27.6%	15.8%	18.7%	15.7%	14.4%	27.9%
Percent Developed Open Space	10.7%	1.2%	0.3%	0.1%	3.4%	0.7%	3.8%
Percent High Intensity Developed	5.7%	0.3%	0.2%	0.0%	2.4%	0.6%	1.9%
Percent Low Intensity Developed	14.8%	4.0%	1.4%	1.0%	14.2%	4.4%	10.3%
Percent Medium Intensity Developed	13.1%	0.8%	0.3%	0.0%	4.9%	0.8%	2.4%
Percent Pasture/Hay	1.5%	2.7%	12.9%	10.9%	1.4%	34.3%	2.6%
Percent Water & Unconsolidated Shore	5.7%	0.6%	0.9%	0.2%	4.3%	0.8%	0.4%
Percent Wetland	8.9%	24.6%	18.4%	18.2%	23.5%	15.3%	7.1%

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The 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 seven AUs addressed by this TMDL. This endpoint is identical to the geometric mean criterion for primary contact recreation in the 2010 Surface Water Quality Standards (TCEQ, 2010).

Source Analysis

Pollutants may come from several sources, both regulated and unregulated. Regulated pollutants, referred to as "point sources," come from a single definable point, such as a pipe, and are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES). WWTFs and stormwater discharges from industries, construction, and the separate storm sewer systems of cities are considered point sources of pollution.

Unregulated sources are typically nonpoint source in origin, meaning the pollutants originate from multiple locations and rainfall runoff washes them into surface waters. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual wasteload allocations (see the "Wasteload Allocation" section), 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 used for allocating bacteria loads or interpreted as precise inventories and loadings.

Regulated Sources

Permitted sources are regulated by permit under the TPDES and the National Pollutant Discharge Elimination System (NPDES) programs. The permitted sources in the TMDL watershed include WWTF outfalls and stormwater discharges from industries, construction, and MS4s.

Domestic and Industrial Wastewater Treatment Facilities

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 4, 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 4. 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 4	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
1	WQ10495-149	TX0115924	City of Houston	Forest Cove WWTF	1002_06	0.95	0.319
2	WQ13526-001	TX0105996	Kings Manor MUD	Kings Manor MUD WWTF	1002_06	0.4	0.222
3	WQ02642-000[a]	TX0093483	PWT Enterprises Inc.	King Kleen Car Wash	1002_06	0.003	0.001
4	WQ14091-001	TX0095630	North Park Business Center Ltd.	North Park Business Center Ltd. WWTF	1002_06	0.0048	0.001
5	WQ15192-001	TX0134996	QUADVEST LP	Grande San Jacinto WWTF	1003_01	0.9	—[f]
6	WQ15012-001	TX0133167	Utilities Investment Company Inc.	Plum Grove WWTF	1003_01	0.225	0.068
7	WQ15061-001	TX0133817	QUADVEST LP	Bella Vista WWTP	1003_01	0.48	—[f]
8	WQ10766-001	TX0053473	City of Cleveland	West WWTF	1003_02	0.75	0.344
9	WQ14996-001	TX0028169	Universal Forest Products Texas LLC	UFP New Waverly WWTF	1003_02	0.02	0.006
10	WQ04249-000[a]	TX0123421	Steely Lumber Co. Inc.	Steely Lumber WWTF	1003_02	Report Only	Report Only
11	WQ11844-001	TX0071765	Forest Glen Inc.	Forest Glen Christian Camp WWTF	1003_03	0.04	0.015
12	WQ10495-142	TX0088501	City of Houston	Kingwood West WWTF	1004_01	2	0.3
13	WQ15288-001	TX0135682	Montgomery County MUD 96	Montgomery County MUD 96 WWTF	1004_01	0.4	—[f]
14	WQ14482-001	TX0126209	Montgomery County MUD 83	Montgomery County MUD 83 WWTF	1004_01	0.6	0.152
15	WQ14755-001	TX0129160	Quadvest LP	Benders Landing WWTF	1004_01	0.9	0.003
16	WQ14586-001	TX0127400	LMV Management Co. Ltd.	ER Woodsons WWTF	1004_01	0.9	0.285
17	WQ13760-001	TX0089672	Montgomery County MUD 56	Montgomery County MUD 56 WWTF	1004_01	0.1	0.068

Reference No. for Figure 4	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
18	WQ13985-001	TX0117706	Montgomery County MUD 89	Rembert Tract WWTF	1004_01	0.5	0.193
19	WQ14523-001	TX0126713	Montgomery County MUD 88	Montgomery County MUD 88 WWTF	1004_01	0.6	0.005
20	WQ14531-001	TX0126799	JTM Housing Ltd. and Quadvest Inc.	Creekside WWTF	1004_01	0.6	0.054
21	WQ15313-001	TX0135941	Montgomery County MUD 127	Montgomery County MUD 127 WWTP	1004_01	0.6	—[f]
22	WQ14604-001	TX0127752	Montgomery County MUD 99	Montgomery County MUD 99 WWTF	1004_01	1.5	0.046
23	WQ02502-000[a]	TX0087793	Hanson Aggregates Central Inc.	Woodlands Plant	1004_01	0.35	0
24	WQ13700-001	TX0090123	Chateau Woods MUD	Chateau Woods WWTF	1004_01	0.2	0.095
25	WQ14414-001	TX0125601	242 LLC	Woodland Lakes Village WWTF	1004_01	0.45	0.319
26	WQ12212-002	TX0093564	City of Shenandoah	City of Shenandoah WWTF	1004_01	3	0.467
27	WQ11658-001	TX0063461	San Jacinto River Authority	Vince Tract Development WWTF	1004_01	0.9	0.474
28	WQ11580-001	TX0075680	Town of Woodloch	Town of Woodloch WWTF	1004_01	0.15	0.075
29	WQ11395-001	TX0022055	Montgomery County MUD 15	Gleneagles Sub-division WWTF	1004_01	0.9	0.146
30	WQ11820-001	TX0069256	Lazy River Improvement District	Lazy River Improvement District WWTF	1004_01	0.1	0.048
31	WQ10978-001	TX0025674	River Plantation MUD	River Plantation MUD WWTF	1004_01	0.6	0.365
32	WQ02365-000[a]	TX0034681	Maverice Tube Corp.	Tenaris Conroe	1004_01	0.1108	0.02
33	WQ14671-001	TX0128431	Montgomery County MUD 112	Montgomery County MUD 112 WWTF	1004_02	0.5	0.015
34	WQ10008-002	TX0022268	City of Conroe	City of Conroe Southwest Regional WWTF	1004_02	10	5.83
35	WQ12761-001	TX0093505	Karbalia, Laura Redow	Westmont MHP WWTF	1004_02	0.05	0.016

Reference No. for Figure 4	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
36	WQ14114-001	TX0119504	Aqua Development Inc.	Aquasource Development Company WWTF	1004_02	0.6	0.009
37	WQ11097-001	TX0020206	City of Panorama Village	City of Panorama Village WWTF	1004_02	0.4	0.25
38	WQ14709-001	TX0102962	Stone Hedge Utility Co. Inc.	Stone Hedge WWTF	1004D_01	0.015	0.005
39	WQ10315-001	TX0068845	City of Willis	City of Willis WWTF	1004D_01	0.8	0.594
40	WQ00584-000 Outfall 001	TX0005592	Huntsman Petrochemical Corp.	Huntsman Petrochemical Conroe Plant	1004G_01[b]	0.75	0.409
41	WQ00584-000[a] (Outfall 002)	TX0005592	Huntsman Petrochemical Corp.	Conroe Chemical Plant	1004G_01[b]	Report Only	Report Only
42	WQ02475-000[a] Outfall 002	TX0087190	Chevron Phillips Chemical Co LP	Drilling Specialties WWTF	1004G_01[b]	Stormwater Only	—
43	WQ02475-000 Outfall 001	TX0087190	Chevron Phillips Chemical Co LP	Drilling Specialties Alamo Plant	1004G_01[b]	0.016	0.006
44	WQ15296-001	TX0135755	Woodlands Oaks Utility LP	Lost Creek WWTP	1004G_01[b]	0.25	—[f]
45	WQ15089-001	TX0134520	D R Horton-Texas LTD	Montgomery County MUD 139 WWTP	1015_01[c]	0.51	—[f]
46	WQ14814-001	TX0129674	Montgomery County MUD 113 C/O Allen Boone Humphries Robinson LLP	Woodforest Interim WWTF	1015_01[c]	0.945	0.116
47	WQ14166-001	TX0122327	Woodland Oaks Utility Co. Inc.	Woodland Oaks WWTF	1015_01[c]	0.498	0.134
48	WQ14800-001	TX0129585	John David Hagerman and Martha Voss Byrd	Fair Oaks WWTF	1015_01[c]	0.7	0.086
49	WQ14305-001	TX0124486	SR Superior LLC	Skye Ranch WWTF	1015_01[c]	0.24	0.029
50	WQ14711-001	TX0128368	Quadvest LP	Mostyn Manor WWTF	1015_01[c]	0.5	0.006
51	WQ15317-001 Outfall 002	TX0136000	QUADVEST LP	Magnolia Lake Creek	1015_01[c]	See Outfall 001	—[f]
52	WQ15317-001 Outfall 001	TX0136000	QUADVEST LP	Magnolia Lake Creek	1015_01[c]	0.250 for both outfalls combined	—[f]

Reference No. for Figure 4	TPDES Permit No.	NPDES Permit No.	Permittee	Facility	AU	Final Permitted Discharge (MGD)	Actual Discharge (MGD)
53	WQ14989-001	TX0132845	The Cardon Group Inc.	Montgomery Co. MUD 125 WWTF	1015_01[c]	0.96	0.118
54	WQ15283-001	TX0135658	Bluejack Development CO LLC	Blaketree MUD 1of Montgomery County	1015_01[c]	0.2	—[f]
55	WQ13527-001	TX0106119	Richards ISD	Richards ISD WWTF	1015_01[c]	0.005	0.0004
56	WQ05111-000[a]	TX0135071	Tenaska Roans Prairie Partners LLC	Tenaska Roans Prairie Generating Station	1015_01[c]	0.105	—[f]
57	WQ12456-001	TX0088901	Crane Co.	Crane Energy Flow Solutions WWTF	1015A_01[d]	0.005	0.002
58	WQ14638-001	TX0128121	MSEC Enterprises Inc.	MSEC WWTF	1015A_01[d]	0.02	0.004
59	WQ15341-001	TX0136191	MSEC Enterprises Inc.	MSEC WWTP 2	1015A_02[d]	0.13	—[f]
60	WQ11437-001	TX0092649	Grimes County MUD 1	Grimes County MUD 1 WWTF	1015B_01[e]	0.025	0.003

Notes: MGD denotes million gallons per day; MUD denotes municipal utility district.

[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.

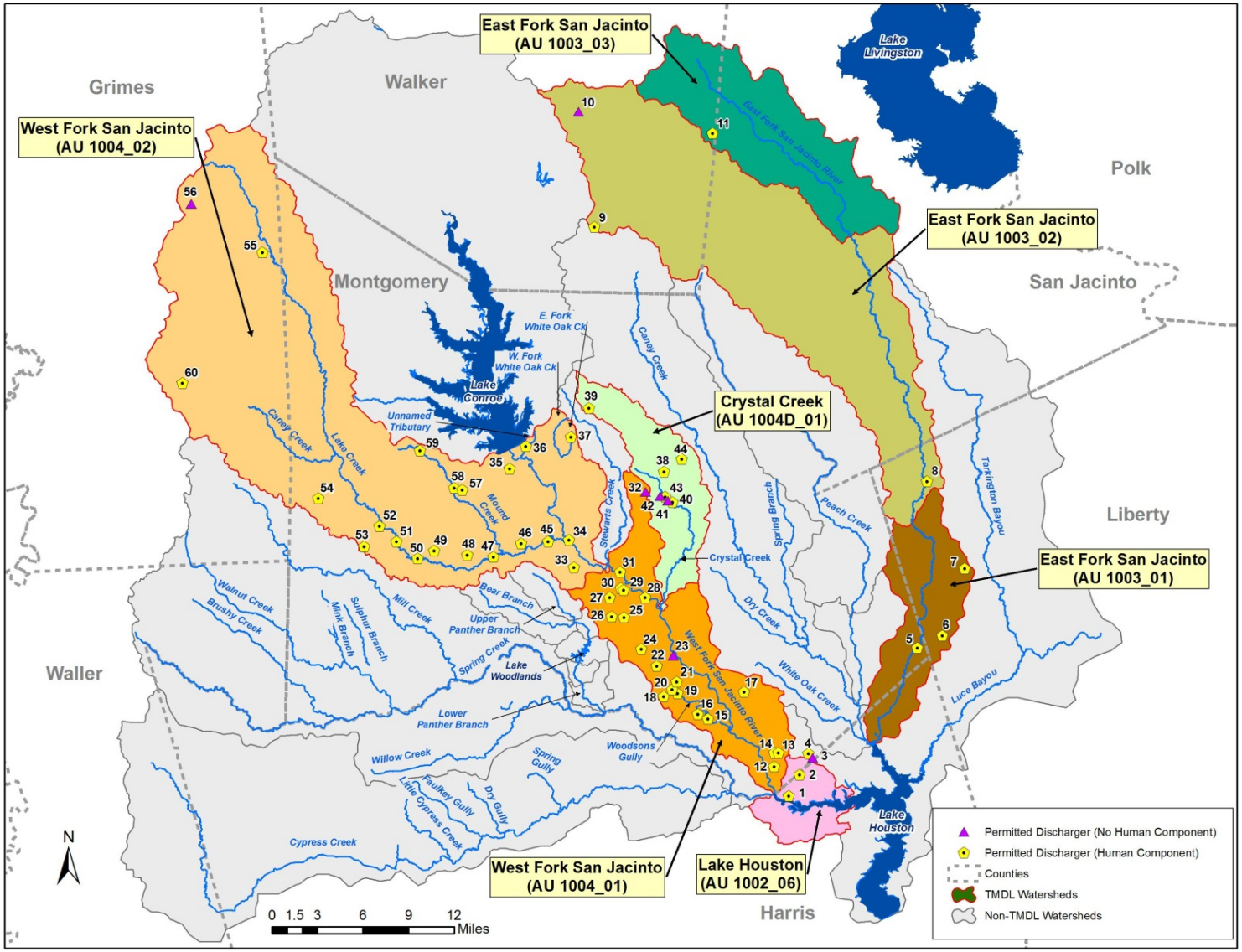

Figure 4. Permitted wastewater operations in Lake Houston, East Fork & West Fork San Jacinto rivers, and Crystal Creek TMDL watersheds

Within AU_03 of the East Fork San Jacinto watershed, there is one WWTF with a permitted discharge of 0.040 million gallons per day (MGD) that has a human waste component. Within AU_02 of the East Fork San Jacinto watershed, 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 AU_01 of the East Fork San Jacinto watershed, there are three domestic WWTFs that are permitted to discharge 1.605 MGD that have a human waste component.

The West Fork San Jacinto (1004_02) watershed includes the drainage areas of Lake Creek (1015_01), Mound Creek (1015A_01), and Caney Creek (1015B_01). Within the entire West Fork San Jacinto (1004_02) watershed, 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 AU_01 of the West Fork San Jacinto watershed, there are 19 WWTFs with a combined permitted discharge of 15.0 MGD that have a human waste component. The watershed also contains two facilities that are authorized to discharge 0.4608 MGD of wastewater and do not contain a human waste component.

The Crystal Creek (1004D_01) watershed includes the drainage area of West Fork Crystal Creek (1004G_01). Within AU_01 of the entire Crystal Creek watershed, there are five WWTFs with a combined permitted discharge of 1.831 MGD that have a human waste component. The watershed 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 AU_06 of the Lake Houston watershed, there are three WWTFs with a combined permitted discharge of 1.3548 MGD that have a human waste component. The watershed also contains one facility that is authorized to discharge 0.003 MGD of wastewater that does not contain a human waste component.

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 database 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 and West Fork San Jacinto Rivers, and Crystal Creek watersheds and is summarized in Table 5. 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.

Table 5. 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.

Water Body	Segment/AU	No. of Incidences	Total Volume (gallons)	Average Volume (gallons)
Lake Houston	1002_06	20	30,230	1,512
East Fork San Jacinto	1003	5	5,050	1,010
West Fork San Jacinto	1004	96	994,902	10,364
Crystal Creek	1004D_01	7	247,900	35,414

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 MS4s, industrial facilities, and regulated construction activities.
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 an MS4 permit is to reduce discharges of pollutants in stormwater to the “maximum extent practicable” by developing and implementing a Stormwater Management Program (SWMP). The

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 entities. 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 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. Census Bureau. The entities regulated under MS4 permits for the TMDL watersheds are provided in Table 6. The percentage of land area under jurisdiction of stormwater permits for each of the TMDL watersheds is presented in Table 7. AUs 1003_03 and 1003_02 of the East Fork San Jacinto River have no areas under MS4 permits. The regulated stormwater area for these AUs was estimated from the other AUs based on an empirical relationship developed between the MS4 permitted area and the total developed land use area in each AU (Millican and Hauck, 2015).

Table 6. TPDES MS4 and MSGP permits associated with TMDL area watersheds

Entity	Permit Number (Notice of Intent Number for Phase II Permits)	AU
Kings Manor MUD MS4	TXR040000 (TXR040387)	1002_06
City of Humble MS4	TXR040000 (TXR040251)	1002_06
Texas Department of Transportation	TXR040000 (TXR040191)	1002_06, 1004_01
City of Houston, Harris County, Harris County Flood Control District, and Texas Department of Transportation	WQ0004685000	1002_06, 1003_01, 1004_01
Montgomery County MUD 15 MS4	TXR040000 (TXR040382)	1004_01

Entity	Permit Number (Notice of Intent Number for Phase II Permits)	AU
Rayford Road MUD MS4	TXR040000 (TXR040147)	1004_01
Spring Creek Utility District MS4	TXR040000 (TXR040216)	1004_01
City of Oak Ridge North MS4	TXR040000 (TXR040273)	1004_01
City of Shenandoah MS4	TXR040000 (TXR040210)	1004_01
Montgomery County Drainage District 6 MS4	TXR040000 (TXR040121)	1004_01
Montgomery County MS4	TXR040000 (TXR040348)	1004_01, 1004_02, 1004D_01
The Woodlands Joint Powers Agency MS4	TXR040000 (TXR040256)	1004_01, 1004_02

Table 7. 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

* Areas based on a total percentage of developed land use of 2.2 percent for AU 1003_02 and 1.1 percent for AU 1003_03 and Figure 6 in Millican and Hauck (2015).

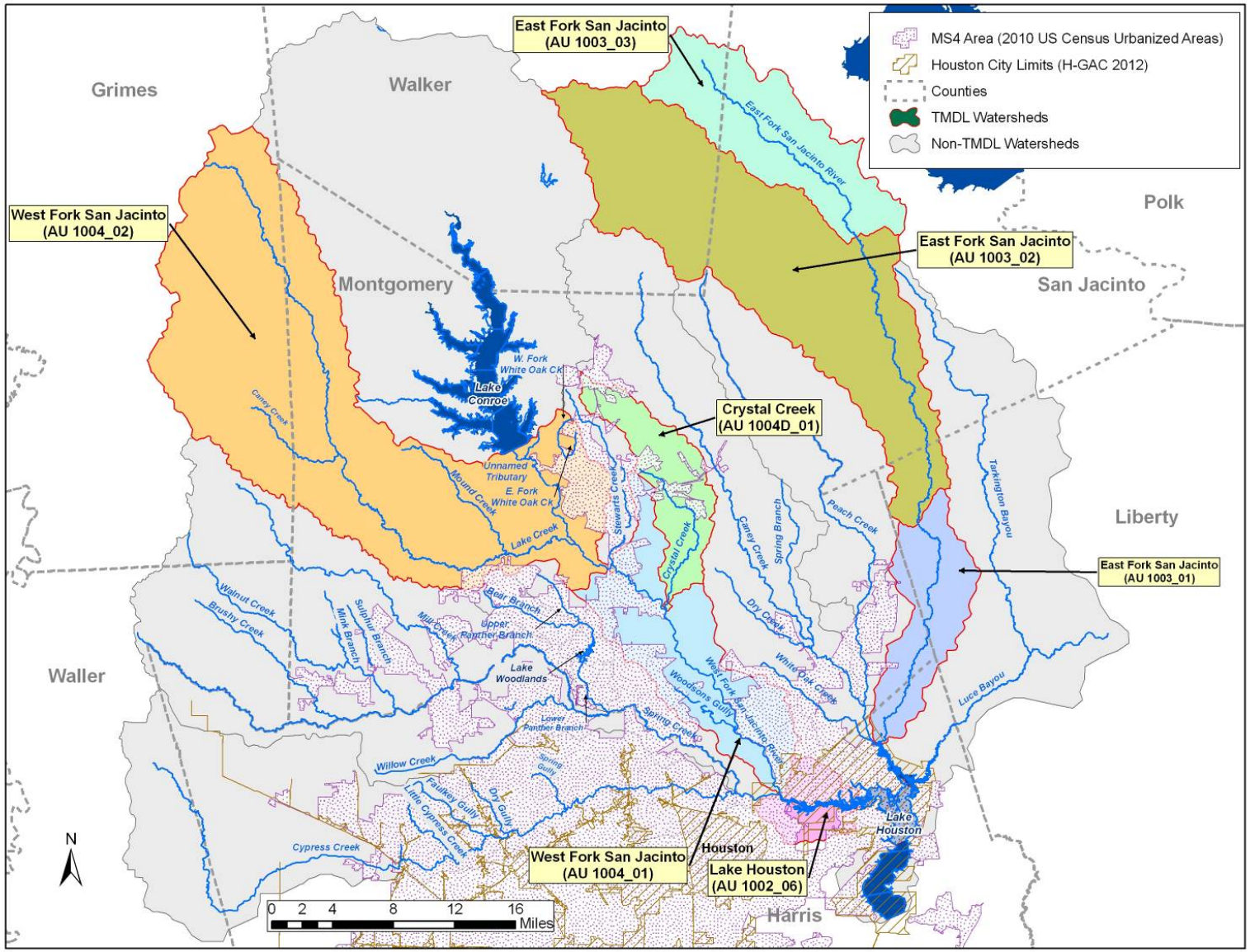

Figure 5. Lake Houston, East Fork and West Fork San Jacinto rivers, and Crystal Creek watersheds showing MS4 permitted areas

Illicit Discharges

Pollutant loads can enter streams from MS4 outfalls that carry authorized sources as well as 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) include:

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials 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 sanitary sewer and storm sewer systems.

Indirect illicit discharges:

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

Unregulated Sources

Unregulated sources of bacteria are generally nonpoint. Nonpoint source loading enters an impaired segment through distributed, nonspecific locations, which may include urban runoff not covered by a permit, wildlife, various agricultural activities, agricultural animals, land application fields, failing on-site sewage facilities (OSSFs), unmanaged and feral animals, and domestic pets.

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 they may be washed into nearby streams by rainfall runoff.

Unregulated 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 2012 Census of Agriculture (United States Department of Agriculture (USDA), 2012). 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 livestock data (Table 8). Activities such as improper grazing management can contribute *E. coli* to nearby water bodies. The livestock numbers in Table 8 are provided to demonstrate that livestock are a potential source of bacteria in the TMDL watersheds. The estimated livestock populations were reviewed by the Texas State Soil and Water Conservation Board (TSSWCB). These livestock numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

Table 8. Livestock statistics estimates for Lake Houston, East and West Fork San Jacinto, and Crystal Creek watersheds

Estimated livestock numbers less than 10 reported as <10; estimates based on data from USDA (2012)

AU	Cattles and Calves	Hogs and Pigs	Chickens	Other Poultry	Horses and Ponies	Sheep and Goats
1002_06	444	<10	77	26	74	47
1003_01	2,357	38	497	43	273	196
1003_02	8,472	676	8,802	21	660	527
1003_03	2,936	193	2,530	10	236	203
1004_01	1,155	31	390	<10	296	202
1004_02	534	14	180	<10	137	94
1004D_01	802	22	271	<10	206	141

Pets can also be sources of *E. coli* bacteria, because storm runoff can carry the animal wastes into streams (EPA, 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). Table 9 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 difficult to quantify.

Table 9. 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 10 were used as an estimate of the number of households within AU 1003_03 due to suspected inaccuracies that resulted from the zip-code level population projections available for that AU.

Failing On-Site Sewage Facilities

Private residential OSSFs, commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) and 2) aerobic systems that have an aerated holding tank and often an above ground sprinkler system for distributing the effluent. In simplest terms, household waste flows into the septic tank or aerated tank, where treatment occurs and 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 percent 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 the geographic regions described in the Reed, Stowe, and Yanke report, which provides insight into expected failure rates in these watersheds. 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.

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 geographic information system (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 6, and an estimate of the number of OSSFs in each AU of the TMDL watersheds is provided in Table 10.

Table 10. OSSF estimates for TMDL watersheds

AU	Segment	OSSFs
1002_06	Lake Houston	687
1003_01	East Fork San Jacinto River	1,326
1003_02	East Fork San Jacinto River	3,570
1003_03	East Fork San Jacinto River	1,290
1004_01	West Fork San Jacinto River	2,165
1004_02	West Fork San Jacinto River	6,948
1004D_01	Crystal Creek	1,695

Bacteria Re-growth 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 instream processes and are not considered in the bacteria source loading estimates of each water body in the TMDL watersheds.

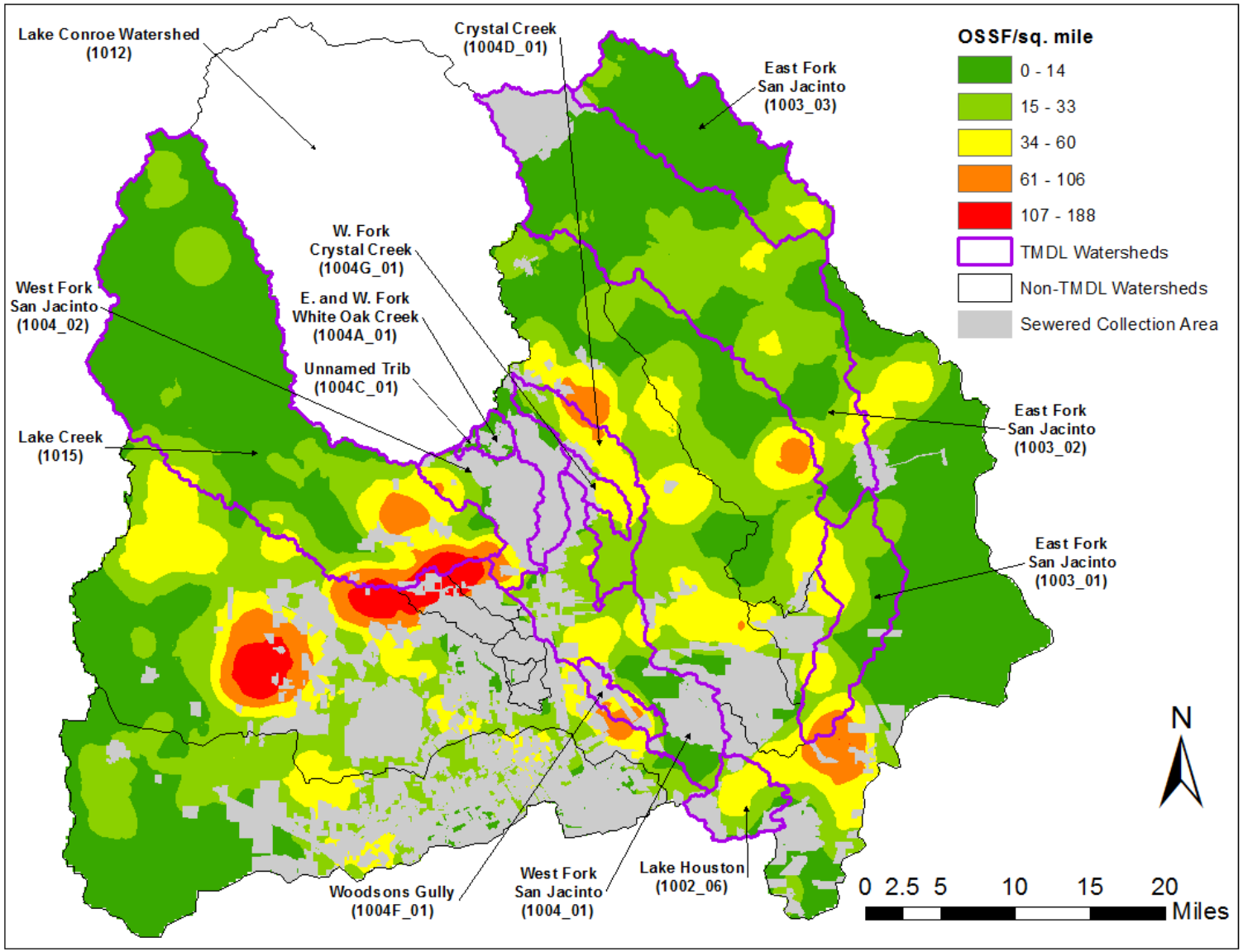

Figure 6. OSSFs densities within the Lake Houston watershed

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 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.

Load Duration Curve Analysis

LDC analyses were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads and are the basis of the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. The strength of this tool is that it 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, or other conditions in the watershed.

The LDC method is not typically applied to reservoir and lake situations; rather, application of the LDC method 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. AU 1002_06 is the uppermost AU on the western arm of Lake Houston (see Figure 1) 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 the dam. The anticipated strong and immediate interconnection of AU 1002_06 to upstream tributaries made it feasible to apply the LDC method to this AU.

The weaknesses of the LDC 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 loads and the 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 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.

Data requirements for the LDC are minimal, consisting of continuous daily streamflow records and historical bacteria data. A 10-year period of record from January 1, 2001, through December 31, 2010, was selected for LDC development, since the previously completed TMDLs in the Lake Houston watershed were based on a 10-year period. While the number of *E. coli* observations required to develop a flow duration curve (FDC) is not rigorously specified, the curves are usually based on more than five years of observations, and encompass inter-annual and seasonal variation. For this report, LDCs were constructed for the most downstream, recently sampled monitoring station within each TMDL watershed. Bacteria data were obtained from the Surface Water Quality Monitoring Information System (SWQMIS) for the period of January 1, 2001, to December 31, 2010.

On numerous creeks and rivers in Texas, U.S. Geological Survey (USGS) streamflow gauging stations have been in operation for a sufficient period to be used as the source of the needed streamflow records. The USGS streamflow gauges used for LDC development and the area of application are:

- USGS gauging station 08068500 (Spring Creek near Spring, Texas) applied to Spring Creek (AU 1008_04) to account for flow from previously completed TMDLs;
- USGS gauging station 08070000 (East Fork San Jacinto River near Cleveland, Texas) applied to AUs 1003_01, 1003_02, and 1003_03;
- USGS gauging station 08068090 (West Fork San Jacinto River above Lake Houston, near Porter, Texas) applied to AUs 1004_01, 1004_02, and 1004D_01; and
- USGS gauging station 08067650 (West Fork San Jacinto River below Lake Conroe, near Conroe, Texas) applied to define releases and spills from Lake Conroe (Segment 1012).

The Lake Houston AU 1002_06 LDC development was based on the combined flows of Spring Creek and the West Fork San Jacinto River, using streamflow data from gauges 08068500 and 08067650.

The required daily streamflow record for each LDC was estimated based on application of a drainage area ratio computed as the drainage area above the LDC location divided by the drainage area of the appropriate USGS gauge. Prior to application of the drainage area ratio, the USGS gauge record was corrected by subtracting upstream WWTF discharges based on discharge monitoring report (DMR) information. After multiplication of the corrected streamflow record by the drainage area ratio, a final adjustment occurred for the purposes of pollutant load computations. The hydrologic records were adjusted to reflect full permitted flows from all upstream WWTFs and future capacity estimates that account for the probability that additional flows from WWTF discharges may occur as a result of population increases. More details on the methods used to develop the LDCs may be found in the *Second Update Technical Support Document for Total Maximum Daily Load for Indicator Bacteria in the Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek Watersheds* (Millican and Hauck, 2015).

FDCs and LDCs were constructed for the most downstream, recently sampled monitoring station within each impaired AU. FDCs and LDCs were also developed for two additional monitoring stations in the East Fork San Jacinto River AU 1003_02 as discussed in more detail in the "Load Duration Curve Results" section of this document. In addition, FDCs and LDCs were developed for the outlet of Lake Conroe (1012) that enters the West Fork San Jacinto River (AU 1004_02), and the outlets of Spring Creek (Segment 1008) and West Fork San Jacinto River which enter Lake Houston (AU 1002_06). Additional details are provided in the technical support document (Millican and Hauck, 2015). The daily flow data in units of cubic feet per second (cfs) were used to first develop an FDC for each station.

In order to develop the TMDL allocation for each impaired AU in a manner consistent with the previously completed TMDLs of the Lake Houston watershed, the most downstream, recently sampled TCEQ monitoring station was selected to define the location of TMDL allocation development. The TMDL allocation is then developed through the FDC and LDC for that downstream monitoring location.

Each FDC was generated by

- ranking the daily flow data from highest to lowest,
- calculating the percent of days each flow was exceeded (rank ÷ quantity of the number of data points + 1), and
- plotting each flow value (y-axis) against its exceedance value (x-axis).

Exceedance values along the x-axis represent the percent of days that flow was at or above the associated flow value on the y-axis. Exceedance values near 100 percent occur during low flow or drought conditions while values approaching zero percent occur during periods of high flow or flood conditions.

Bacteria LDCs were developed by multiplying each streamflow value along the FDCs 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

Where:

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

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

The resulting curve plots each bacteria load value (y-axis) against its exceedance value (x-axis). Exceedance values along the x-axis represent the percent of days that the bacteria load was at or above the allowable load on the y-axis.

For the LDCs at each TCEQ monitoring station, historical bacteria data obtained from the TCEQ SWQMIS database were superimposed on the allowable bacteria LDC. Each historical *E. coli* measurement was associated with the streamflow on the day of measurement and converted to a bacteria load. The associated streamflow for each bacteria loading was compared to the FDC data to determine its value for "percent days flow exceeded," which becomes the "percent of days load exceeded" value for purposes of plotting the *E. coli* loading. Each load was then plotted on the LDC at its percent exceedance. This process was repeated for each *E. coli* measurement at each station. Points above the LDC represent exceedances of the bacteria criterion and its associated allowable loadings.

The flow exceedance frequency can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of FDCs and LDCs. The hydrologic classification scheme utilized for the TMDL watersheds is as follows: wet conditions (0 – 30 percent), moderate conditions (30 – 70 percent), and dry conditions (70 – 100 percent). To maintain consistency, these three flow regimes were based on previously completed TMDLs for the Lake Houston watershed. Additional information explaining the LDC method may be found in Cleland (2003) and Nevada Division of Environmental Protection (NDEP; 2003).

The median loading (15 percent exceedance) of the wet conditions flow regime (0-30 percent exceedance) is used for the TMDL calculations, because it represents a reasonable yet high value for the allowable pollutant load allocation.

Load Duration Curve Results

For developing the TMDL allocation for each of the impaired AUs, LDCs were constructed for the most downstream, recently sampled monitoring station within each TMDL watershed (Figures 7–9 and 12–15). Because of recent changes in the locations of monitoring along the East Fork San Jacinto River AU 1003_02, LDCs were also constructed for two additional monitoring stations in this AU (Figures 10 and 11). These two LDCs, however, were not used for developing the TMDL allocation for AU 1003_02, but are provided as supporting

evidence of indicator bacteria conditions in this AU. 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, 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 two 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. Exceedances of the geometric mean criterion of 126 MPN by the historical data were generally more common at higher flows than at lower flows at the majority of monitoring stations.

Figure 7 represents the LDC for Lake Houston AU 1002_06 and is based on *E. coli* bacteria measurements at sampling location 11213 (Lake Houston West Fork San Jacinto arm at US Highway 59). The LDC indicates that *E. coli* levels often exceed the single and geometric mean water quality criteria under the wet conditions flow regime, often exceed only the geometric mean criterion under the moderate conditions, and are often less than both criteria under the dry conditions. On Figure 7, the geometric means of the measured data for each flow regime generally support these observations. Wet-weather influenced *E. coli* observations are found under all flow conditions. The allocation goal for AU 1002_06 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

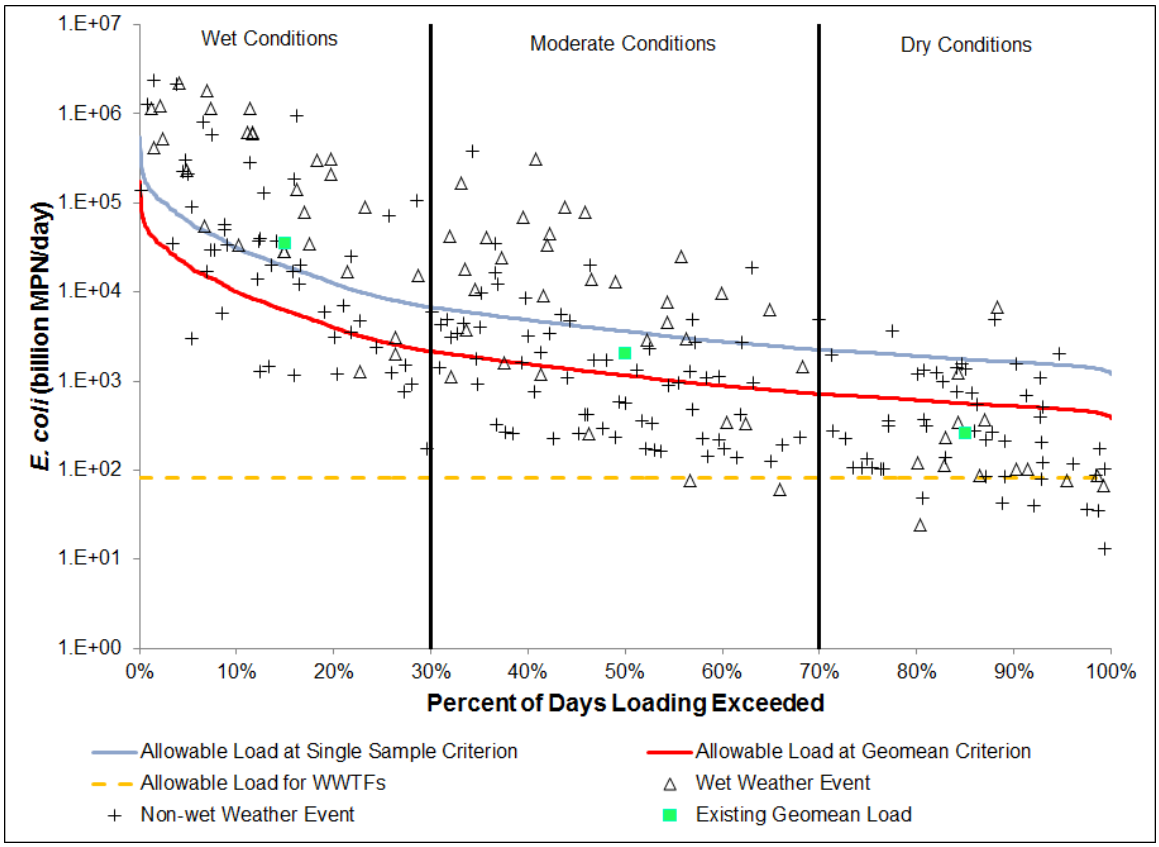

Figure 7. LDC for station 11213, Lake Houston (1002_06)

Figure 8 represents the LDC for East Fork San Jacinto River AU 1003_01 and is based on *E. coli* bacteria measurements at sampling location 11235 (East Fork San Jacinto River at FM 1485). The LDC indicates that *E. coli* levels often exceed the single and geometric mean water quality criteria under the wet conditions flow regime and are often less than both criteria under the moderate and dry conditions. On Figure 8, the geometric means of the measured data for each flow regime generally support these observations. Wet-weather influenced *E. coli* observations are found under all flow conditions, though such observations are less likely under dry conditions. The allocation goal for AU 1003_01 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

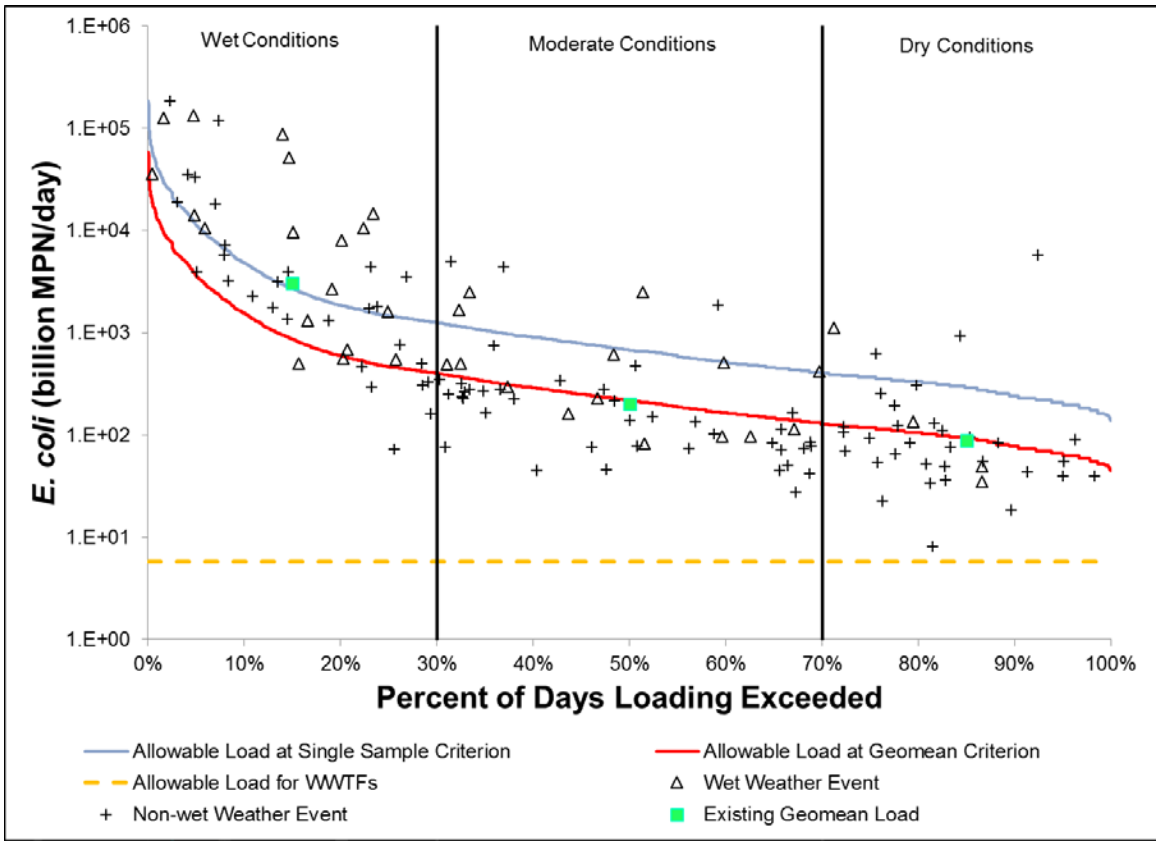

Figure 8. LDC for station 11235, East Fork San Jacinto River (1003_01)

Figure 9 represents the LDC for East Fork San Jacinto River AU 1003_02 and is based on *E. coli* bacteria measurements at sampling location 11238 (East Fork San Jacinto River at SH 105). The LDC indicates that only two *E. coli* measurements were made during the period used for developing the LDC (January 1, 2001 – December 31, 2010). Beginning in 2011, station 11238 has been monitored approximately quarterly. As the only station actively monitored in AU 1003_02, this location was selected for development of the TMDL. The allocation goal for AU 1003_02 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

Because of the paucity of data at station 11238, the LDCs for stations 11237 and 14242 on the East Fork San Jacinto River AU 1003_02 are provided in Figures 10 and 11 as supporting information.

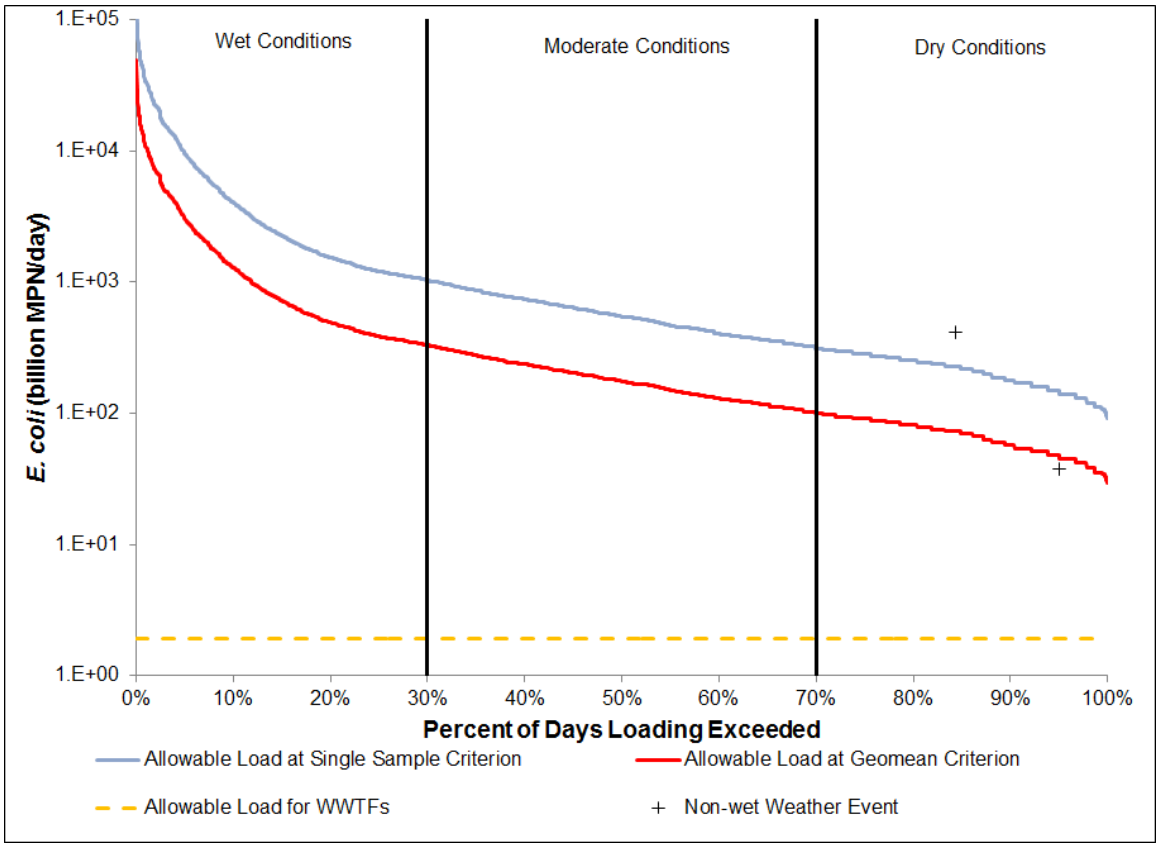

Figure 9. LDC for station 11238, East Fork San Jacinto River (1003_02)

Figure 10 represents one of two supporting LDCs for East Fork San Jacinto River AU 1003_02 and is based on *E. coli* bacteria measurements at sampling location 11237 (East Fork San Jacinto River at FM 945). The *E. coli* data are not abundant at this station, but *E. coli* levels are more likely to exceed the single and geometric mean water quality criteria under the wet conditions flow regime and are often less than both criteria under moderate and dry conditions. On Figure 10, the geometric means of the measured data for each flow regime generally support these observations. The LDC for station 11237 was not used to provide information for the final TMDL equation, but along with the LDC for station 14242 (Figure 11) is provided as supporting information of conditions in AU 1003_02. Sampling stopped at this station in 2011.

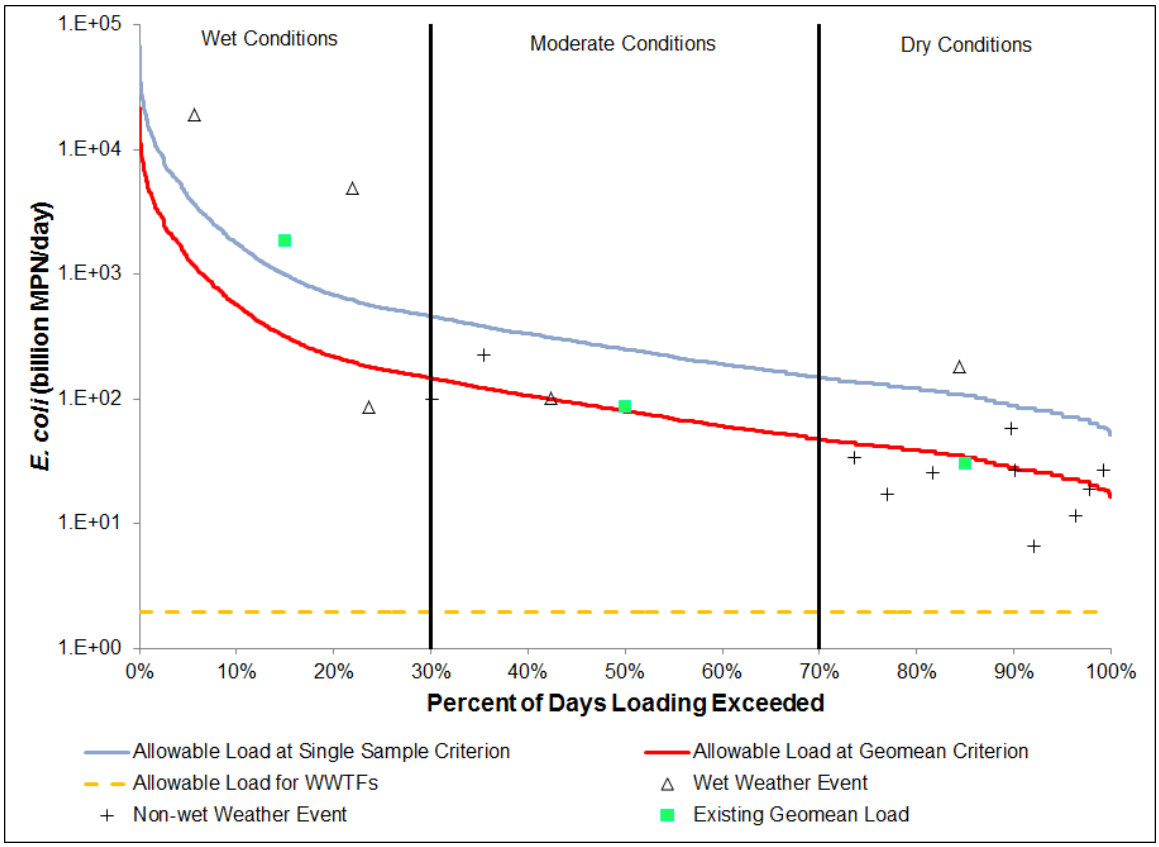

Figure 10. LDC for station 11237, East Fork San Jacinto River (1003_02)

Figure 11 represents one of two supporting LDCs for East Fork San Jacinto River AU 1003_02 and is based on *E. coli* bacteria measurements at sampling location 14242 (East Fork San Jacinto River at US Highway 59). The LDC indicates that *E. coli* levels often exceed the single and geometric mean water quality criteria under the wet conditions flow regime and are often less than both criteria under the moderate and dry conditions. On Figure 11, the geometric means of the measured data for each flow regime generally support these observations. The LDC for station 14242 was not used to provide information for the final TMDL equation, but along with the LDC for station 11237 (Figure 10) is provided as supporting information of conditions in AU 1003_02. Sampling stopped at this station in 2010.

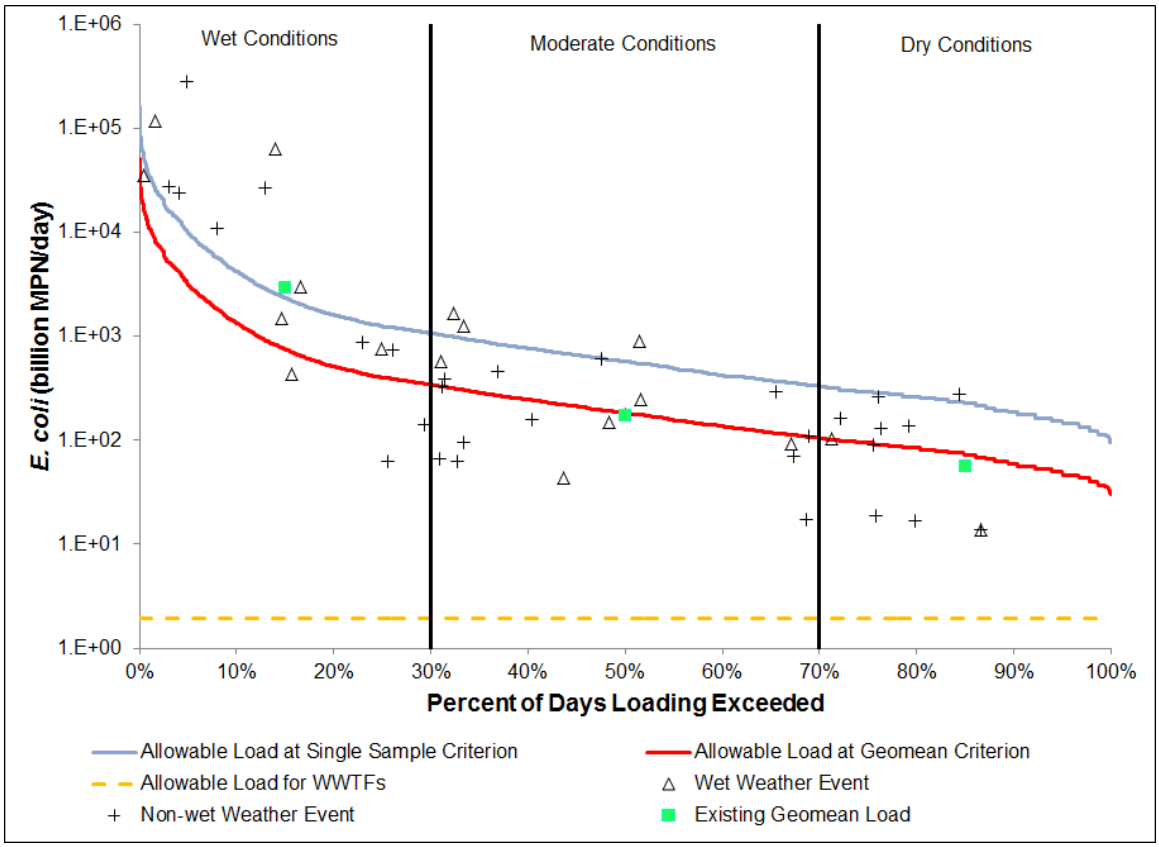

Figure 11. LDC for station 14242, East Fork San Jacinto River (1003_02)

Figure 12 represents the LDC for East Fork San Jacinto River AU 1003_03 and is based on *E. coli* bacteria measurements at sampling location 17431 (East Fork San Jacinto River at SH 150). The LDC indicates that *E. coli* levels are generally close to the geometric mean criterion under all three flow conditions. On Figure 12, the geometric means of the measured data for each flow regime generally support these observations, except the wet conditions geometric mean which is higher than even the single sample criterion. Wet-weather influenced *E. coli* observations have been infrequent at this location. The allocation goal for AU 1003_03 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

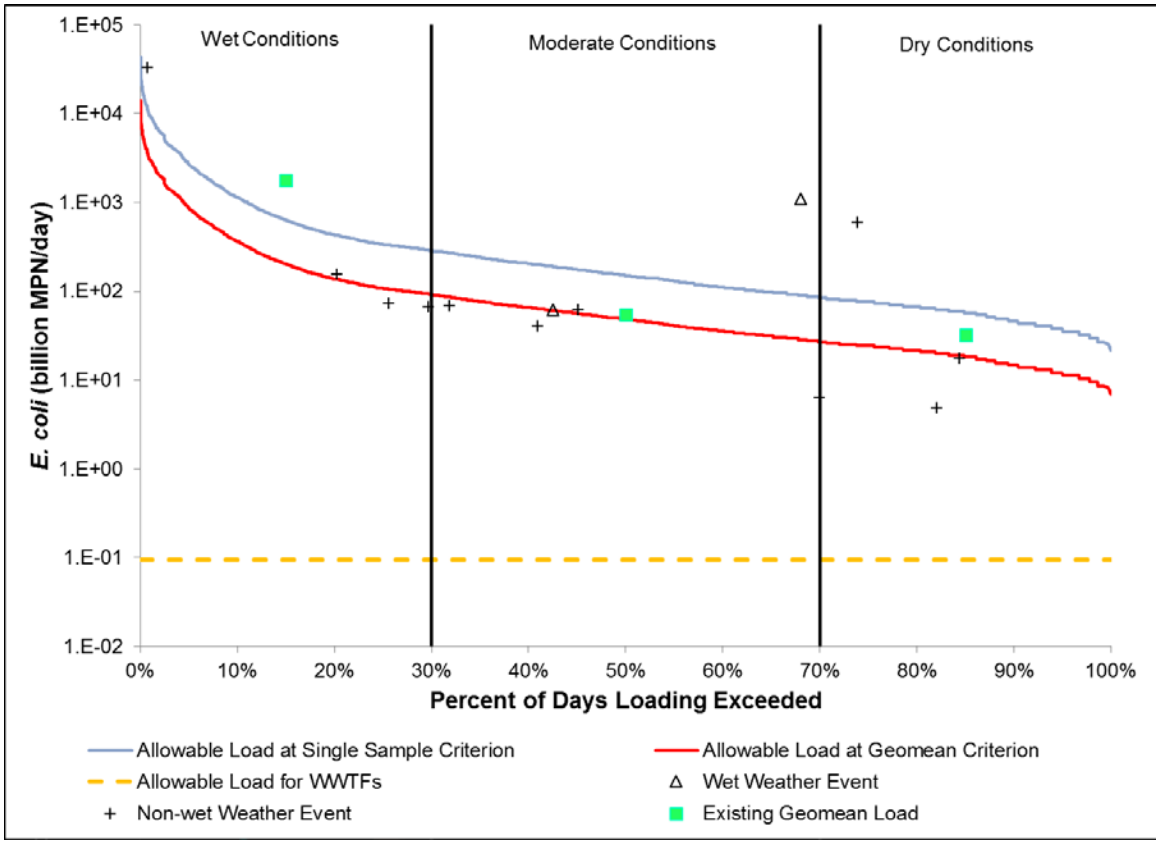

Figure 12. LDC for station 17431, East Fork San Jacinto River (1003_03)

Figure 13 represents the LDC for West Fork San Jacinto River AU 1004_01 and is based on *E. coli* bacteria measurements at sampling location 11243 (West Fork San Jacinto River at SH 242). The LDC indicates that *E. coli* levels often exceed the single and geometric mean water quality criteria under the wet conditions flow regime, often exceed only the geometric mean criterion under the moderate conditions, and are often less than both criteria under the dry conditions. On Figure 13, the geometric means of the measured data for each flow regime generally support these observations. Wet-weather influenced *E. coli* observations are found under all flow conditions. The allocation goal for AU 1004_01 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

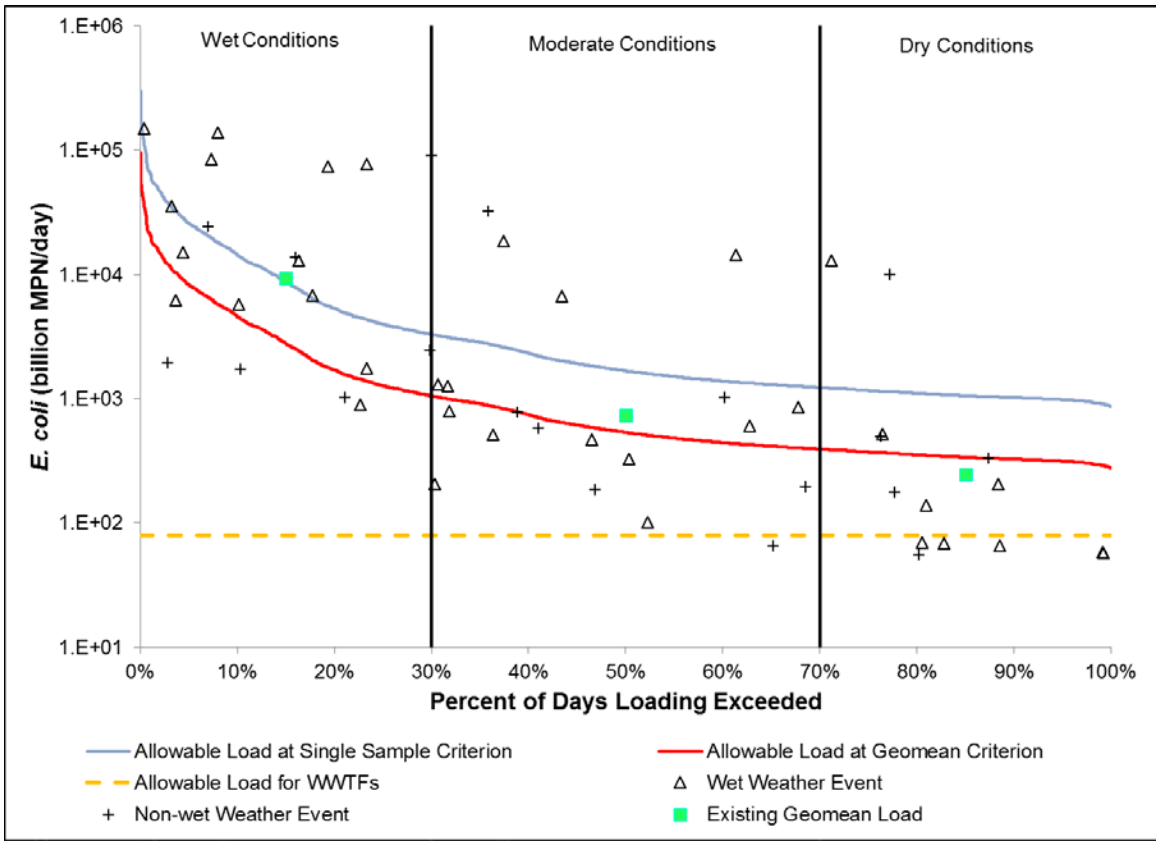

Figure 13. LDC for station 11243, West Fork San Jacinto River (1004_01)

Figure 14 represents the LDC for West Fork San Jacinto River AU 1004_02 and is based on *E. coli* bacteria measurements at sampling location 11250 (West Fork San Jacinto River at FM 2854). The shapes of the allowable loading curves under wet conditions and the higher flows under moderate conditions reflect releases from Lake Conroe which contribute downstream flows about 30 to 40 percent of the time. The LDC indicates that *E. coli* levels often exceed the single and geometric mean water quality criteria under the moderate conditions flow regime and often exceed only the geometric mean criterion under the wet conditions and dry conditions. On Figure 14, the geometric means of the measured data for each flow regime generally support these observations. Wet-weather influenced *E. coli* observations are found under all flow conditions, though such observations are less likely under dry conditions. The allocation goal for AU 1004_02 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

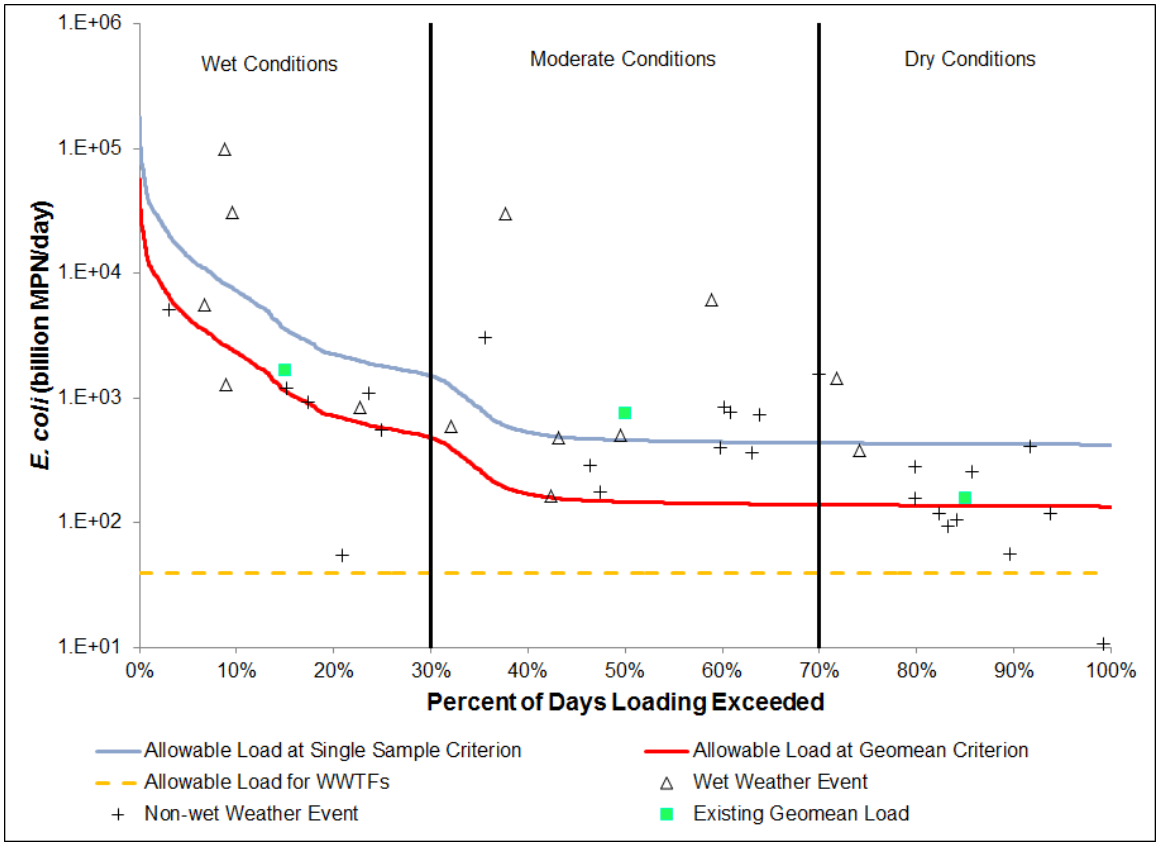

Figure 14. LDC for station 11250, West Fork San Jacinto River (1004_02)

Figure 15 represents the LDC for Crystal Creek AU 1004D_01 and is based on *E. coli* bacteria measurements at sampling location 16635 (Crystal Creek at SH 242). The LDC indicates that *E. coli* levels often exceed the single and geometric mean water quality criteria under the wet conditions flow regime, often exceed only the geometric mean criterion under the moderate conditions, and are less than both criteria under the dry conditions about half the time. On Figure 15, the geometric means of the measured data for each flow regime generally support these observations. Wet-weather influenced *E. coli* observations are found under all flow conditions, though such observations are less likely under dry conditions. The allocation goal for AU 1004_01 used in the final TMDL equation was based on the flow regime with the highest bacteria load (0–30th percentile).

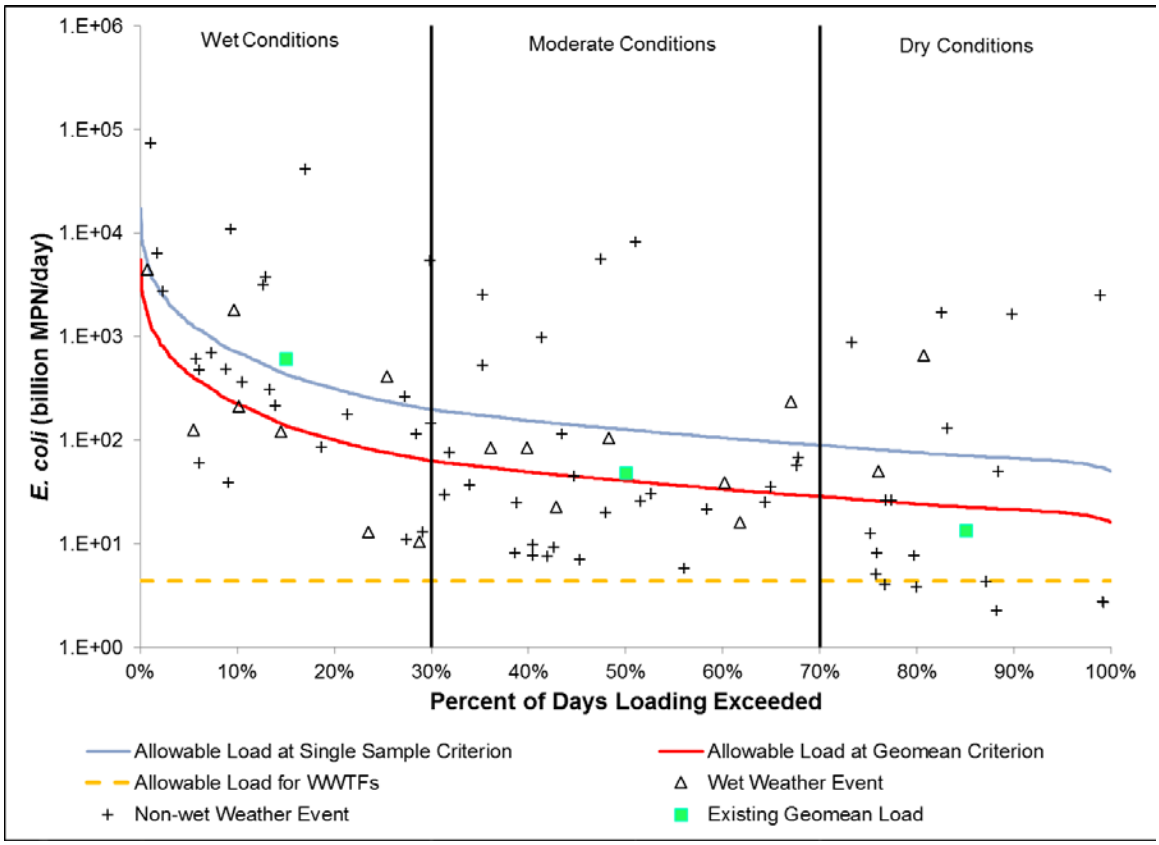

Figure 15. LDC for station 16635, Crystal Creek (1004D_01)

Margin of Safety

The margin of safety (MOS) is used to account for uncertainty in the analysis used to develop the TMDL and thus provide a higher level of assurance that the goal of the TMDL will be met. According to EPA guidance (EPA, 1991), the MOS can be incorporated into the TMDL using two methods:

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

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

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

Pollutant Load Allocation

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 selected scenarios were calculated using the following equation:

$$TMDL = \Sigma WLA + \Sigma LA + \Sigma FG + MOS$$

Where:

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

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

FG = loadings associated with future growth from potential permitted facilities

MOS = margin of safety load

As stated in 40 CFR 130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures.

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

Wasteload Allocation

The wasteload allocation is the sum of loads from regulated sources.

Wastewater Treatment Facilities

TPDES-permitted WWTFs are allocated a daily waste load (WLA_{WWTF}) calculated as their full permitted discharge flow rate multiplied by ½ of 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:

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

Where:

Target = 63 MPN/100 mL

Flow (MGD) = full permitted flow

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

Stormwater

Stormwater discharges from MS4, industrial, and construction areas are considered permitted or regulated point sources. Therefore, the wasteload allocation calculations must also include an allocation for regulated stormwater discharges (WLA_{SW}). A simplified approach for estimating the wasteload allocation 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 load allocation 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:

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

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 (see Load Allocation section)

LA_{RES} = loading from a significant upstream reservoir (see Load Allocation section)

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

In urbanized areas currently regulated by an MS4 permit, development and/or re-development of land must implement the control measures/programs outlined in an approved SWMP. Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of BMPs as specified in both the NPDES or TPDES permit and the SWMP.

An iterative, adaptive management approach will be used to address stormwater discharges. This approach encourages the implementation of structural or non-structural controls, implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (e.g., more stringent controls or specific BMPs) as necessary to protect water quality.

Implementation of Wasteload Allocations

The TMDLs in this document will result in protection of existing beneficial uses and conform to Texas's antidegradation policy. The three-tiered antidegradation policy in the Standards prohibits an increase in loading that would cause or contribute to degradation of an existing use. The antidegradation policy applies to point source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality.

The TCEQ intends to implement the individual wasteload allocations through the permitting process as monitoring requirements and/or effluent limitations as required by the amendment of 30 Texas Administrative Code Chapter 319 which became effective November 26, 2009. WWTFs discharging to the TMDL segments will be assigned an effluent limit based on the TMDL. Monitoring requirements are based on permitted flow rates and are listed in Section 319.9.

The permit requirements will be implemented during the routine permit renewal process. However, there may be a more economical or technically feasible means of achieving the goal of improved water quality and circumstances may warrant

changes in individual wasteload allocations after this TMDL is adopted. Therefore, the individual wasteload allocations, as well as the wasteload allocations for stormwater, are non-binding until implemented via a separate TPDES permitting action, which may involve preparation of an update to the state's WQMP. Regardless, all permitting actions will demonstrate compliance with the TMDL.

The executive director or commission may establish interim effluent limits and/or monitoring-only requirements at a permit amendment or permit renewal. These interim limits will allow a permittee time to modify effluent quality in order to attain the final effluent limits necessary to meet the TCEQ- and EPA-approved TMDL allocations. The duration of any interim effluent limits may not be any longer than three years from the date of permit re-issuance. New permits will not contain interim effluent limits because compliance schedules are not allowed for a new permit.

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the wasteload allocations. For NPDES/ TPDES-regulated municipal, construction stormwater discharges, and industrial stormwater discharges, water quality-based effluent limits that implement the wasteload allocation for stormwater may be expressed as BMPs or other similar requirements, rather than as numeric effluent limits.

The November 26, 2014, memorandum from EPA relating to establishing wasteload allocations for stormwater sources states:

> "Incorporating greater specificity and clarity echoes the approach first advanced by EPA in the 1996 Interim Permitting Policy, which anticipated that where necessary to address water quality concerns, permits would be modified in subsequent terms to include "more specific conditions or limitations [which] may include an integrated suite of BMPs, performance objectives, narrative standards, monitoring triggers, numeric [water quality-based effluent limits], action levels, etc."

Using this iterative adaptive BMP approach to the maximum extent practicable is appropriate to address the stormwater component of this TMDL.

Updates to Wasteload Allocations

This TMDL is, by definition, the total of the sum of the wasteload allocations, the sum of the load allocations, and the MOS. Changes to individual wasteload allocations may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual wasteload allocations do not ordinarily require a revision of the TMDL document; instead, changes will be made through updates to the TCEQ's WQMP. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Load Allocation

The load allocation is the sum of loads from unregulated sources. Complexities of the load allocation term occur as a result of two of the complexities discussed previously in the Problem Definition:

- The pollutant load allocations from previously completed indicator bacteria TMDLs for watersheds upstream of Lake Houston (TCEQ, 2011); and
- Lake Conroe (Segment 1012) as a major non-impaired reservoir.

TMDLs were previously completed for Stewarts Creek (AU 1004E_02), a direct tributary into West Fork San Jacinto River AU 1004_01, and for Spring Creek (AU 1008_04) and Cypress Creek (AU 1009_04), which are direct tributaries into Lake Houston AU 1002_06. Because the pollutant load allocations for these three water bodies are already specified in TCEQ adopted and EPA approved TMDLs (TCEQ, 2011), their load allocations are designated as tributary load allocations (LA_{TRIB}) in this pollutant load allocation.

To accommodate the disruption in downstream bacteria loadings from Lake Conroe (Segment 1012), the bacteria loadings associated with its releases are considered separately within the impaired 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), and designated as a significant upstream reservoir loadings (LA_{RES}).

The total load allocation, therefore, becomes defined as the sum of tributary loadings from previously completed TMDLs (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 that AU and upstream AUs not associated with completed TMDLs or a significant reservoir (LA_{AU}). The load allocation term becomes fully expressed as:

$$LA_{TOTAL} = LA_{AU} + \Sigma LA_{TRIB} + LA_{RES}$$

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 within the AU

The LA_{TRIB} is calculated as:

LA_{TRIB} = Criterion * Q_{TRIB} (cfs) * conversion factor

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, 2011)

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

LA_{RES} is calculated as:

LA_{RES} = Criterion * Q_{RES} (cfs) * conversion factor

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:

$$LA_{AU} = TMDL - \Sigma WLA_{WWTF} - \Sigma WLA_{SW} - \Sigma LA_{TRIB} - LA_{RES} - \Sigma FG - MOS$$

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 wasteload allocation and load allocation:

$$TMDL = \Sigma WLA_{WWTF} + \Sigma WLA_{SW} + LA_{AU} + \Sigma LA_{TRIB} + LA_{RES} + \Sigma FG + MOS$$

Margin of Safety Equation

The MOS 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 MOS is expressed mathematically as the following:

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

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

Allowance for Future Growth

The future growth component of the TMDL equation addresses the requirement to account for future loadings that may occur due to population growth, changes in community infrastructure, and development. Specifically, this TMDL component takes into account the probability that new flows from WWTF discharges may occur in the future. The assimilative capacity of streams increases as the amount of flow increases.

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 and zip code within the watershed to generate an estimate of the watershed's population. This estimation assumes that the population is uniformly distributed within the area of each census tract and zip code, 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, 2011). The projected population percentage increase of each watershed was multiplied by the corresponding full-permitted WWTF discharge ($WWTF_{FP}$), 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 is calculated as follows:

$$FG = WWTF_{FP} * POP_{2008\text{-}2035} * \text{conversion factor} * \text{target}$$

Where:

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

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

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

Target = 63 MPN/100 mL

Compliance with these TMDLs is based on keeping the bacteria concentrations in the selected waters below the limits that were set as criteria for the individual segments. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Consequently, increases in flow allow for increased loadings. The LDCs and tables in this TMDL will guide determination of the assimilative capacity of the stream under changing conditions, including future growth.

TMDL Calculations

The allowable loading of *E. coli* that the impaired AUs within the TMDL watersheds can receive on a daily basis was based on the median value within the wet conditions flow regime of the LDC (or 15 percent flow exceedance value) for the most downstream, recently sampled station of each AU (Figures 7 – 9 and 12 – 15).

Table 11 summarizes the calculation of TMDL, LA_{TRIB}, and LA_{RES} for each AU. Within the TMDL watersheds, there 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), and 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 11. 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 11).

Based on the information in Table 11, the MOS can be computed (Table 12).

Table 13 summarizes the daily allowable loading of *E. coli* assigned to WLA_{WWTF} based on full permitted flow of the 53 regulated dischargers located within the TMDL watersheds that contain a human waste component. 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 11. Summary of allowable *E. coli* 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/day)	LA_{RES} (Billion MPN/day)	TMDL (Billion MPN/day)
1002_06	Lake Houston	11213	2,010.2	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	311.0	—	—	958.7

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

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

Table 12. Computed MOS for impaired AUs within the TMDL watersheds

AU	Segment Name	MOS (Billion MPN/day of *E. coli*)
1002_06	Lake Houston	106.57
1003_01	East Fork San Jacinto River	43.32
1003_02	East Fork San Jacinto River	36.14
1003_03	East Fork San Jacinto River	10.16
1004_01	West Fork San Jacinto River	88.77
1004_02	West Fork San Jacinto River	9.12
1004D_01	Crystal Creek	6.89

Table 13. Wasteload allocations for TPDES-permitted facilities

TPDES Permit No.	NPDES Permit No.	Facility	AU	Final Permitted Discharge (MGD)	WLA_{WWTF} (Billion MPN/day of *E. coli*)
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
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
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

TPDES Permit No.	NPDES Permit No.	Facility	AU	Final Permitted Discharge (MGD)	WLA_{WWTF} (Billion MPN/day of *E. coli*)
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
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 a tributary to Lake Creek, its watershed contributes to impaired West Fork San Jacinto AU 1004_02.

Table 14 summarizes the computation of the future growth loadings. The future growth allocations for AUs within the TMDL watersheds were calculated based on population projections and full permitted wastewater discharges.

Table 14. 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 of *E. coli*)
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	118.150
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	116.070
1004_02 (indiv.)	79,711	189,735	138.0%	16.538	22.827	54.440
1004D_01 (indiv.)	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 and 1003_03

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

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 the MS4 permitted area and the total developed land use area in each AU. Table 15 summarizes the computation of the term WLA_{SW}.

Table 15. Regulated stormwater *E. coli* 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	—	—	10.16	0.000560	0.11
1004_01	2,779	79.58	116.07	44.86	958.7	88.77	0.132[d]	196.81
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

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. Table 16 summarizes the computation of the term LA_{AU}.

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 for Spring Creek (1008_04) and Cypress Creek (1009_04), which are tributaries to Lake Houston (1002_06), and for Stewarts Creek (1004E_02), which is a tributary to the West Fork San Jacinto River (1004_01). The pre-existing TMDLs for Spring, Cypress, and Stewarts Creeks represent the LA_{TRIB}.

The LA_{RES} represents the loading occurring 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).

Table 16. Computed *E. coli* unregulated stormwater terms for AUs within the TMDL watersheds

AU	Segment	LA_{TRIB} (Billion MPN/day)	LA_{RES} (Billion MPN/day)	LA_{AU} (Billion MPN/day)
1002_06	Lake Houston	3106.9	958.7	1535.70
1003_01	East Fork San Jacinto River	0.0	0.0	809.81
1003_02	East Fork San Jacinto River	0.0	0.0	681.11
1003_03	East Fork San Jacinto River	0.0	0.0	192.76
1004_01	West Fork San Jacinto River	44.86	958.7	1,294.21
1004_02	West Fork San Jacinto River	0.0	958.7	75.26
1004D_01	Crystal Creek	0.0	0.0	100.92

Table 17 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 MPN/100 mL for each component of the TMDL.

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are provided in Table 18. The WLA_{WWTF} component of the final TMDL allocations includes potential future growth loadings. The LA_{TOTAL} component of the final TMDL allocations includes the loadings from upstream tributaries that have pre-existing approved TMDLs (LA_{TRIB}) and Lake Conroe (LA_{RES}), and loadings arising from within each segment from non-regulated sources (LA_{AU}).

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix A provides guidance for recalculating the allocations in Table 18. The seven figures (Figures A-1 through A-7) of Appendix A were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for *E. coli*. The equations provided, along with the figures, allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion for *E. coli*.

Table 17. *E. coli* TMDL allocation summary for impaired AUs of the TMDL watersheds

All loads expressed as billion MPN/day

AU	Segment Name	TMDL[a]	MOS[b]	WLA_{WWTF}[c]	WLA_{SW}[d]	LA_{AU}[e]	LA_{TRIB}[f]	LA_{RES}[g]	LA_{TOTAL}[h]	Future Growth[i]
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	10.16	0.095	0.11	192.76	0	0	192.76	0.175
1004_01	West Fork San Jacinto River	2,779	88.77	79.58	196.81	1,294.21	44.86	958.7	2,297.77	116.07
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] TMDL = Median Flow (wet conditions flow regime) * 126 MPN/100 mL * Conversion Factor; where the Conversion Factor = 24,465,756 100 mL/ft^3 * seconds/day; Median Flow from Table 11

[b] MOS = 0.05 * (TMDL – $\sum LA_{TRIB}$ – LA_{RES}) (see Table 12)

[c] WLA_{WWTF} = Target (63 MPN/day) * Flow (MGD) * Conversion Factor; where Flow is the full permitted flow from regulated discharging facilities (Table 13); Conversion Factor = 37,854,000 100 mL/MGD. The WLA_{WWTF} for a particular AU is an aggregate of the WLA_{WWTF} totals for all upstream AUs plus the AU listed

[d] WLA_{SW} = (TMDL - $\sum WLA_{WWTF}$ – $\sum LA_{TRIB}$ – LA_{RES} - $\sum FG$ - MOS) * FDA_{SWP} (see Table 15)

[e] LA_{AU} = TMDL - $\sum WLA_{WWTF}$ - $\sum WLA_{SW}$ – $\sum LA_{TRIB}$ – LA_{RES} - $\sum FG$ - MOS (see Table 16)

[f] LA_{TRIB} = Criterion (126 MPN/day) * Q_{TRIB} (cfs) * Conversion Factor; where the Conversion Factor = 24,465,756 100 mL/ft^3 * seconds/day; Q_{TRIB} from Table 11

[g] LA_{RES} = Criterion (126 MPN/day) * Q_{RES} (cfs) * Conversion Factor; where the Conversion Factor = 24,465,756 100 mL/ft^3 * seconds/day; Q_{RES} from Table 11

[h] LA_{TOTAL} = LA_{AU} + LA_{TRIB} + LA_{RES}

[i] FG = $WWTF_{FP}$ * $Pop_{2008-2035}$ * Conversion Factor * Target; where Target = 63 MPN/100 mL; Conversion Factor = 37,854,000 100 mL/MGD; $WWTF_{FP}$ is full permitted flows (Table 12); and $Pop_{2008-2035}$ is from Table 14

Table 18. Final *E. coli* 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	0.11	192.76	10.16
1004_01	2,779	195.65	196.81	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 WWTFs

Seasonal Variation

Federal regulations (40 CFR 30.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Seasonality was examined by comparing *E. coli* concentrations obtained from routine monitoring samples collected in the warmer months (May through September) against those collected during the cooler months (November through March). The months of April and October were considered transitional between the warm and cool seasons and were excluded from the seasonal analysis. This analysis indicated that there was a statistically significant difference 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. More information on the analyses of seasonal variation is provided in Millican and Hauck (2015).

Public Participation

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

The public participation efforts of this project were a joint effort of the TCEQ and H-GAC. On May 14, 2013, an overview of this project was provided at the annual meeting of the Bacteria Implementation Group (BIG) held at H-GAC offices in Houston. A series of three public meeting over the two-day period of July 30 and 31, 2103, were coordinated by TCEQ and H-GAC with H-GAC as the lead in making meeting arrangements and public notification. The three meetings were held at the City of Cleveland Civic Center, San Jacinto River Authority offices near Conroe, and Kingwood Branch Library in northeast Houston. Extensive

public notification began approximately three weeks prior to the meetings and included two separate run dates in nine local newspapers; press releases in local newspapers, TV, and radio; e-mails to contacts of H-GAC, and social media postings by H-GAC. The meetings provided the opportunity to give stakeholders an overview of the TMDL process and specifics of these seven TMDLs as well as soliciting questions and suggestions from the stakeholders in attendance. To ensure that absent or new stakeholders could get information about past meetings and pertinent material related to the project, two Web pages have been set up:

- <www.tceq.texas.gov/waterquality/tmdl/82-sanjacintobacteria>, and
- <www.h-gac.com/community/water/tmdl/studies/san-jacinto-river-east-west-forks.aspx>.

Additional meetings have been held in the project watershed since the initial set of public meetings:

- a work group session on November 7, 2013;
- three public meetings in various parts of the project watershed on March 5 and 6, 2014;
- a kickoff meeting on April 29, 2014, to finalize the coordination committee;
- a coordination committee meeting on May 21, 2014, to set up the work groups for the project;
- two rounds of work group meetings (seven meetings between June 25, 2014, and July 9, 2014; six meetings between August 21, 2014, and September 3, 2014);
- coordination committee meetings on October 1, 2014, to discuss the work group meetings and the possibility of joining the BIG effort, and on November 3, 2014, and April 13, 2015, to further discuss joining the BIG;
- joint meetings with the BIG's Coordination and Policy Work Group on February 2, March 30, and July 16, 2015, to discuss details of joining the BIG effort; and
- a coordination group meeting on September 22, 2015, to begin the process of formally joining the BIG effort.

On October 1, 2014, the coordination committee voted unanimously to formally request to join the BIG. On September 9, 2015, the BIG members voted unanimously to accept the addition of this project's TMDL watershed to the area covered by the BIG I-Plan.

Implementation and Reasonable Assurance

The issuance of TPDES permits consistent with TMDLs provides reasonable assurance that wasteload allocations in this TMDL report will be achieved. Per

federal requirements, each TMDL is included in an update to Texas WQMP as a plan element.

The WQMP coordinates and directs the state's efforts to manage water quality and maintain or restore designated uses throughout Texas. The WQMP is continually updated with new, more specifically focused plan elements, as identified in federal regulations (40 CFR Sec. 130.6(c)). Commission adoption of a TMDL is the state's certification of the associated WQMP update.

This TMDL applies to all segments in the project watershed (Figure 1). Future water quality monitoring may identify additional segments with contact recreation use impairments not specifically addressed in this TMDL. If necessary, the TMDL allocations in this report will be revised to incorporate additional impaired segments and included in an update to the Texas WQMP.

Because the TMDL does not reflect or direct specific implementation by any single pollutant discharger, the TCEQ certifies additional elements to the WQMP after the TMDL Implementation Plan (I-Plan) is approved by the commission. Based on the TMDL and I-Plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits.

For MS4 permits, the TCEQ will normally establish BMPs, which are a substitute for effluent limitations, as allowed by federal rules where numeric effluent limitations are infeasible. When such practices are established in an MS4 permit, the TCEQ will not identify specific implementation requirements applicable to a specific TPDES stormwater permit through an effluent limitation update. Rather, the TCEQ might revise a stormwater permit, require a revised SWMP or Pollution Prevention Plan, or implement other specific revisions affecting stormwater dischargers in accordance with an adopted I-Plan.

Strategies for achieving pollutant loads in TMDLs from both point and nonpoint sources are reasonably assured by the state's use of an I-Plan. The TCEQ is committed to supporting implementation of all TMDLs adopted by the commission.

I-Plans for Texas TMDLs use an adaptive management approach that allows for refinement or addition of methods to achieve environmental goals. This adaptive approach reasonably assures that the necessary regulatory and voluntary activities to achieve pollutant reductions will be implemented. Periodic, repeated evaluations of the effectiveness of implementation methods ascertain whether progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. I-Plans will be adapted as necessary to reflect needs identified in evaluations of progress.

Key Elements of an I-Plan

An I-Plan includes a detailed description and schedule of the regulatory and voluntary management measures to implement the wasteload allocations and

load allocations of particular TMDLs within a reasonable time. I-Plans also identify the organizations responsible for carrying out management measures, and a plan for periodic evaluation of progress. As noted in the Public Participation section, the implementation of the TMDLs for bacteria in the Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek watersheds will be conducted through the ongoing work of the I-Plan for the BIG area, approved by the TCEQ on January 30, 2013.

Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to an impairment.

The TCEQ works with stakeholders and interested governmental agencies to develop and support I-Plans and track their progress. For this project, the BIG I-Plan has already been developed and approved, and will be revised to include the Lake Houston, East Fork San Jacinto River, West Fork San Jacinto River, and Crystal Creek watersheds. Because these TMDLs address agricultural sources of pollution, the TCEQ will also work in close partnership with the TSSWCB. The TSSWCB is the lead agency in Texas responsible for planning, implementing, and managing programs and practices for preventing and abating agricultural and silvicultural nonpoint sources of water pollution. The cooperation demonstrated while developing the BIG I-Plan is a cornerstone for the shared responsibility necessary to carry it out and to make revisions as necessary.

Ultimately, the I-Plan identifies the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the approved I-Plan may not approximate the predicted loadings identified category-by-category in the TMDL and its underlying assessment. The I-Plan is adaptive for this very reason; it allows for continuous update and improvement.

In most cases, it is not practical or feasible to approach all TMDL implementation as a one-time, short-term restoration effort. This is particularly true when a challenging wasteload reduction or load reduction is required by the TMDL, there is high uncertainty with the TMDL analysis, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements.

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

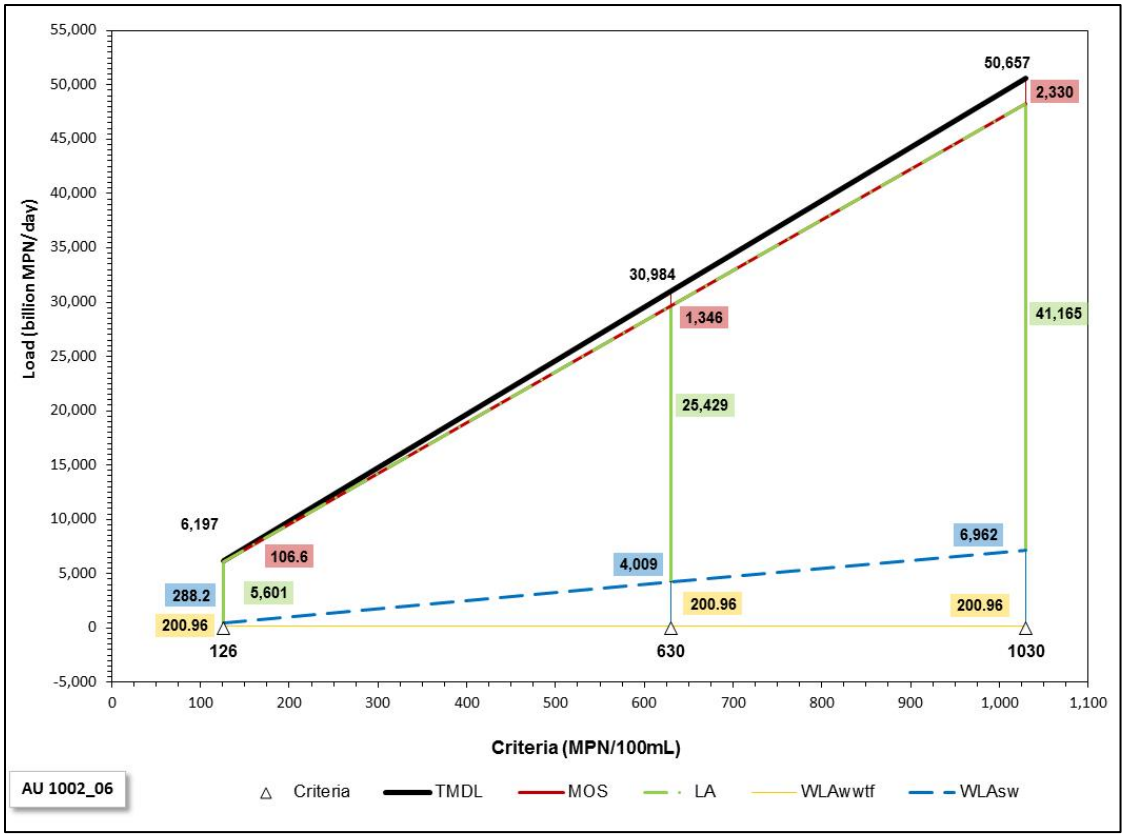

Figure A-1. Allocation loads for Lake Houston (1002_06) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 49.180966 * Std$$

$$WLA_{WWTF} = 200.96$$

$$WLA_{sw} = 7.382068 * Std - 641.97$$

$$LA = 39.339850 * Std + 644.46$$

$$MOS = 2.459049 * Std - 203.27$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety

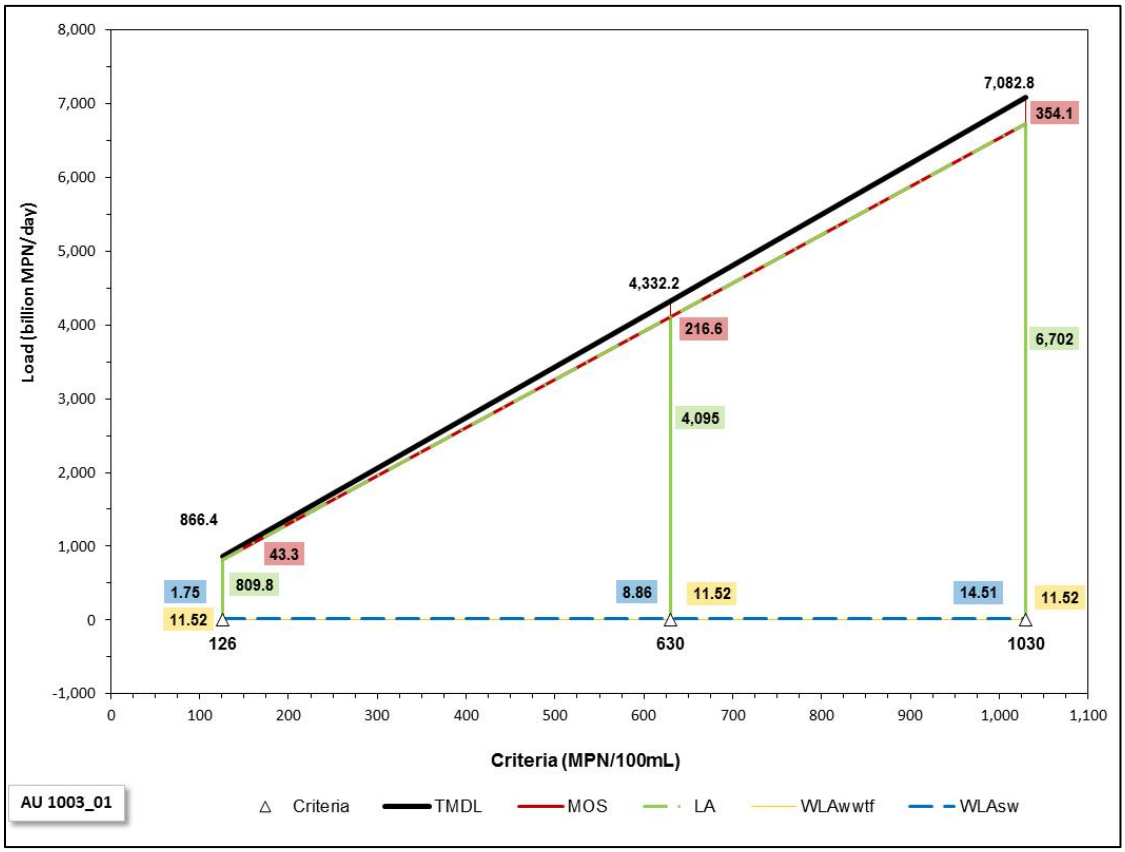

Figure A-2. Allocation loads for East Fork San Jacinto (1003_01) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 6.876550 * Std$$

$$WLA_{WWTF} = 11.52$$

$$WLA_{sw} = 0.014115 * Std - 0.03$$

$$LA = 6.518607 * Std - 11.53$$

$$MOS = 0.343828 * Std$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety

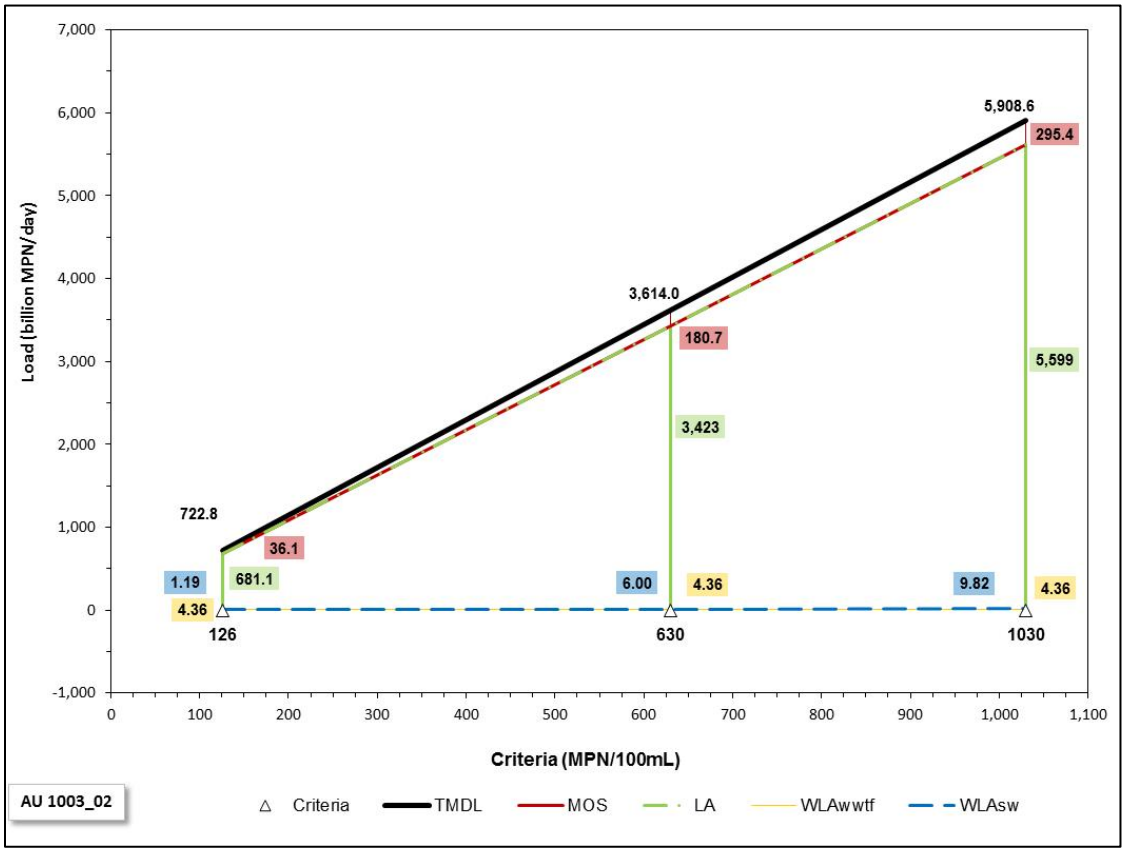

Figure A-3. Allocation loads for East Fork San Jacinto River (1003_02) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 5.736493 * Std$$

$$WLA_{WWTF} = 4.36$$

$$WLA_{sw} = 0.009546 * Std - 0.013$$

$$LA = 5.440132 * Std - 4.35$$

$$MOS = 0.286825 * Std$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety

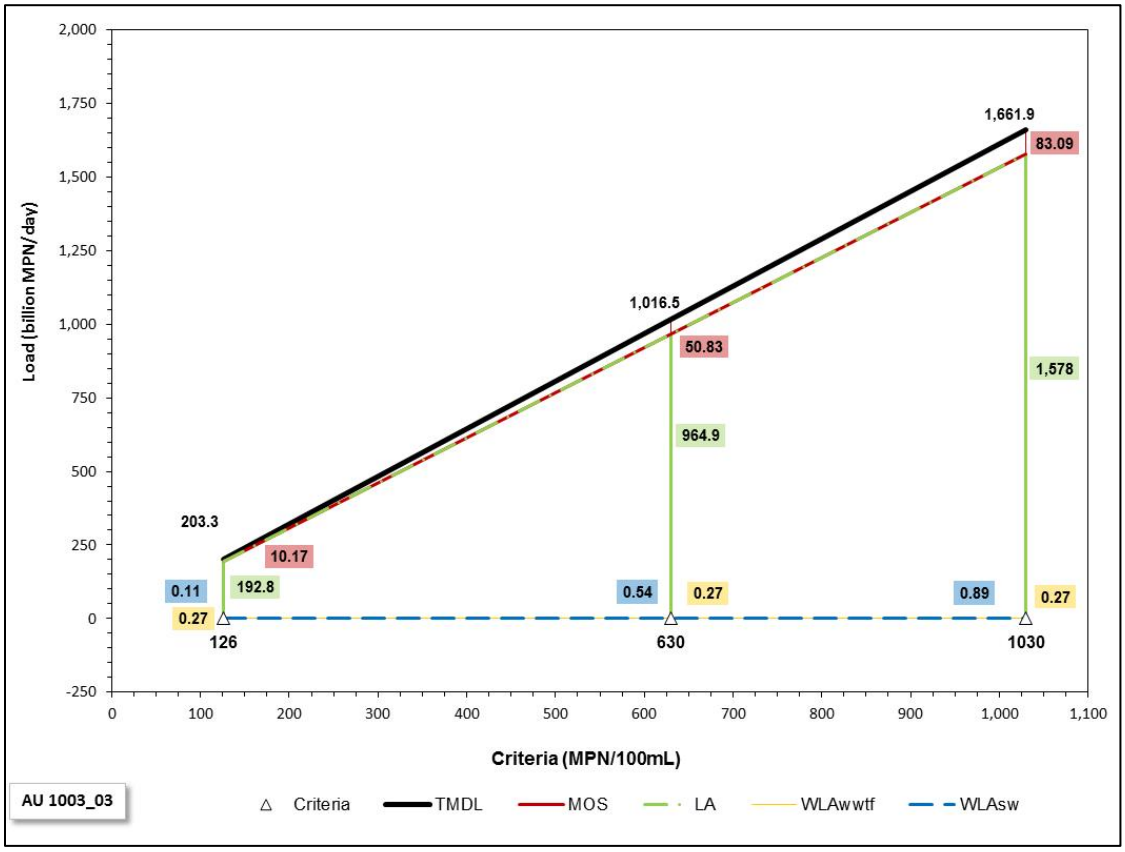

Figure A-4. Allocation loads for East Fork San Jacinto River (1003_03) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 1.613479 * Std$$

$$WLA_{WWTF} = 0.270$$

$$WLA_{sw} = 0.000861 * Std$$

$$LA = 1.531950 * Std - 0.273$$

$$MOS = 0.080668 * Std + 0.005$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety

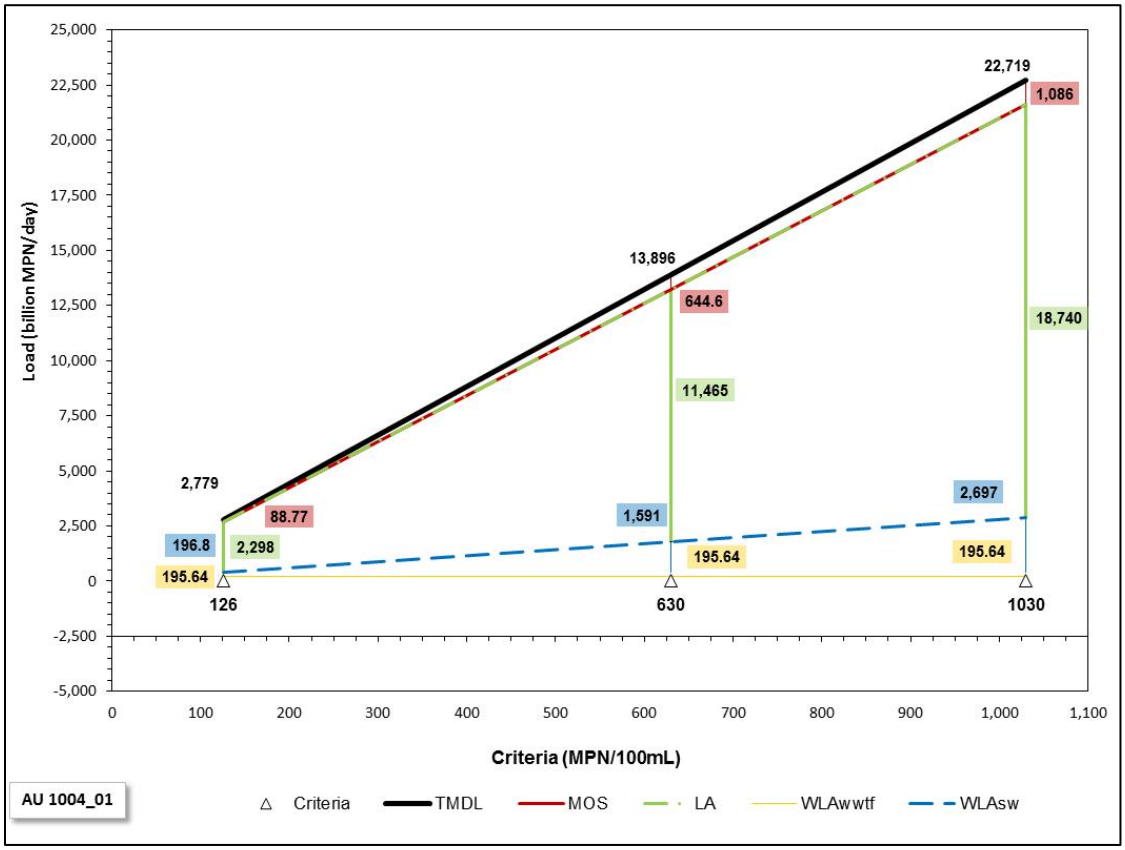

Figure A-5. Allocation loads for West Fork San Jacinto River (1004_01) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 22.057008 * Std - 0.18$$

$$WLA_{WWTF} = 195.64$$

$$WLA_{sw} = 2.765941 * Std - 151.69$$

$$LA = 18.188213 * Std + 6.07$$

$$MOS = 1.102854 * Std - 50.19$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety

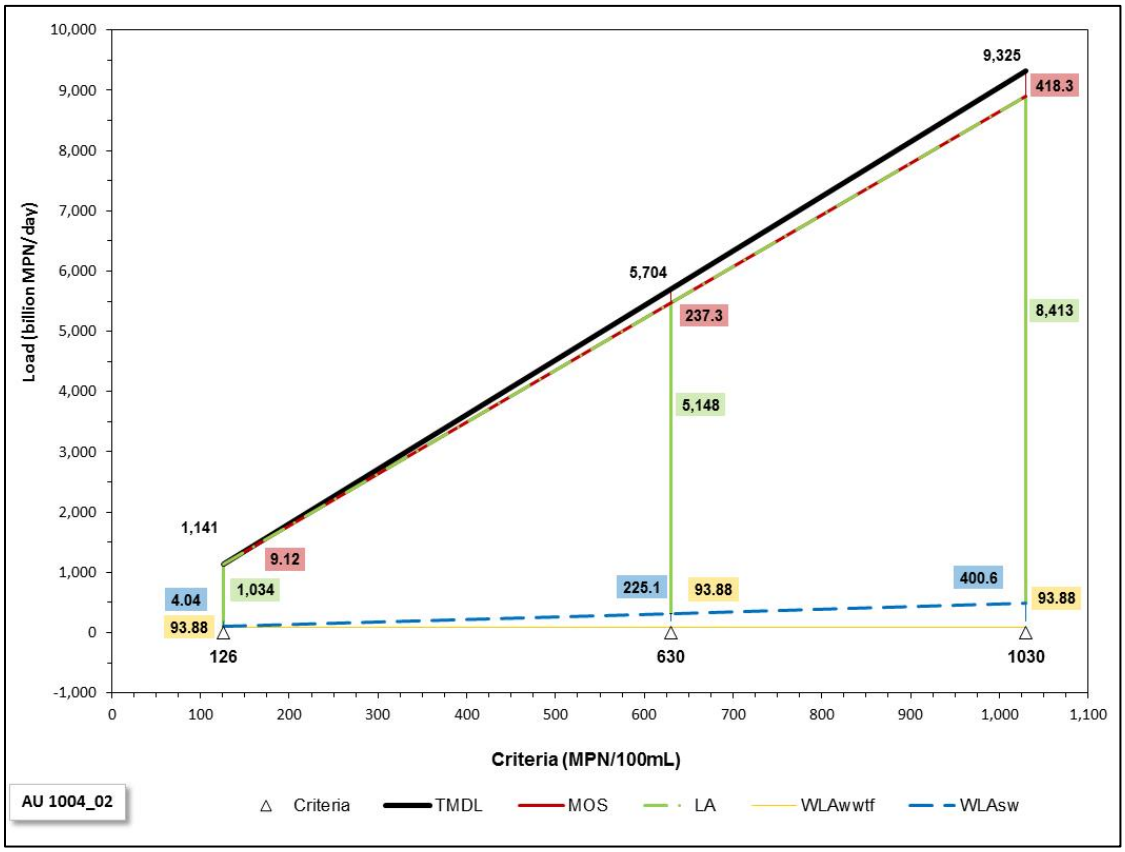

Figure A-6. Allocation loads for West Fork San Jacinto River (1004_02) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 9.053587 * Std$$

$$WLA_{WWTF} = 93.88$$

$$WLA_{sw} = 0.438650 * Std - 51.23$$

$$LA = 8.162261 * Std + 5.49$$

$$MOS = 0.452676 * Std - 47.92$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety

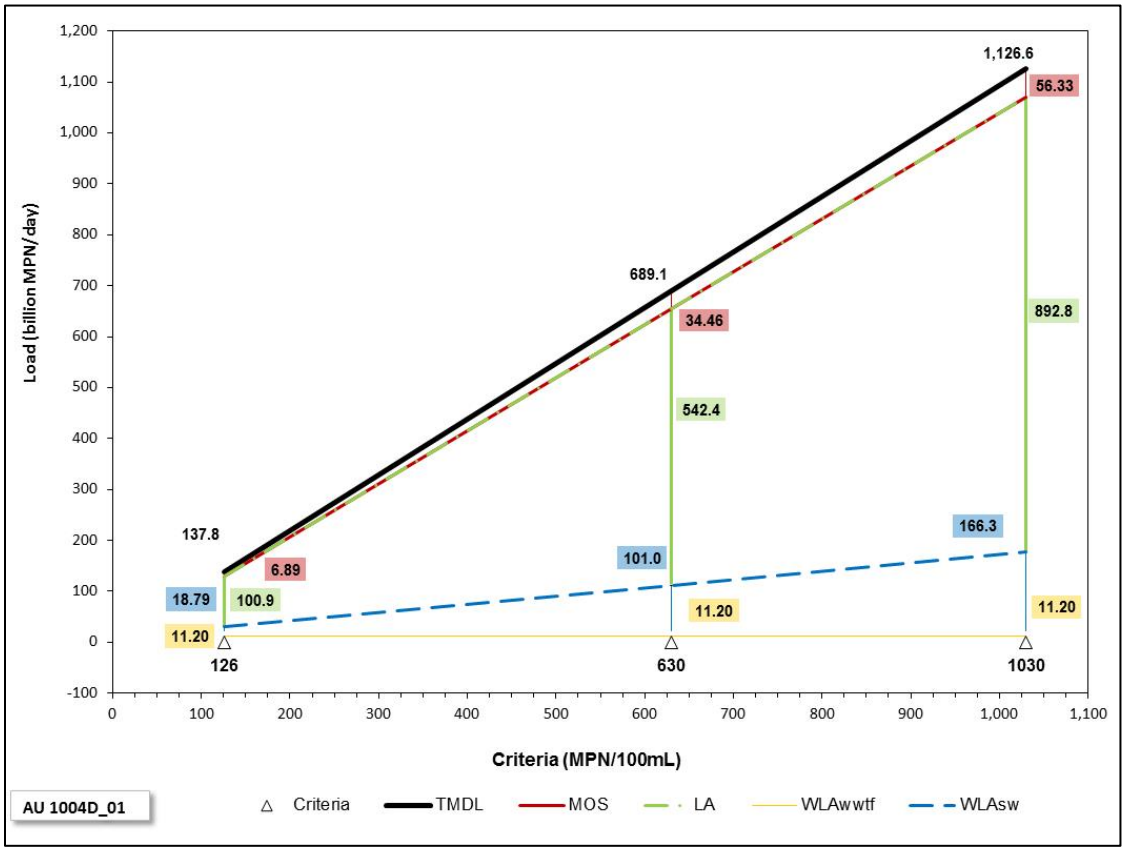

Figure A-7. Allocation loads for Crystal Creek (1004D_01) as a function of water quality criteria

Equations for calculating new TMDL and allocations (in billion MPN/day of *E. coli*)

$$TMDL = 1.093840 * Std$$

$$WLA_{WWTF} = 11.20$$

$$WLA_{sw} = 0.163153 * Std - 1.77$$

$$LA = 0.875996 * Std - 9.45$$

$$MOS = 0.054691 * Std$$

Where:

Std = Revised Contact Recreation Standard

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

WLA_{SW} = Wasteload allocation (permitted stormwater)

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

MOS = Margin of Safety