JAMES MIERTSCHIN & ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERING
P.O. BOX 162305 • AUSTIN, TEXAS 78716-2305 • (512) 327-2708

TECHNICAL SUPPORT DOCUMENT FOR INDICATOR BACTERIA TOTAL MAXIMUM DAILY LOADS

LAKE HOUSTON WATERSHED

SAN JACINTO RIVER BASIN

SEGMENTS:

1004E	**STEWARTS CREEK**
1008	**SPRING CREEK**
1008H	**WILLOW CREEK**
1009	**CYPRESS CREEK**
1009C	**FAULKEY GULLY**
1009D	**SPRING GULLY**
1009E	**LITTLE CYPRESS CREEK**
1010	**CANEY CREEK**
1011	**PEACH CREEK**

Prepared For:

Texas Commission on Environmental Quality (TCEQ)
Austin, Texas

Prepared By:

James Miertschin & Associates, Inc.

September 2009

JAMES MIERTSCHIN & ASSOCIATES, INC.
ENVIRONMENTAL ENGINEERING
P.O. BOX 162305 • AUSTIN, TEXAS 78716-2305 • (512) 327-2708

TECHNICAL SUPPORT DOCUMENT FOR INDICATOR BACTERIA TOTAL MAXIMUM DAILY LOADS LAKE HOUSTON WATERSHED

CONTRACT NO. 582-7-80171
WORK ORDER NO. 3

Prepared for:

TMDL Program
Texas Commission on Environmental Quality
Post Office Box 13087
Austin, Texas 78711-3087

Prepared by:

James Miertschin & Associates

September 2009

TABLE OF CONTENTS

Section | Page

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

Section 303(d) of the Federal Clean Water Act and U.S. Environmental Protection Agency (EPA) regulation 40 CFR 130.7 require states to identify waterbodies that do not meet, or are not expected to meet, applicable water quality standards. The compilation of subject waterbodies is known as the 303(d) list. Each state must assign priorities to waterbodies on the list, in order to schedule development of total maximum daily loads (TMDL). The TMDL is an allocation of point and nonpoint source pollutant loadings that will enable the waterbody to meet water quality standards.

The Texas Commission on Environmental Quality (TCEQ) is responsible for the monitoring and assessment of water quality to evaluate compliance with State water quality standards. Pursuant to the Clean Water Act, one of the areas of TCEQ responsibility is the development of the 303(d) list for Texas and subsequent development of TMDLs.

Fourteen stream segments in the Lake Houston Watershed of the San Jacinto River Basin have been included on the 303(d) list due to high levels of indicator bacteria which exceed the state criteria for contact recreation. The TCEQ is currently moving forward with the development of TMDLs for nine of these 14 segments. These nine segments are listed in Table 1-1.

Table 1-1: TMDL Stream Segments

Segment ID	Segment Name	Year First Placed on 303(d) List
1004E	Stewarts Creek	2006
1008	Spring Creek	1996
1008H	Willow Creek	2006
1009	Cypress Creek	1996
1009C	Faulkey Gully	2006
1009D	Spring Gully	2006
1009E	Little Cypress Crk	2006
1010	Caney Creek	2006
1011	Peach Creek	2006

The TCEQ has retained James Miertschin & Associates, Inc. (JMA) to provide support for data analysis, TMDL development, and report preparation. Previous work efforts involved the compilation and assessment of historical water quality data for bacterial indicators on the study segments, followed by the development of monitoring plans for supplemental data collection, and execution of supplemental data collection activities.

1.2 TMDL STUDY AREA

The Lake Houston Watershed of the San Jacinto River Basin is located in East Texas, and includes the northern portion of the City of Houston, as well as the City of Conroe and numerous smaller municipalities. The total drainage area for Lake Houston is 2,850 square miles. Figure

1-1 shows the location of the watershed, as well as the individual stream segments which are the focus of this TMDL project. As shown, the TMDL Watersheds are located primarily within Harris and Montgomery Counties, but also include portions of Grimes, Liberty, San Jacinto, Walker, and Waller Counties. Peach Creek forms the divide between Montgomery and San Jacinto County. Spring Creek is the divide between much of Harris and Montgomery County.

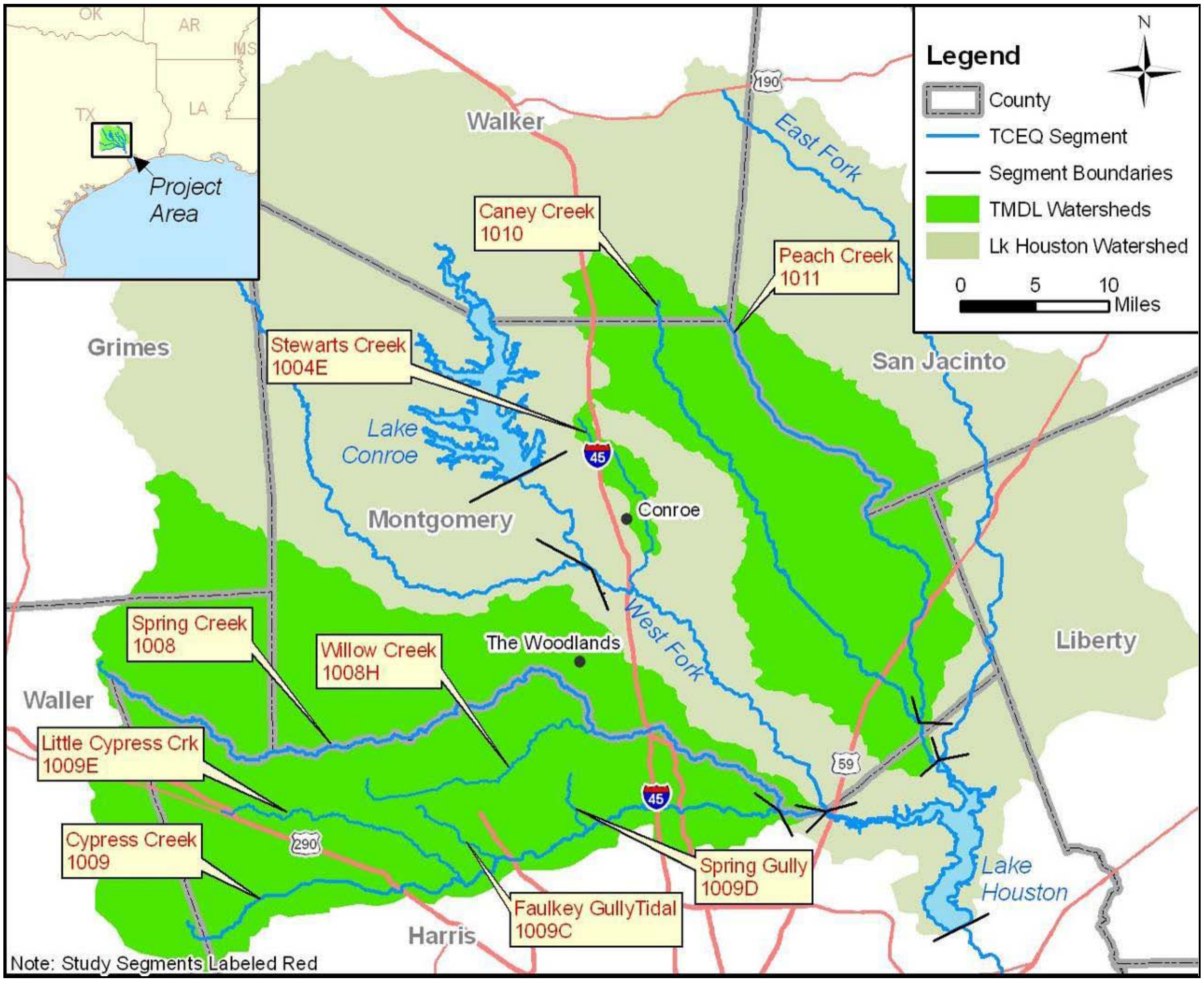

Figure 1-1: TMDL Study Area

1.3 GENERAL TMDL APPROACH

The EPA has identified certain items that should be considered when developing TMDLs. These items, which will be discussed in detail in this report, typically include the following (adapted from EPA, 2008):

- Watershed Characterization
    - Compile and analyze available watershed and waterbody data
    - Characterize instream conditions and impairments
    - Gain basic understanding of factors influencing impairment
    - Identify water quality standards and TMDL target

- Identify potential sources
- Linkage Analysis
    - Develop linkage between pollutant loading and water quality
    - Estimate existing loading sources
    - Determine loading capacity of waterbody
- Allocation Analysis
    - Select appropriate resolution for allocations (spatial, temporal, source, etc.)
    - Evaluate potential allocation options
    - Select allocation options which are most appropriate and feasible
    - Apply appropriate margin of safety (MOS)
- TMDL Report and Submittal

The EPA recommends that all of these activities be performed with stakeholder and public involvement. Stakeholders should include (EPA, 2008):

- State and Federal Agencies
- Representatives from potential pollutant sources (permitted facilities, land owners, etc.)
- Citizens groups, watershed organizations, and other interested parties

1.4 DESIGNATED USES AND APPLICABLE WATER QUALITY STANDARDS

The most recent Texas Surface Water Quality Standards include criteria for *E. coli* and fecal coliform bacteria for each classified stream segment in the State (TCEQ, 2006b). The preferred indicator for freshwater is *E. coli*, but fecal coliform can still be used as an alternative indicator during the transition period to the new indicator. For saltwater, the new indicator is Enterococci bacteria. These bacteria all serve as indicators of the potential presence of pathogenic organisms. Classified segments are designated as either contact recreation or non-contact recreation waters.

All of the stream segments considered by this project are freshwater, and all include contact recreation as a designated beneficial use. *E. coli* sampling in the study area began in 2000, and became the predominant type of bacteria sampling by 2002 (when *E. coli* samples began to greatly outnumber the quantity of fecal coliform samples collected). As a result, *E. coli* data will be used exclusively for the development of these TMDLs.

The nomenclature of bacteria analysis can be difficult for the uninitiated. Depending upon the type of analysis and the preference of the analyst, a unit of bacteria can be referred to as an "organism" or "org", "colony forming units" or "cfu", "most probable number" or "MPN", or simply as a "count". Since all of these units attempt to quantify the same thing, they will be considered equivalent for the purposes of this report, and "colony forming unit" will be used as standard nomenclature. The concentration of bacteria is typically presented per 100 milliliters of water, which is equivalent to $1/10^{th}$ of a Liter, or 1 deciliter (dL). For the purposes of this report, bacteria concentrations will be reported as cfu/dL.

For contact recreation waters, the geometric mean of *E. coli* counts should not exceed 126 cfu/dL. In addition, the *E. coli* content of a single grab sample should not equal or exceed 394 cfu/dL. However, when determining long-term compliance with bacteria standards, TCEQ allows up to 25% of samples to exceed the grab sample criterion.

TCEQ Water Quality Assessment

To comply with the federal Clean Water Act, the TCEQ conducts biannual assessments of water quality for every stream segment throughout the state. These assessments are performed in accordance with TCEQ's "2008 Guidance for Assessing and Reporting Surface Water Quality in Texas" (TCEQ 2008a). In many cases, long stream segments are divided into "assessment units" or "AUs" in order to provide greater spatial resolution. Table 1-2 provides the 2008 TCEQ assessment results for the subject stream segments (TCEQ, 2008b).

Table 1-2: TCEQ Surface Water Quality Assessment Results for *E. coli*

Segment	Segment Name	AU	Assessment Unit (AU) Description	Stations	# Samples	#* Exceed	Geo. Mean**
1004E	Stewarts Creek	1004E_02	From Airport Rd to Confluence with West Fork San Jacinto River	16626	88	**33**	**225**
1008	Spring Creek	1008_02	Field Store Road to SH 249	11323, 11314	104	**40**	**343**
		1008_03	SH 249 to IH 45	17489, 11313	107	**45**	**361**
		1008_04	IH 45 to confluence with Lake Houston	11312	52	**24**	**463**
1008H	Willow Creek	1008H_01	Entire water body	11185	35	**18**	**413**
1009	Cypress Creek	1009_01	Upper portion of segment to downstream of US 290	11333	56	**19**	**284**
		1009_02	US 290 to SH 249	11332, 11331	127	**58**	**464**
		1009_03	SH 249 to IH 45	11330, 11328	163	**98**	**678**
		1009_04	IH 45 to confluence with Spring Creek	11324	23	6	**433**
1009C	Faulkey Gully	1009C_01	From an unnamed lake 0.3 miles southeast of Telge Road to the confluence with Cypress Creek	17496	36	**15**	**550**
1009D	Spring Gully	1009D_01	Entire water body	17481	36	**22**	**651**
1009E	Little Cypress Creek	1009E_01	Entire water body	14159	35	**20**	**612**
1010	Caney Creek	1010_02	FM 1097 to SH 105	14241	55	13	**278**
		1010_03	SH 105 to FM 2090	11335	4	0	83
		1010_04	FM 2090 to lower segment boundary	11334	119	30	**187**
1011	Peach Creek	1011_01	Upper segment boundary to US Hwy 59	11337, 11338, 16625	59	12	110
		1011_02	US Hwy 59 to confluence with Caney Creek	11336, 17746	111	26	**239**

*number of samples exceeding the grab sample criterion of 394 cfu/dL

**to be compared with the geometric mean criterion of 126 cfu/dL

Note: **Bold Red** text indicates that stream was determined to be non-supporting of criterion

1.5 WATER QUALITY TARGET

The TMDLs will be developed for the geometric mean criterion, which appears to be more conservative than the grab sample criterion. As illustrated in Table 1-2, all stations that exceed the grab sample criterion also exceed the geometric mean criterion, but this is not true the other way around. Furthermore, use of the geometric mean criterion was recommended by TCEQ staff.

The TMDLs will be developed at the Assessment Unit (AU) scale. This relatively fine resolution recognizes the significant spatial variability in *E. coli* levels throughout the watershed. For AUs with just one water quality monitoring station, a TMDL will be developed based on that single station. For AUs with multiple stations, a TMDL will be developed for the station requiring the greatest loading reductions.

2.0 WATERSHED CHARACTERIZATION

The stream segments addressed by this project are located within the Lake Houston watershed of the San Jacinto River Basin. The southern portion of the watershed includes portions of the City of Houston and its northern suburbs. The Woodlands and the City of Conroe are the largest municipalities located entirely within the watershed. The northern portions of the watershed are relatively rural and include portions of the Sam Houston National Forest.

2.1 TOPOGRAPHY

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 and drainage patterns are more easily defined. The conservation pool elevation of Lake Houston is 44.1 feet (above sea level), and the conservation pool elevation of Lake Conroe is 201 feet (TPWD, 2009).

2.2 HYDROGEOLOGY

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

2.3 SOILS

Soil conditions vary throughout the Lake Houston watershed based on geological and physiographic characteristics. In Montgomery County, surface soils are generally light-colored or reddish loams, with clayey and loamy subsoils. The northern portion of Harris County is also characterized by loamy soils (TSHA, 2001). Figure 2-1 presents the soil associations of the Lake Houston Watershed (NRCS, 2007).

Key	Soil Association
s7158	Ozan-Atasco-Aldine
s7179	Brackett-Bolar-Aledo
s7192	Lake charles-Beaumont
s7198	Morey-Mocarey-Bernard
s7217	Splendora-Segno-Landman-Boy
s7249	Gessner-Clodine-Addicks
s7257	Conroe
s7286	Huntsburg-Fetzer-Depcor-Boy-Annona
s7324	Greenvine-Falba-Burlewash-Arol
s7333	Latium-Frelsburg-Crockett-Carbengle-Brenham-Bosque-Bleiblerville
s7349	Tonkavar-Shiro-Gomery-Elmina
s7351	Nahatche-Kaufman-Gowker
s7364	Nahatche-Hatliff
s7365	Pluck-Kian-Hatliff
s7374	Wockley-Segno-Monaville-Hockley
s7389	Katy-Clodine-Aris
s7392	Tinn-Kaufman-Gladewater

Key	Soil Association
s7398	Sealy-Kenney-Chazos
s7403	Waller-Sorter-Kirbyville
s7520	Waller-Otanya-Kirbyville-Dallardsville
s7551	Pinetucky-Doucette
s7650	Waller-Sorter
s7705	Woodville-Vamont
s7725	Woodville-Wiergate-Burkeville
s7740	Wockley-Hockley-Gessner
s7744	Woodville-Pinetucky

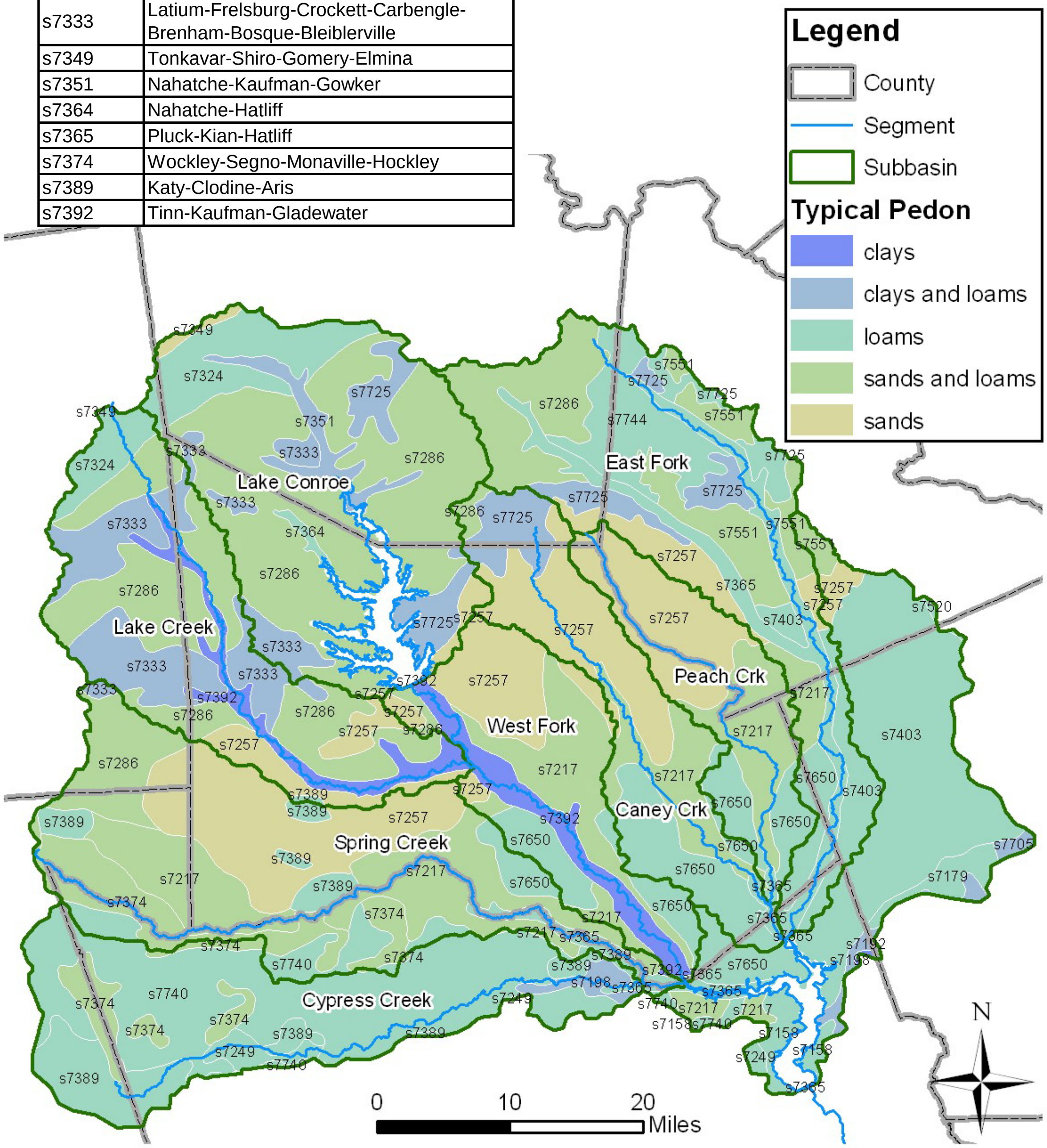

Figure 2-1: Soil Associations of the Lake Houston Watershed

2.4 CLIMATE

The Lake Houston Watershed is located within the Upper Coast and East Texas climatic divisions. The Gulf of Mexico is the principal source of moisture that drives precipitation in the region. Annual average precipitation generally increases from west to east across the watershed. Annual precipitation data (1997-2006) for key weather stations is provided in Table 2-1. These data were obtained through the EPA BASINS program (EPA, 2007). In 2007, the annual precipitation totals at Tomball, Conroe, and Houston International were 53.2, 50.5, and 65.5 inches, respectively (NWS, 2008).

Table 2-1: Annual Rainfall Totals for Lake Houston Watershed (in)

Station ID	Location	Year										Average
		1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	
TX411810	Cleveland	66.9	67.4	38.1	50.0	63.4	65.7	54.0	68.0	42.5	55.8	57.2
TX411956	Conroe	55.8	57.9	28.6	35.6	70.5	53.5	46.9	69.4	33.8	59.4	51.1
TX412206	Cypress	63.1	56.7	30.8	45.6	59.7	54.7	37.5	58.6	37.7	57.8	50.2
TX414300	Houston IAH	60.2	54.8	28.0	47.6	71.2	59.7	45.7	65.1	41.2	57.9	53.1
TX416024	Montgomery	50.5	55.6	27.2	43.2	53.9	53.3	31.7	62.9	37.6	60.9	47.7
TX416280	New Caney	73.5	59.7	25.4	41.0	62.8	63.1	54.2	74.2	40.1	60.0	55.4
TX419076	Tomball	59.0	57.4	31.2	37.9	63.9	59.0	41.9	62.5	40.8	59.5	51.3
Average		61.3	58.5	29.9	43.0	63.6	58.4	44.6	65.8	39.1	58.8	52.3

Temperature and precipitation in the study area vary throughout the year. Temperatures average in the low eighties in the summer and the low fifties in the winter. Maximum precipitation periods are in the late spring and autumn. The Gulf of Mexico is the primary driver of precipitation throughout the region and it is not unusual for hurricanes to affect rainfall in the early autumn period. Table 2-2 presents monthly precipitation and temperature data for the City of Conroe.

Table 2-2: Monthly Climate Averages for Conroe (1997-2006)

Month	Conroe (TX411956)	
	Prec (in)	Temp (F)
January	3.9	53
February	4.2	55
March	3.1	61
April	2.5	69
May	4.5	76
June	6.4	81
July	2.1	84
August	3.1	84
September	3.7	79
October	7.5	70
November	6.5	60
December	3.9	51
Total/Average	51.2	69

2.5 POPULATION

Population varies greatly throughout the Lake Houston Watershed. County population data for the study area are provided in Table 2-3 (TWDB, 2006). Harris County, which intersects the southern portion of the watershed, has a population of greater than 3 million. In contrast, Grimes and San Jacinto Counties have populations of less than 30,000. Montgomery County, which is centrally located within the watershed, has the highest anticipated growth (85% increase from 2000-2020), due to the northward expansion of the Houston metropolitan area. The locations of these counties were shown previously in Figure 1-1.

Table 2-3: County Population Data and Projections

County Name	2000 U.S. Census	2000 Density (#/square mi)	2010 TWDB Projection	2020 TWDB Projection	Growth (2000-2020)
Grimes	23,552	30	26,635	30,073	28%
Harris	3,400,578	1,967	3,951,682	4,502,786	32%
Liberty	70,154	60	81,930	94,898	35%
Montgomery	293,768	281	417,692	542,051	85%
San Jacinto	22,246	39	27,443	32,541	46%
Walker	61,758	78	70,672	77,915	26%
Waller	32,663	64	41,137	51,175	57%

There are numerous municipalities in the study area as shown in Table 2-4 (TWDB, 2006). The largest municipality is the City of Houston, which intersects the Cypress Creek watershed. The Woodlands, which is the second largest municipality, is located within the Spring Creek Watershed. Conroe, the third largest municipality, intersects the Stewarts Creek watershed.

Table 2-4: City Population Data and Projections

Segment	City	2000 U.S. Census	2010 TWDB Projection	2020 TWDB Projection	Growth Rate (2000-2020)
1008	Magnolia	1,111	1,350	1,496	35%
1008	Oak Ridge North	2,991	3,743	4,202	40%
1008	Shenandoah	1,503	1,503	1,503	0%
1008	The Woodlands	55,649	60,080	111,470	100%
1008	Tomball	9,089	12,059	15,429	70%
1009	Houston	1,953,631	2,240,974	2,520,926	29%
1009	Waller	2,092	2,637	3,240	55%
1010	Patton Village	1,391	1,721	1,923	38%
1010	Roman Forest	1,279	1,623	1,833	43%
1010	Splendora	1,275	2,017	2,470	94%
1010	Woodbranch	1,305	1,305	1,305	0%
1011	Cut and Shoot	1,158	1,515	1,733	50%
1011	New Waverly	950	1,087	1,199	26%
1011	Willis	3,985	5,695	6,739	69%
1004E	Conroe	36,811	49,602	57,413	56%
1004E	Panorama Village	1,965	2,538	2,888	47%

Population estimates were developed for the study watersheds by intersecting block-group level census data with the watershed boundaries. Table 2-5 presents the results of this analysis. As shown, growth rates were generally highest in the Spring Creek and Cypress Creek watersheds. Figures 2-2 and 2-3 show population density in the watershed for 1990 and 2007, respectively.

Table 2-5: Estimated TMDL Watershed Populations

Segment	Stream Name	1990 Census Population	2000 Census Population	2007 Estimated Population	Annual Growth Rate (1990-07)
1004E	Stewarts Creek	11,292	14,386	16,968	2.42%
1008	Spring Creek	102,873	171,503	238,381	5.07%
1008H	Willow Creek	13,265	21,098	29,767	4.87%
1009	Cypress Creek	172,889	233,357	325,668	3.80%
1009C	Faulkey Gully	7,136	12,688	19,153	5.98%
1009D	Spring Gully	2,693	4,360	9,126	7.44%
1009E	Little Cypress Crk	7,377	19,492	31,102	8.83%
1010	Caney Creek	33,485	49,758	60,274	3.52%
1011	Peach Creek	14,064	18,229	21,888	2.64%

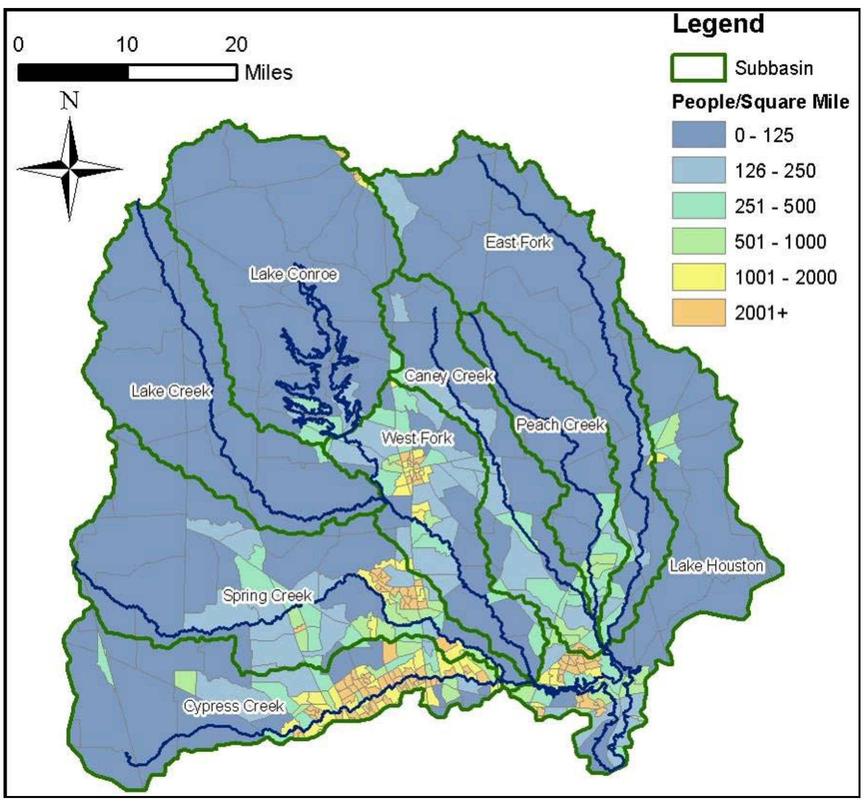

Figure 2-2: 1990 Population Data for Lake Houston Watershed

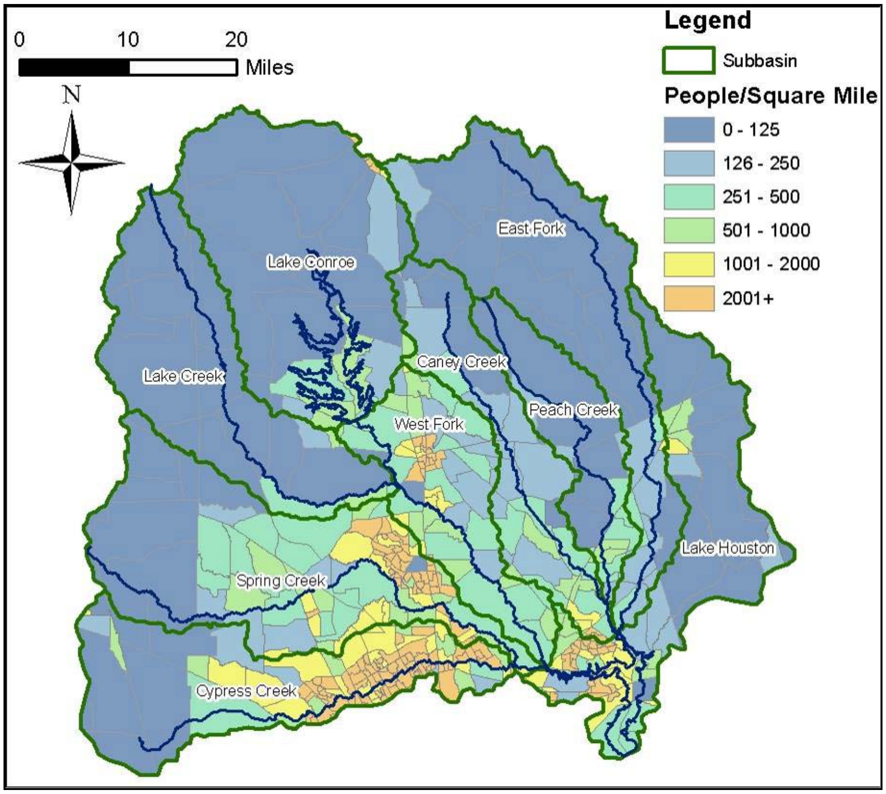

Figure 2-3: 2007 Population Data for Lake Houston Watershed

2.6 AGRICULTURE

Agriculture is one of the primary land uses in the study area. This section provides a general description of agricultural activities in the subject counties. Additional data are provided in Section 3.0.

Harris County

There are 2,210 farms in Harris county with an average size of 117 acres and a median size of 20 acres (USDA, 2007). The total land area for farms decreased by 17% from 1997 to 2007, but farmland still accounts for about 22% of the county's total area. Cattle are the primary type of livestock raised in the county. Cropland accounts for about 35% of the county's total farmland.

Montgomery County

There are 1,886 farms in Montgomery County with an average size of 90 acres and a median size of 20 acres (USDA, 2007). The total land area for farms decreased by 12% from 1997 to 2007, but farmland still accounts for about 29% of the county's total area. Cattle are the primary type of livestock raised in the county, though there are also significant chicken operations. Cropland accounts for about 20% of the county's total farmland.

Other Counties

The percentage of land in farms tends to increase farther from the Houston metropolitan area. Grimes and Waller Counties, on the western edge of the watershed, have the highest percent farmland, 85% and 82%, respectively. In the eastern and northern portions of the watershed, much of the land is still forested, limiting the amount of farmland. For Liberty, San Jacinto, and Walker Counties, the percentage of land in farms is 40%, 24%, and 44%, respectively (USDA, 2007).

2.7 LAND COVER

A map of watershed land cover is provided in Figure 1-2. These data are from the 2001 National Land Cover Database developed by the USGS and partner agencies (MRLC, 2001). Table 2-6 provides a summary of land cover data by TMDL watershed. As shown, the western portion of the watershed is primarily cropland and pasture. The central and south-central portions of the watershed are more heavily urbanized. Finally, the eastern portion of the watershed is primarily forested land.

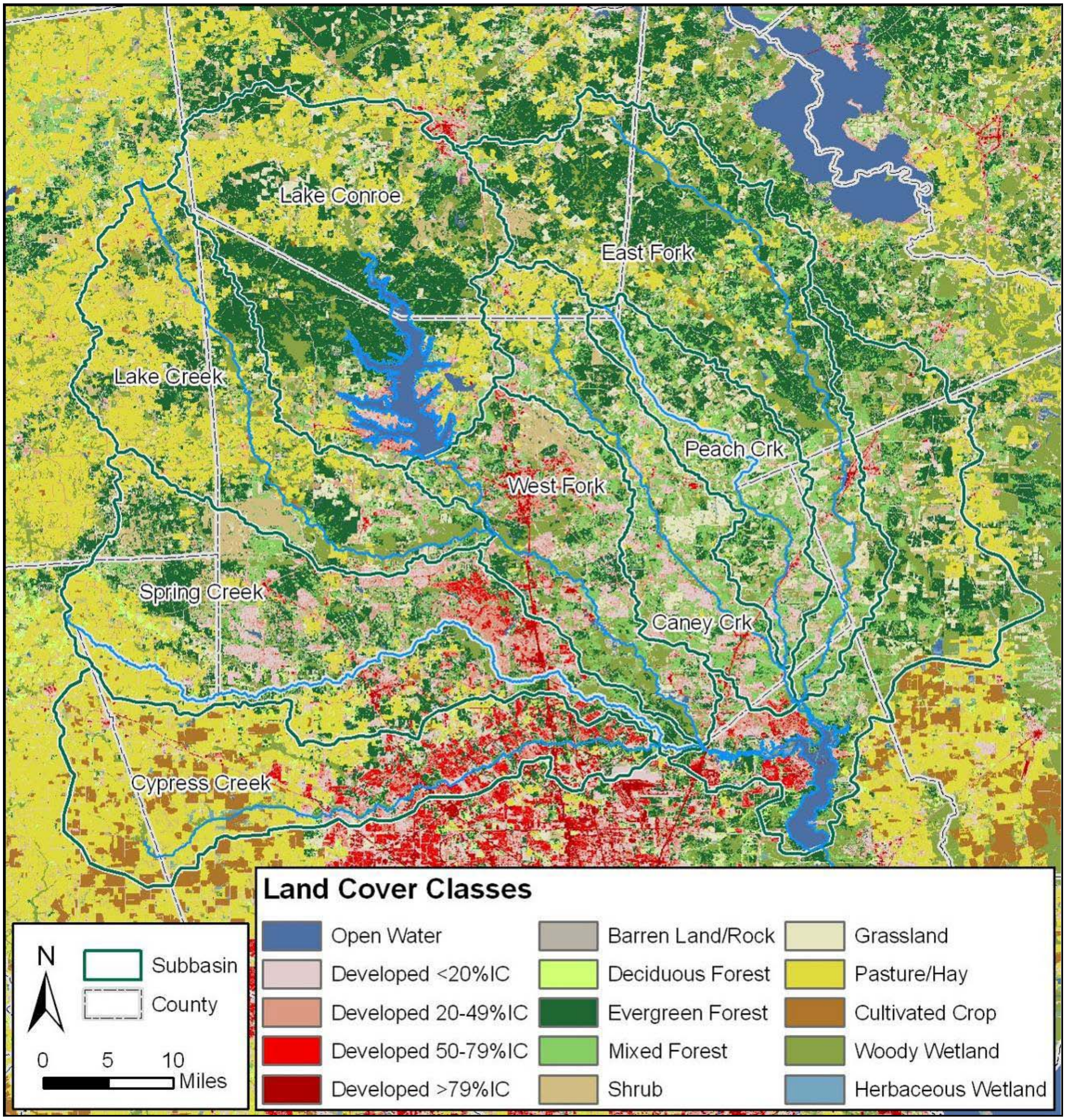

Figure 2-4: 2001 USGS Land Cover Data for Lake Houston Watershed

Table 2-6: Land Cover Data for TMDL Watersheds.

Land Cover	Stewarts Creek 1004E	Spring Creek 1008	Willow Creek 1008H	Cypress Creek 1009	Faulkey Gully 1009C	Spring Gully 1009D	Little Cypress Crk 1009E	Caney Creek 1010	Peach Creek 1011
Percent of Watershed									
Open water	0%	1%	0%	0%	0%	1%	1%	0%	0%
Developed, Open	12%	11%	13%	11%	16%	22%	8%	12%	9%
Developed, Low	19%	9%	9%	8%	14%	10%	4%	5%	2%
Developed, Meduim	6%	3%	3%	7%	14%	11%	3%	1%	0%
Developed, High	3%	1%	1%	2%	1%	1%	0%	0%	0%
Barren Land	0%	0%	0%	1%	2%	3%	0%	0%	0%
Deciduous Forest	0%	2%	4%	3%	3%	8%	5%	0%	1%
Evergreen Forest	13%	20%	23%	8%	18%	17%	7%	13%	22%
Mixed Forest	15%	10%	4%	1%	1%	3%	1%	23%	29%
Shrub/Scrub	17%	11%	3%	3%	1%	1%	3%	7%	9%
Grassland/Herbaceous	3%	5%	4%	2%	4%	8%	2%	14%	14%
Pasture Hay	1%	17%	31%	37%	24%	15%	47%	11%	1%
Cultivated Crops	0%	0%	1%	12%	0%	1%	13%	0%	0%
Woody Wetlands	11%	10%	2%	5%	3%	2%	6%	13%	12%
Herbaceous Wetlands	0%	0%	1%	1%	0%	1%	1%	0%	0%
Acres of Watershed									
Open water	43	1,603	102	776	4	23	226	625	167
Developed, Open	1,323	30,625	4,357	22,833	1,153	759	2,751	16,020	9,062
Developed, Low	2,111	26,399	3,084	16,007	991	335	1,382	7,571	2,255
Developed, Meduim	660	8,010	1,097	14,787	1,027	371	1,195	1,577	401
Developed, High	301	1,839	378	3,336	45	18	110	313	63
Barren Land	40	1,094	142	1,434	135	90	81	305	133
Deciduous Forest	7	5,374	1,391	5,840	227	282	1,655	116	547
Evergreen Forest	1,463	57,568	7,559	15,810	1,292	612	2,405	17,448	21,764
Mixed Forest	1,729	26,879	1,189	2,557	77	91	305	31,251	29,494
Shrub/Scrub	1,867	30,879	890	5,865	56	19	935	10,015	9,217
Grassland/Herbaceous	369	12,702	1,419	5,123	268	276	887	18,993	14,068
Pasture Hay	140	49,008	10,266	77,456	1,716	517	16,782	14,992	1,317
Cultivated Crops	0	956	395	24,653	0	25	4,672	33	0
Woody Wetlands	1,207	27,910	821	9,786	228	67	2,019	18,369	12,347
Herbaceous Wetlands	3	948	189	2,186	13	36	242	357	156
Total Watershed Area	11,264	281,792	33,280	208,448	7,232	3,520	35,648	137,984	100,992

3.0 WATER QUALITY AND HYDROLOGIC DATA ASSESSMENT

3.1 AMBIENT WATER QUALITY

E. coli bacteria data have been routinely collected at numerous monitoring stations throughout the TMDL watershed. The agencies that routinely collect and submit these data include the following (the TCEQ entity codes for these agencies are shown in parentheses).

- Houston-Galveston Area Council (HG)
- Houston Health and Human Services (HH)
- Houston Water Quality Control (HW)
- San Jacinto River Authority (SJ)
- TCEQ (WC) Regional Office (FO)
- U.S. Geological Survey (GS)

Supplemental data have been collected by James Miertschin & Associates (JMA) as part of this TMDL project. The supplemental sampling will be discussed in greater detail in subsequent Section 3.4.

Table 3-1 provides a summary of the *E. coli* monitoring results (through 2007) for the study segments. Table 3-2 provides a description of the agency sampling station locations. Figures 3-1 through 3-3 show the locations of monitoring stations throughout the TMDL study segments. These maps also show the locations of wastewater discharges and USGS flow gages.

As demonstrated throughout the following tables and figures, bacteria impairments in the study segments are substantial and widespread. Only a few stations on Peach Creek and Caney Creek appear to be meeting the water quality criteria with respect to *E. coli*. The impairments appear to be the most severe in the Spring Creek and Cypress Creek watersheds (including subsegments), where the historical geometric mean *E. coli* values are often several times higher than the state criterion. Most stations include more than 50 *E. coli* samples throughout the period of record.

Table 3-1: Summary of *E. coli* Sampling Results by Station

Segment ID	AU	Station ID	Start Date	End Date	Geo. Mean (cfu/dL)	# Samples	# Exceed. 394 cfu/dL	% Exceed. 394 cfu/dL
Stewarts Creek								
1004E	1004E_02	16626	6/13/00	11/7/07	228	101	41	41%
Spring Creek								
1008	1008_02	11323	1/15/02	11/8/07	336	69	25	36%
		11314	6/20/00	11/8/07	409	52	24	46%
	1008_03	17489	1/15/02	11/8/07	403	67	26	39%
		11313	6/20/00	11/8/07	334	55	27	49%
	1008_04	11312	12/11/01	11/8/07	522	63	32	51%
*Lower Panther Branch**								
1008C	1008C_01	16628	10/31/02	7/19/07	173	20	12	60%
Willow Creek								
1008H	1008H_01	11185	1/28/02	11/13/07	456	70	33	47%
Cypress Creek								
1009	1009_01	11333	1/16/02	11/9/07	313	65	24	37%
	1009_02	11332	1/30/01	11/9/07	371	87	35	40%
		11331	6/20/00	11/9/07	595	56	31	55%
	1009_03	11330	1/29/02	11/9/07	930	67	41	61%
		11328	6/20/00	11/9/07	641	138	83	60%
	1009_04	11324	1/3/01	12/18/07	459	29	11	38%
Faulkey Gully								
1009C	1009C_01	17496	1/16/02	11/8/07	624	72	32	44%
Spring Gully								
1009D	1009D_01	17481	1/29/02	11/8/07	679	72	46	64%
Little Cypress Creek								
1009E	1009E_01	14159	1/16/02	11/8/07	556	71	41	58%
Caney Creek								
1010	1010_02	14241	6/27/00	11/2/07	293	60	15	25%
	1010_03	11335	12/12/02	11/2/07	99	10	1	10%
	1010_04	11334	6/27/00	11/2/07	202	145	39	27%
Peach Creek								
1011	1011_01	11337	12/12/02	11/2/07	149	10	5	50%
		11338	12/12/02	11/2/07	95	10	5	50%
		16625	6/27/00	11/2/07	117	56	13	23%
	1011_02	11336	6/27/00	11/2/07	243	132	32	24%
		17746	10/27/03	11/2/07	253	16	6	38%

*Not part of this TMDL project, but a major tributary to impaired segment 1008 (Spring Creek)

Table 3-2: Station Location Descriptions and Corresponding USGS Gages

Segment	TCEQ #	TCEQ Description	USGS #
Stewarts Creek			
1004E	16626	STEWARTS CREEK 175 METERS DOWNSTREAM OF SH LOOP 336 SOUTHEAST OF CONROE	-
Spring Creek			
1008	11323	SPRING CREEK IMMEDIATELY UPSTREAM OF DECKER PRAIRIE ROSEHILL ROAD	-
1008	11314	SPRING CREEK IMMEDIATELY UPSTREAM OF SH 249	08068275
1008	17489	SPRING CREEK IMMEDIATELY DOWNSTREAM OF KUYKENDAHL ROAD NORTHEAST OF HOUSTON	-
1008	11313	SPRING CREEK BRIDGE AT IH 45 20 MILES NORTH OF HOUSTON	08068500
1008	11312	SPRING CREEK IMMEDIATELY DOWNSTREAM OF RILEY FUZZEL ROAD	-
Willow Creek			
1008H	11185	WILLOW CREEK IMMEDIATELY UPSTREAM OF GOSLING ROAD	-
Lower Panther Branch			
1008C	16628	LOWER PANTHER BRANCH 134 DOWNSTREAM OF SAWDUST RD APPROX 240 M DOWNSTREAM OF PERMIT WQ0011401-001 LOCATED AT 2436 SAWDUST ROAD	-
Cypress Creek			
1009	11333	CYPRESS CREEK IMMEDIATELY DOWNSTREAM OF HOUSE HAHL ROAD NEAR CYPRESS	08068740
1009	11332	CYPRESS CREEK IMMEDIATELY DOWNSTREAM OF GRANT ROAD NEAR CYPRESS	08068800
1009	11331	CYPRESS CREEK AT SH 249	-
1009	11330	CYPRESS CREEK AT STEUBNER-AIRLINE ROAD IN HOUSTON	08068900
1009	11328	CYPRESS CREEK BRIDGE ON IH 45 15 MI NORTH OF HOUSTON	08069000
1009	11324	CYPRESS CREEK IMEDIATELY DOWNSTREAM OF CYPRESSWOOD DRIVE/OLD TETTAR RD EXTENSION	08069200
Faulkey Gully			
1009C	17496	FAULKEY GULLY OF CYPRESS CREEK 105 METERS DOWNSTREAM OF LAKEWOOD FOREST DRIVE NORTHWEST OF HOUSTON	-
Spring Gully			
1009D	17481	SPRING GULLY AT SPRING CREEK OAKS DRIVE IN TOMBALL	-
Little Cypress Creek			
1009E	14159	LITTLE CYPRESS CREEK IMMEDIATELY DOWNSTREAM OF KLUGE ROAD IN HOUSTON	-
Caney Creek			
1010	14241	CANEY CREEK AT SH 105	08070495
1010	11335	CANEY CREEK IMMEDIATELY UPSTREAM OF FM 2090 WEST OF SPLENDORA	08070500
1010	11334	CANEY CREEK IMMEDIATELY DOWNSTREAM OF FM 1485	08070600
Peach Creek			
1011	11338	PEACH CREEK AT SH 105 WEST OF CLEVELAND	08070900
1011	16625	PEACH CREEK IMMEDIATELY UPSTREAM OF OLD HWY 105	-
1011	11337	PEACH CREEK BRIDGE AT FM 2090 IN SPLENDORA	08071000
1011	11336	PEACH CREEK AT FM 1485	08071100
1011	17746	PEACH CREEK AT LAKE HOUSTON STATE PARK FOOTBRIDGE 1.09 KM DOWNSTREAM OF FM 1485	-

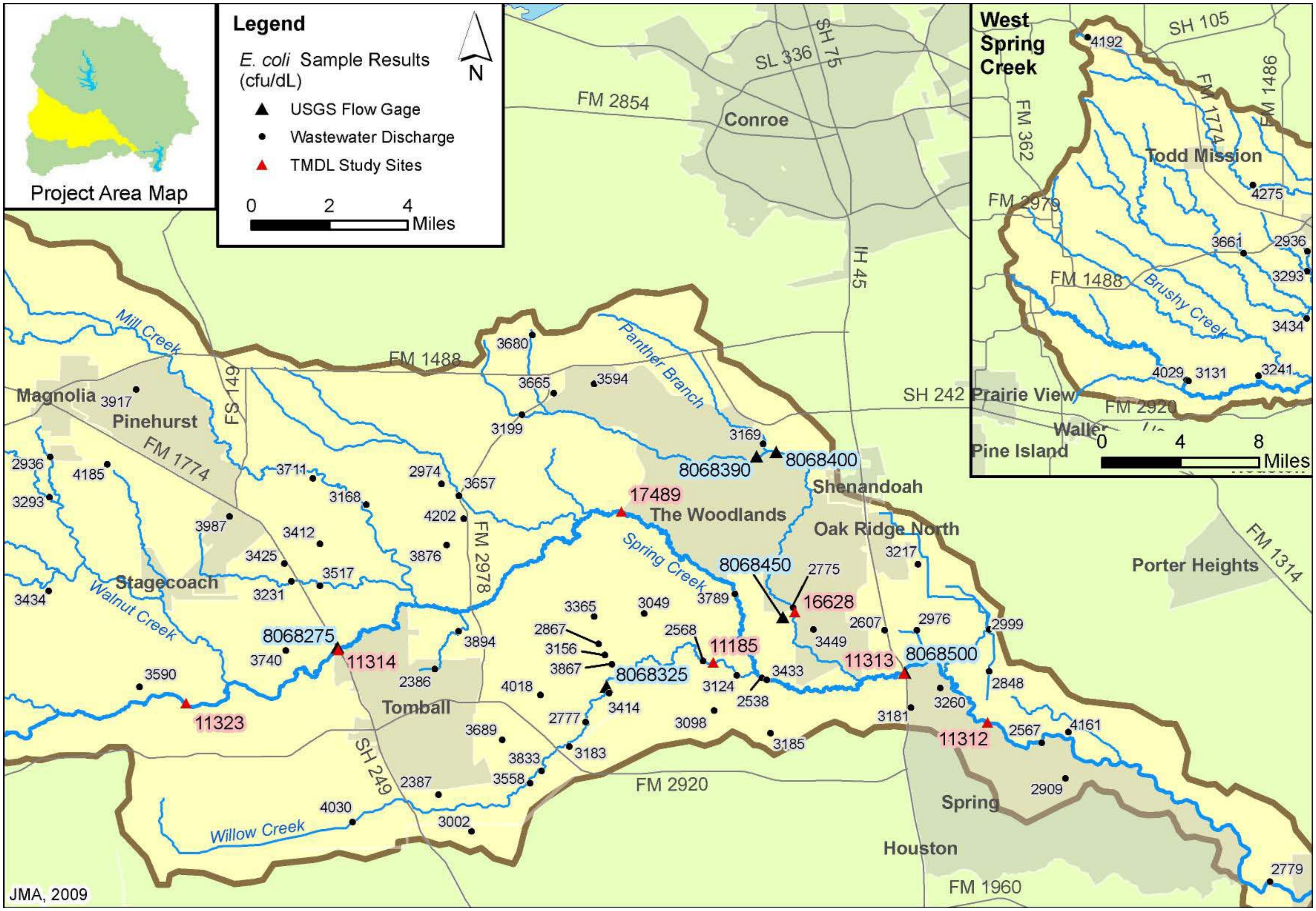

Figure 3-1: Spring Creek Watershed Map

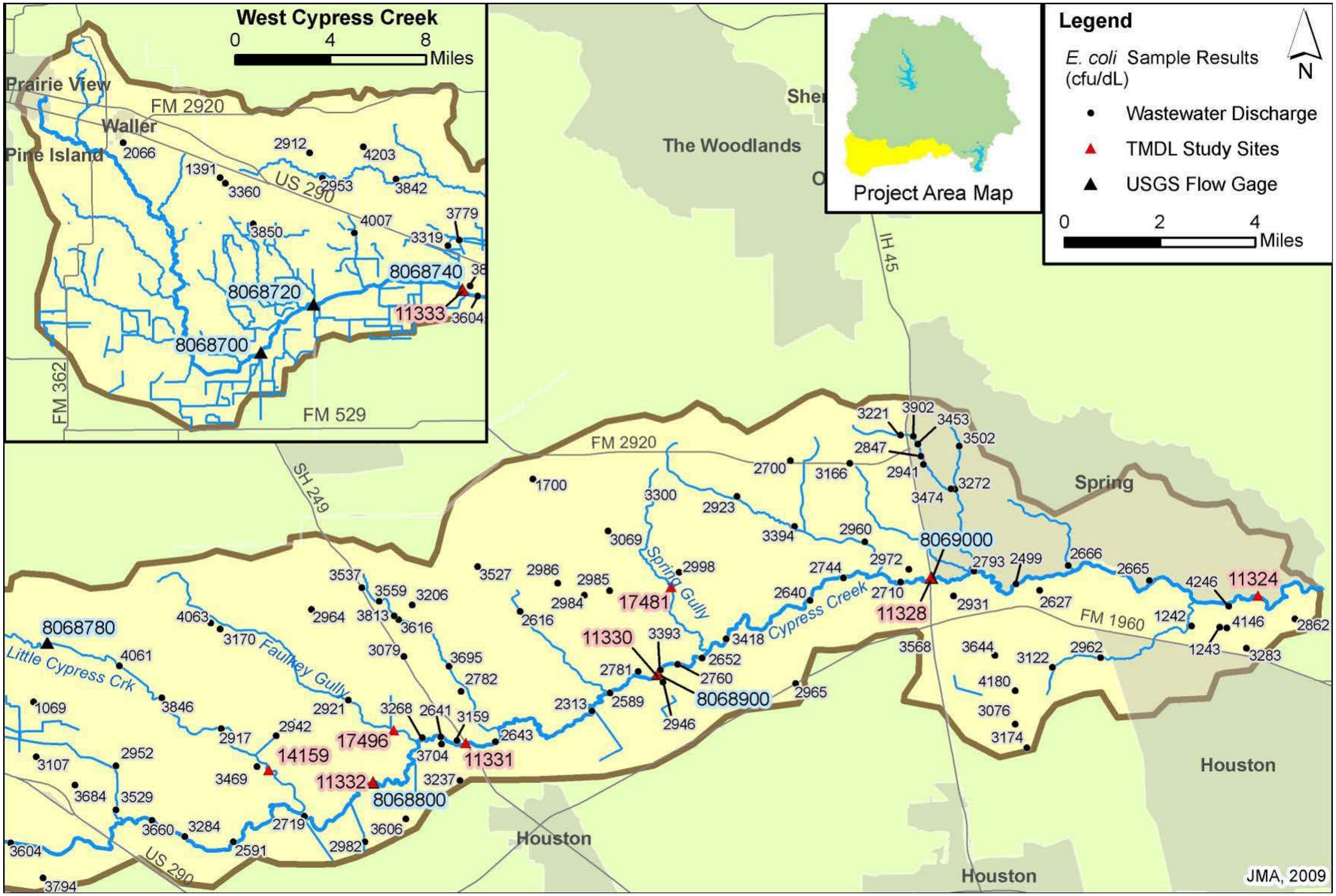

Figure 3-2: Cypress Creek Watershed Map

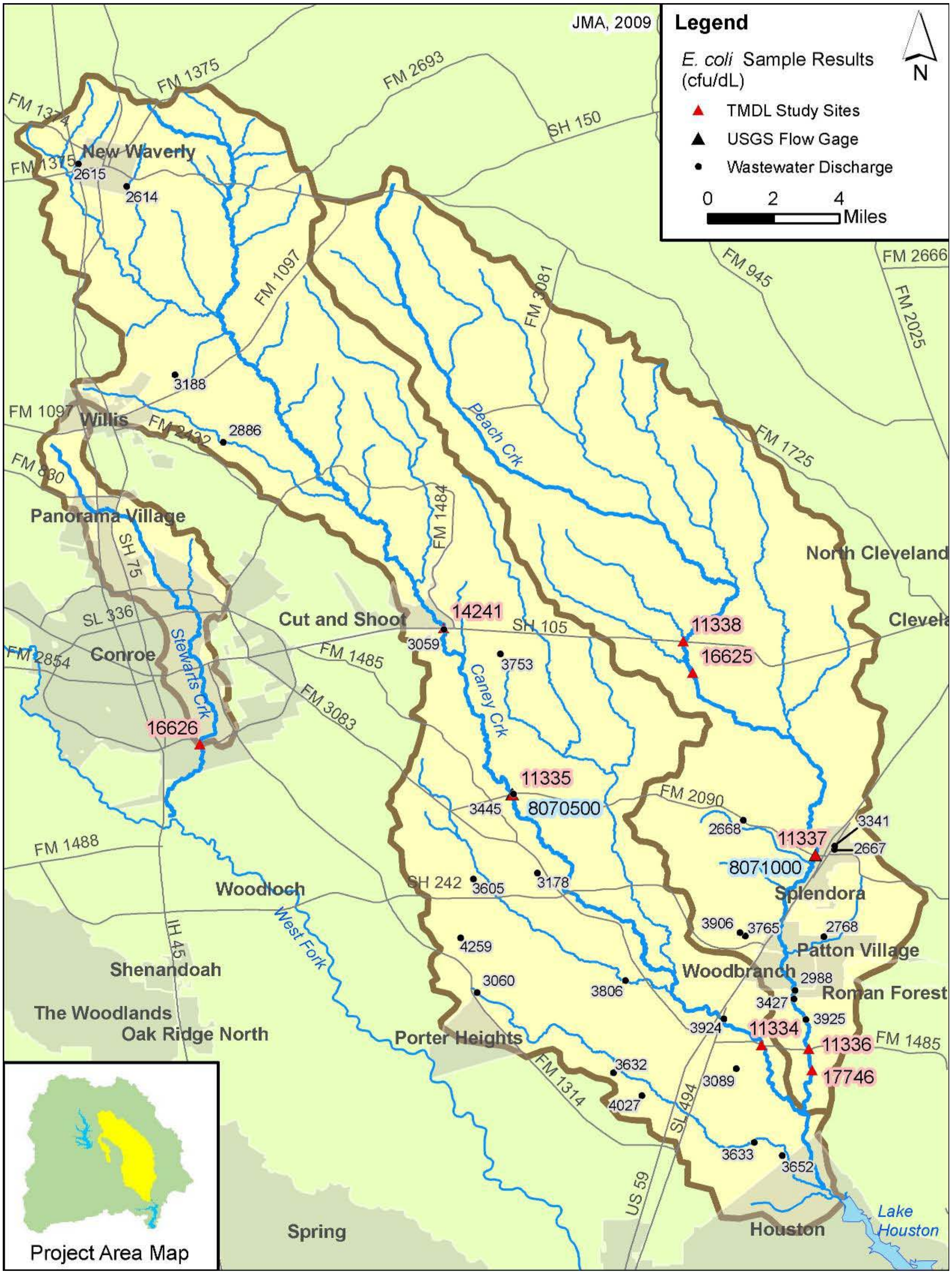

Figure 3-3: Eastern Creeks Watershed Map

3.2 TEMPORAL VARIABILITY OF WATER QUALITY

3.2.1 Runoff Induced Variability

Stormwater runoff typically contains high levels of fecal bacteria, including *E. coli*. As a result, runoff is often the primary driver of temporal variability in *E. coli* levels. To assess the impacts of stormwater runoff in the study area, *E. coli* data were evaluated based on the hydrologic conditions in which they were collected.

Table 3-3 presents a summary of *E. coli* sampling results for selected stations under different flow conditions. The stations used for this analysis were selected based on their proximity to USGS flow gages. The flow conditions (determined from USGS flow gaging data) include the following:

- *Peaking flows conditions* (days when the flow increases by 50% or more)
- *Sustained high flow conditions* (days following a peaking condition, when flows remain elevated above baseflow conditions by at least 20%)
- *Baseflow conditions* (days that do not meet either of the conditions listed above)

The historical *E. coli* data were assigned to the flow categories based on the dates they were collected. However, it was recognized that *E. coli* samples collected on peaking flow days may be collected prior to the runoff event (i.e. the sample was collected in the morning, followed by a thunderstorm in the afternoon). To account for this, *E. coli* samples collected on peak flow days with counts of less than 500 cfu/dL were assigned to the baseflow category.

As shown in Table 3-3, there is a strong relationship between the flow condition and the geometric mean *E. coli* levels. The geometric means of samples in the peaking flow category are over an order of magnitude higher than samples in the baseflow category. Geometric means in the sustained high flow categories are intermediate to the peak flow and baseflow categories, as expected. Paired t-tests suggest that the *E. coli* geometric means of the different flow conditions are significantly different ($P<0.05$).

The results suggest that runoff has a large impact on *E. coli* levels within the study area. Peaking flow days (which are the result of rainfall/runoff) exhibit *E. coli* levels that are typically between 2,000 and 10,000 cfu/dL. Baseflow days generally exhibit *E. coli* levels below 300 cfu/dL. However, even under baseflow conditions, none of the studied stations demonstrated *E. coli* levels below the geometric mean criterion of 126 cfu/dL.

Table 3-3: *E. coli* Results for Varying Runoff/Flow Conditions

Water Quality Station	Stream	Nearby USGS Gage	Base-flow	Sustained high flow, 3+ days after peak	Sustained high flow, 1-2 days after peak	Peaking flow
E. coli Geometric Mean for Each Flow Condition (cfu/dL)						
11313	Spring (d/s)	8068500	127	430	661	2,710
11314	Spring (u/s)	8068275	185	343	455	3,218
11328	Cypress (d/s)	8069000	286	803	1,046	6,911
11333	Cypress (u/s)	8068740	157	782	626	7,238
11336	Peach	8071000	155	323	787	9,323
14159	Little Cypress	8068780	280	362	826	10,147
Number of E. coli Samples for Each Flow Condition						
11313	Spring (d/s)	8068500	25	14	9	7
11314	Spring (u/s)	8068275	25	9	8	10
11328	Cypress (d/s)	8069000	79	18	20	21
11333	Cypress (u/s)	8068740	42	4	14	5
11336	Peach	8071000	99	14	13	6
14159	Little Cypress	8068780	30	16	18	7

3.2.2 Seasonal Variability

E. coli levels may also vary by season. This is the result of numerous factors, including seasonal rainfall patterns, seasonal variability of loading sources (i.e. migratory birds), and seasonal variability of temperature and solar radiation, which affect the rate of bacteria die-off. To assess the seasonal variability, *E. coli* data were evaluated based on the season in which they were collected.

Two seasons, one warm and one cool, were considered for this analysis. The warm season covers May through September and the cool season includes November through March. The analysis uses the same stations considered in Section 3.3.1.

As shown in Table 3-4, there are no consistent relationships between seasonal conditions and *E. coli* concentrations. Most of the stations exhibit only small variations between summer and winter geometric mean values. Exceptions are the Little Cypress Creek station (#14159), which appears to have higher *E. coli* concentrations during the warm season, and the upstream Spring Creek station (#11328), which appears to have higher *E. coli* levels during the cool season. A t-test of log-tranformed, baseflow values on Little Cypress Creek demonstrated that the seasonal difference is statistically significant ($P<0.05$). However, a similar t-test for the upstream Spring Creek station did not show statistical significance ($P>0.1$).

Table 3-4: *E. coli* Results for Different Seasonal Conditions

Water Quality Station	Stream	Baseflow Samples		All Samples	
		Warm	Cool	Warm	Cool
E. coli Geometric Mean for Each Seasonal Condition (cfu/dL)					
11313	Spring (d/s)	117	138	291	364
11314	Spring (u/s)	98	249	171	744
11328	Cypress (d/s)	308	266	562	744
11333	Cypress (u/s)	171	181	277	391
11336	Peach	158	163	198	323
14159	Little Cypress	760	168	855	373
Number of E. coli Samples for Each Seasona Condition					
11313	Spring (d/s)	13	9	26	23
11314	Spring (u/s)	13	8	23	23
11328	Cypress (d/s)	34	35	62	57
11333	Cypress (u/s)	15	20	25	29
11336	Peach	47	37	55	60
14159	Little Cypress	9	17	30	29

3.2.3 Long-Term Variability

E. coli levels may also exhibit variability over a period of years or decades. This variation could be the result of numerous factors, including varying long-term hydrologic conditions, watershed urbanization, and changing land use practices. To assess potential long-term variability, *E. coli* data were assessed over multi-year periods. However, the assessment was limited by the historical period of record for *E. coli*, which began in 2000.

The *E. coli* data were divided into two four-year periods for the purpose of this analysis. (Shorter periods would have resulted in an insufficient number of samples per period at some stations.) The analysis focuses on the same stations used in the previous two sections.

As shown in Table 3-5, there are no clear, basin-wide, long-term trends. Four of the six stations have higher *E. coli* geometric means in the second four-year period. The Little Cypress Creek station (#14159) and the upstream Cypress Creek (#11333) station are the two stations that exhibit higher concentrations in the first four-year period. A t-test was performed on the log-transformed, baseflow samples for each station to determine if the two periods were significantly different. With the notable exception of Station 11328 (P<0.1) on Cypress Creek, the changes were not found to be significant.

Figures 3-4 through 3-9 present the historical *E. coli* and flow records for the six stations. Again, these six stations were chosen for temporal analysis due to their proximity to USGS flow gaging stations. As shown, the *E. coli* measurements at these stations show a great deal of temporal variability, much of which appears to be random in nature.

Table 3-5: *E. coli* Results for Two Multi-Year Period

Water Quality Station	Stream	Baseflow Samples		All Samples	
		2000-03	2004-07	2000-03	2004-07
E. coli Geometric Mean for Multi-Year Period (cfu/dL)					
11313	Spring (d/s)	117	143	239	533
11314	Spring (u/s)	139	264	336	548
11328	Cypress (d/s)	224	377	425	956
11333	Cypress (u/s)	187	141	318	310
11336	Peach	123	199	189	293
14159	Little Cypress	470	188	633	520
Number of E. coli Samples for Each Multi-Year Period					
11313	Spring (d/s)	15	10	32	23
11314	Spring (u/s)	14	11	31	21
11328	Cypress (d/s)	42	37	68	70
11333	Cypress (u/s)	16	26	24	41
11336	Peach	52	46	64	68
14159	Little Cypress	13	17	24	47

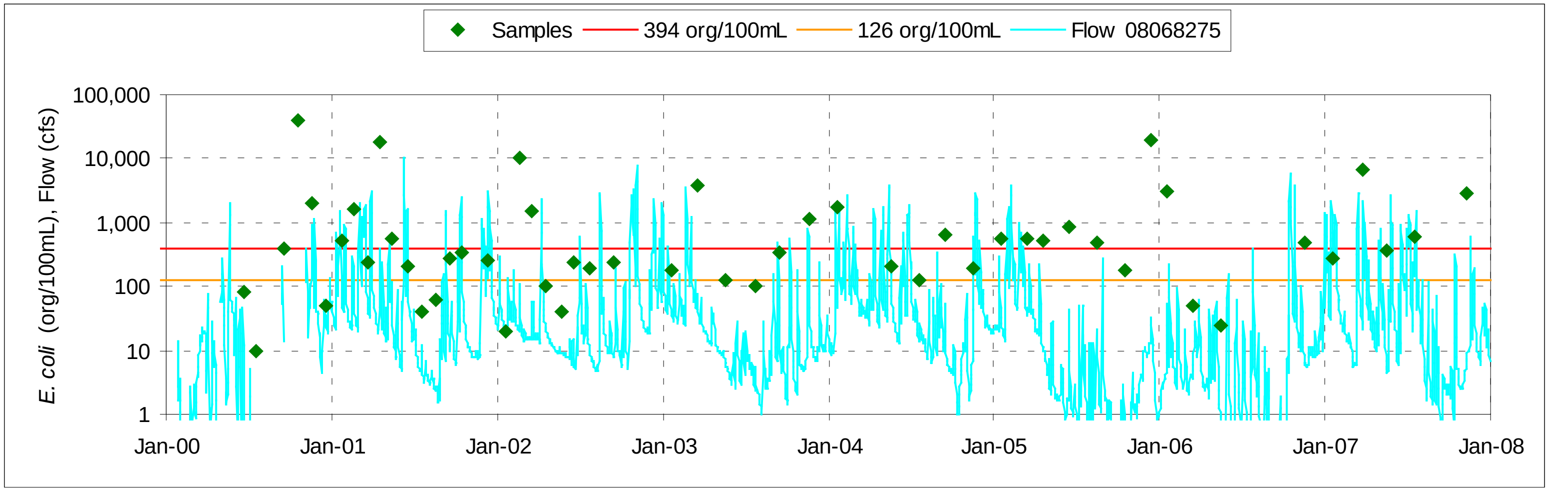

Figure 3-4: *E. coli* and Flow, Spring Creek at SH 249 (#11314)

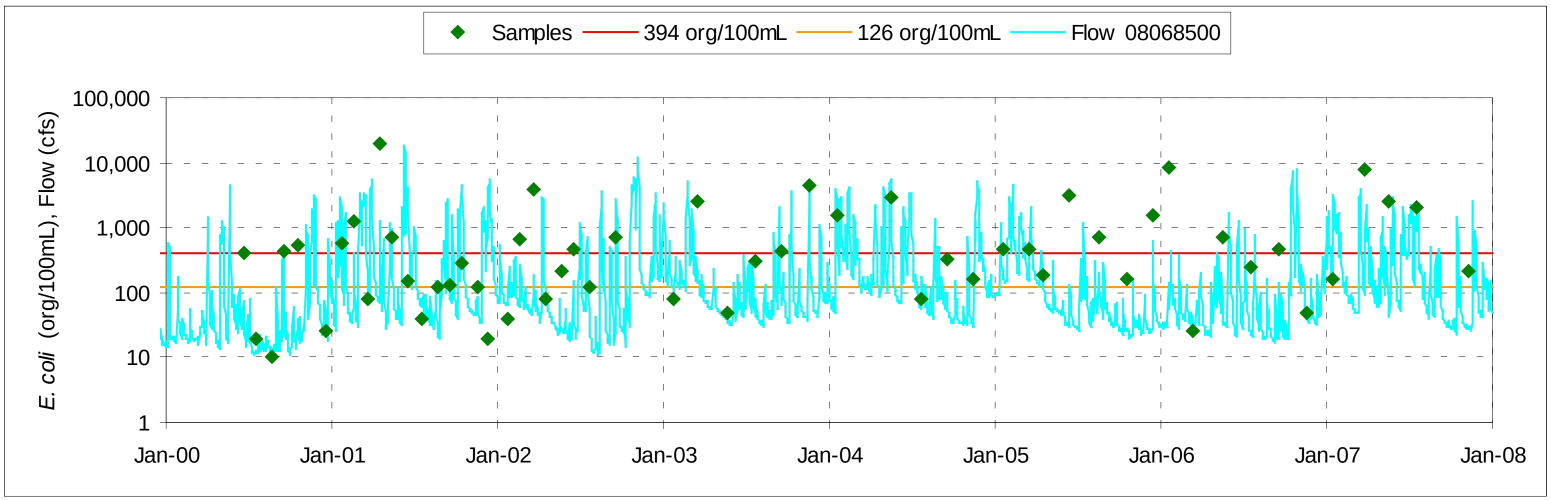

Figure 3-5: *E. coli* and Flow, Spring Creek at IH 45 (#11313)

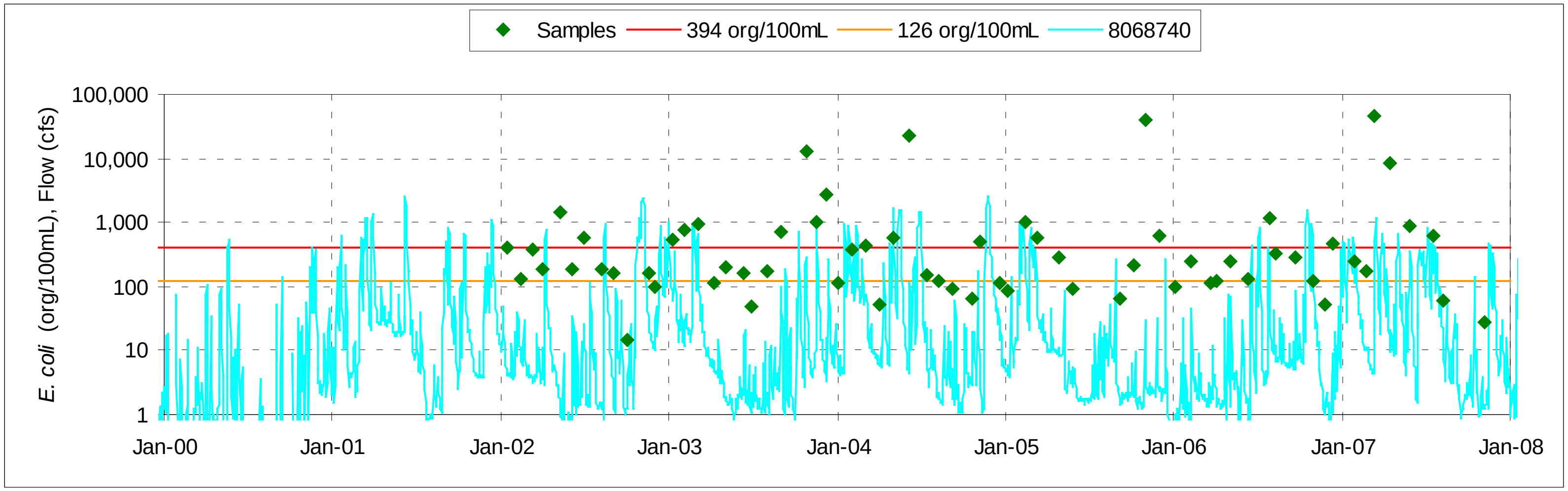

Figure 3-6: *E. coli* and Flow, Cypress Creek at House Hahl Rd. (#11333)

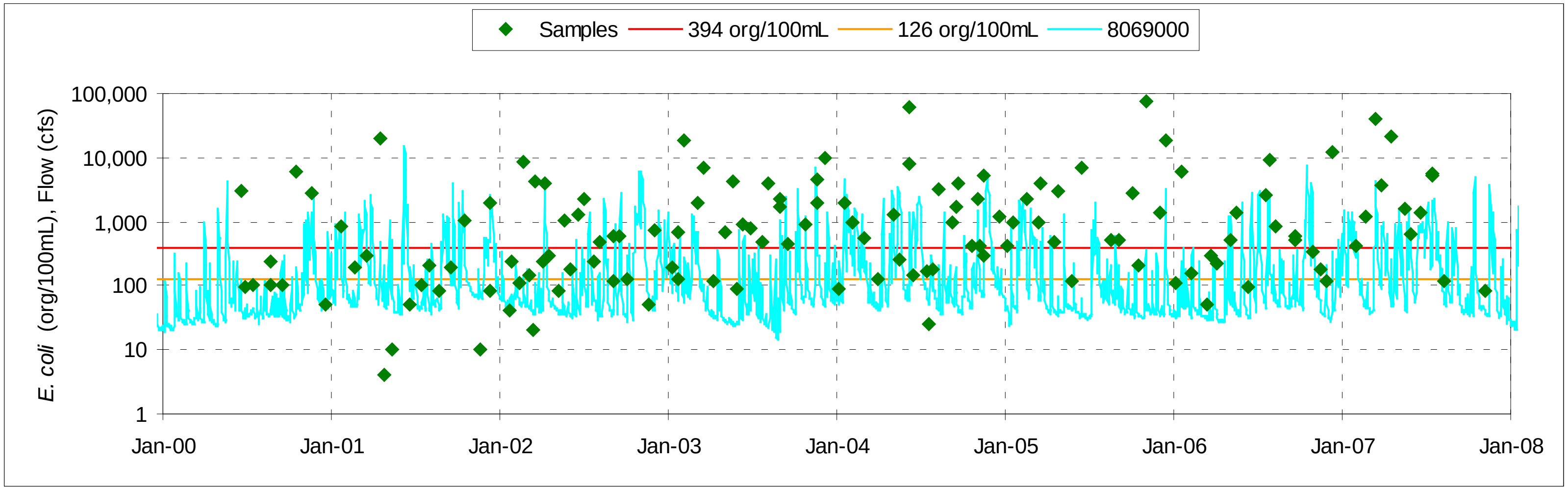

Figure 3-7: *E. coli* and Flow, Cypress Creek at IH 45 (#11328)

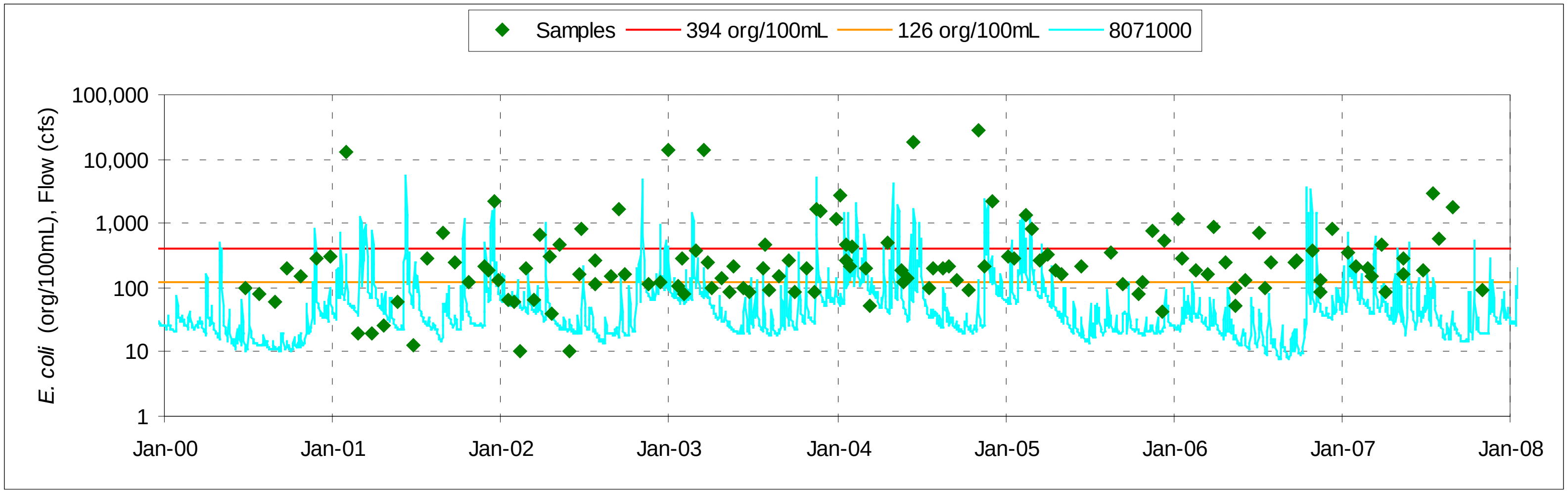

Figure 3-8: *E. coli* and Flow, Peach Creek at FM 1485 (#11336)

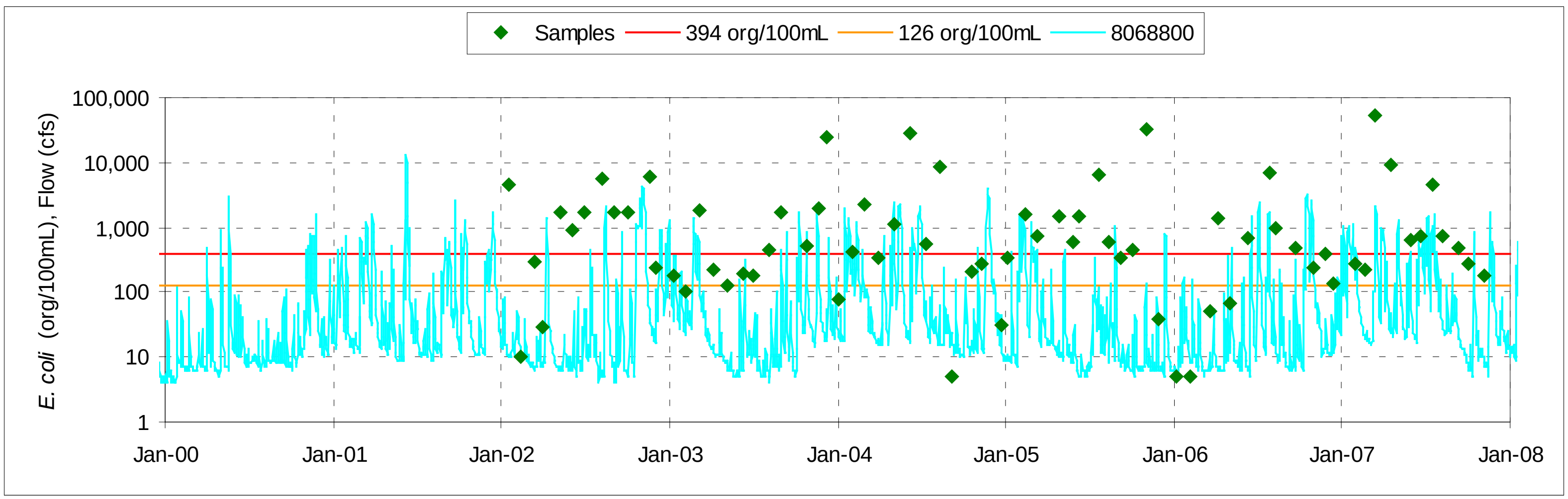

Figure 3-9: *E. coli* and Flow, Little Cypress Crk. at Kluge Rd. (#14159)

3.3 TMDL PROJECT SAMPLING

As part of the TMDL project, supplemental water quality monitoring activities were performed to help identify potential sources of bacteria contamination and to provide additional data for determining TMDL allocations. The monitoring activities included the collection of bacteria samples throughout each of the impaired segments. Project sampling activities occurred in 2007, 2008, and 2009.

The scope of the monitoring activities was developed in a TCEQ-approved Monitoring Plan (JMA, 2007). In general, the monitoring plan included activities to assess the extent of impairment, provide data to support the technical analysis of problems, identify potential sources of contamination, and support the determination of loadings essential to TMDL development.

This section provides a summary of important monitoring results. More detailed sampling data can be found in other project reports (JMA, 2008; JMA, 2009).

3.3.1 Spatial Variability of Instream Sampling Results

The 2007-2008 sampling included two sets of synoptic surveys, which covered all of the TMDL segments included in this report, and other segments which are being considered for TMDL development. During the synoptic surveys, samples were collected from all historical monitoring sites, as well as some new sites, and selected wastewater outfalls. All samples were collected under baseflow conditions (not influenced by rainfall runoff) over a relatively short time period.

For the sake of brevity, the discussion of spatial variability presented in this section will be limited to the segment scale. Figures 3-10 and 3-11 present the instream synoptic sampling results, by segment, from west to east across the Lake Houston Watershed. The statistics presented in these figures are based on samples collected at multiple locations across the subject stream segments. The results are interesting because they appear to be at odds with much of the historical data. The historical data generally suggest that *E. coli* levels are highest in the more highly urbanized areas, such as the Spring Creek and Cypress Creek watersheds. However, the synoptic survey results presented here suggest that *E. coli* levels were highest in the more rural, eastern watersheds. This may be a result of the relatively dry, baseflow conditions in which the synoptic surveys were conducted. At some monitoring sites in the eastern watersheds, a chlorine residual was actually present in the stream proper, indicative of how wastewater discharges dominate the baseflow of these more highly urbanized areas.

Examination of synoptic sampling results on a finer, station-level resolution, generally did not reveal any clear spatial patterns. This underscores the highly variable nature of *E. coli* concentrations, and the need to define bacteria TMDLs at a fine level of spatial resolution.

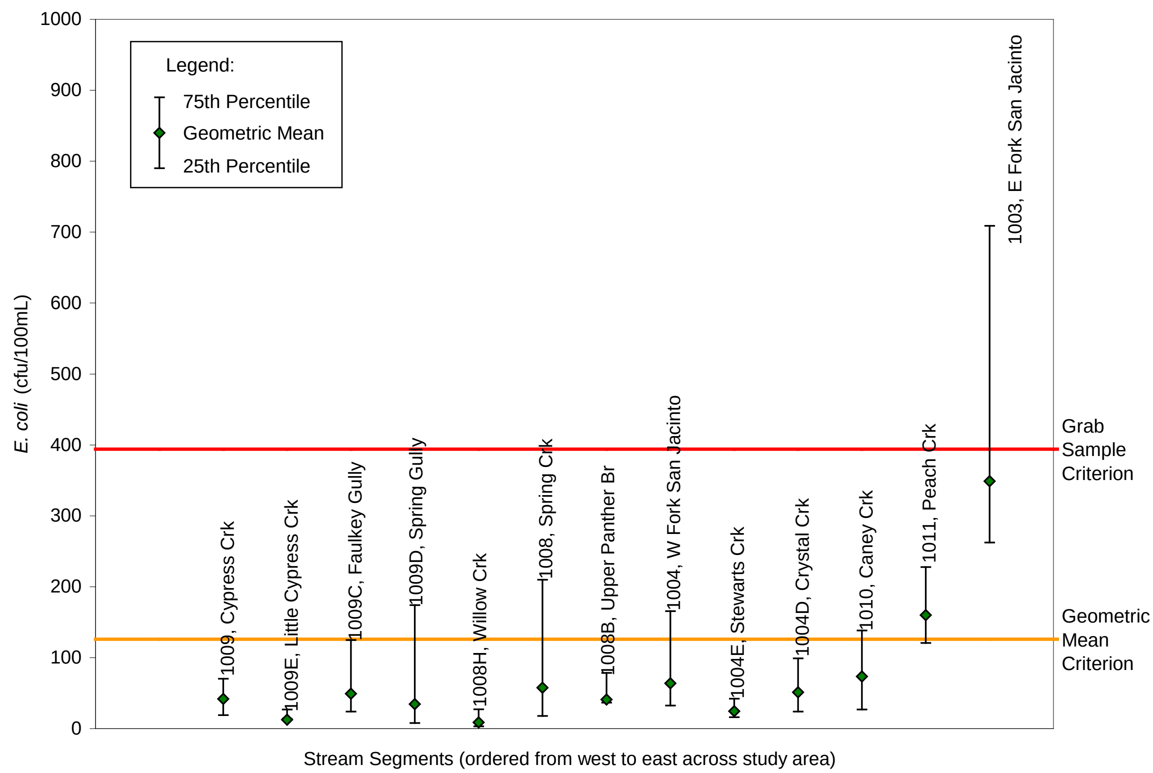

Figure 3-10: In-stream Synoptic Results by Segment, Nov. 2007

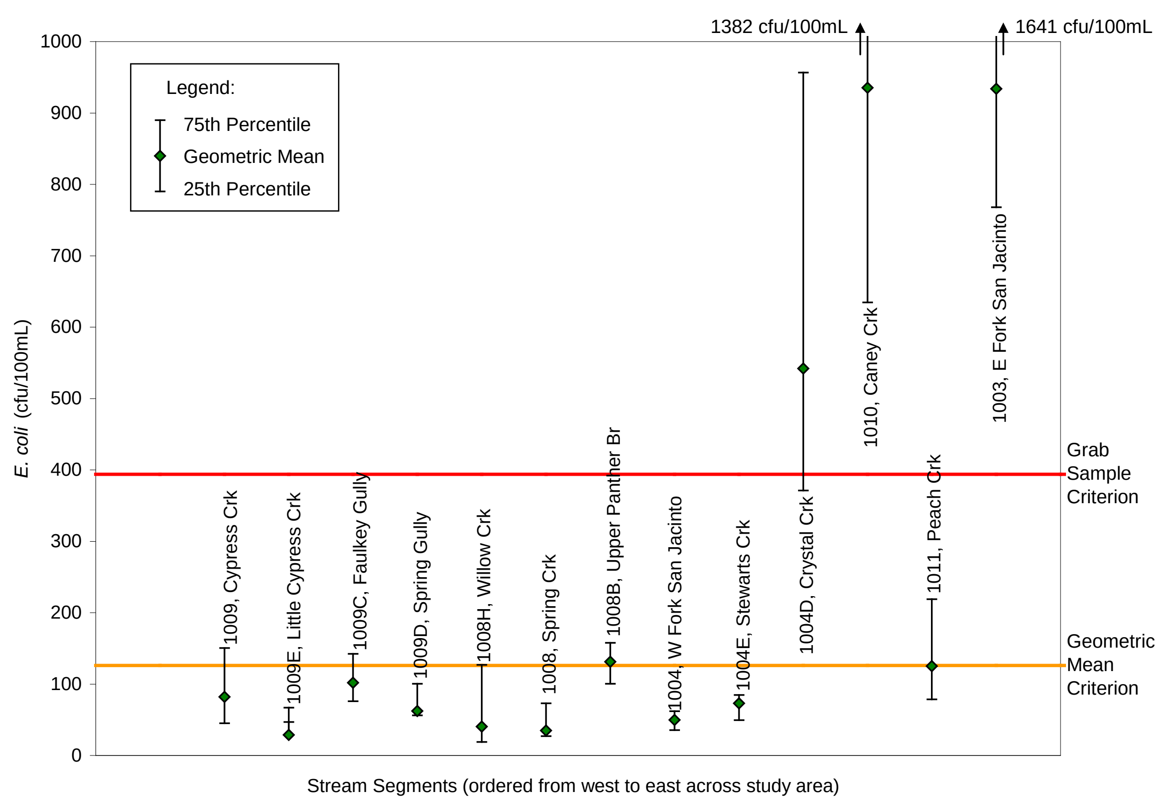

Figure 3-11: In-stream Synoptic Results by Segment, Jun. 2008

3.3.2 WWTF Sampling Results

Thirty-seven WWTF samples were collected during the two synoptic surveys. The results for these surveys are presented graphically in Figures 3-12 and 3-13. The two highest bacteria counts were from WWTFs in the Peach Creek (>20,000 cfu/dL) and Caney Creek (2,500 cfu/dL) watersheds, during the November 2007 survey. In the November survey, six WWTFs had bacteria counts of greater than 100 cfu/100mL, while in the June survey, only two WWTFs had such high bacteria levels.

Chlorine residuals were also measured at the WWTF outfalls. For facilities that were not required to dechlorinate, chlorine residuals ranged from <0.05 mg/L to >3.5 mg/L (the reporting limits of the test). High bacteria counts were not observed in any discharges with chlorine residuals of greater than 0.5 mg/L.

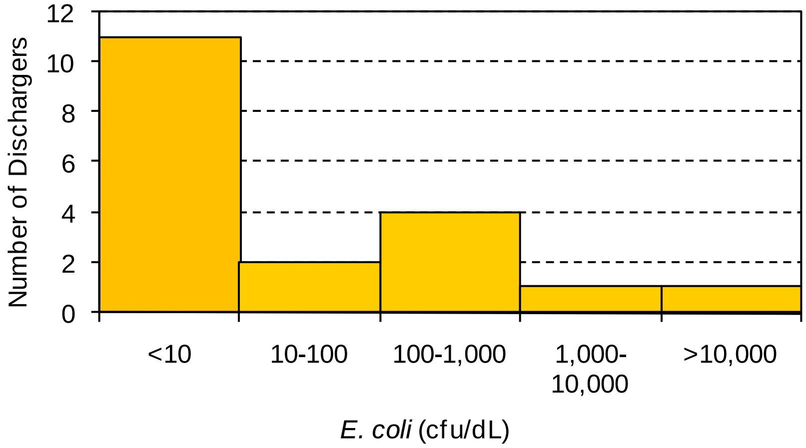

Figure 3-12: WWTF Synoptic Sampling Histogram, Nov. 2007

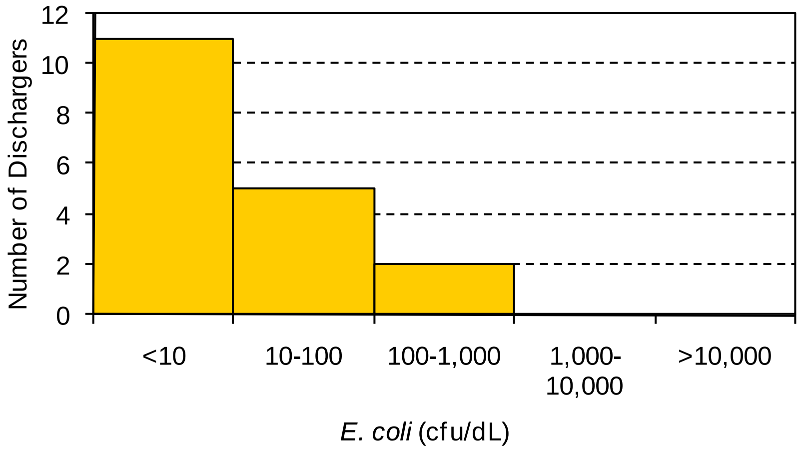

Figure 3-13: WWTF Synoptic Sampling Histogram, Jun. 2008

Additional WWTF sampling was performed in the Willow Creek watershed. One survey was conducted during dry weather in May 2008, and the other survey was conducted during a rainfall event in February 2008. The results are provided graphically in Figures 3-14 and 3-15. In the dry weather survey, none of the 13 WWTFs had discharges with more than 100 cfu/dL. However, in the wet weather survey, four of the 13 facilities had discharges exceeding 100 cfu/dL. These results suggest that the disinfection systems of some WWTFs may not adequately handle wet weather events. Table 3-6 presents a complete inventory of WWTF sampling conducted over the course of the project.

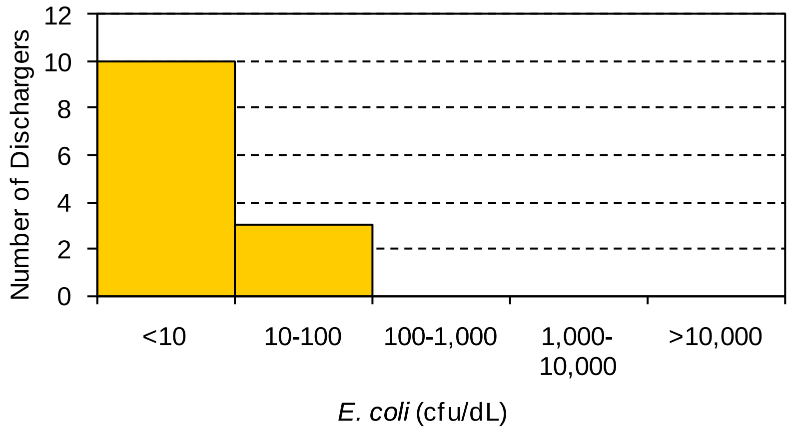

Figure 3-14: Dry Weather WWTF Sampling Histogram, Willow Creek, May 2008

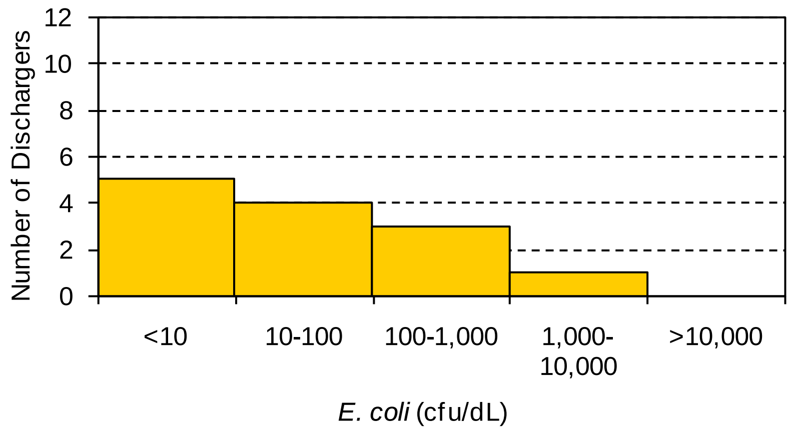

Figure 3-15: Wet Weather WWTF Sampling Histogram, Willow Creek, Feb. 2008

Table 3-6: Project Sampling at WWTFs

TX Permit ID	EPA Permit ID	Facility Name	Date	Time	*E. coli* (cfu/dL)	Cl_2 (mg/L)
Segment: 1003						
10766-001	TX0053473	City of Cleveland	2-Nov-07	12:32	2	-
10766-001	TX0053473	City of Cleveland	4-Jun-08	10:51	7	1.60
Segment: 1004D						
00584-000	TX0005592	Huntsman Petrochemical Corp	5-Jun-08	11:48	845	<0.05
Segment: 1008B						
12597-001	TX0091715	The Woodlands WWTF	7-Nov-07	15:50	106	<0.05
12597-001	TX0091715	San Jacinto River Authority	13-Jun-08	13:43	65	0.06
14141-001	TX0120073	Aqua Development, Inc	7-Nov-07	15:55	<1	>3.5
14141-001	TX0120073	Aqua Development, Inc	13-Jun-08	12:35	53	<0.05
Segment: 1008H						
10616-002	TX0117595	City of Tomball	8-Nov-07	12:12	1	0.08
10616-002	TX0117595	City of Tomball	12-Feb-08	13:48	2	<0.05
10616-002	TX0117595	City of Tomball	13-May-08	14:38	2	<0.05
10616-002	TX0117595	City of Tomball	18-Jun-08	10:54	7	<0.05
10910-001	TX0058548	Northampton MUD	8-Nov-07	9:27	<1	>3.5
10910-001	TX0058548	Northhampton MUD	12-Feb-08	17:35	4	1.3
10910-001	TX0058548	Northhampton MUD	13-May-08	9:23	<1	>3.5
10910-001	TX0058548	Northampton MUD	18-Jun-08	12:35	57	0.9
11404-001	TX0026255	Dowdell PUD	8-Nov-07	11:30	1	2
11404-001	TX0026255	Dowdell PUD	12-Feb-08	16:38	74	0.9
11404-001	TX0026255	Dowdell PUD	13-May-08	17:39	1	3.5
11404-001	TX0026255	Dowdell PUD	18-Jun-08	11:40	1	>3.5
11630-001	TX0058530	Harris Co. MUD #1	12-Feb-08	16:16	230	0.8
11630-001	TX0058530	Harris Co. MUD #1	14-May-08	9:03	15	0.9
12044-001	TX0078433	Harris Co. MUD #368	12-Feb-08	14:16	1	>3.5
12044-001	TX0078433	Harris Co. MUD #368	13-May-08	12:19	8	1.4
12153-001	TX0081264	NW Harris Co. MUD #19	12-Feb-08	17:03	68	>3.5
12153-001	TX0081264	NW Harris Co. MUD #19	14-May-08	10:25	9	>3.5
12519-001	TX0089915	Timberwilde (Aqua Utilities)	12-Feb-08	16:00	220	0.5
12519-001	TX0089915	Timberwilde (Aqua Utilities)	14-May-08	9:32	43	3
12643-001	TX0091987	Pinewood Community LP	12-Feb-08	16:15	<1	3.0
12643-001	TX0091987	Pinewood Community LP	13-May-08	17:31	<1	2.2
13487-001	TX0119628	Timbercrest Community LP	12-Feb-08	16:39	31	2.4
13487-001	TX0119628	Timbercrest Community LP	14-May-08	8:25	2	2.8
13619-001	TX0083976	Willow Oaks (Aqua Utilities)	12-Feb-08	17:07	240	0.25
13619-001	TX0083976	Willow Oaks (Aqua Utilities)	13-May-08	17:14	<1	3.5
13942-001	TX0117633	Inline Utilities Inc.	12-Feb-08	14:43	8500	0.2
13942-001	TX0117633	Inline Utilities Inc.	13-May-08	10:25	5	0.3
14421-001	TX0125687	Harris Co. MUD #401	12-Feb-08	15:48	73	0.4
14421-001	TX0125687	Harris Co. MUD #401	13-May-08	9:53	33	0.7
14475-001	TX0126152	NW Harris Co. MUD #19	12-Feb-08	15:54	6	0.3
14475-001	TX0126152	NW Harris Co. MUD #19	13-May-08	16:42	3	0.4

Table 3-6 (continued): Project Sampling at WWTFs

TX Permit ID	EPA Permit ID	Facility Name	Date	Time	*E. coli (cfu/dL)*	Cl_2 (mg/L)
		Segment: 1009C				
11832-001	TX0072354	Faulkey Gully MUD	9-Nov-07	12:12	300	0.1
11832-001	TX0072354	Faulkey Gully MUD	19-Jun-08	11:45	52	<0.05
11939-001	TX0075795	Northwest Harris Co MUD #15	9-Nov-07	15:24	174	<0.05
11939-001	TX0075795	Northwest Harris Co MUD #15	19-Jun-08	12:20	310	<0.05
12600-001	TX0091171	Elite Computer Consultants, LP	19-Jun-08	14:58	4	2.3
		Segment: 1009D				
12025-002	TX0077941	Bilma PUD	8-Nov-07	15:11	1	1.8
12025-002	TX0077941	Bilma PUD	26-Mar-08	11:56	<1	1.3
12025-002	TX0077941	Bilma PUD	18-Jun-08	15:10	2	1.9
12025-002	TX0077941	Bilma PUD	18-Mar-09	12:00	1	3.25
12025-002	TX0077941	Bilma PUD	14-Apr-09	11:12	<1	>3.5
12025-002	TX0077941	Bilma PUD	21-May-09	9:02	12	1.5
12025-002	TX0077941	Bilma PUD	11-Jun-09	8:40	2	1.3
12025-002	TX0077941	Bilma PUD	16-Jul-09	8:56	33	2.2
13152-001	TX0098647	Northwest Harris Co MUD #32	8-Nov-07	15:55	718	<0.05
13152-001	TX0098647	NWHC MUD #32	25-Mar-08	10:42	6	1.7
13152-001	TX0098647	NWHC MUD #32	27-Mar-08	10:03	8000	0.4
13152-001	TX0098647	Northwest Harris Co MUD #32	18-Jun-08	15:35	68	1.4
13152-001	TX0098647	NWHC MUD #32	18-Mar-09	8:06	97	1.7
13152-001	TX0098647	NWHC MUD #32	14-Apr-09	7:13	14	1.8
13152-001	TX0098647	NWHC MUD #32	21-May-09	11:24	<1	>3.5
13152-001	TX0098647	NWHC MUD #32	11-Jun-09	11:15	<1	>3.5
13152-001	TX0098647	NWHC MUD #32	16-Jul-09	11:37	14200	0.1
		Segment: 1009E				
11824-001	TX0072346	Northwest Harris County MUD #5	9-Nov-07	12:35	8	1.7
11824-001	TX0072346	Northwest Harris County MUD #5	19-Jun-08	11:43	<1	>3.5
11887-001	TX0073393	Grant Rd PUD	9-Nov-07	13:36	<1	2
11887-001	TX0073393	Grant Rd PUD	19-Jun-08	12:37	420	0.2
13753-001	TX0113107	Harris Co MUD #360	9-Nov-07	15:10	<1	>3.5
13753-001	TX0113107	Harris Co MUD #360	19-Jun-08	14:12	2	1.8
		Segment: 1010				
12274-001	TX0084638	New Caney MUD	2-Nov-07	16:10	25	0.08
13690-001	TX0111473	Conroe ISD	2-Nov-07	13:20	2500	0.20
13690-001	TX0111473	Conroe ISD	5-Jun-08	10:35	<1	3.25
14029-001	TX0117145	Lone Star Ranch	2-Nov-07	15:15	19	>3.5
14029-001	TX0117145	Lone Star Ranch	5-Jun-08	7:58	1	>3.5
		Segment: 1011				
11386-001	TX0078344	Montgomery Co MUD #16	2-Nov-07	16:35	2	2.80
11993-001	TX0077241	City of Woodbranch Village	2-Nov-07	17:15	>20000	<0.05
11993-001	TX0077241	City of Woodbranch Village	4-Jun-08	16:15	5	0.07
13638-001	TX0093220	Roman Forest Consolidated MUD	2-Nov-07	17:20	1	2.50
13638-001	TX0093220	Roman Forest Consolidated MUD	4-Jun-08	16:02	1	1.00

3.3.3 Drainage Outfall Sampling Results

The vast majority of drainage outfall samples were collected along Spring Gully, in a series of surveys conducted in 2008 and 2009. The first major survey of Spring Gully was in March of 2008, which included numerous instream samples as well. During this survey, the median in-stream bacteria concentration was 80 cfu/dL and the median drainage outfall concentration was 360 cfu/dL. Figure 3-16 presents a histogram of outfall sampling results. As shown, most of the outfalls had *E. coli* counts greater than 100 cfu/dL. Flow rates from these outfalls were low, typically ranging from 0.002 to 0.02 cfs.

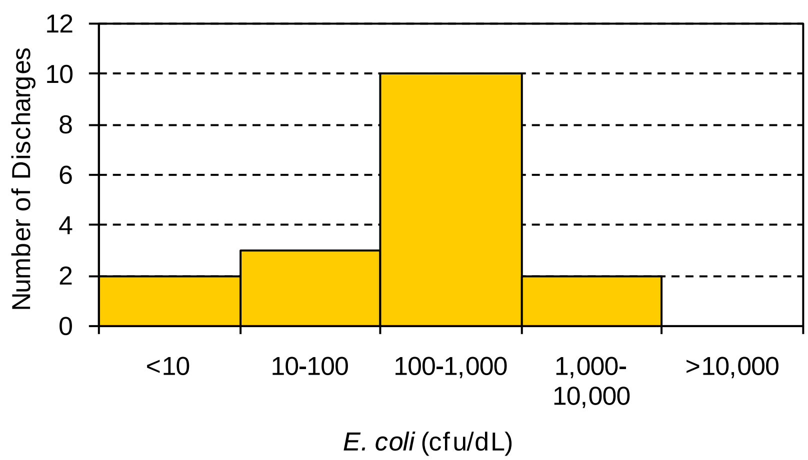

Figure 3-16: Drainage Outfall Sampling Histogram, Spring Gully, March 2008

The second major sampling event of Spring Gully outfalls included monthly surveys from March to July 2009. During these surveys, the median in-stream bacteria concentration was 76 cfu/dL and the median drainage outfall concentration was 210 cfu/dL. Figure 3-17 presents a histogram of outfall sampling results. As shown, most of the outfalls had *E. coli* counts greater than 100 cfu/dL. Flow rates from these outfalls were similar to those encountered in the March 2008 survey. More detailed samplings data and discussion can be found in the project report (see JMA, 2009).

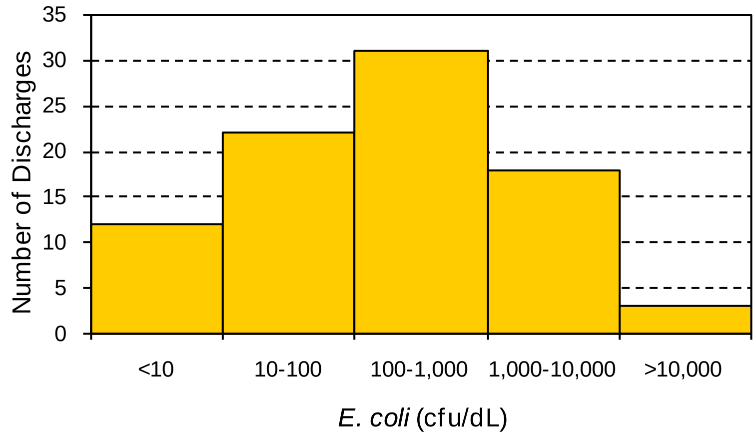

Figure 3-17: Drainage Outfall Sampling Histogram, Spring Gully, March-July 2009

3.3.4 Results of Sediment Studies

Sediment Source Study Results

Sediment erosion is one suspected source of *E. coli* loading. To investigate this possibility, sediment samples were collected along the East Fork San Jacinto River, Stewarts Creek, Willow Creek, and Spring Gully. A summary of the results is provided in Figure 3-18 (counts reported per gram of sediment – dry weight). Bacteria counts were generally highest near the stream bank. Moving away from the stream bank, bacteria counts generally decreased. Willow Creek had the highest bacteria counts near the stream bank (2,123 cfu/g). The East Fork had the highest bacteria counts at distances further from the bank (273 cfu/g at 50 feet). Based on typical instream suspended sediment concentrations (less than 0.01 g/dL during baseflow conditions, and around 0.1 g/dL during periods of intense runoff), these values do not suggest that sediment erosion is a major cause of the bacteria impairments.

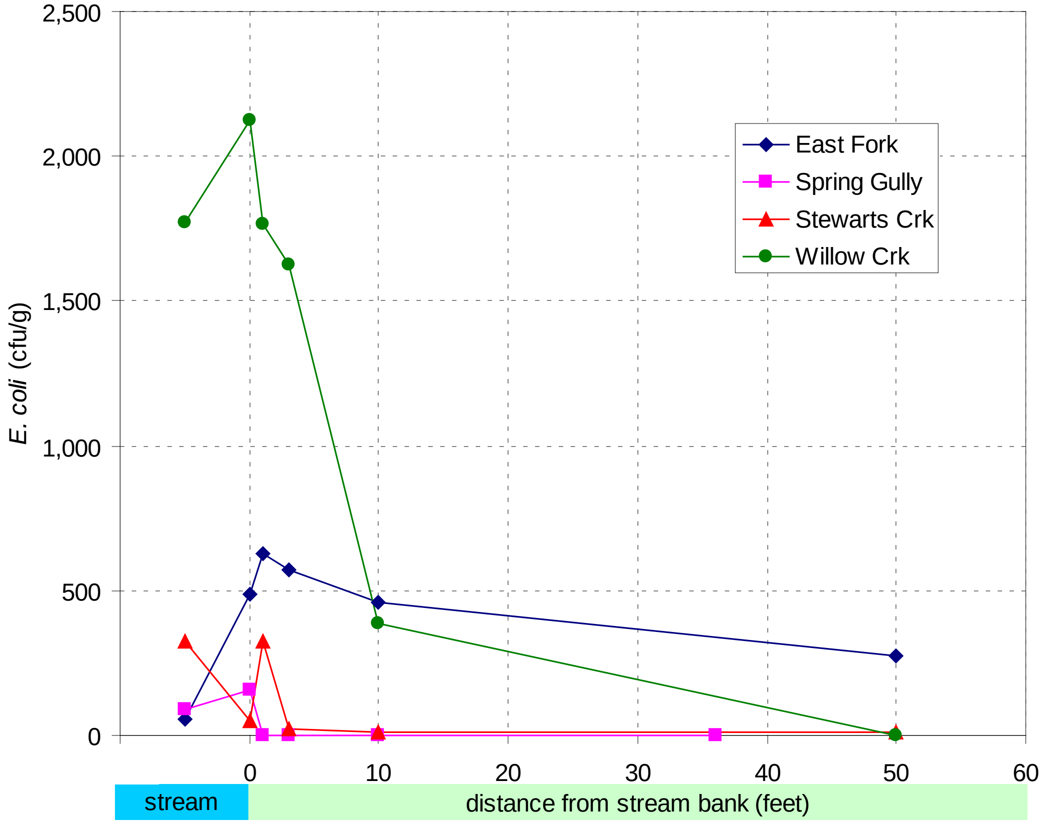

Figure 3-18: Sediment Sampling Results Summary

Resuspension Study Results

The resuspension of stream bed sediments is another suspected source of bacteria loading. Resuspension studies were conducted on Spring Gully and Willow Creek (two studies on Spring Gully and one on Willow Creek). The immediate effect of sediment resuspension on bacteria levels varied from study to study. Only one study suggested bacteria levels increased significantly (to around 1,000 cfu/dL) following resuspension (another study suggested no increase, and the third study was inconclusive). A bacteria count of around 1,000 cfu/dL is a relatively high value for baseflow conditions, but it is not unusually high under storm flow conditions when sediment resuspension would be most likely to occur.

4.0 SOURCE CHARACTERIZATION AND ASSESSMENT

The TMDL development described in this report included examination of potential sources of bacteria loading in the Lake Houston watershed. The potential sources include both point and nonpoint sources. To characterize and evaluate the sources, a variety of information was employed, including agricultural and land use information, water quality monitoring and point source data, past TMDL studies, literature sources, and input from State and local management agencies. This section documents the available information and its interpretation.

4.1 POINT SOURCES

Point sources have traditionally been defined as loading sources that enter a waterbody at a specific geographic point. In recent years, the definition of point sources has been expanded to include any discharge from a permitted entity. Permits for point sources are administered through the National Pollution Discharge Elimination System (NPDES) and the Texas Pollution Discharge Elimination System (TPDES).

There are two types of point sources in the study area with the potential to contribute significant bacteria loads. The first type is wastewater treatment facilities (WWTFs), and the second type is municipal separate storm sewer systems (MS4s).

4.1.1 Wastewater Treatment Facilities (WWTFs)

WWTFs can contribute bacteria loads to surface water streams through effluent discharges. There are numerous WWTFs located in the study watershed, and virtually all of them are used to treat domestic sewage. Since raw sewage has high levels of pathogens, an important part of the treatment process is the elimination of bacteria (including *E. coli*) and other microbes through disinfection. Chlorination is the primary type of disinfection used in the study area, though some WWTFs use ultraviolet (UV) radiation. Disinfection is required by TPDES permit for all municipal WWTFs.

WWTFs are tabulated in Tables 4-1, 4-2, 4-3, and 4-4, for the Spring, Cypress, Caney, and Peach Creek watersheds, respectively. The WWTFs are listed by the TCEQ Record ID, which corresponds to the IDs mapped in Figures 3-1 through 3-3. The WWTF data were obtained from the TCEQ and EPA. However, a few of the WWTFs listed may still be in the design or construction phase. WWTFs with a current flow value of zero generally fall into this category.

Table 4-5 provides a summary of the WWTF information for each TMDL Segment. As shown, Stewarts Creek is the only impaired segments with no WWTF discharges. In contrast, Cypress Creek has over 100 WWTFs (inclusive of the Spring Gully, Faulkey Gully, and Little Cypress subsegments).

Table 4-1: WWTFs in Spring Creek Watershed

TCEQ Record #	TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	Current Flow (MGD)	Monit. Req'd
			Assessment Unit: 1008_02				
2936	11871-001	TX0072702	City of Magnolia	Montgomery	0.65	0.27	C
3131	12402-001	TX0086053	Houston Oaks Golf Management, LP	Waller	0.01	0.00	C
3241	12898-001	TX0095125	Aqua Utilities, Inc	Montgomery	0.08	0.03	C
3293	13115-001	TX0097969	Clovercreek MUD	Montgomery	0.12	0.03	C
3434	13653-001	TX0110663	Magnolia ISD	Montgomery	0.02	0.00	C
3590	14007-001	TX0117846	AquaSource Development Co	Montgomery	0.13	unk	C
3661	14133-001	TX0119857	White Oak Utilities, Inc	Montgomery	0.20	0.04	C
3740	14266-001	TX0094315	HMV Special Utility District	Montgomery	0.03	0.03	C
4185	14542-001	TX0126934	1774 Utilities, Corp	Montgomery	0.15	0.01	C
4029	14624-001	TX0127973	Rosehill Utilities, Inc	Waller	0.02	unk	C
			Assessment Unit: 1008_03				
2386	10616-001	TX0022381	City of Tomball	Harris	1.50	0.67	C
2538	10857-001	TX0025399	Montgomery Co WCID #1	Montgomery	0.42	0.24	C
2974	11968-001	TX0077275	Tecon Water Company, LP	Montgomery	0.05	unk	C
3098	12303-001	TX0085693	Aqua Utilities, Inc	Harris	0.02	0.01	C
3124	12382-001	TX0087475	C&P Utilities, Inc/□ J&S Water Company, LLC5	Harris	0.12	0.07	C
3168	12587-001	TX0090905	Tecon Water Company, LP	Montgomery	0.46	unk	C
3185	12650-001	TX0092088	Spring Oaks Mobile Home Park, Inc.	Harris	0.03	0.01	C
3231	12851-001	TX0094552	Richard Clark Enterprises, LLC	Montgomery	0.06	unk	C
3412	13614-001	TX0108553	Richfield Investment Corp	Montgomery	0.61	unk	C
3425	13636-001	TX0109622	Richfield Investment Corp	Montgomery	0.41	unk	C
3433	13648-001	TX0042099	Encanto Real UD	Harris	0.25	0.08	C
3517	13863-001	TX0115827	H.H.J., Inc	Montgomery	0.80	0.00	C
3657	14124-001	TX0119598	Magnolia ISD	Montgomery	0.02	0.07	C
3711	14218-001	TX0123587	Diocese of Galveston-Houston	Montgomery	0.02	0.01	F
3789	14347-001	TX0124907	The Woodlands Land Development Co. LP	Harris	unk	unk	unk
3876	14491-001	TX0126306	Is Zen Center	Montgomery	0.04	0.00	C
3894	14517-001	TX0125547	South Central Water Company	Harris	0.04	0.00	C
3917	14551-001	TX0127035	AUC Group, LP	Montgomery	0.95	unk	C
3987	14592-001	TX0127663	South Central Water Company	Montgomery	0.32	0.00	C
4192	14662-001	TX0128333	Navasota ISD	Grimes	0.02	0.00	C
4202	14684-001	TX0128520	Jason Andrew Thompson	Montgomery	unk	0.00	unk
4275	14711-001	TX0128821	Maw Magnolia LTD	Montgomery	unk	0.00	unk
			Assessment Unit: 1008_04				
2567	10908-001	TX0020974	Harris County WCID #92	Harris	0.70	0.42	C
2607	11001-001	TX0024759	Southern Montgomery County MUD	Montgomery	2.00	0.97	C
2779	11406-001	TX0056537	Harris Co. MUD #26	Harris	1.50	0.54	C
2848	11574-001	TX0026221	Spring Creek UD	Montgomery	0.93	0.44	C
2909	11799-001	TX0071528	Harris Co. MUD #82	Harris	2.20	0.46	C
2976	11970-001	TX0076538	Montgomery Co. MUD #19	Montgomery	0.72	unk	C
2999	12030-001	TX0078263	Rayford Road MUD	Montgomery	0.00	unk	C
3181	12637-001	TX0091791	Spring Center, Inc	Harris	0.01	0.00	C
3217	12788-001	TX0095621	Eastwood Mobile Home Park LP	Montgomery	0.05	0.01	C
3260	12979-004	TX0119181	Northgate Crossing MUD #2	Harris	0.95	0.19	C
4161	14656-001	TX0128295	Montgomery Co MUD #94	Montgomery	1.08	unk	C
			Assessment Unit: 1008C_01				
2775	11401-001	TX0054186	San Jacinto River Authority	Montgomery	7.80	unk	C
3169	12597-001	TX0091715	San Jacinto River Authority	Montgomery	7.80	3.28	F
3199	12703-001	TX0092843	Magnolia ISD	Montgomery	0.05	0.01	C
3449	13697-001	TX0090000	Cedarstone One Investors, Inc	Montgomery	0.00	0.00	C
3594	14013-001	TX0118028	AquaSource Development Co	Montgomery	0.05	unk	C
3665	14141-001	TX0120073	Aqua Development, Inc	Montgomery	0.45	unk	C
			Assessment Unit: 1008H_01				
2387	10616-002	TX0117595	City of Tomball	Harris	1.50	0.90	C
2568	10910-001	TX0058548	Northampton MUD	Harris	0.75	0.38	C
2777	11404-001	TX0026255	Dowdell PUD	Harris	0.95	0.23	C
2867	11630-001	TX0058530	Harris Co. MUD #1	Harris	1.50	0.25	C
3002	12044-001	TX0078433	Harris Co MUD #368	Harris	1.60	0.46	C
3049	12153-001	TX0081264	North Harris Co MUD #19	Harris	0.25	0.10	C
3156	12519-001	TX0089915	Aquasource Utility, Inc	Harris	0.10	0.03	C
3183	12643-001	TX0091987	Pinewood Community LP	Harris	0.10	0.06	C
3365	13487-001	TX0119628	Timbercrest Community Association	Harris	0.20	0.07	C
3414	13619-001	TX0083976	Aqua Utilities, Inc	Harris	0.04	0.02	C
3558	13942-001	TX0117633	Inline Utilities, LLC	Harris	0.25	0.10	C
3689	14181-001	TX0122530	Aqua Development, Inc	Harris	0.08	0.02	C
3833	14421-001	TX0125687	2920 Venture, LTD/□Harris County MUD #4014	Harris	0.60	0.00	C
3867	14475-001	TX0126152	Northwest Harris Co. MUD #19	Harris	0.70	0.00	C
4018	14606-001	TX0127795	South Central Water Company	Harris	0.08	0.00	C
4030	14610-001	TX0127850	501 Maple Ridge, LTD	Harris	0.64	0.00	C

Source: TCEQ Central Records & EPA Envirofacts, June 2007
C=chlorine residual, F=fecal coliform, N=none, unk=unknown

Table 4-2: WWTFs in Cypress Creek Watershed

TCEQ Record #	TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	Current Flow (MGD)	Monit. Req'd
Assessment Unit: 1009_01							
2066	01310-001	TX0032476	City of Waller	Waller	0.90	unk	C
3319	13296-002	TX0105376	Harris Co MUD #358	Harris	2.00	0.79	C
3850	14448-001	TX0125938	Houston Warren Ranch Partners, LLC	Harris	0.55	0	C
4007	14576-001	TX0127311	523 Venture, Inc/□Becker Road LP[3]	Harris	0.20	0	C
Assessment Unit: 1009_02							
1069	02608-000	TX0092258	Center Point Energy Houston Electric LLC	Harris	0.02	0.002	N
2591	10962-001	TX0062049	Harris County WCID #113	Harris	0.30	0.11	C
2641	11084-001	TX0046833	Lake Forest Plant Advisory Council	Harris	2.76	1.33	C
2719	11267-001	TX0046868	Timberlake ID	Harris	0.40	0.26	C
2952	11912-002	TX0075159	Northwest Harris Co MUD #10	Harris	1.50	0.48	C
2982	11986-001	TX0076791	Tower Oak Bend WSC	Harris	0.05	unk	C
3107	12327-001	TX0086011	Cypress Hill MUD #1	Harris	0.80	0.38	C
3159	12541-001	TX0090182	Chasewood Utilities, Inc	Harris	0.10	0.02	C
3237	12877-001	TX0094706	Harris Co MUD #230	Harris	0.76	0.20	C
3268	13020-001	TX0096920	Harris Co MUD #286	Harris	0.60	0.21	C
3284	13059-001	TX0098434	Kwik-Kopy Corp	Harris	0.02	0.008	C
3529	13881-001	TX0116009	Harris Co MUD #365	Harris	1.20	0.53	C
3604	14028-001	TX0117129	Harris Co MUD 371	Harris	0.25	0.10	C
3606	14030-001	TX0075221	Northwest Harris Co MUD #9	Harris	1.50	0.51	C
3660	14130-001	TX0081272	Northwest Harris Co MUD #10	Harris	0.05	0.001	C
3684	14172-001	TX0121126	Utilities Investment Company, Inc	Harris	0.18	0.06	C
3704	14209-001	TX0123366	CTP Utilities Inc	Harris	0.18	0	C
3779	14327-001	TX0124770	Harris Co. MUD #391	Harris	0.95	0.16	C
3794	14354-001	TX0124974	Harris Co. MUD #374	Harris	0.65	unk	C
3868	14476-001	TX0126161	Rouse-Houston, LP	Harris	0.80	0.03	C
Assessment Unit: 1009_03							
1700	04313-000	TX0113948	Northwest Airport Management LP	Harris	variable	unk	N
2313	10528-001	TX0026450	Harris Co. FWSD # 52	Harris	0.70	0.32	C
2589	10955-001	TX0046710	Harris County WCID #116	Harris	1.30	0.65	C
2616	11024-001	TX0021211	Harris Co WCID #119	Harris	1.00	0.42	C
2640	11081-001	TX0046761	Ponderosa Joint Powers Agency	Harris	4.87	2.90	C
2643	11089-001	TX0046701	Prestonwood Frest UD	Harris	0.95	0.32	C
2652	11105-001	TX0046639	Bammel UD	Harris	2.60	1.06	C
2700	11215-001	TX0046663	Meadowhill Regional MUD	Harris	2.40	0.52	C
2710	11239-001	TX0055166	CNP UD	Harris	2.50	0.86	F
2744	11314-001	TX0046744	Aqua Texas, Inc	Harris	0.40	unk	C
2760	11366-001	TX0046779	Cypress-Klein UD	Harris	0.70	0.31	C
2781	11409-001	TX0046817	Kleinwood Joint Powers Board	Harris	5.00	2.16	C
2782	11410-002	TX0046841	Charterwood MUD	Harris	1.60	0.28	C
2923	11835-001	TX0072150	Bridgestone MUD	Harris	2.50	0.85	C
2946	11900-001	TX0074217	Tina Lee Tilles DBA Turk Brothers Building	Harris	0.00	0.0004	C
2960	11925-001	TX0074632	Harris Co MUD #104	Harris	0.60	0.20	C
2965	11941-001	TX0074322	Harris Co MUD #58	Harris	0.60	0.12	C
2972	11964-001	TX0076481	Harris Co WCID #110	Harris	1.00	0.49	C
2984	11988-001	TX0076856	Harris Co MUD #24	Harris	2.00	0.62	C
2985	11988-002	TX0113123	Harris Co MUD #24	Harris	0.06	0.03	N
2986	11988-003	TX0113115	Harris Co MUD #24	Harris	0.06	0.06	N
3079	12248-001	TX0084760	UA Holdings 1994-5	Harris	0.10	0.03	C
3206	12730-001	TX0090344	Champ's Water Company	Harris	0.02	0.003	C
3393	13569-001	TX0078930	Samuel Victor Pinter	Harris	0.00	0.0002	C
3394	13573-001	TX0108120	Northwest Harris County MUD #36	Harris	0.20	0.11	C
3418	13625-001	TX0081337	Northwest Harris Co MUD #20	Harris	0.40	0.60	C
3527	13875-002	TX0115983	Harris Co MUD #383	Harris	1.50	0.55	C
3537	13893-001	TX0122211	Dia-Den LTD	Harris	0.02	0.002	C
3559	13942-002	TX0125466	Inline Utilities, LLC	Harris	0.10	0	C
3568	13963-001	TX0087424	Luther's Bar-B-Q, Inc.	Harris	0.01	unk	C
3616	14044-001	TX0092894	149 Enterprises, Inc	Harris	0.01	unk	C
3695	14193-001	TX0122963	Kennard Tom Foley	Harris	0.04	0.00	C
3813	14390-001	TX0125181	Huffsmith-Kohrville, Inc	Harris	0.05	0	C
Assessment Unit: 1009_04							
2499	10783-001	TX0023612	Inverness Forest ID	Harris	0.50	0.20	C
2627	11044-001	TX0046671	Memorial Hills UD	Harris	0.50	0.19	C
2665	11141-001	TX0046728	Treschwig Joint Powers Board	Harris	2.00	1.20	C
2666	11142-002	TX0046680	Timber Lane UD	Harris	2.62	0.93	F
2793	11444-001	TX0046736	Harris County WCID #99	Harris	0.23	0.09	C
2847	11572-001	TX0047775	Pilchers Property LP/□Northland Joint Venture[1]	Harris	0.06	0.03	C
2862	11618-003	TX0118371	Hunter's Glen MUD	Harris	1.40	0.36	C
2931	11855-001	TX0072567	North Park PUD	Harris	1.31	0.40	C

Source: TCEQ Central Records & EPA Envirofacts, June 2007
C=chlorine residual, F=fecal coliform, N=none, unk=unknown

Table 4-2 (continued): WWTFs in Cypress Creek Watershed

TCEQ Record #	TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	Current Flow (MGD)	Monit. Req'd
Assessment Unit: 1009_04							
2941	11886-001	TX0073105	Six Flag Splashtown L.P.	Harris	0.06	unk	C
2962	11933-001	TX0075671	Woodcreek MUD	Harris	0.60	0.23	C
3076	12239-001	TX0084085	Harris Co MUD #36	Harris	0.99	unk	C
3122	12378-002	TX0092967	Richey Rd MUD	Harris	0.45	0.32	C
3166	12579-001	TX0090824	Spring West MUD	Harris	0.76	0.10	C
3174	12614-001	TX0091481	Harris Co MUD #16	Harris	0.50	0.15	C
3221	12812-001	TX0093939	Regency 1-45/ Spring Cypress Retal, L.P.	Harris	0.06	0.002	C
3272	13027-001	TX0096865	Harris County	Harris	0.01	unk	C
3283	13054-001	TX0097209	CW-MHP Ltd	Harris	0.01	0.002	C
3453	13711-001	TX0085910	Spring Cypress WSC	Harris	0.04	0.02	C
3474	13765-001	TX0116068	Harris Co MUD #249	Harris	0.80	0.21	C
3502	13819-001	TX0113930	Arthur Edward Bayer	Harris	0.06	0	C
3644	14106-001	TX0119270	Aqua Development, Inc	Harris	0.08	unk	C
3902	14526-001	TX0031305	Spring ISD	Harris	0.03	0.001	C
4146	14644-001	TX0128198	Redfin Development Co. Inc.	Harris	unk	0	unk
4180	12470-001	TX0089184	Harris Co MUD #221	Harris	1.80	0.69	C,F
4246	14696-001	TX0128660	Loan Oak Partners LP	Harris	unk	unk	unk
Assessment Unit: 1009C_01							
2921	11832-001	TX0072354	Faulkey Gully MUD	Harris	1.42	0.67	C,F
2964	11939-001	TX0075795	Northwest Harris Co MUD #15	Harris	3.12	0.43	C
3170	12600-001	TX0091171	Elite Computer Consultants, LP	Harris	0.01	0.001	C
4063	11824-002	TX0128210	Northwest Harris Co. MUD #5	Harris	0.40	0.0	C
Assessment Unit: 1009D_01							
2998	12025-002	TX0077941	Bilma PUD	Harris	0.75	0.29	C
3069	12224-001	TX0083801	Klein ISD	Harris	0.01	0.005	C
3300	13152-001	TX0098647	Northwest Harris Co MUD #32	Harris	0.65	0.36	C
Assessment Unit: 1009E_01							
1242	03076-000	TX0118605	Skinner Nurseries, Inc.	Harris	variable	unk	F
1391	03627-000	TX0118320	Vopak Logistics Services USA, Inc	Harris	variable	0.33	N
2912	11814-001	TX0071609	Boys and Girls Country of Houston	Harris	0.10	0.02	C
2917	11824-001	TX0072346	Northwest Harris County MUD #5	Harris	0.80	0.44	C
2942	11887-001	TX0073393	Grant Rd PUD	Harris	0.31	0.17	C
2953	11913-001	TX0075183	Northwest Freeway MUD	Harris	0.45	0.15	C
3360	13472-001	TX0090841	Hockley Rail Car, Inc	Harris	0.01	0.0004	C
3469	13753-001	TX0113107	Harris Co MUD #360	Harris	0.80	0.25	C
3842	14434-001	TX0125806	Westside Water, LLC	Harris	0.10	0.02	C
3846	14441-001	TX0125881	Harris County MUD #389	Harris	0.30	0	C
4061	14643-001	TX0128180	Northwest Harris Co MUD #10	Harris	0.09	0	C
4203	14675-001	TX0128457	Quadvest, LP	Harris	0.32	0	C

Source: TCEQ Central Records & EPA Envirofacts, June 2007
C=chlorine residual, F=fecal coliform, N=none, unk=unknown

Table 4-3: WWTFs in Caney Creek Watershed

TCEQ Record #	TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	Current Flow (MGD)	Monit. Req'd
Assessment Unit: 1010_02							
2614	11020-001	TX0056685	City of New Waverly	Walker	0.09	unk	C
2615	11020-002	TX0087831	City of New Waverly	Walker	unk	unk	unk
2886	11715-001	TX0068659	Texas National MUD WWTF	Montgomery	0.08	0.01	C
3188	12670-001	TX0092517	Mountain Man, Inc./ Ranch Utilities, LP[2]	Montgomery	0.18	0.05	C
Assessment Unit: 1010_03							
3059	12204-001	TX0083216	Conroe ISD	Montgomery	0.02	0.02	C
Assessment Unit: 1010_04							
4027	01497-001	TX0127710	The Signorelli Co.	Montgomery	0.60	0.01	C
3060	12205-001	TX0083208	Conroe ISD	Montgomery	0.02	0.01	C
3089	12274-001	TX0084638	New Caney MUD	Montgomery	1.06	0.67	C
3178	12621-001	TX0091677	Martin Realty & Land, Inc	Montgomery	0.15	unk	C
3445	13690-001	TX0111473	Conroe ISD	Montgomery	0.10	0.09	C
3605	14029-001	TX0117145	LGI Housing, LLC/□Quadvest, LP6	Montgomery	0.60	0.12	C
3632	14081-001	TX0118311	Martin Realty & Land, Inc.	Montgomery	0.15	0.00	C
3633	14083-001	TX0118818	White Oak Developers, Inc.	Montgomery	0.20	0.00	F
3652	14116-001	TX0071412	Montgomery County MUD #24	Montgomery	unk	unk	unk
3753	14285-001	TX0124281	C&R Water Supply, Inc.	Montgomery	0.30	0.09	C
3806	14379-001	TX0125300	East Montgomery Co MUD #3	Montgomery	0.08	0.04	unk
3924	14559-001	TX0127094	Whitestone Houston Land, Ltd.	Montgomery	0.90	unk	C
4259	14694-001	TX0128651	Elan Development, LP	Montgomery	0.18	0.00	C

Source: TCEQ Central Records & EPA Envirofacts, June 2007
C=chlorine residual, F=fecal coliform, N=none, unk=unknown

Table 4-4: WWTFs in Peach Creek Watershed

TCEQ Record #	TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	Current Flow (MGD)	Monit. Req'd
			Assessment Unit: 1011_01				
2667	11143-001	TX0082511	Splendora ISD	Montgomery	0.04	0.02	C
2668	11143-002	TX0117463	Splendora ISD	Montgomery	0.04	0.01	C
3341	13389-001	TX0102512	City of Splendora	Montgomery	0.30	0.10	C
			Assessment Unit: 1011_02				
2768	11386-001	TX0078344	Montgomery Co MUD #16	Montgomery	0.18	0.05	C
2988	11993-001	TX0077241	City of Woodbranch Village	Montgomery	0.13	0.06	C
3427	13638-001	TX0093220	Roman Forest Consolidated MUD	Montgomery	0.32	0.17	C
3765	14311-001	TX0124583	East Montgomery Co MUD #4	Montgomery	0.75	0.00	C
3906	14536-001	TX0126853	Flying J Inc.	Montgomery	0.05	0.00	C
3925	14560-001	TX0127108	Whitestone Houston Land, Ltd.	Montgomery	0.90	unk	C

Source: TCEQ Central Records & EPA Envirofacts, June 2007
C=chlorine residual, F=fecal coliform, N=none, unk=unknown

Table 4-5: Summary of WWTFs in TMDL Segments

Watershed	# of WWTFs	Permitted Flow (MGD)	Current Flow (MGD)
Stewarts Creek (1004E)	0	0	0
Spring Creek (1008)	65	43	16
Willow Creek (1008H)	18	9.5	2.7
Cypress Creek (1009)	101	74	28
Faulkey Gully (1009C)	4	4.9	1.1
Spring Gully (1009D)	3	1.4	0.7
Little Cypress Crk (1009E)	11	3.3	1.4
Caney Creek (1010)	18	4.7	1.2
Peach Creek (1011)	9	2.7	0.4

WWTF effluent accounts for a significant portion of the flow in many of the TMDL study segments. Table 4-6 presents the median stream flow measured at USGS gages, along with the estimated discharge from WWTFs upstream of these gages. As shown, WWTF effluent accounts for over 50% of the median flow at some of these gaging sites. Only at the Peach Creek and Caney Creek gaging stations does WWTF effluent account for less than 1% of stream flow.

Table 4-6: Percent WWTF Effluent of Median Stream Flows

Station	Stream	Location	Median USGS Flow (cfs)	Current WWTF Flow (cfs)	Percent WWTF Effluent
08068275	Spring Creek	near Tomball, TX	12.5	0.64	5%
08068325	Willow Creek	near Tomball, TX	6.7	2.9	43%
08068450	Panther Branch	near Spring, TX	19	11.1	59%
08068500	Spring Creek	near Spring, TX	70	18.8	27%
08068780	Little Cypress Crk	near Cypress, TX	1.3	0.8	62%
08068800	Cypress Creek	near Cypress, TX	21	7.4	35%
08069000	Cypress Creek	near Westfield, TX	63	34.8	55%
08070500	Caney Creek	near Splendora, TX	31	0.20	0.7%
08071000	Peach Creek	at Splendora, TX	34	0.19	0.5%

4.1.2 Municipal Separate Storm Sewer Systems (MS4s)

Storm sewer systems that are inside large municipalities (with populations in excess of 100,000) and "urbanized areas" (as defined by the US Census Bureau) are required to obtain an MS4 permit from the TCEQ. The permitted MS4s located in the Lake Houston Watershed include the City of Houston metropolitan area and The Woodlands metropolitan area. Figure 4-1 provides a map of these MS4 areas. Table 4-7 tabulates the portions of the TMDL watersheds that fall within these MS4 areas.

Table 4-7: MS4 Areas within the TMDL Study Watersheds

Segment	Receiving Stream	Permit Number	Permitted Entity	MS4 Area (Acres)	MS4 Area (percent)
1004E	Stewarts Creek	WQ0004685000	Houston	0	0%
1008	Spring Creek	WQ0004685000	Houston	9,718	3%
1008	Spring Creek	TXR040256	The Woodlands	23,574	8%
1008H	Willow Creek	WQ0004685000	Houston	4,160	12%
1009	Cypress Creek	WQ0004685000	Houston	63,037	30%
1009C	Faulkey Gully	WQ0004685000	Houston	2,582	36%
1009D	Spring Gully	WQ0004685000	Houston	1,172	33%
1009E	Little Cypress Crk	WQ0004685000	Houston	2,852	8%
1010	Caney Creek	WQ0004685000	Houston	8,830	6%
1011	Peach Creek	WQ0004685000	Houston	0	0%

MS4 permits address a variety of potential sources including illicit discharges, construction site runoff, and general (post-construction) urban runoff. Illicit discharges can be a source of bacteria, especially if sanitary sewage facilities are the source of the discharge. Construction site runoff can also contribute bacteria through soil erosion. However, since construction sites make up only a small fraction of the total watershed, and since they generally do not include any large sources of bacteria, they are not expected to be a major cause of the impairment. General urban runoff generally represents the vast majority of the MS4 discharge and corresponding bacteria load.

General urban runoff is expected to be one the largest source of bacteria in the TMDL segments. With a myriad of potential contributions from humans, pets, and wildlife, the *E. coli* levels found in urban runoff are often orders of magnitude higher than what is typically found in streams under non-runoff conditions.

Urban runoff is generally more frequent and more intense than rural runoff. This is due to the large amounts of impervious area found in urban watersheds. The impervious areas (such as roads, parking lots, and buildings) prevent the rainfall from infiltrating into the soil column and underlying aquifer. Instead, most rainfall is converted to runoff, which can scour pollution from the land surface, and carry the pollutants to receiving waterbodies.

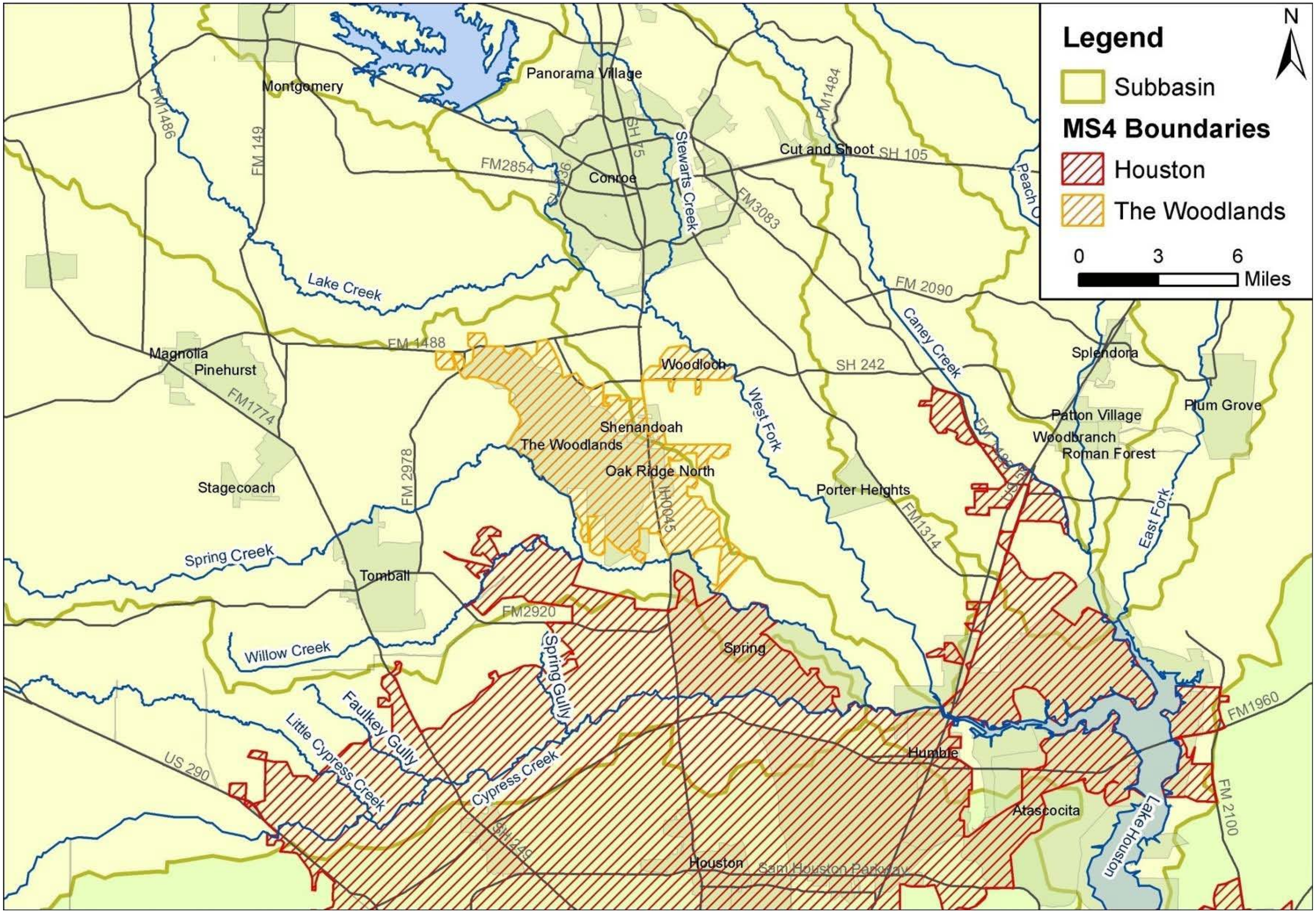

Figure 4-1: MS4 Areas of the Lake Houston Watershed

4.1.3 Sanitary Sewer Overflows (SSOs)

Sanitary sewer overflows (SSO) occur when untreated sewage is unintentionally discharged into the environment. SSOs can result from heavy rainfall, improper system operation and maintenance, and blockage in sewer collection lines. The TCEQ Region 12-Houston maintains a database of SSO data collected from wastewater operators in the Lake Houston Watershed. Approximately 670 SSOs were reported in the impaired segments of the Lake Houston Watershed between September 2001 and December 2008. The reported SSOs averaged 14,009 gallons per event. The data is summarized by stream segment in Table 4.8, and by permit in Table 4.9.

Table 4-8: Sanitary Sewer Overflow Summary by Segment

Segment	Stream Name	Number of Occurrences	Date Range		Amount (Gal.)		Total Amt (Gal.)	Average (Gal.)
			From	To	Min	Max		
1008	Spring Creek	191	9/1/01	12/29/08	0	3,972,507	5,779,640	30,260
1008H	Willow Creek	34	3/2/02	9/14/08	0	18,000	80,093	2,356
1009	Cypress Creek	350	9/4/01	12/29/08	0	159,000	1,320,169	3,772
1009C	Faulkey Gully	13	11/29/01	9/15/08	0	12,000	33,085	2,545
1009D	Spring Gully	24	6/1/03	9/8/08	15	5,000	16,305	679
1009E	Little Cypress Creek	21	5/6/02	12/1/08	20	70,000	145,952	6,950
1010	Caney Creek	27	2/7/02	11/6/08	0	204,500	551,475	20,425
1011	Peach Creek	6	9/18/01	9/18/08	0	700,000	1,403,000	233,833

Table 4-9: Sanitary Sewer Overflow Summary by Permit

TPDES Permit No.	NPDES Permit No.	Facility Name	# of Events	Date Range		Amount (Gal.)		Total Amount (Gal.)	Average (Gal.)
				From	To	Min	Max		
		Segment: 1008							
10616-001	TX0022381	City of Tomball	19	01/01/02	09/15/08	0	1,440	10,095	594
10857-001	TX0025399	Montgomery Co WCID #1	28	10/13/01	11/23/08	0	181,690	1,090,274	41,934
10908-001	TX0020974	Harris County WCID #92	15	09/03/01	12/16/08	50	3,972,507	3,992,673	266,178
11001-001	TX0024759	Southern Montgomery County MUD	15	01/10/02	09/14/08	0	8,000	24,170	1,859
11401-001	TX0054186	San Jacinto River Authority	14	05/11/02	05/29/08	25	30,000	42,213	3,015
11406-001	TX0056537	Harris Co. MUD #26	1	08/28/05	08/28/05	1,000	1,000	1,000	1,000
11574-001	TX0026221	Spring Creek UD	4	12/15/06	09/10/08	25	2,500	3,175	794
11799-001	TX0071528	Harris Co. MUD #82	2	06/17/02	09/24/03	100	2,000	2,100	1,050
11970-001	TX0076538	Montgomery Co. MUD #19	1	10/16/07	10/16/07	500	500	500	500
12030-001	TX0078263	Rayford Road MUD	1	06/06/06	06/06/06	2,000	2,000	2,000	2,000
12587-001	TX0090905	Tecon Water Company, LP	55	10/13/01	12/29/08	0	20,000	128,850	2,431
12597-001	TX0091715	San Jacinto River Authority	3	01/26/05	09/29/07	0	27,545	33,099	16,550
12637-001	TX0091791	Spring Center, Inc	1	05/09/03	05/09/03	2	2	2	2
12788-001	TX0095621	Eastwood Mobile Home Park LP	4	04/26/02	07/28/03	150	1,000	3,150	788
12898-001	TX0095125	Aqua Utilities, Inc	1	04/29/05	04/29/05	8,000	8,000	8,000	8,000
12979-004	TX0119181	Northgate Crossing MUD #2	2	02/19/08	09/18/08	200	40,000	40,200	20,100
13648-001	TX0042099	Encanto Real UD	12	09/01/01	01/04/07	300	24,000	33,100	2,758
13863-001	TX0115827	H.H.J., Inc	1	05/07/08	05/07/08	20,000	20,000	20,000	20,000
14007-001	TX0117846	AquaSource Development Co	5	12/26/02	01/02/08	100	4,000	6,300	1,260
14141-001	TX0120073	Aqua Development, Inc	2	05/03/02	07/29/03	200	500	700	350
14266-001	TX0094315	HMV Special Utility District	1	02/10/04	02/10/04	19,000	19,000	19,000	19,000
14347-001	TX0124907	The Woodlands Land Development Co. LP	2	08/03/06	10/02/08	50	45,000	45,050	22,525
14656-001	TX0128295	Montgomery Co MUD #94	2	04/26/08	10/19/08	450	1,200	1,650	825
		Segment: 1008H							
10616-002	TX0117595	City of Tomball	9	09/14/05	09/14/08	0	10,000	12,090	1,511
10910-001	TX0058548	Northampton MUD	9	12/26/02	10/16/07	0	18,000	27,900	3,986
11630-001	TX0058530	Harris Co. MUD #1	5	03/02/02	02/18/08	75	5,000	12,075	2,415
12044-001	TX0078433	Harris Co MUD #368	2	01/22/03	04/08/07	200	300	500	250
12303-001	TX0085693	Aqua Utilities, Inc	5	02/20/05	11/18/07	0	1,200	4,200	1,050
12519-001	TX0089915	Aquasource Utility, Inc	1	03/07/05	03/07/05	500	500	500	500
14181-001	TX0122530	Aqua Development, Inc	3	11/26/03	09/05/06	0	11,000	11,050	5,525

Table 4-9(continued): Sanitary Sewer Overflow Summary by Permit

TPDES	NPDES	Facility Name	# of	Date Range		Amount (Gal.)		Total Amount	Average
Permit No.	Permit No.		Events	From	To	Min	Max	(Gal.)	(Gal.)
		Segment: 1009							
10528-001	TX0026450	Harris Co. FWSD # 52	11	01/03/02	10/16/06	4	2,000	4,601	418
10783-001	TX0023612	Inverness Forest ID	4	10/11/01	10/15/07	1,000	75,000	81,500	20,375
10955-001	TX0046710	Harris County WCID #116	12	01/24/02	12/30/06	4	3,000	7,859	655
11024-001	TX0021211	Harris Co WCID #119	8	03/10/04	09/16/08	250	67,000	102,208	12,776
11044-001	TX0046671	Memorial Hills UD	10	11/09/01	10/19/06	15	159,000	203,315	20,332
11081-001	TX0046761	Ponderosa Joint Powers Agency	13	09/04/01	08/29/08	0	30,000	75,175	6,834
11084-001	TX0046833	Lake Forest Plant Advisory Council	11	04/23/02	06/15/07	30	60,000	78,680	7,153
11089-001	TX0046701	Prestonwood Frest UD	3	08/30/03	11/03/08	69	5,000	6,569	2,190
11105-001	TX0046639	Bammel UD	9	10/22/02	07/24/07	0	20,000	29,250	4,875
11141-001	TX0046728	Treschwig Joint Powers Board	38	11/10/01	05/05/08	0	25,000	116,111	3,225
11142-002	TX0046680	Timber Lane UD	12	03/03/02	09/19/08	100	30,000	82,700	6,892
11215-001	TX0046663	Meadowhill Regional MUD	7	06/19/03	12/12/08	500	10,000	20,700	2,957
11239-001	TX0055166	CNP UD	2	03/05/07	09/06/07	480	500	980	490
11267-001	TX0046868	Timberlake ID	3	08/25/03	05/05/05	500	1,000	2,500	833
11314-001	TX0046744	Aqua Texas, Inc	6	05/04/02	02/27/05	2,000	6,000	23,200	3,867
11366-001	TX0046779	Cypress-Klein UD	1	10/22/02	10/22/02	6,000	6,000	6,000	6,000
11409-001	TX0046817	Kleinwood Joint Powers Board	21	10/20/01	11/12/08	15	15,000	35,740	1,702
11410-002	TX0046841	Charterwood MUD	6	10/30/07	11/05/08	50	540	1,023	171
11835-001	TX0072150	Bridgestone MUD	11	09/09/02	11/14/07	45	20,000	39,785	3,617
11855-001	TX0072567	North Park PUD	7	03/13/02	04/21/06	0	2,500	3,455	576
11912-002	TX0075159	Northwest Harris Co MUD #10	14	03/07/02	10/02/08	100	3,500	15,100	1,079
11925-001	TX0074632	Harris Co MUD #104	6	10/28/01	06/26/08	20	25,000	47,020	7,837
11941-001	TX0074322	Harris Co MUD #58	4	10/09/01	11/18/04	400	1,000	2,700	675
11964-001	TX0076481	Harris Co WCID #110	14	05/14/02	09/25/08	90	56,160	106,145	7,582
11988-001	TX0076856	Harris Co MUD #24	5	02/03/02	12/29/08	250	15,000	17,650	3,530
12239-001	TX0084085	Harris Co MUD #36	2	03/04/04	10/23/07	1,000	1,000	2,000	1,000
12470-001	TX0089184	Harris Co MUD #221	11	02/20/02	09/18/08	10	45,000	66,213	6,019
12579-001	TX0090824	Spring West MUD	14	07/15/02	09/17/08	0	5,000	18,490	1,422
12614-001	TX0091481	Harris Co MUD #16	2	12/10/07	05/28/08	300	500	800	400
12877-001	TX0094706	Harris Co MUD #230	11	02/05/03	05/16/08	30	15,000	16,082	1,462
13020-001	TX0096920	Harris Co MUD #286	1	12/16/04	12/16/04	2,700	2,700	2,700	2,700
13296-002	TX0105376	Harris Co MUD #358	5	01/27/04	04/05/08	20	2,000	5,420	1,084
13573-001	TX0108120	Northwest Harris County MUD #36	1	03/31/02	03/31/02	1,000	1,000	1,000	1,000
13625-001	TX0081337	Northwest Harris Co MUD #20	8	01/19/02	10/15/07	30	2,000	4,080	510
13875-002	TX0115983	Harris Co MUD #383	11	08/08/02	11/26/07	0	765	2,424	242
13881-001	TX0116009	Harris Co MUD #365	7	10/04/02	12/28/06	150	1,200	4,485	641
14028-001	TX0117129	Harris Co MUD 371	3	10/22/06	09/14/08	0	500	550	275
14030-001	TX0075221	Northwest Harris Co MUD #9	4	11/30/04	03/12/08	100	5,000	8,100	2,025
14172-001	TX0121126	Utilities Investment Company, Inc	1	08/24/07	08/24/07	2,000	2,000	2,000	2,000
14327-001	TX0124770	Harris Co. MUD #391	10	05/23/07	12/16/08	0	3,000	8,350	928
14354-001	TX0124974	Harris Co. MUD #374	4	08/28/05	09/13/08	0	2,000	3,000	1,000
11832-001	TX0072354	Faulkey Gully MUD	7	11/29/01	10/20/07	120	12,000	20,980	2,997
11939-001	TX0075795	Northwest Harris Co MUD #15	6	11/12/06	09/15/08	0	7,000	9,560	1,912
		Segment: 1009D							
13152-001	TX0098647	Northwest Harris Co MUD #32	24	06/01/03	09/08/08	15	5,000	16,305	679
		Segment: 1009E							
11913-001	TX0075183	Northwest Freeway MUD	5	04/30/04	02/08/07	120	600	1,640	328
13753-001	TX0113107	Harris Co MUD #360	14	05/06/02	12/01/08	20	70,000	134,012	9,572
14441-001	TX0125881	Harris County MUD #389	2	11/03/05	11/12/05	1,300	9,000	10,300	5,150
		Segment: 1010							
11020-001	TX0056685	City of New Waverly	2	09/30/02	09/17/08	600	137,500	138,100	69,050
11020-002	TX0087831	City of New Waverly	4	09/27/02	09/17/08	700	204,500	291,600	72,900
11715-001	TX0068659	Texas National MUD WWTF	3	02/23/08	11/06/08	1,000	5,800	9,800	3,267
12205-001	TX0083208	Conroe ISD	1	11/04/02	11/04/02	39,600	39,600	39,600	39,600
13690-001	TX0111473	Conroe ISD	1	02/07/02	02/07/02	5,000	5,000	5,000	5,000
14029-001	TX0117145	LGI Housing, LLC/□Quadvest, LP6	2	04/15/02	09/20/08	0	750	750	750
14116-001	TX0071412	Montgomery County MUD #24	6	07/12/02	06/18/08	185	800	2,550	425
14285-001	TX0124281	C&R Water Supply, Inc.	7	07/16/02	10/31/08	0	1,500	2,800	467
		Segment: 1011							
13389-001	TX0102512	City of Splendora	2	09/18/01	08/13/07	500	1,000	1,500	750
13638-001	TX0093220	Roman Forest Consolidated MUD	1	09/18/08	09/18/08	700,000	700,000	700,000	700,000

4.2 NONPOINT SOURCES

Nonpoint sources have traditionally been defined as loading sources that are dispersed over the watershed, with no single point of origination. In recent years, the definition of nonpoint sources has been refined to include all non-permitted sources. Several nonpoint sources exist in the Lake Houston watershed, including failing septic systems, leaking wastewater collection infrastructure, livestock, and wildlife.

Nonpoint sources can be "direct" or "indirect" (runoff-related). Some nonpoint sources fall into both categories. For example, livestock wading in a stream can contribute fecal matter directly to the stream, as a "direct source". However, when livestock are not in the stream, they contribute fecal matter to the land surface, and are considered an "indirect source". Indirect loading only reaches streams if carried by rainfall runoff.

4.2.1 Failing Septic Systems

Private residential sewage treatment systems (septic systems) typically consist of one or more septic tanks and a drainage or distribution field. Household waste flows into the septic tank, where solids settle out. The liquid portion of the waste flows to the distribution system which may consist of perforated pipes buried in a soil or gravel bed. Effluent in the bed may move vertically to groundwater, laterally to surface water, or upward to the ground surface. As it moves, the majority of the liquid portion is consumed by evapotranspiration of vegetation planted on top of the distribution field or adjacent to it. Properly designed, installed, and maintained septic systems would be expected to contribute virtually no fecal coliform to surface waters. The principal removal mechanism for the fecal coliform would be die-off as the liquid moves through the soil. Various studies have attempted to quantify the transport and delivery of bacteria in effluent from septic systems. For example, it has been reported that less than 0.01% of fecal coliform originating in the household waste moves farther than 6.5 feet downgradient from the drainfield (Weiskel, 1996).

A septic system failure can occur via two mechanisms, direct and indirect. First, drainfield failures, broken pipes, or overloading could result in uncontrolled, direct discharges to the streams. Such failures would not be expected to be common in the study watershed, but they could occur in reaches with older homes located near a watercourse or in remote areas. As a second mechanism, an overloaded drainfield could experience surfacing of effluent, and the pollutants would then be available for surface accumulation and subsequent washoff under runoff conditions.

The number of septic systems in the study area was estimated using information from the 1990 US Census, which included a question regarding the means of household sewage disposal (US Census, 2006). Unfortunately, this question was not posed in the 2000 Census. Based on the 1990 data, the number of septic systems in the study area was estimated by intersecting the census tracts with the study area watershed. The spatial distribution of septic systems in 1990 is shown in Figures 4-2 and 4-3. Figure 4-2 shows the density of septic systems, while 4-3 shows the percentage of homes served by septic systems according to the 1990 Census.

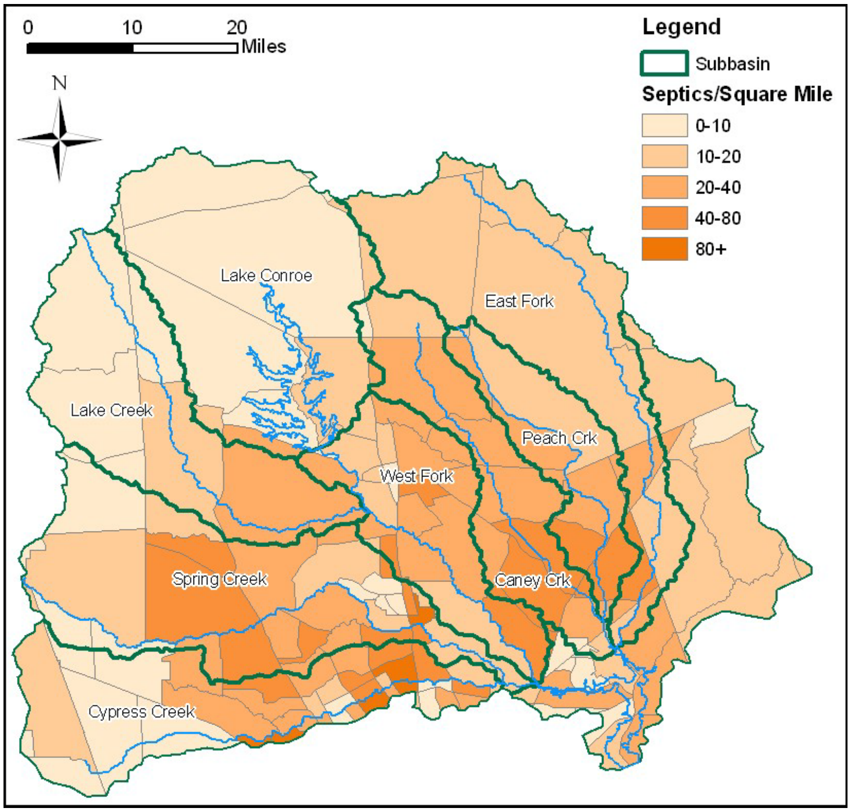

Figure 4-2: Septic System Density of Lake Houston Watershed (1990)

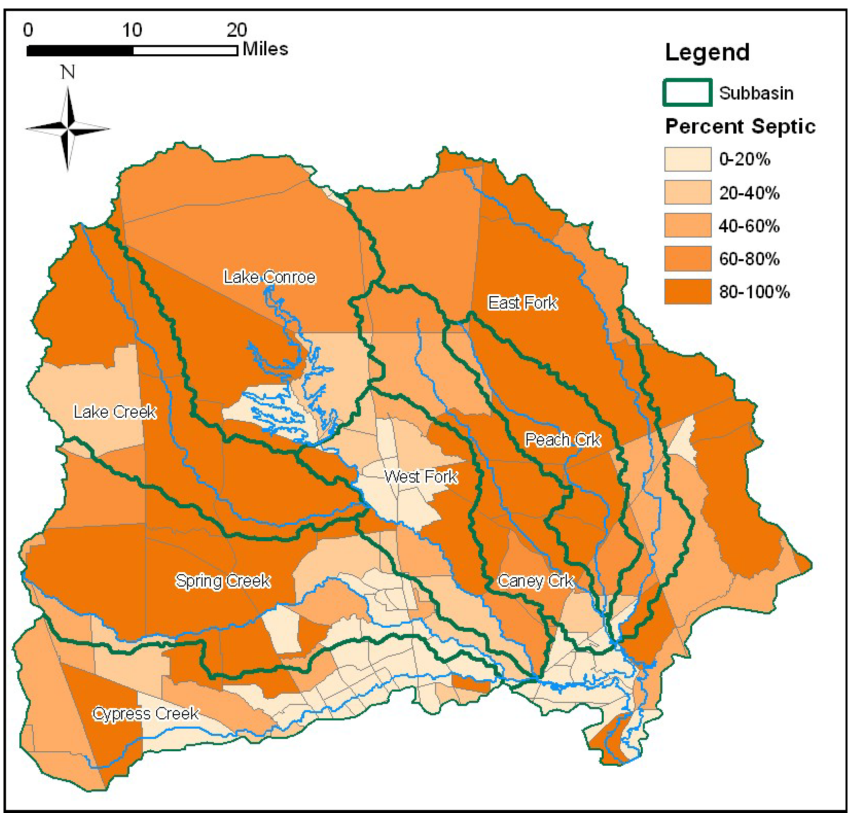

Figure 4-3: Percent of Households Served by Septic Systems (1990)

Beginning in 1992, county health departments (and other agencies) began registering and recording new septic system installations (TCEQ 2009). These data were used to determine areal growth rates for each county, which were then applied to the study watersheds. Table 4-10 provides the septic system estimates for 1990 and 2007 for each TMDL watershed.

Septic system failure rates for different regions of Texas have been estimated in a report by Reed, Stowe, and Yank (2001). According to this report, septic systems in east-central Texas have a failure rate of about 12% and septic systems in far-east Texas have a failure rate of about 19%. Because the study area is intersected by both of these two regions, a failure rate of 15.5% could be considered applicable. Table 4-8 also includes the estimated number of failed septic systems for 1990 and 2007.

Table 4-10: Septic System Estimates for TMDL Watersheds

Segment	Stream Name	1990 Septic Systems	2007 Septic Systems	Annual Growth Rate 1990-2007	1990 Failed Systems	2007 Failed Systems
1004E	Stewarts Creek	474	957	4.2%	7	15
1008	Spring Creek	11,334	18,926	3.1%	176	293
1008H	Willow Creek	1,843	2,399	1.6%	29	37
1009	Cypress Creek	7,587	10,934	2.2%	118	169
1009C	Faulkey Gully	494	615	1.3%	8	10
1009D	Spring Gully	151	210	2.0%	2	3
1009E	Little Cypress Crk	1,159	1,755	2.5%	18	27
1010	Caney Creek	6,919	12,189	3.4%	107	189
1011	Peach Creek	4,688	7,537	2.8%	73	117

4.2.2 Leaking Wastewater Infrastructure

Leaking wastewater (sewer) lines are a difficult to detect but potentially significant source of bacteria, especially in highly urbanized areas where most residences are served by a central collection system. As with failing septic systems, wastewater lines located close to streams would normally be assumed to have the highest potential to act as bacterial sources. Wastewater lines, especially large collector lines, tend to be installed along creeks and streams because the elevation profile along the waterway channel provides an economical arrangement for the gravity transport of collected sewage. In general, wastewater lines will only leak when their hydraulic grade line is higher than that of the stream to which they parallel. Also, sewers will typically only leak if they become cracked or are improperly installed. Even lines not located in proximity to creeks have the potential to contribute bacteria if leakage intersects storm drainage conveyances.

There is little published information available on sewer exfiltration (leakage) in general. An EPA Report (2003) summarizes the limited information available on the subject. Based primarily on this report, factors that influence sewer exfiltration are as follows:

1. Age of lines
2. Material of construction (vitrified clay pipe is particularly susceptible to leaks)
3. Type and spacing of pipe joints
4. Depth of flow in sewer

5. Surrounding groundwater depth
6. Surrounding soil type
7. Geologic faults

4.2.3 Livestock

Livestock population estimates for Harris County were based upon the 2007 Agricultural Census (USDA, 2007). The types of livestock explicitly included in the present analysis included cattle, hogs, poultry, horses, sheep, and goats. Animal population estimates are presented in Table 4-11. Other types of livestock had small populations compared to the major livestock species listed above, and therefore, the fecal loads from these other animal groups were assumed to be negligible.

Table 4-11: Livestock Population Estimates

Segment	Stream Name	Cattle and Calves	Hogs and Pigs	Chickens	Other Poultry	Horses and Ponies	Sheep and Goats
1004E	Stewarts Creek	343	8	117	39	94	45
1008	Spring Creek	18,627	222	40,344	1,167	2,603	1,393
1008H	Willow Creek	2,064	39	334	112	375	195
1009	Cypress Creek	17,165	221	2,553	756	2,490	1,369
1009C	Faulkey Gully	333	6	54	18	60	31
1009D	Spring Gully	133	3	22	7	24	13
1009E	Little Cypress Crk	3,052	58	493	166	554	288
1010	Caney Creek	6,471	117	1,689	1,275	1,446	705
1011	Peach Creek	4,322	78	820	327	739	455

Fecal coliform bacteria produced by livestock can enter surface waters through several pathways: washoff of waste deposited on the land surface, washoff of concentrated waste from land application sites, direct deposition of waste material in the stream, and potential discharges from animal confinement areas or waste handling systems.

Fecal coliform bacteria production rates for livestock are displayed in Table 4-12. For the present study, all of the data regarding manure production rates and fecal coliform density were based upon values reported in the literature (ASAE, 2003; EPA, 2000).

Table 4-12: Fecal Coliform Production Rates for Livestock

Animal	Fecal Coliform (count/animal/day)
Beef Cow	1.04E+11
Dairy Cow	1.01E+11
Swine	1.08E+10
Chicken	1.36E+08
Sheep	1.20E+10
Horse	4.20E+08
Turkey	9.30E+07
Duck	2.43E+07
Geese	4.90E+10

These bacteria generation rates were used to estimate the total potential fecal coliform loading derived from livestock in the study watershed, as shown in Table 4-13. These estimated loads are potential loads in that some mechanism is needed to deliver the loads to a water source. Comparable *E. coli* generation data was not available in the literature, but it can be expected that the *E. coli* is generally lower than the Fecal Coliform.

Table 4-13: Fecal Coliform Production Rates for Livestock (x 10^9/day)

Segment	Stream Name	Cattle and Calves	Hogs and Pigs	Chickens	Other Poultry	Horses and Ponies	Sheep and Goats
1004E	Stewarts Creek	35,698	90	16	4	39	542
1008	Spring Creek	1,937,204	2,397	5,487	109	1,093	16,711
1008H	Willow Creek	214,684	422	45	10	157	2,337
1009	Cypress Creek	1,785,111	2,388	347	70	1,046	16,428
1009C	Faulkey Gully	34,623	68	7	2	25	377
1009D	Spring Gully	13,872	27	3	1	10	151
1009E	Little Cypress Crk	317,373	623	67	15	233	3,455
1010	Caney Creek	672,935	1,267	230	119	607	8,456
1011	Peach Creek	449,529	842	111	30	310	5,461

4.2.4 Pets

Domestic pets (dogs and cats) in urban and suburban areas are a potential source of bacteria loading. On average there are 0.632 dogs and 0.713 cats per household (American Veterinary Medical Association, 2007). Using U.S. Census data (U.S. Census Bureau, 2000), dog and cat populations can be estimated for each segment of the watershed. Table 4-14 summarizes the estimated number of dogs and cats for the watershed of the study area.

Table 4-14: Estimated Number of Pets

Segment	Stream Name	Dogs	Cats
1004E	Stewarts Creek	2,811	3,171
1008	Spring Creek	37,513	42,320
1008H	Willow Creek	4,561	5,145
1009	Cypress Creek	52,411	59,128
1009C	Faulkey Gully	2,640	2,978
1009D	Spring Gully	860	970
1009E	Little Cypress Creek	3,915	4,417
1010	Caney Creek	10,689	12,058
1011	Peach Creek	4,295	4,845

Table 4-15 provides an estimate of fecal coliform loads from pets. These estimates are based on estimated fecal coliform production rates of 3.3×10^9 per day for dogs and 5.4×10^8 per day for cats (Schueler 2000). The portion of these loads that is expected to reach waterbodies through wash-off of land surfaces and conveyance in runoff is unknown.

Table 4-15: Estimated Fecal Coliform Production by Pets (x 10^9/day)

Segment	Stream Name	Dogs	Cats	Total (counts/day)
1004E	Stewarts Creek	9,276	1,712	10,988
1008	Spring Creek	123,792	22,853	146,645
1008H	Willow Creek	15,050	2,778	17,828
1009	Cypress Creek	172,956	31,929	204,886
1009C	Faulkey Gully	8,710	1,608	10,318
1009D	Spring Gully	2,838	524	3,362
1009E	Little Cypress Creek	12,921	2,385	15,306
1010	Caney Creek	35,272	6,512	41,784
1011	Peach Creek	14,174	2,617	16,790

4.2.5 Wildlife

Fecal coliform and *E. coli* bacteria inhabit the intestines of all warm-blooded animals, including wildlife such as deer, raccoons, and birds. The identification of potential bacteria contributions from wildlife in the Lake Houston watershed is important in developing the TMDLs. Streams and rivers naturally attract wildlife because they provide a source of water. When wildlife have direct access to streams and rivers, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a waterbody. Another source of bacteria loading occurs when wildlife waste deposited on land surfaces is washed into nearby streams and rivers by rainfall runoff. Currently, insufficient data is available to estimate wildlife populations and spatial distribution in the Lake Houston Watershed. As a result, bacteria contributions from wildlife cannot be assessed.

4.2.6 Bacteria Regrowth and Die-off

There exists literature that suggests that under appropriate conditions, fecal organisms can regrow during flow through pipe networks, and in organic rich matter (e.g. sludge and compost). There is also information that suggests that regrowth can occur in the receiving stream. However, there is no conclusory determination whether bacteria regrowth may constitute a substantial source of bacteria concentrations in most stream segments. It is well documented that die-off of bacteria takes place in the receiving stream due to the presence of sunlight or predators. Indicator bacteria regrowth and die-off are both in-stream processes that are not considered in development of the bacteria source loading allocation for each TMDL assessment unit.

5.0 TECHNICAL APPROACH AND METHODS

5.1 INTRODUCTION

Load duration curves (LDCs) are a relatively new methodology for developing TMDLs. LDCs are graphical tools for analyzing water quality data and are capable of promoting "effective communication between TMDL developers and implementers, so that actions will lead to measurable water quality improvements" (Cleland, 2003). Many states have begun to use the LDC methodology for better characterization of pollutant sources and for the development of more robust TMDL targets, than what is achieved by less sophisticated methodologies (Nevada DEP, 2003). The LDC methodology has been applied to the development of bacteria TMDLs in other watershed in the greater Houston area, including Greens Bayou, Halls Bayou, Hunting Bayou, Brays Bayou, Sims Bayou, and the general Houston Ship Channel watershed

5.2 LOAD DURATION CURVE DEVELOPMENT

Load duration curves utilize historical flow and water quality monitoring data to define a relationship between stream flow (volume per time) and pollutant load (mass or number of bacteria per time). The actual "curve" represents the maximum pollutant load allowable under different flow conditions, based on state criteria. This curve is then compared to actual water quality samples that are plotted as points, either falling above or below the curve. The load duration curve methodology is a reasonable TMDL development method for the Lake Houston watershed due to the large number of samples collected along the river segments. The available sample data provides good definition of the variation in bacteria load under different flow regimes. If required, more detailed water quality modeling can be performed in the implementation phase of the TMDL.

Stream flow data is essential for determining instream pollutant loads. Fortunately, there are several USGS flow gaging stations in the TMDL study area. Table 5-1 identifies the USGS gaging stations utilized in this project. Locations of these gages are previously presented in Figures 3-1 through 3-3.

Table 5-1: Summary of USGS Gaging Station

Station	Stream	Location	Flow Records	Drainage Area (sqmi)	Median Flow** (cfs)	Median Flow/Area (cfs/sqmi)
08068275	Spring Creek	near Tomball, TX	1999-2008	186	12.5	0.07
08068325	Willow Creek	near Tomball, TX	2006-2008	41	6.7	0.17
08068450	Panther Branch	near Spring, TX	1972-1976, 1999-2008	33	19	0.57
08068500	Spring Creek	near Spring, TX	1939-2008	404	70	0.17
08068700	Cypress Creek	at Sharp Rd nr Hockley, TX	none*	81	-	-
08068720	Cypress Creek	at Katy-Hockley Rd nr Hockley, TX	1975-2008	105	1.9	0.02
08068740	Cypress Creek	at House-Hahl Rd nr Cypress, TX	1975-2008	138	6.4	0.05
08068780	Little Cypress Creek	near Cypress, TX	1982-1992, 1997-2008	43	1.3	0.03
08068800	Cypress Creek	at Grant Rd nr Cypress, TX	1982-1992, 2001-2008	219	21	0.10
08068900	Cypress Creek	at Stuebner-Airline Rd nr Westfield, TX	1987-1989	290	-	-
08069000	Cypress Creek	near Westfield, TX	1944-2008	290	63	0.22
08070500	Caney Creek	near Splendora, TX	1944-2008	105	31	0.30
08071000	Peach Creek	at Splendora, TX	1943-1977, 1999-2008	118	34	0.29

*gage height data only

**For period of record: 1999-2008

5.2.1 Period of Record Used for TMDL Development

When developing flow statistics for a watershed, it is typically desirable to use a long period of record (multiple decades of data). However, in the Lake Houston Watershed, there are several areas where recent development appears to have affected local hydrology. These changes are manifested through higher peak flows during runoff events (as a result of increased impervious cover), and higher low flows due to increased continual discharge of wastewater treatment facilities.

Historical low flow data were analyzed to determine whether base flows have increased over time due to WWTF discharges. Annual low flows (represented by the 90th percentile flow) were determined for Spring Creek and Cypress Creek (USGS gages 08068500 and 08069000) for the last two decades (1989-2008). A t-test was then performed to determine if the flows in the second decade were higher than the first decade. The resulting P-values (<0.01 for Cypress Creek and <0.1 for Spring Creek) suggest that baseflows have significantly increased over the last two decades.

For Caney Creek and Peach Creek, where development has been less rapid, no significant increase in baseflows was observed. However, the Peach Creek flow gage is missing data prior to 1999.

The period of flow record used in this study is 1999-2008. There are multiple reasons for limiting the period of record to this most recent decade. First, as discussed above, recent development has altered hydrologic patterns in portions of the watershed, making older data uncharacteristic of current conditions. Second, the period of record for *E. coli* data (2000-2007) falls entirely within this most recent decade. Third, several of the USGS gaging stations were inactive prior to this decade.

5.2.2 Flow Duration Curves

Flow duration curves (FDCs) are useful for characterizing the range and frequency of flows that occur in a stream segment. FDCs are developed by plotting daily streamflow values versus the percent of the time that the streamflow value is exceeded. For this report, FDCs were developed using the USGS gages and period of record (1999-2008) described in the previous sections. Figures 5-1 through 5-3 present FDCs for gages within the study area.

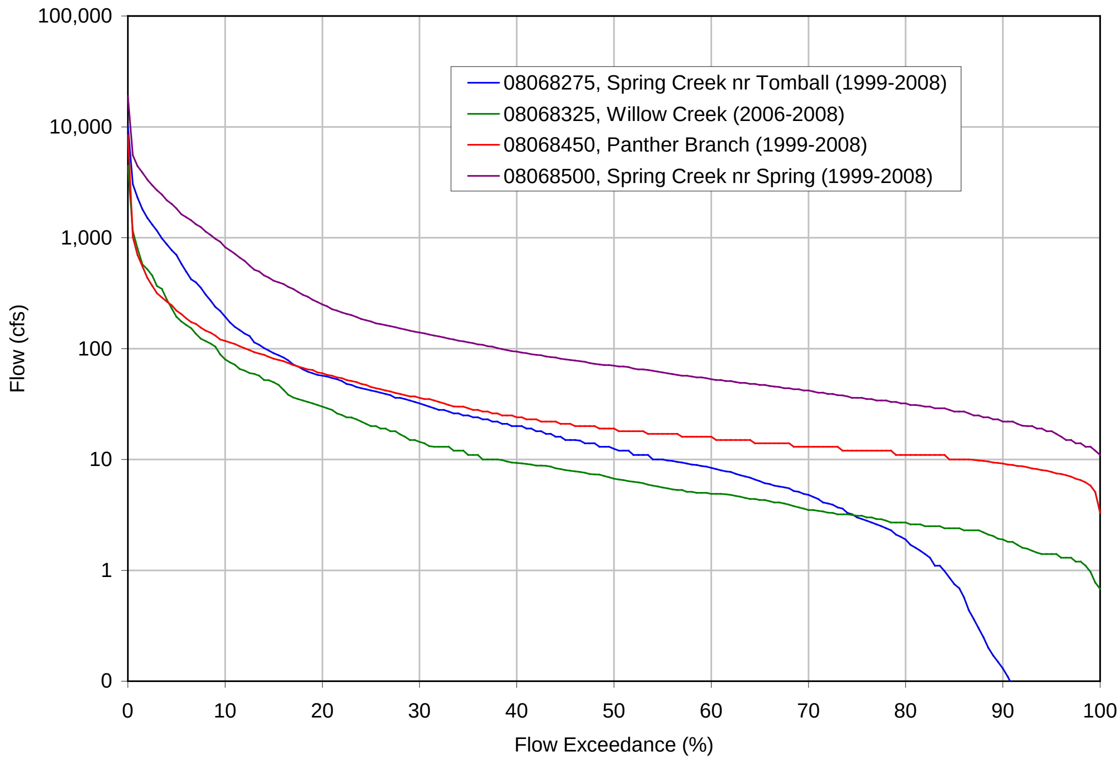

Figure 5-1: Flow Duration Curves for Spring Creek

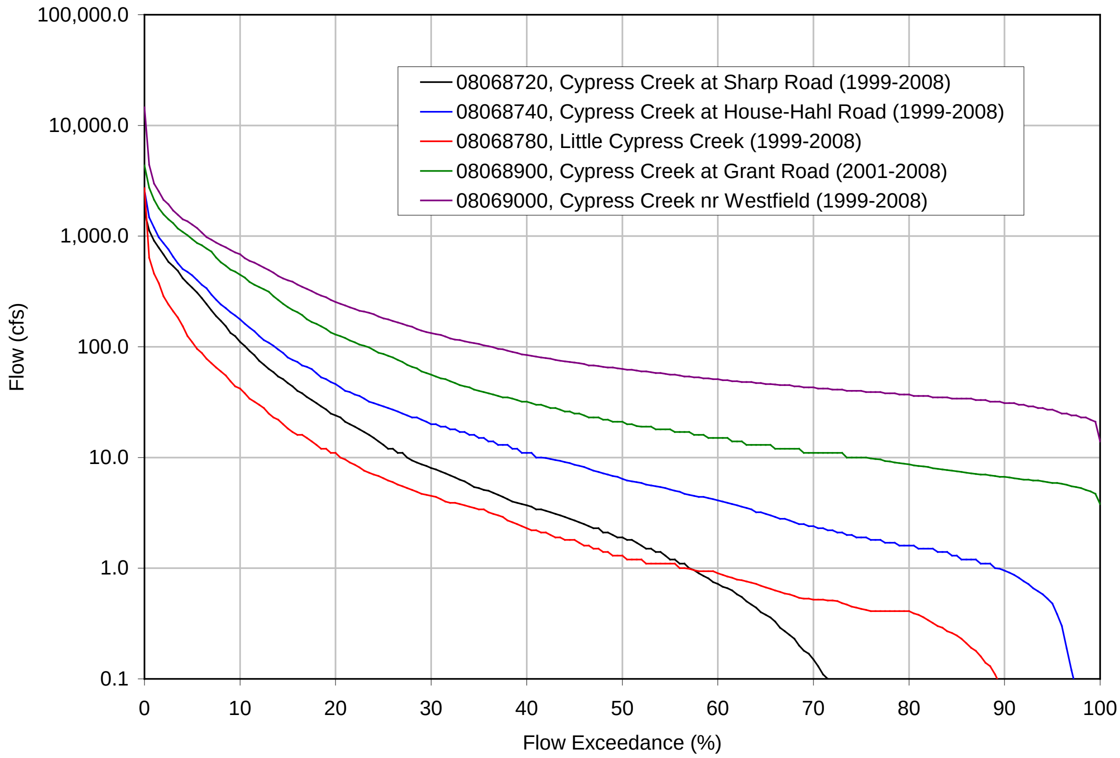

Figure 5-2: Flow Duration Curves for Cypress Creek

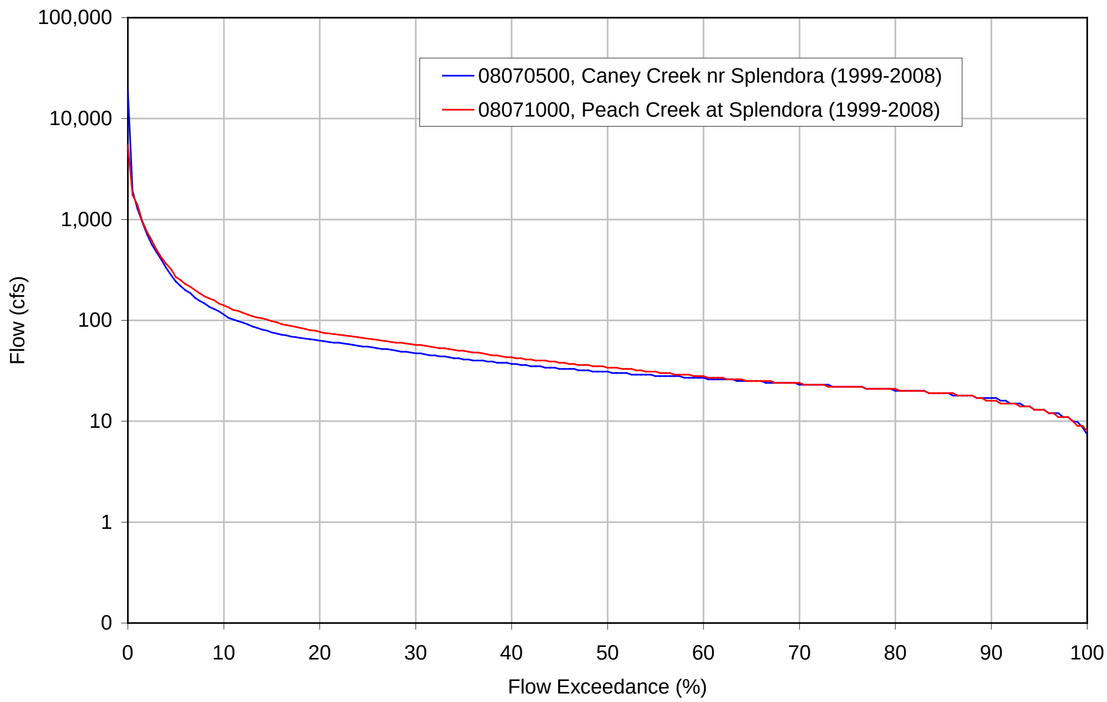

Figure 5-3: Flow Duration Curves for Eastern Creeks

5.2.3 Application of Water Quality Criteria

Stream flow distribution has been divided into three flow regimes: Wet, Moderate and Dry conditions. These flow regimes are listed in Table 5-2 with flow exceedance percentiles and illustrated in all LDC figures. Wet conditions correspond to large storm-induced runoff events. The Moderate conditions typically represent periods of medium base flows, but can also represent small runoff events and periods of flow recession following large storm events. The Dry conditions represent relatively low flow conditions, resulting from extended periods of little or no rainfall and are maintained primarily by wastewater treatment plant flows.

Table 5-2: Flow Regime Classifications

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

Flow duration curves (FDCs) can be multiplied by pertinent state water quality criteria to create load duration curves (LDCs). For the present study, the maximum allowable geometric mean of *E. coli* samples (126 cfu/dL) and the grab sample value (394 cfu/dL) were considered. When a flow (volume/time) is multiplied by a bacterial concentration (number/volume), the result is a pollutant loading rate (number/time). As an example, Figure 5-4 shows the resulting LDC for Station 14241 on Caney Creek.

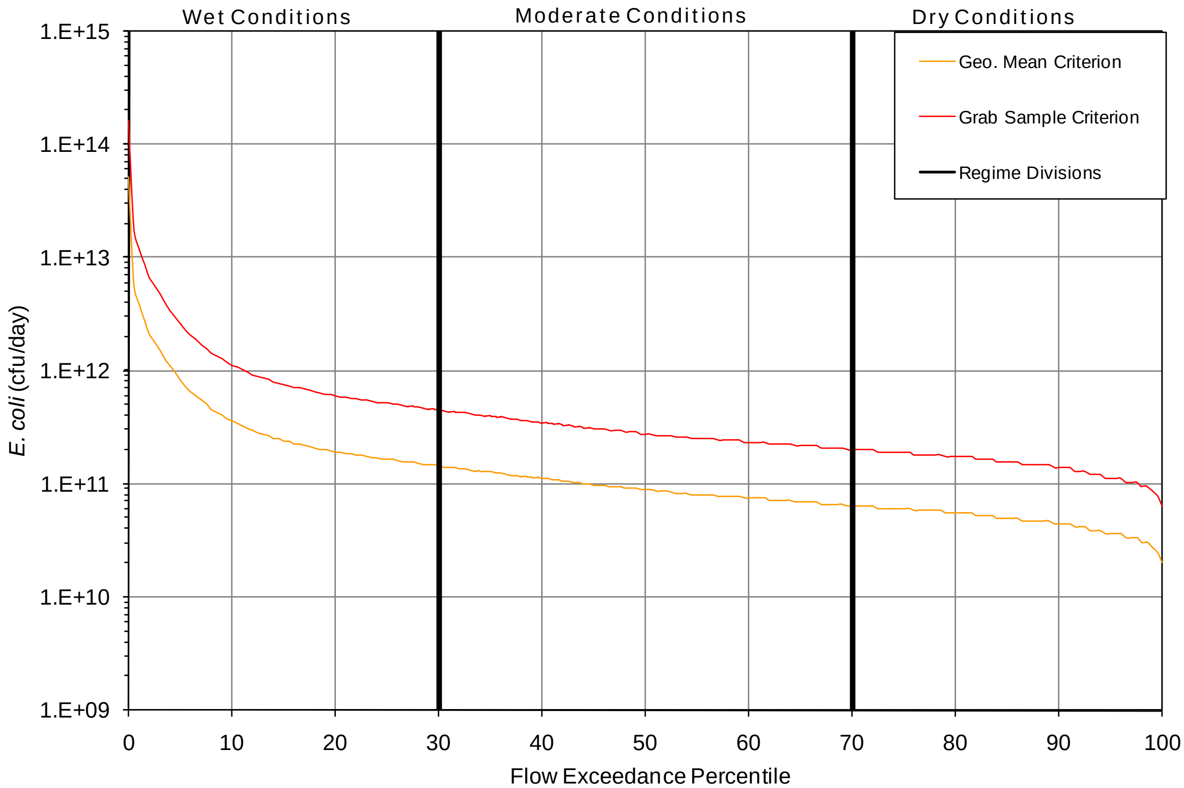

Figure 5-4: LDC Criteria Curves for Station 14241 (Caney Creek at SH 105)

5.2.4 Integration of Water Quality Sampling Data

The next step in LDC development is the plotting of existing water quality sampling data. To accomplish this, measured pollutant concentrations must be converted to daily loads. This can be approximated if the instantaneous sample concentration generally reflects the average (flow-weighted) concentration for the day in which it was collected. This average concentration can then be multiplied by the daily stream flow value, adapted from a nearby USGS gage, in order to calculate the daily load. These loads are then plotted versus their corresponding daily streamflow exceedance percentile.

The plotted loads can then be compared to the LDCs for water quality criteria. The degree to which a plotted load exceeds the criterion LDC reflects the degree to which the measured concentration exceeded the criterion on the day the sample was taken. For example, if a load is plotted 50% higher than the 394 cfu/dL criterion LDC, this means that the concentration sampled on that day was 50% higher than 394, or 591cfu/dL.

Figure 5-5 shows the LDC for Station 14241 on Caney Creek, including the sampled *E. coli* loads. From this figure, it is clear that a number of samples exceed the state's water quality criteria, particularly under high flow conditions. A more detailed discussion of this LDC, and the LDCs for other stations, is presented in Section of 5.3

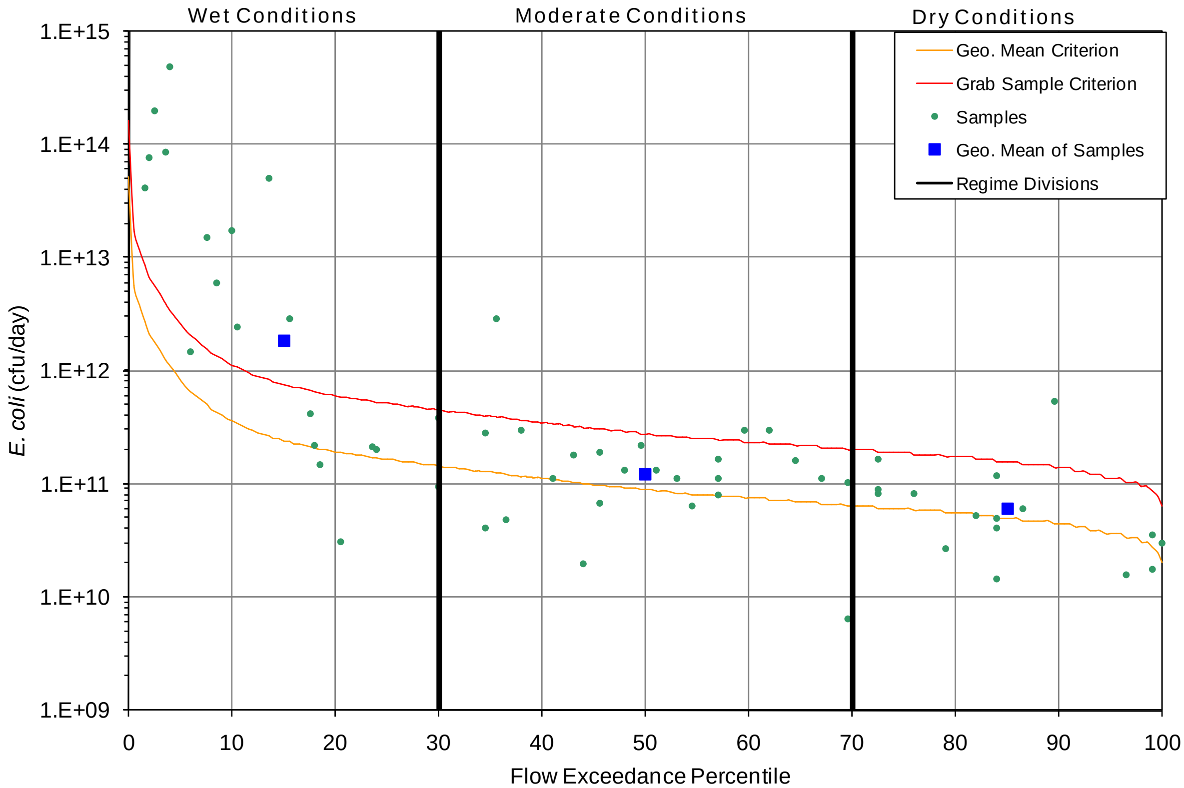

Figure 5-5: LDC for Station 14241 (Caney Creek at SH 105)

5.3 LOAD DURATION CURVE ANALYSIS

This section presents load duration curves for various water quality sampling stations throughout the study area. The bacterial loads are the product of each grab sample bacteria concentration and the corresponding mean daily streamflow rate. The LDCs are analyzed for compliance with state criteria and for source assessment. Sources are assessed by observing how bacteria levels vary under different flow conditions (flow percentile). Data scatter is also considered, and comparisons are made between LDCs at upstream and downstream locations. This section does not attempt to quantify TMDL load reductions, which will be discussed in Section 6. LDCs of respective streams are presented in order from most upstream to most downstream location.

Station 14241 – Caney Creek at SH 105

The load duration curve for Station 14241 was shown previously in Figure 5-5. Under the moderate and dry flow regimes, there are relatively few exceedances of the grab sample criterion, although the majority of the samples are above the geometric mean criterion. Under wet flow conditions, an increasing number of samples lie above the criteria curve, indicating that state criteria may be exceeded under sustained high flow conditions.

Station 11334 – Caney Creek at FM 1485

The load duration curve for Station 11334 is shown in Figure 5-6. Criteria exceedances are again most typical under relatively high flow conditions. Fifty-five percent (55%) of samples in the Wet flow regime exceed the grab sample criteria. Bacteria levels at both Moderate and Dry conditions generally meet state criteria.

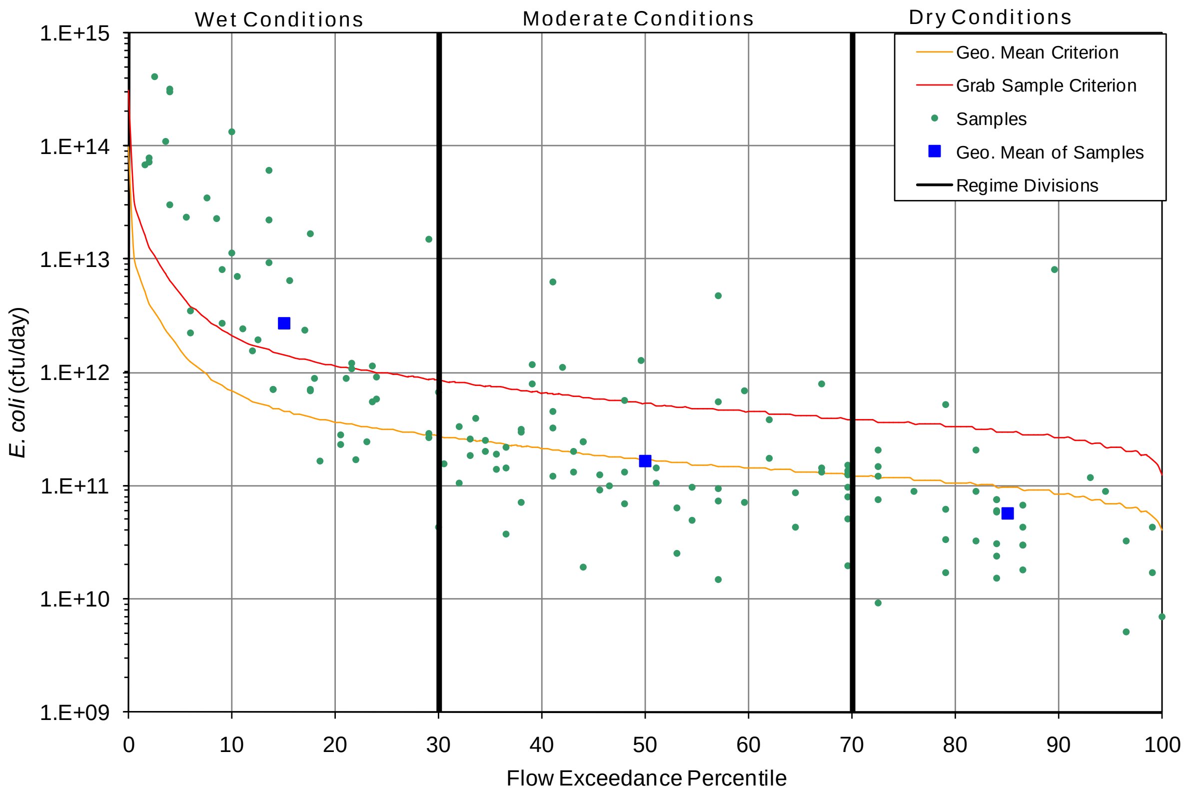

Figure 5-6: LDC for Station 11334 (Caney Creek at FM 1485)

Station 11336/17746 – Peach Creek at FM 1485 and Footbridge

The load duration curves for Stations 11336 and 17746 are shown in Figure 5-7. As with the previous stations, it is clear that exceedances of water quality criteria appear to be common under relatively high flow conditions. Forty-two percent (42%) and 71% of samples exceed the grab sample criterion in the Wet flow regimes at Station 11336 and 17746, respectively.

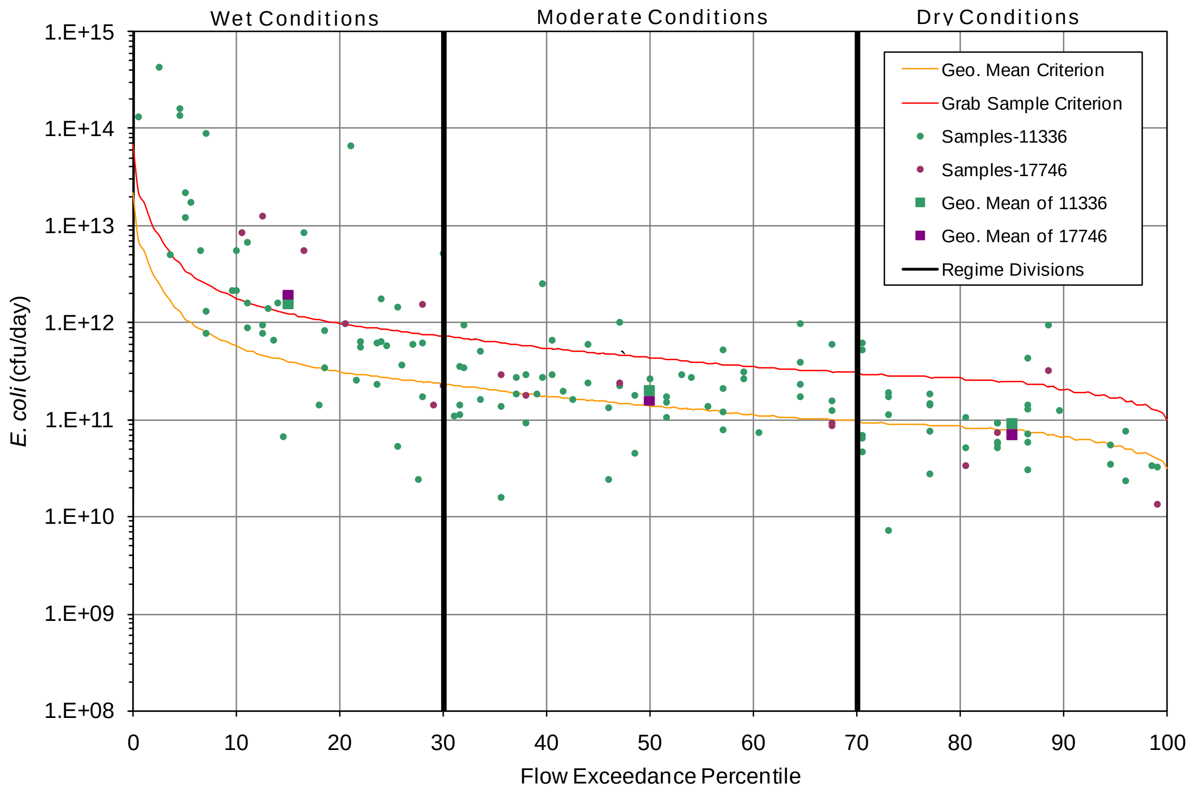

Figure 5-7: LDC for Station 11336/17746 (Peach Creek at FM 1485 and Footbridge)

Station 16626 – Stewarts Creek

The load duration curve for Station 16626 is shown in Figure 5-8. As with the previous stations, it is clear that exceedances of water quality criteria appear to be common under relatively high flow conditions. Sixty-two percent (62%) and 43% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively. Bacteria levels at Dry flows generally meet state criteria.

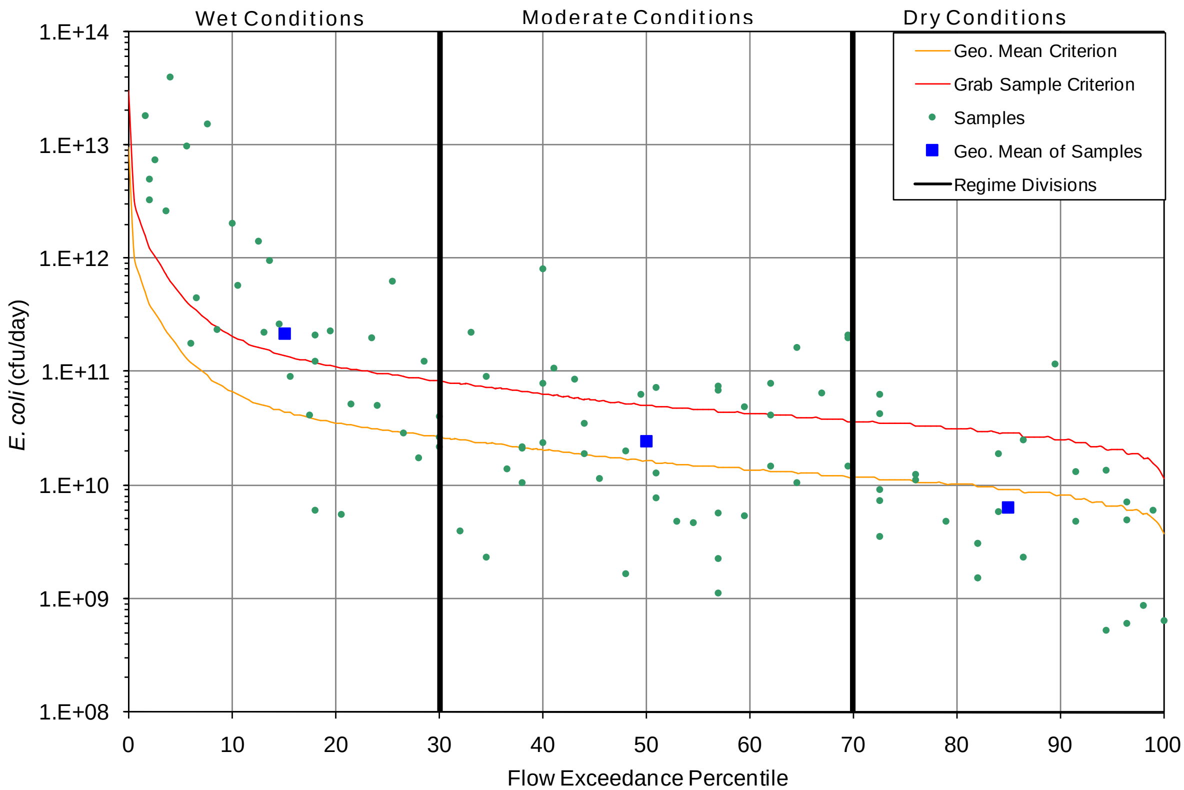

Figure 5-8: LDC for Station 16626 (Stewarts Creek)

Station 11323 – Spring Creek at Rosehill Rd

The load duration curve for Station 11323 is shown in Figure 5-9. Exceedances of state criteria appear to be most common under high flow conditions. Eighty-seven percent (87%) of samples exceed the grab sample criterion in the Wet flow regime. Although generally below the grab sample criteria, 63% of samples in both Moderate and Dry flow regimes exceed the geometric mean criteria.

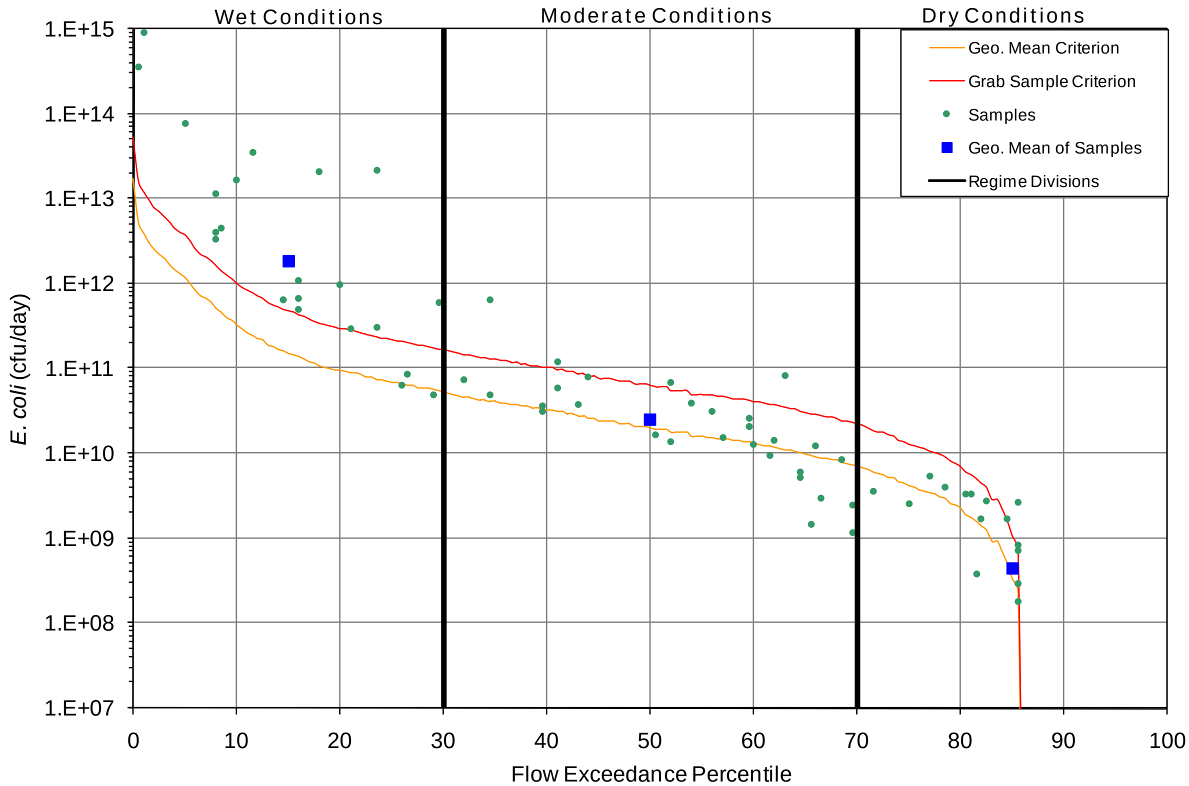

Figure 5-9: LDC for Station 11323 (Spring Creek at Rosehill Rd)

Station 11314 – Spring Creek at SH 249

The load duration curve for Station 11314 is shown in Figure 5-10. As with the previous stations, it is clear that exceedances of water quality criteria appear to be common under relatively high flow conditions. Seventy percent (70%) and 30% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively.

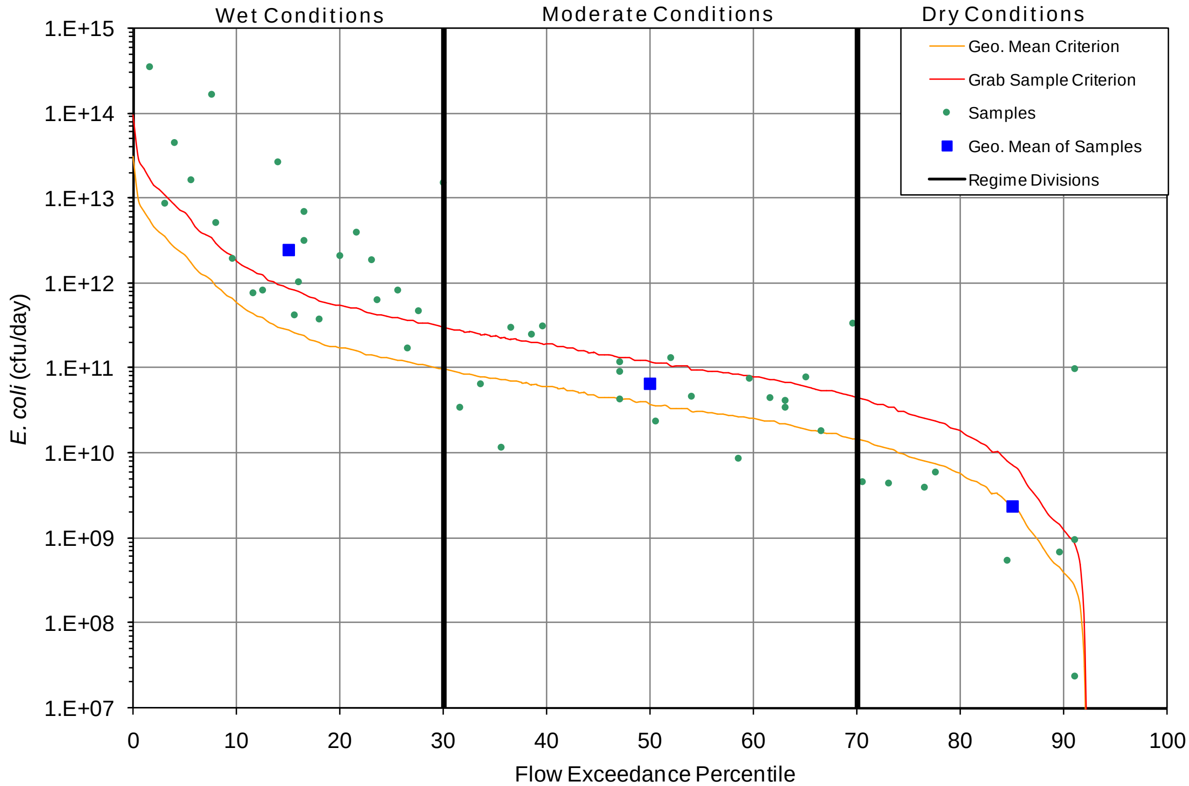

Figure 5-10: LDC for Station 11314 (Spring Creek at SH 249)

Station 17489 – Spring Creek at Kuykendahl Rd

The load duration curve for Station 17489 is shown in Figure 5-11. As with the previous station, criteria exceedances are most typical under relatively high flow conditions. Seventy-four (74%) and 27% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively.

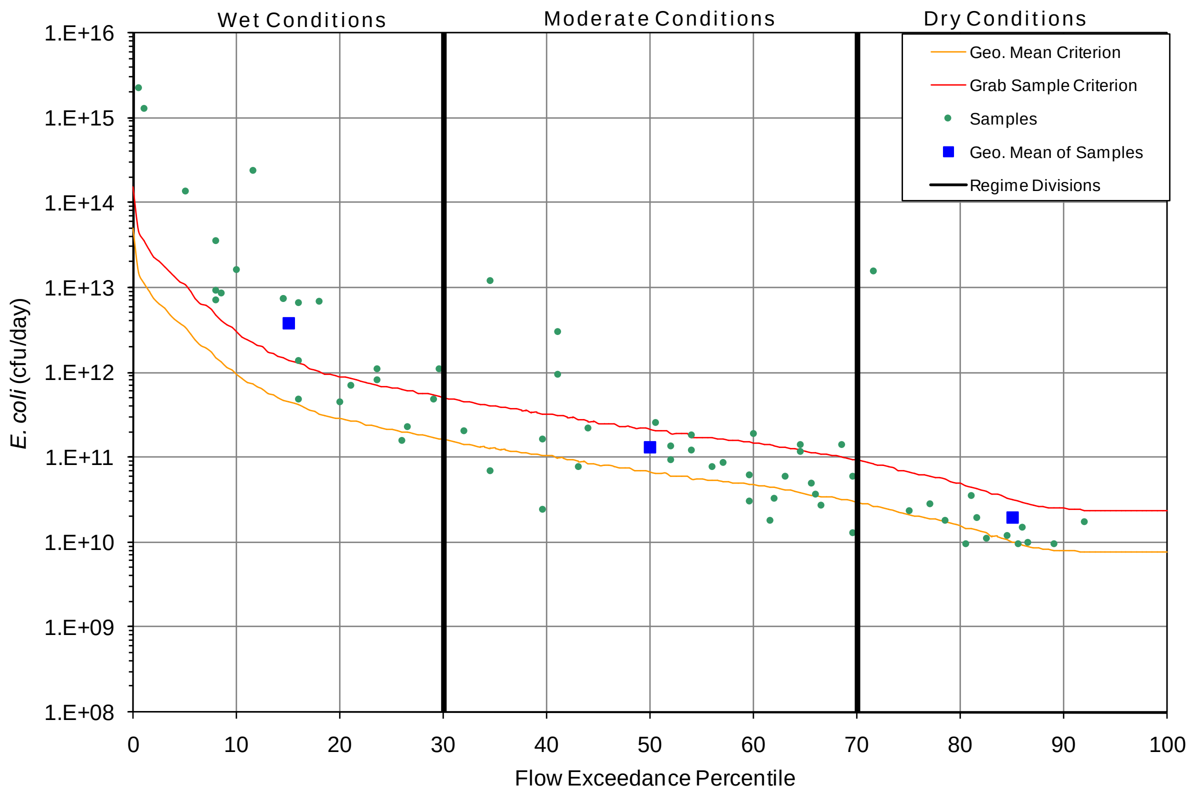

Figure 5-11: LDC for Station 17489 (Spring Creek at Kuykendahl Rd)

Station 11313 – Spring Creek at IH 45

The load duration curve for Station 11313 is shown in Figure 5-12. As with the previous two stations, it is clear that exceedances of water quality criteria appear to be common under relatively high flow conditions. Seventy-four percent (74%) and 45% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively. Additionally, 25% of samples during Dry flow conditions exceed the grab sample criteria, although the geometric mean fell slightly below state criteria.

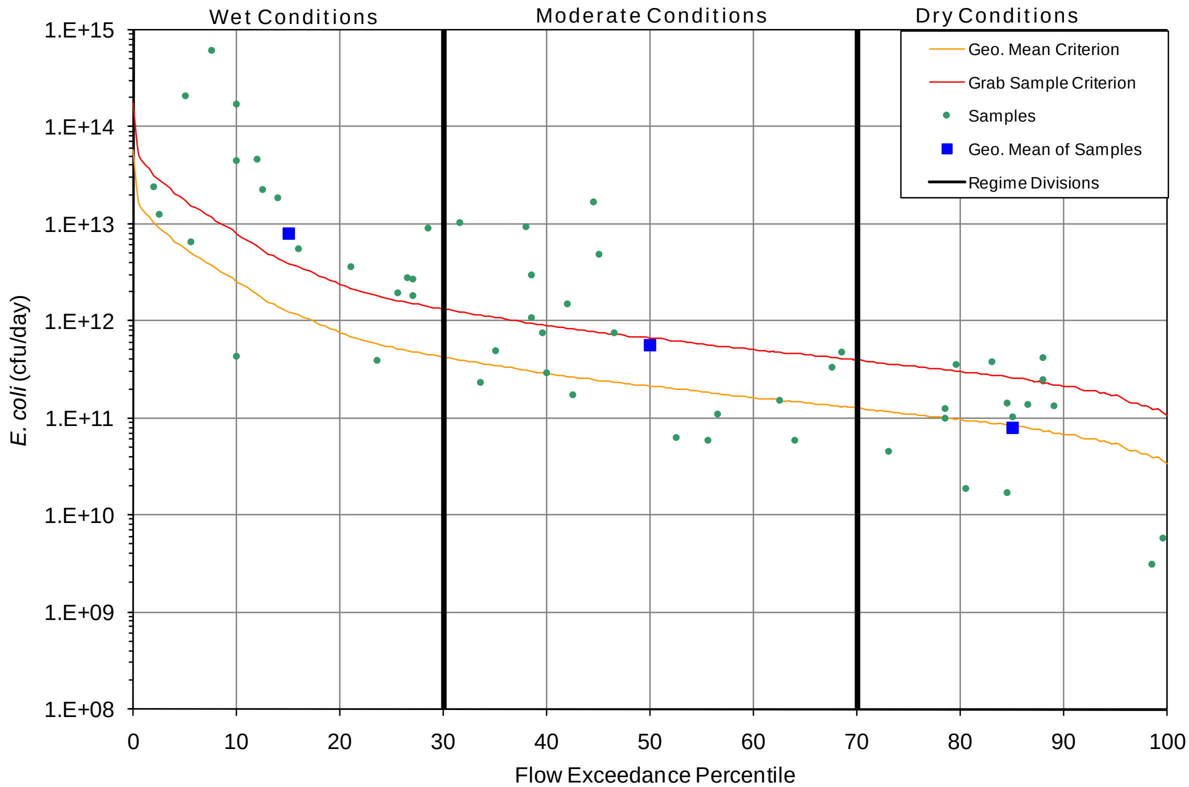

Figure 5-12: LDC for Station 11313 (Spring Creek at IH 45)

Station 11312 – Spring Creek at Riley Fuzzel Rd

The load duration curve for Station 11312 is shown in Figure 5-13. As with the previous stations, it is clear that exceedances of water quality criteria appear to be common under relatively high flow conditions. Ninety-six percent (96%) and 32% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively. Bacteria levels at Dry flow conditions generally meet state criteria. For relatively high flow conditions, bacteria levels at this station appear to be higher than the previous upstream stations.

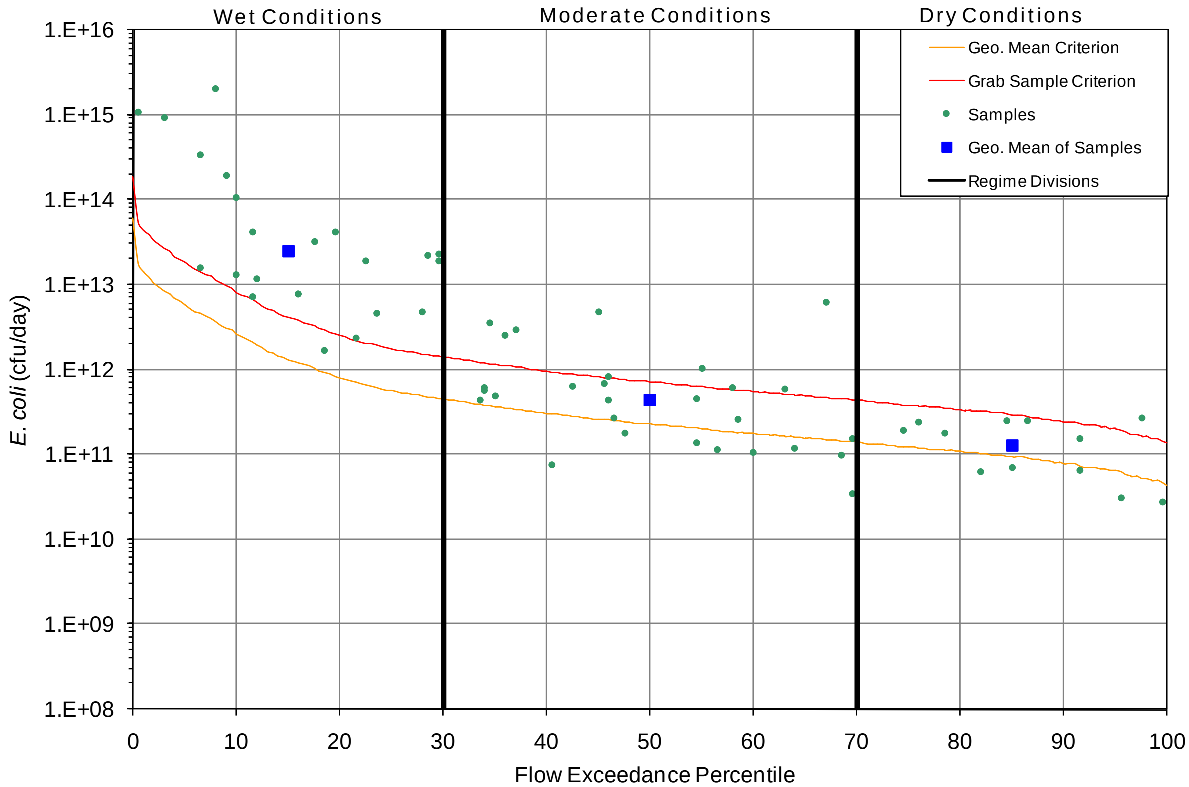

Figure 5-13: LDC for Station 11312 (Spring Creek at Riley Fuzzel Rd)

Station 11185 – Willow Creek at Gosling Rd

The load duration curve for Station 11185 is shown in Figure 5-14. This station experienced greater distribution in sample variation than generally observed. Seventy-seven percent (77%), 30% and 40% of samples exceed the grab sample criterion in the Wet, Moderate, and Dry flow regimes, respectively.

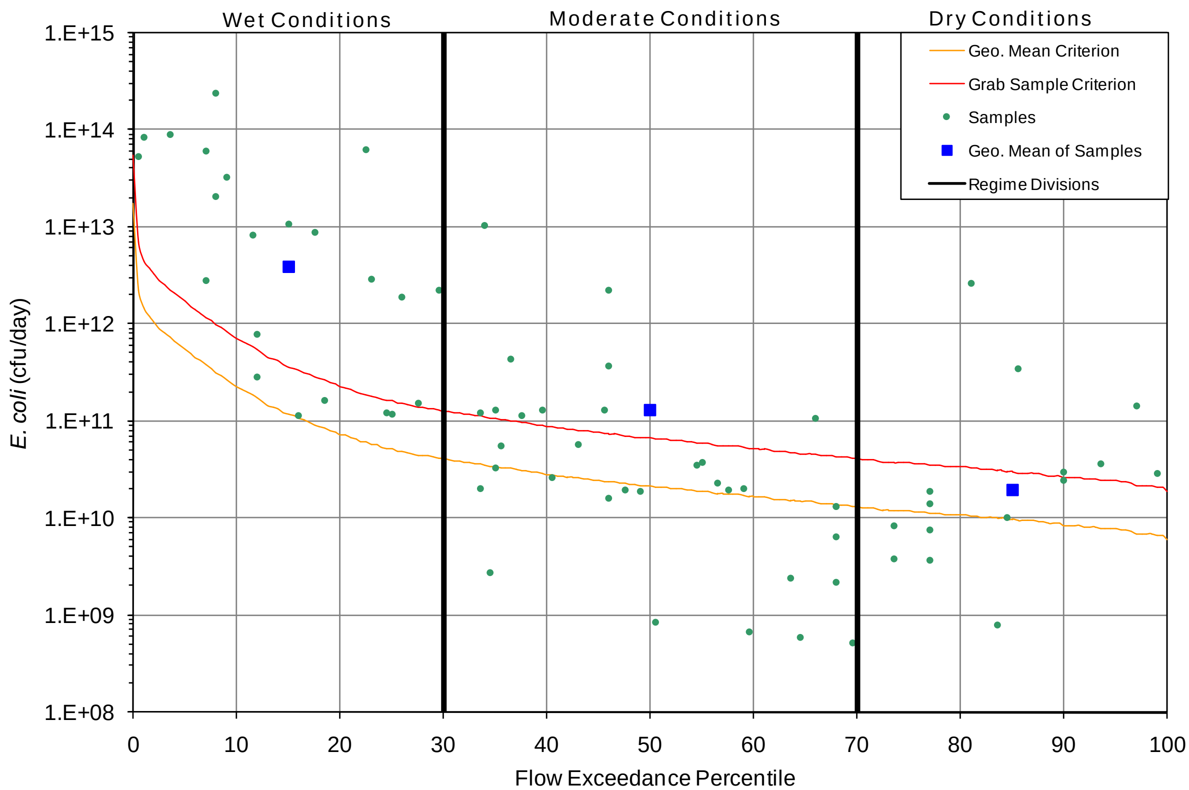

Figure 5-14: LDC for Station 11185 (Willow Creek at Gosling Rd)

Station 11333 – Cypress Creek at Hahl Rd

The load duration curve for Station 11333 is shown in Figure 5-15. Exceedances of state criteria appear to be most common under high flow conditions, beginning at approximately the 35 flow exceedance percentile. Eighty percent (80%) and 22% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively. Samples collected during Dry conditions generally meet state criterion.

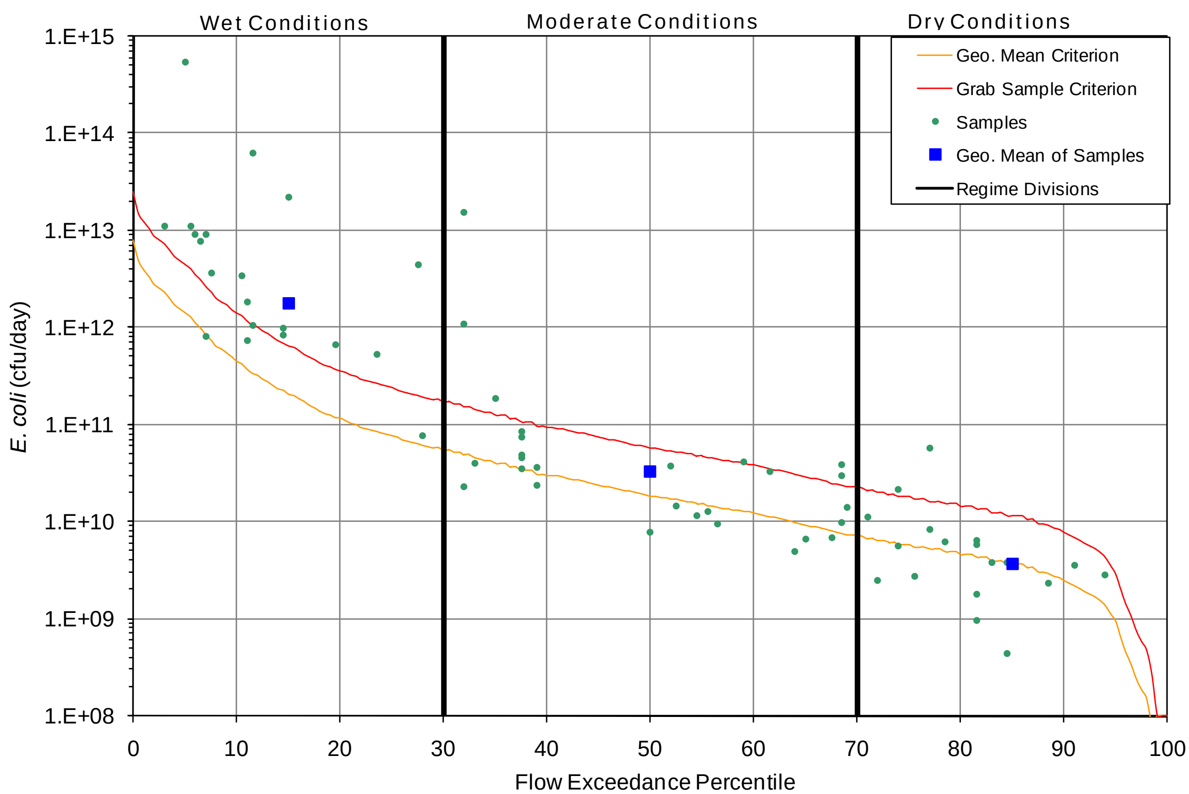

Figure 5-15: LDC for Station 11333 (Cypress Creek at Hahl Rd)

Station 11332 – Cypress Creek at Grant Rd

The load duration curve for Station 11332 is shown in Figure 5-16. Water quality criteria exceedances appear to be common under approximately the 45 flow exceedance percentile. Eighty-one percent (81%) and 22% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively.

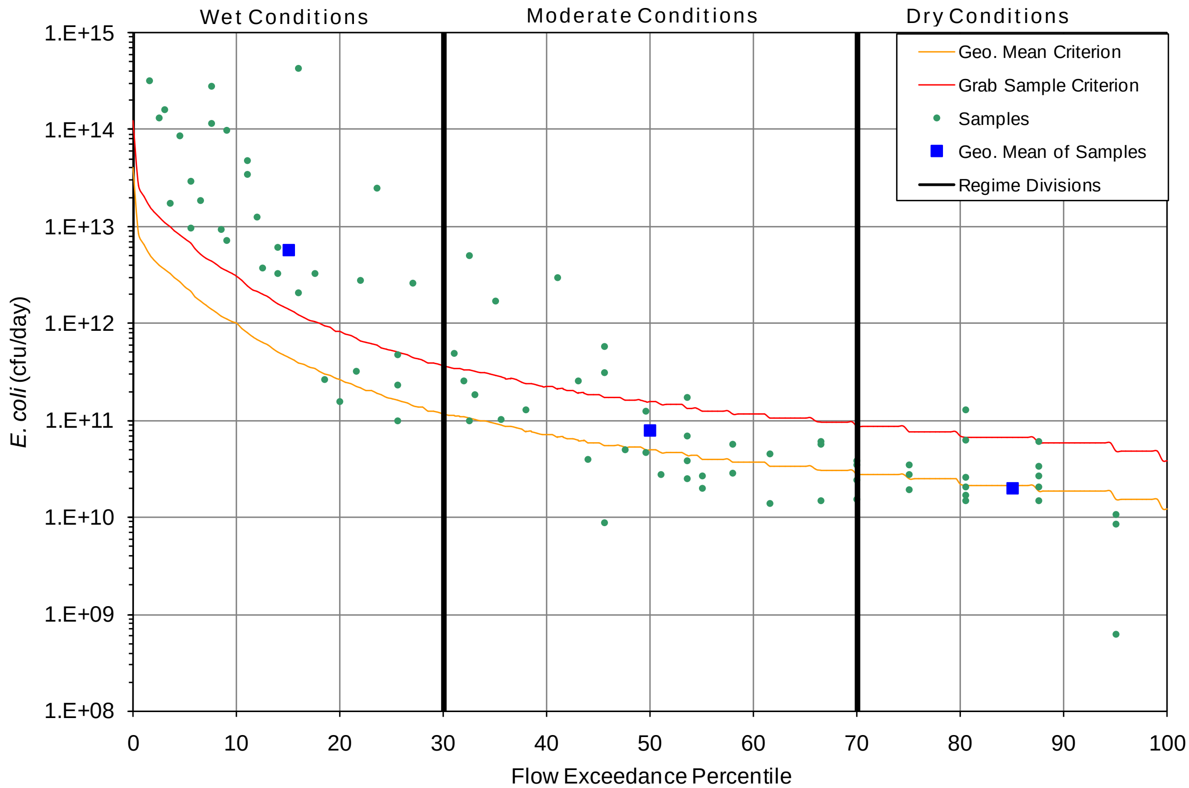

Figure 5-16: LDC for Station 11332 (Cypress Creek at Grant Rd)

Station 11331 – Cypress Creek at SH 249

The load duration curve for Station 11331 is shown in Figure 5-17. Seventy-four percent (74%) and 55% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively. A comparison of the data at this station to the two previous upstream stations suggests that bacteria levels are typically slightly higher at this station.

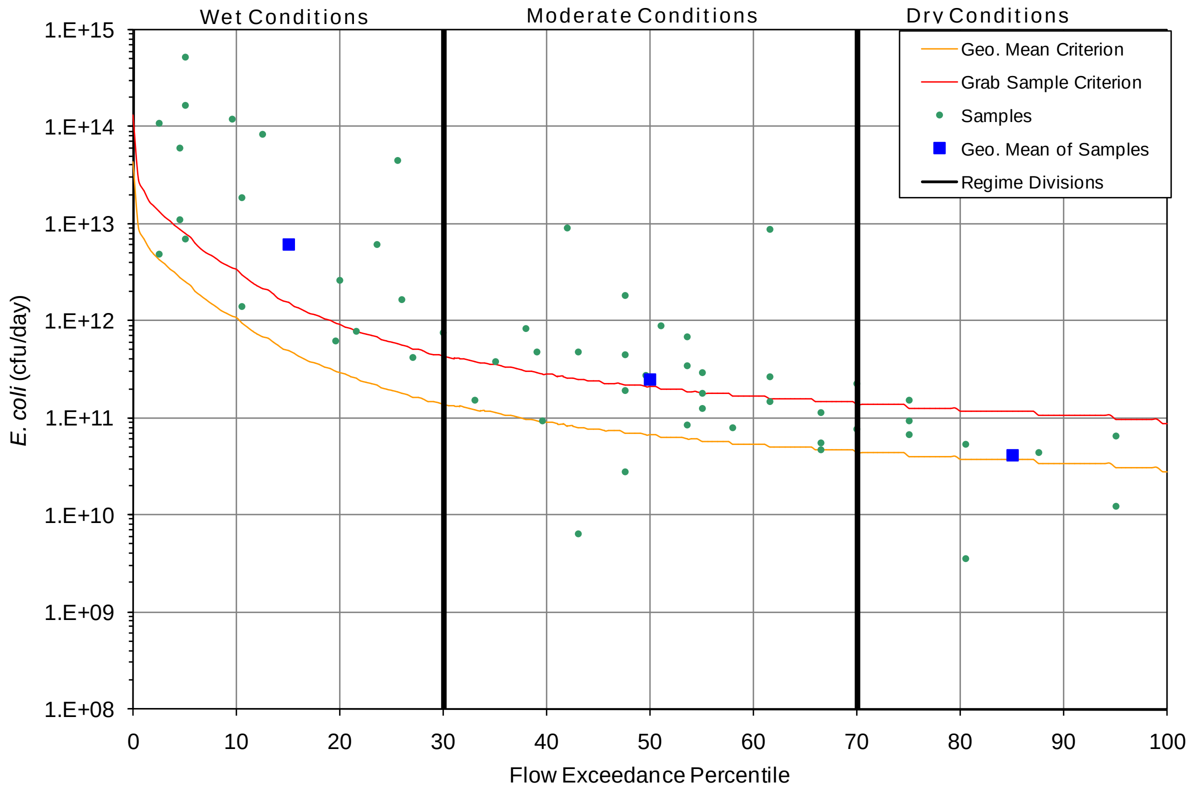

Figure 5-17: LDC for Station 11331 (Cypress Creek at SH 249)

Station 11330 – Cypress Creek at Steubner-Airline Rd

The load duration curve for Station 11330 is shown in Figure 5-18. Exceedances of water quality criteria at this station occur commonly under all flow conditions, again more frequently under higher flow regimes. Eighty-eight percent (88%), 52%, and 37% of samples exceed the grab sample criterion in the Wet, Moderate, and Dry flow regimes, respectively. Additionally, the geometric means of samples exceed the grab sample criteria at all flow regimes.

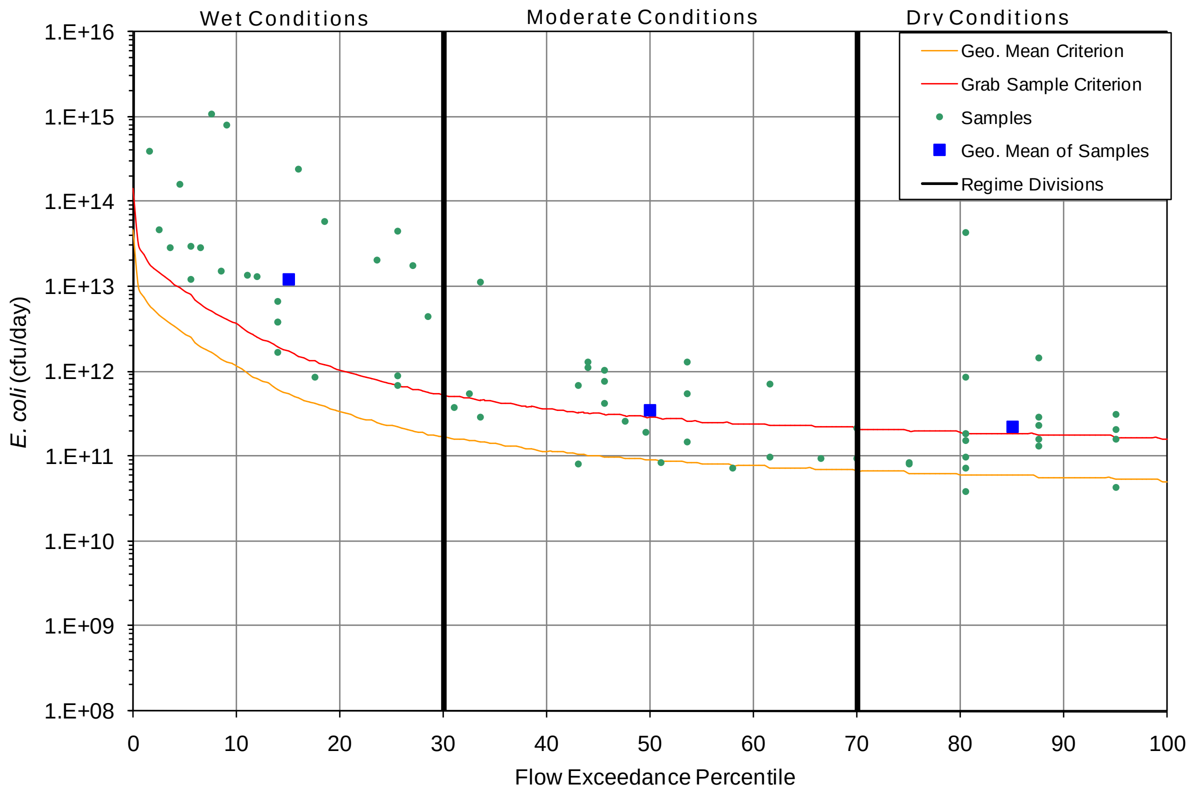

Figure 5-18: LDC for Station 11330 (Cypress Creek at Steubner-Airline Rd)

Station 11328 – Cypress Creek at IH 45

The load duration curve for Station 11328 is shown in Figure 5-19. As with the previous station, exceedances of water quality criteria appear common under all flow regimes and most prominently during Wet conditions. Eighty-three percent (83%), 56%, and 31% of samples exceed the grab sample criterion in the Wet, Moderate, and Dry flow regimes, respectively.

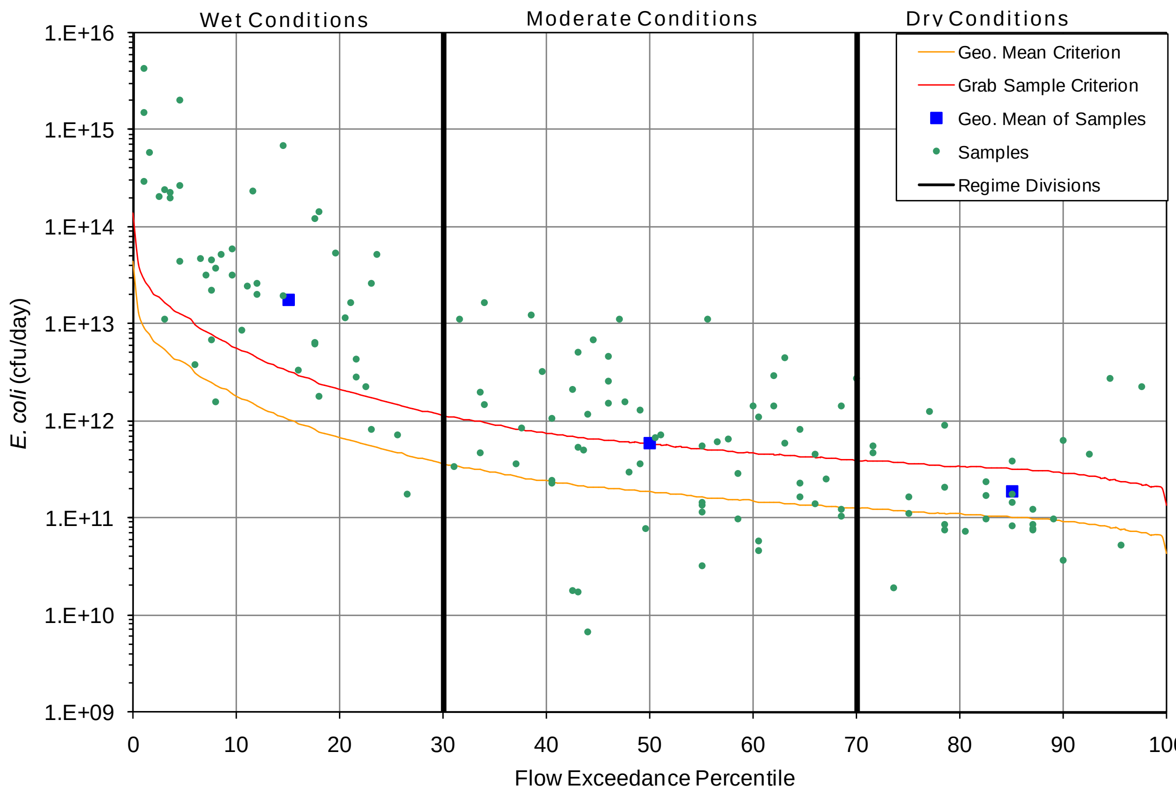

Figure 5-19: LDC for Station 11328 (Cypress *Creek at IH 45*)

Station 11324 – Cypress Creek at Cypresswood Dr

The load duration curve for Station 11324 is shown in Figure 5-20. For this station, there are relatively few samples taken under Dry flow conditions. Seventy-eight percent (78%) and 24% of samples exceed the grab sample criterion in the Wet and Moderate flow regimes, respectively. Bacteria levels collected during Dry flow conditions generally meet state criteria, with zero samples that exceed the grab sample criteria.

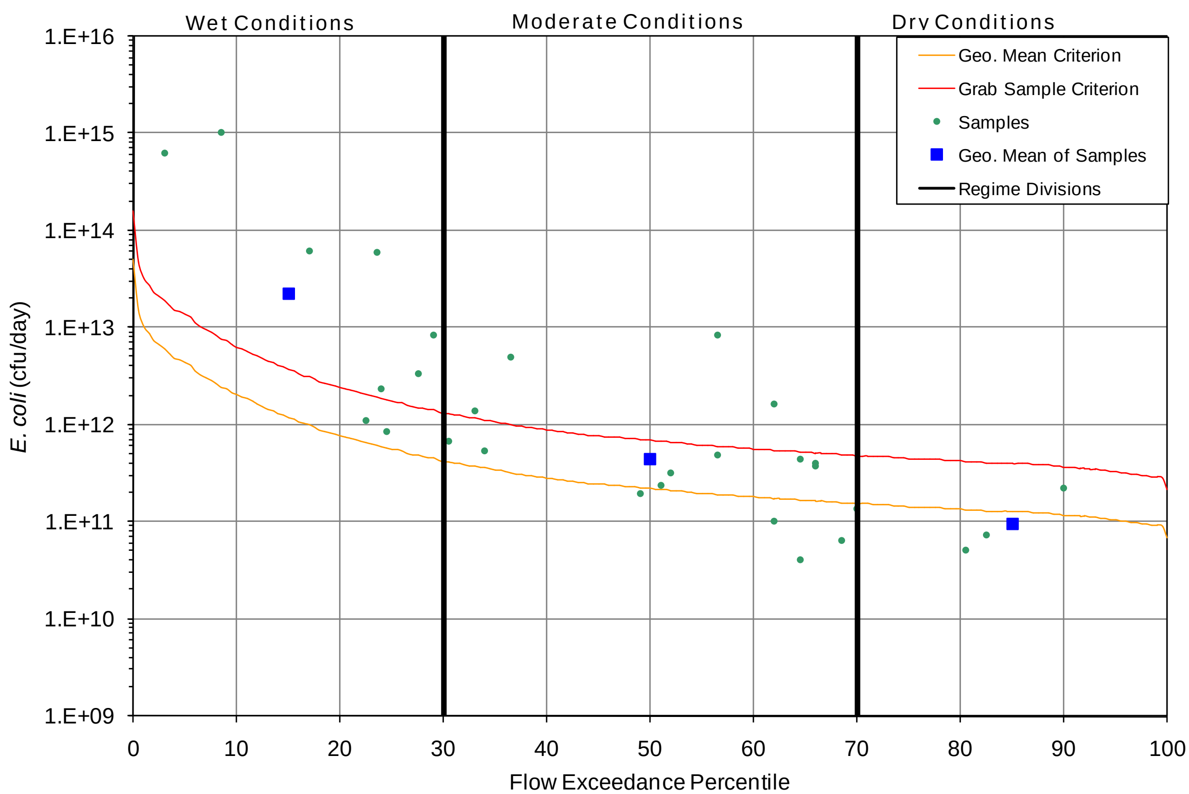

Figure 5-20: LDC for Station 11324 (Cypress Creek at Cypresswood Dr)

Station 17496 – Faulkey Gully at Lakewood Forest Dr

The load duration curve for Station 17496 is shown in Figure 5-21. As with the previous stations, exceedances of water quality criteria appear common under all flow regimes and most prominently during Wet conditions. Sixty-eight percent (68%), 42%, and 25% of samples exceed the grab sample criterion in the Wet, Moderate, and Dry flow regimes, respectively.

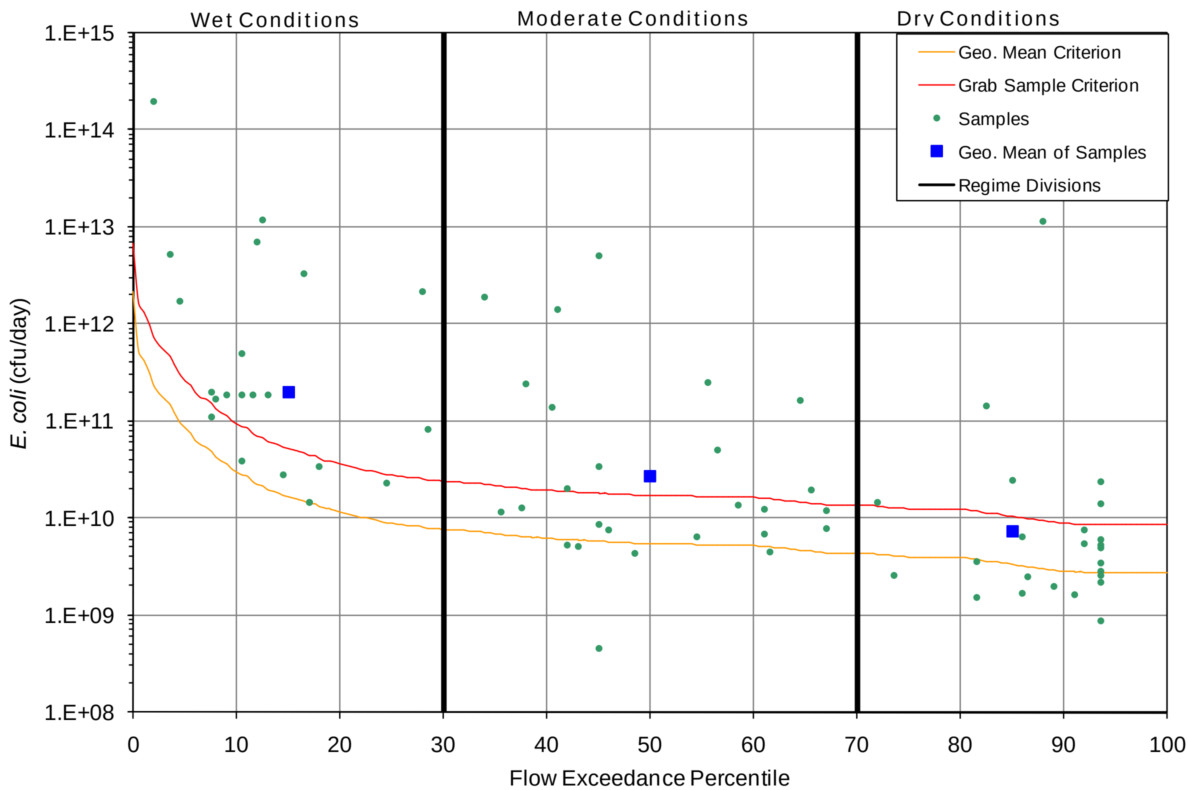

Figure 5-21: LDC for Station 17496 (Faulkey Gully at Lakewood Forest Dr)

Station 17481 – Spring Gully at Spring Creek Oaks Dr

The load duration curve for Station 17496 is shown in Figure 5-21. For this station, exceedances of water quality criteria appear common under all flow regimes. Eight-five percent (85%), 47%, and 67% of samples exceed the grab sample criterion in the Wet, Moderate, and Dry flow regimes, respectively.

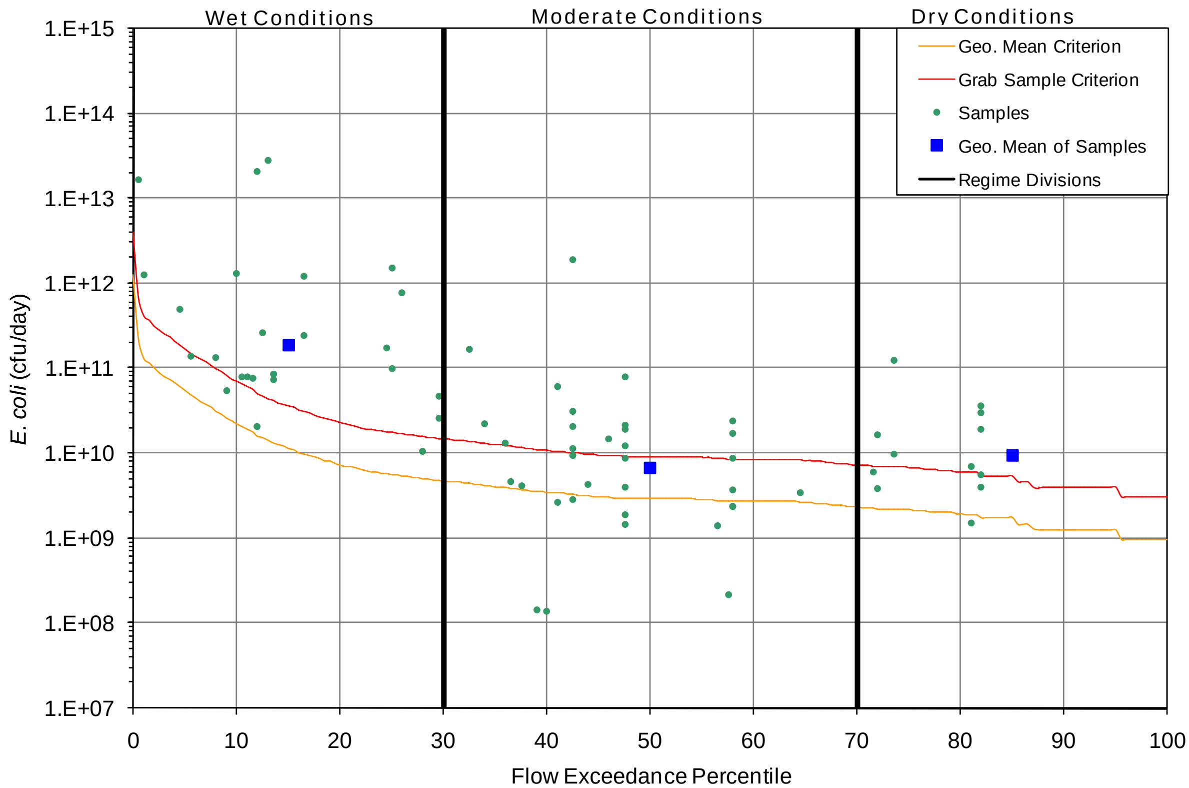

Figure 5-22: LDC for Station 17481 (Spring Gully at Spring Creek Oaks)

Station 14159 – Little Cypress Creek at Kluge Rd

The load duration curve for Station 14159 is shown in Figure 5-23. As with the previous stations, exceedances of water quality criteria appear common under all flow regimes and most prominently during Wet conditions. Eighty-two percent (82%), 40%, and 54% of samples exceed the grab sample criterion in the Wet, Moderate, and Dry flow regimes, respectively.

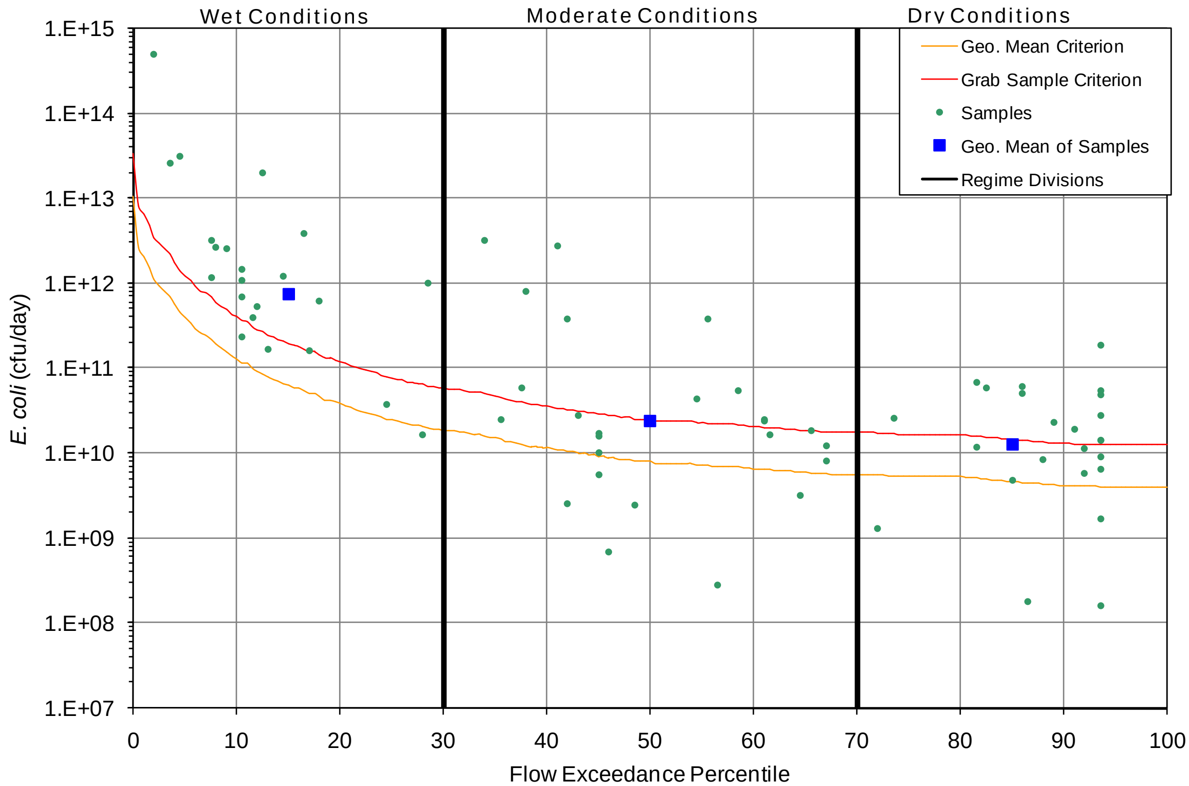

Figure 5-23: LDC for Station 14159 (Little Cypress Creek at Kluge Rd)

6.0 TMDL DEVELOPMENT

The preceding section described how water quality data were analyzed using the load duration curve (LDC) methodology. The locations and flow conditions corresponding with exceedances of water quality criteria were identified based on this analysis. Section 6.0 describes the development of a TMDL to quantify the loading reductions that will be required to bring the river into compliance with promulgated bacteria criteria.

6.1 DEFINITION

A total maximum daily load (TMDL) is defined as the maximum quantity of a pollutant that can be assimilated by a waterbody in one day while complying with water quality standards. A TMDL can be further defined by the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

where… $\sum WLA$ = Sum of Wasteload Allocations (Point Source Allocation)
$\sum LA$ = Sum of Load Allocations (Nonpoint Source Allocation)
MOS = Margin of Safety

In this equation, the wasteload allocation (WLA) and load allocation (LA) represent the maximum allowable point and nonpoint source contributions, respectively. The margin of safety is included to account for variability due to unknowns and/or model assumptions. For the purposes of TMDL development, the WLA includes wastewater treatment facilities and permitted stormwater systems. Within urbanized areas stormwater runoff is regulated by municipal separate storm sewer system (MS4) permits. Table 4-7 previously presented MS4 coverage of watersheds, which ranged from 0-36% depending on level of development. The LA portion of the TMDL represents the loading assigned to nonpoint sources, which would include nonpermitted stormwater runoff, direct deposition from animals, failing septic systems, and leaking wastewater infrastructure. For development of TMDLs in areas that have regulated stormwater point sources, the TMDL equation presented above would be modified as follows:

$$TMDL = \sum WLA_{WWTF} + \sum WLA_{MS4} + \sum LA_{\text{unregulated stormwater and nonpoint sources}} + MOS$$

6.2 ENDPOINT

The TMDL endpoint represents the water quality conditions that must be achieved so that the waterbody can support its beneficial uses. The endpoint for this study is defined by the Texas Surface Water Quality Standards. According to these standards, the geometric mean criterion for *E. coli* is 126 cfu/dL and the grab sample criterion is 394 cfu/dL (which may be exceeded by no more than 25% of samples). For this TMDL, the endpoint will be considered achieved when the geometric mean criterion is achieved for the "critical conditions" described in the following section.

6.3 CRITICAL CONDITIONS

Critical conditions are used to determine the load reductions required for the TMDL. Using the load duration curve approach, critical conditions are defined by the flow regime under which the maximum percent load reduction is required to achieve compliance with water quality standards. In Section 5.0, this analysis defined the three flow categories (see Table 5-2). TCEQ has previously adopted this flow categorization for the Buffalo and Whiteoak Bayous TMDL study.

Critical conditions were determined in terms of location, as bacteria levels vary significantly across individual stations. From the analysis presented in Section 5.0, it can be observed that some stations will require greater load reductions than others. The required loading reductions were calculated for all stations within an assessment unit.

6.4 MARGIN OF SAFETY

A margin of safety can be incorporated into a TMDL analysis using either of two methods:

1. An *Implicit MOS* is incorporated through the application of conservative analysis assumptions.
2. An *Explicit MOS* is incorporated by reducing the allowable loading of the waterbody by a specified numerical value.

For this TMDL, an explicit MOS of 5% has been applied to the state's water quality criteria. This effectively reduces the geometric mean criterion from 126 to 120 cfu/dL, and reduces the grab sample criterion from 394 to 374 cfu/dL. Furthermore, the critical conditions were defined conservatively (defined by location of greatest exceedance), and therefore could be considered an additional implicit margin of safety.

6.5 CRITICAL LOAD REDUCTIONS

Loading reductions are required when the existing bacteria levels exceed the TMDL (including MOS). Because the state criteria are in terms of geometric mean and grab sample concentrations, the TMDL is represented by load duration curves for 120 cfu/dL and 374 cfu/dL. The required geometric mean loading reduction can be determined for each flow regime by calculating the difference between the loads corresponding to the geometric mean concentration and the 120 cfu/dL criterion curve. The highest and overall loading reductions for all analyzed stations are shown in Table 6-1. Wet condition (high flow) constituted the largest required reduction at all stations, and range from 75-96%. The geometric mean criterion was also exceeded by 100% of stations under moderate flow conditions and approximately 75% of stations under dry conditions.

Table 6-1: TMDL Percent Reductions for Contact Recreation Criteria in the Lake Houston Watershed

Assesment Unit	Station #	Stream Name	Indicator Bacteria Species	Highest Reduction		Overall Reduction
				Percent Reduction	Corresponding Flow Regime	
1004E_02	16626	Stewarts Creek	*E. Coli*	81%	Wet Conditions	47%
1008_02	11323	Spring Creek	*E. Coli*	92%	Wet Conditions	64%
1008_02	11314		*E. Coli*	89%	Wet Conditions	71%
1008_03	17489		*E. Coli*	89%	Wet Conditions	70%
1008_03	11313		*E. Coli*	85%	Wet Conditions	64%
1008_04	11312		*E. Coli*	95%	Wet Conditions	77%
1008H_01	11185	Willow Creek	*E. Coli*	96%	Wet Conditions	74%
1009_01	11333	Cypress Creek	*E. Coli*	89%	Wet Conditions	62%
1009_02	11332		*E. Coli*	93%	Wet Conditions	68%
1009_02	11331		*E. Coli*	92%	Wet Conditions	80%
1009_03	11330		*E. Coli*	96%	Wet Conditions	87%
1009_03	11328		*E. Coli*	94%	Wet Conditions	81%
1009_04	11324		*E. Coli*	95%	Wet Conditions	74%
1009C_01	17496	Faulkey Gully	*E. Coli*	92%	Wet Conditions	81%
1009D_01	17481	Spring Gully	*E. Coli*	94%	Wet Conditions	82%
1009E_01	14159	Little Cypress Creek	*E. Coli*	92%	Wet Conditions	78%
1010_02	14241	Caney Creek	*E. Coli*	87%	Wet Conditions	59%
1010_04	11334		*E. Coli*	84%	Wet Conditions	41%
1011_02	11336	Peach Creek	*E. Coli*	75%	Wet Conditions	51%
1011_02	17746		*E. Coli*	81%	Wet Conditions	53%

6.6 WASTELOAD ALLOCATION (POINT SOURCE)

The TMDL wasteload allocation (WLA) represents the maximum allowable contribution of point sources. As previously defined, the WLA includes the summation of WWTF and MS4 discharges. Effluent from approximately 200 WWTFs accounts for over 50% of the median flow at multiple TMDL study segments and is most predominant at low flow conditions. Only at the Peach Creek and Caney Creek gaging stations does WWTF effluent account for less than 1% of stream flow.

According to permit requirements, wastewater treatment plants are required to provide disinfection. If disinfection is achieved then bacteria concentrations should be negligible. The daily wasteload allocation for TPDES permitted facilities is calculated by multiplying a nominal bacteria concentration of 63 cfu/dL, one half of the geometric mean criteria, with the total permitted flow. Tables 6-2 through 6-5 identify each assessment unit's TPDES permitted facilities with their June 2007 permitted flow and corresponding *E. coli* daily wasteload allocation (cfu/day).

Table 6-2: Spring Creek Wasteload Allocations for TPDES-Permitted Facilities

TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (cfu/day)
		Assessment Unit: 1008_02			
11871-001	TX0072702	City of Magnolia	Montgomery	0.65	1.55E+09
12402-001	TX0086053	Houston Oaks Golf Management, LP	Waller	0.01	2.38E+07
12898-001	TX0095125	Aqua Utilities, Inc	Montgomery	0.08	1.79E+08
13115-001	TX0097969	Clovercreek MUD	Montgomery	0.12	2.86E+08
13653-001	TX0110663	Magnolia ISD	Montgomery	0.02	3.58E+07
14007-001	TX0117846	AquaSource Development Co	Montgomery	0.13	3.10E+08
14133-001	TX0119857	White Oak Utilities, Inc	Montgomery	0.20	4.77E+08
14266-001	TX0094315	HMV Special Utility District	Montgomery	0.03	5.96E+07
14542-001	TX0126934	1774 Utilities, Corp	Montgomery	0.15	3.58E+08
14624-001	TX0127973	Rosehill Utilities, Inc	Waller	0.02	4.77E+07
		Assessment Unit: 1008_03			
10616-001	TX0022381	City of Tomball	Harris	1.50	3.58E+09
10857-001	TX0025399	Montgomery Co WCID #1	Montgomery	0.42	1.00E+09
11968-001	TX0077275	Tecon Water Company, LP	Montgomery	0.05	1.24E+08
12303-001	TX0085693	Aqua Utilities, Inc	Harris	0.02	3.58E+07
12382-001	TX0087475	C&P Utilities, Inc/ J&S Water Company, LLC5	Harris	0.12	2.86E+08
12587-001	TX0090905	Tecon Water Company, LP	Montgomery	0.46	1.10E+09
12650-001	TX0092088	Spring Oaks Mobile Home Park, Inc.	Harris	0.03	5.96E+07
12851-001	TX0094552	Richard Clark Enterprises, LLC	Montgomery	0.06	1.43E+08
13614-001	TX0108553	Richfield Investment Corp	Montgomery	0.61	1.45E+09
13636-001	TX0109622	Richfield Investment Corp	Montgomery	0.41	9.66E+08
13648-001	TX0042099	Encanto Real UD	Harris	0.25	5.96E+08
13863-001	TX0115827	H.H.J., Inc	Montgomery	0.80	1.91E+09
14124-001	TX0119598	Magnolia ISD	Montgomery	0.02	4.77E+07
14218-001	TX0123587	Diocese of Galveston-Houston	Montgomery	0.02	3.58E+07
14347-001	TX0124907	The Woodlands Land Development Co. LP	Harris	unk	unk
14491-001	TX0126306	Is Zen Center	Montgomery	0.04	8.35E+07
14517-001	TX0125547	South Central Water Company	Harris	0.04	9.06E+07
14551-001	TX0127035	AUC Group, LP	Montgomery	0.95	2.27E+09
14592-001	TX0127663	South Central Water Company	Montgomery	0.32	7.63E+08
14662-001	TX0128333	Navasota ISD	Grimes	0.02	5.72E+07
14684-001	TX0128520	Jason Andrew Thompson	Montgomery	unk	unk
14711-001	TX0128821	Maw Magnolia LTD	Montgomery	unk	unk
		Assessment Unit: 1008_04			
10908-001	TX0020974	Harris County WCID #92	Harris	0.70	1.67E+09
11001-001	TX0024759	Southern Montgomery County MUD	Montgomery	2.00	4.77E+09
11406-001	TX0056537	Harris Co. MUD #26	Harris	1.50	3.58E+09
11574-001	TX0026221	Spring Creek UD	Montgomery	0.93	2.22E+09
11799-001	TX0071528	Harris Co. MUD #82	Harris	2.20	5.25E+09
11970-001	TX0076538	Montgomery Co. MUD #19	Montgomery	0.72	1.71E+09
12030-001	TX0078263	Rayford Road MUD	Montgomery	0.00	3.58E+06
12637-001	TX0091791	Spring Center, Inc	Harris	0.01	1.43E+07
12788-001	TX0095621	Eastwood Mobile Home Park LP	Montgomery	0.05	1.19E+08
12979-004	TX0119181	Northgate Crossing MUD #2	Harris	0.95	2.27E+09
14656-001	TX0128295	Montgomery Co MUD #94	Montgomery	1.08	2.58E+09
		Assessment Unit: 1008C_01			
11401-001	TX0054186	San Jacinto River Authority	Montgomery	7.80	1.86E+10
12597-001	TX0091715	San Jacinto River Authority	Montgomery	7.80	1.86E+10
12703-001	TX0092843	Magnolia ISD	Montgomery	0.05	1.14E+08
13697-001	TX0090000	Cedarstone One Investors, Inc	Montgomery	0.00	7.15E+06
14013-001	TX0118028	AquaSource Development Co	Montgomery	0.05	1.19E+08
14141-001	TX0120073	Aqua Development, Inc	Montgomery	0.45	1.07E+09
		Assessment Unit: 1008H_01			
10616-002	TX0117595	City of Tomball	Harris	1.50	3.58E+09
10910-001	TX0058548	Northampton MUD	Harris	0.75	1.79E+09
11404-001	TX0026255	Dowdell PUD	Harris	0.95	2.27E+09
11630-001	TX0058530	Harris Co. MUD #1	Harris	1.50	3.58E+09
12044-001	TX0078433	Harris Co MUD #368	Harris	1.60	3.82E+09
12153-001	TX0081264	North Harris Co MUD #19	Harris	0.25	5.96E+08
12519-001	TX0089915	Aquasource Utility, Inc	Harris	0.10	2.38E+08
12643-001	TX0091987	Pinewood Community LP	Harris	0.10	2.38E+08
13487-001	TX0119628	Timbercrest Community Association	Harris	0.20	4.77E+08
13619-001	TX0083976	Aqua Utilities, Inc	Harris	0.04	9.54E+07
13942-001	TX0117633	Inline Utilities, LLC	Harris	0.25	5.96E+08
14181-001	TX0122530	Aqua Development, Inc	Harris	0.08	1.79E+08
14421-001	TX0125687	2920 Venture, LTD/Harris County MUD #4014	Harris	0.60	1.43E+09
14475-001	TX0126152	Northwest Harris Co. MUD #19	Harris	0.70	1.67E+09
14606-001	TX0127795	South Central Water Company	Harris	0.08	1.91E+08
14610-001	TX0127850	501 Maple Ridge, LTD	Harris	0.64	1.53E+09

Table 6-3: Cypress Creek Wasteload Allocations for TPDES-Permitted Facilities

TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (cfu/day)
		Assessment Unit: 1009_01			
01310-001	TX0032476	City of Waller	Waller	0.90	2.15E+09
13296-002	TX0105376	Harris Co MUD #358	Harris	2.00	4.77E+09
14448-001	TX0125938	Houston Warren Ranch Partners, LLC	Harris	0.55	1.31E+09
14576-001	TX0127311	523 Venture, Inc/Becker Road LP[3]	Harris	0.20	4.77E+08
		Assessment Unit: 1009_02			
02608-000	TX0092258	Center Point Energy Houston Electric LLC	Harris	0.02	4.77E+07
10962-001	TX0062049	Harris County WCID #113	Harris	0.30	7.15E+08
11084-001	TX0046833	Lake Forest Plant Advisory Council	Harris	2.76	6.58E+09
11267-001	TX0046868	Timberlake ID	Harris	0.40	9.54E+08
11912-002	TX0075159	Northwest Harris Co MUD #10	Harris	1.50	3.58E+09
11986-001	TX0076791	Tower Oak Bend WSC	Harris	0.05	1.19E+08
12327-001	TX0086011	Cypress Hill MUD #1	Harris	0.80	1.91E+09
12541-001	TX0090182	Chasewood Utilities, Inc	Harris	0.10	2.38E+08
12877-001	TX0094706	Harris Co MUD #230	Harris	0.76	1.81E+09
13020-001	TX0096920	Harris Co MUD #286	Harris	0.60	1.43E+09
13059-001	TX0098434	Kwik-Kopy Corp	Harris	0.02	3.58E+07
13881-001	TX0116009	Harris Co MUD #365	Harris	1.20	2.86E+09
14028-001	TX0117129	Harris Co MUD 371	Harris	0.25	5.96E+08
14030-001	TX0075221	Northwest Harris Co MUD #9	Harris	1.50	3.58E+09
14130-001	TX0081272	Northwest Harris Co MUD #10	Harris	0.05	1.14E+08
14172-001	TX0121126	Utilities Investment Company, Inc	Harris	0.18	4.36E+08
14209-001	TX0123366	CTP Utilities Inc	Harris	0.18	4.29E+08
14327-001	TX0124770	Harris Co. MUD #391	Harris	0.95	2.27E+09
14354-001	TX0124974	Harris Co. MUD #374	Harris	0.65	1.55E+09
14476-001	TX0126161	Rouse-Houston, LP	Harris	0.80	1.91E+09
		Assessment Unit: 1009_03			
04313-000	TX0113948	Northwest Airport Management LP	Harris	variable	variable
10528-001	TX0026450	Harris Co. FWSD # 52	Harris	0.70	1.67E+09
10955-001	TX0046710	Harris County WCID #116	Harris	1.30	3.10E+09
11024-001	TX0021211	Harris Co WCID #119	Harris	1.00	2.37E+09
11081-001	TX0046761	Ponderosa Joint Powers Agency	Harris	4.87	1.16E+10
11089-001	TX0046701	Prestonwood Frest UD	Harris	0.95	2.27E+09
11105-001	TX0046639	Bammel UD	Harris	2.60	6.20E+09
11215-001	TX0046663	Meadowhill Regional MUD	Harris	2.40	5.72E+09
11239-001	TX0055166	CNP UD	Harris	2.50	5.96E+09
11314-001	TX0046744	Aqua Texas, Inc	Harris	0.40	9.54E+08
11366-001	TX0046779	Cypress-Klein UD	Harris	0.70	1.67E+09
11409-001	TX0046817	Kleinwood Joint Powers Board	Harris	5.00	1.19E+10
11410-002	TX0046841	Charterwood MUD	Harris	1.60	3.82E+09
11835-001	TX0072150	Bridgestone MUD	Harris	2.50	5.96E+09
11900-001	TX0074217	Tina Lee Tilles DBA Turk Brothers Building	Harris	0.00	2.38E+06
11925-001	TX0074632	Harris Co MUD #104	Harris	0.60	1.43E+09
11941-001	TX0074322	Harris Co MUD #58	Harris	0.60	1.43E+09
11964-001	TX0076481	Harris Co WCID #110	Harris	1.00	2.38E+09
11988-001	TX0076856	Harris Co MUD #24	Harris	2.00	4.77E+09
11988-002	TX0113123	Harris Co MUD #24	Harris	0.06	1.43E+08
11988-003	TX0113115	Harris Co MUD #24	Harris	0.06	1.43E+08
12248-001	TX0084760	UA Holdings 1994-5	Harris	0.10	2.38E+08
12730-001	TX0090344	Champ's Water Company	Harris	0.02	3.67E+07
13569-001	TX0078930	Samuel Victor Pinter	Harris	0.00	3.58E+06
13573-001	TX0108120	Northwest Harris County MUD #36	Harris	0.20	4.77E+08
13625-001	TX0081337	Northwest Harris Co MUD #20	Harris	0.40	9.54E+08
13875-002	TX0115983	Harris Co MUD #383	Harris	1.50	3.58E+09
13893-001	TX0122211	Dia-Den LTD	Harris	0.02	4.29E+07
13942-002	TX0125466	Inline Utilities, LLC	Harris	0.10	2.36E+08
13963-001	TX0087424	Luther's Bar-B-Q, Inc.	Harris	0.01	1.19E+07
14044-001	TX0092894	149 Enterprises, Inc	Harris	0.01	2.38E+07
14193-001	TX0122963	Kennard Tom Foley	Harris	0.04	8.35E+07
14390-001	TX0125181	Huffsmith-Kohrville, Inc	Harris	0.05	1.26E+08
		Assessment Unit: 1009_04			
10783-001	TX0023612	Inverness Forest ID	Harris	0.50	1.19E+09
11044-001	TX0046671	Memorial Hills UD	Harris	0.50	1.19E+09
11141-001	TX0046728	Treschwig Joint Powers Board	Harris	2.00	4.77E+09
11142-002	TX0046680	Timber Lane UD	Harris	2.62	6.25E+09
11444-001	TX0046736	Harris County WCID #99	Harris	0.23	5.37E+08
11572-001	TX0047775	Pilchers Property LP/Northland Joint Venture[1]	Harris	0.06	1.43E+08
11618-003	TX0118371	Hunter's Glen MUD	Harris	1.40	3.34E+09
11855-001	TX0072567	North Park PUD	Harris	1.31	3.12E+09

Table 6-3 (continued): Cypress Creek Wasteload Allocations for TPDES-Permitted Facilities

TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (cfu/day)
		Assessment Unit: 1009_04			
11886-001	TX0073105	Six Flag Splashtown L.P.	Harris	0.06	1.43E+08
11933-001	TX0075671	Woodcreek MUD	Harris	0.60	1.43E+09
12239-001	TX0084085	Harris Co MUD #36	Harris	0.99	2.36E+09
12378-002	TX0092967	Richey Rd MUD	Harris	0.45	1.07E+09
12579-001	TX0090824	Spring West MUD	Harris	0.76	1.82E+09
12614-001	TX0091481	Harris Co MUD #16	Harris	0.50	1.19E+09
12812-001	TX0093939	Regency 1-45/ Spring Cypress Retal, L.P.	Harris	0.06	1.43E+08
13027-001	TX0096865	Harris County	Harris	0.01	2.38E+07
13054-001	TX0097209	CW-MHP Ltd	Harris	0.01	2.38E+07
13711-001	TX0085910	Spring Cypress WSC	Harris	0.04	8.35E+07
13765-001	TX0116068	Harris Co MUD #249	Harris	0.80	1.91E+09
13819-001	TX0113930	Arthur Edward Bayer	Harris	0.06	1.43E+08
14106-001	TX0119270	Aqua Development, Inc	Harris	0.08	1.91E+08
14526-001	TX0031305	Spring ISD	Harris	0.03	7.15E+07
14644-001	TX0128198	Redfin Development Co. Inc.	Harris	unk	unk
12470-001	TX0089184	Harris Co MUD #221	Harris	1.80	4.29E+09
14696-001	TX0128660	Loan Oak Partners LP	Harris	unk	unk
		Assessment Unit: 1009C_01			
11832-001	TX0072354	Faulkey Gully MUD	Harris	1.42	3.39E+09
11939-001	TX0075795	Northwest Harris Co MUD #15	Harris	3.12	7.44E+09
12600-001	TX0091171	Elite Computer Consultants, LP	Harris	0.01	1.91E+07
11824-002	TX0128210	Northwest Harris Co. MUD #5	Harris	0.40	9.54E+08
		Assessment Unit: 1009D_01			
12025-002	TX0077941	Bilma PUD	Harris	0.75	1.79E+09
12224-001	TX0083801	Klein ISD	Harris	0.01	2.62E+07
13152-001	TX0098647	Northwest Harris Co MUD #32	Harris	0.65	1.55E+09
		Assessment Unit: 1009E_01			
03076-000	TX0118605	Skinner Nurseries, Inc.	Harris	variable	variable
03627-000	TX0118320	Vopak Logistics Services USA, Inc	Harris	variable	variable
11814-001	TX0071609	Boys and Girls Country of Houston	Harris	0.10	2.38E+08
11824-001	TX0072346	Northwest Harris County MUD #5	Harris	0.80	1.91E+09
11887-001	TX0073393	Grant Rd PUD	Harris	0.31	7.39E+08
11913-001	TX0075183	Northwest Freeway MUD	Harris	0.45	1.07E+09
13472-001	TX0090841	Hockley Rail Car, Inc	Harris	0.01	1.43E+07
13753-001	TX0113107	Harris Co MUD #360	Harris	0.80	1.91E+09
14434-001	TX0125806	Westside Water, LLC	Harris	0.10	2.38E+08
14441-001	TX0125881	Harris County MUD #389	Harris	0.30	7.15E+08
14643-001	TX0128180	Northwest Harris Co MUD #10	Harris	0.09	2.25E+08
14675-001	TX0128457	Quadvest, LP	Harris	0.32	7.63E+08

Table 6-4: Caney Creek Wasteload Allocations for TPDES-Permitted Facilities

TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (cfu/day)
		Assessment Unit: 1010_02			
11020-001	TX0056685	City of New Waverly	Walker	0.09	2.10E+08
11020-002	TX0087831	City of New Waverly	Walker	unk	unk
11715-001	TX0068659	Texas National MUD WWTF	Montgomery	0.08	1.79E+08
12670-001	TX0092517	Mountain Man, Inc./ Ranch Utilities, LP[2]	Montgomery	0.18	4.17E+08
		Assessment Unit: 1010_03			
12204-001	TX0083216	Conroe ISD	Montgomery	0.02	4.77E+07
		Assessment Unit: 1010_04			
01497-001	TX0127710	The Signorelli Co.	Montgomery	0.60	1.43E+09
12205-001	TX0083208	Conroe ISD	Montgomery	0.02	3.58E+07
12274-001	TX0084638	New Caney MUD	Montgomery	1.06	2.53E+09
12621-001	TX0091677	Martin Realty & Land, Inc	Montgomery	0.15	3.58E+08
13690-001	TX0111473	Conroe ISD	Montgomery	0.10	2.38E+08
14029-001	TX0117145	LGI Housing, LLC/□Quadvest, LP6	Montgomery	0.60	1.43E+09
14081-001	TX0118311	Martin Realty & Land, Inc.	Montgomery	0.15	3.58E+08
14083-001	TX0118818	White Oak Developers, Inc.	Montgomery	0.20	4.77E+08
14116-001	TX0071412	Montgomery County MUD #24	Montgomery	unk	unk
14285-001	TX0124281	C&R Water Supply, Inc.	Montgomery	0.30	7.15E+08
14379-001	TX0125300	East Montgomery Co MUD #3	Montgomery	0.08	1.91E+08
14559-001	TX0127094	Whitestone Houston Land, Ltd.	Montgomery	0.90	2.15E+09
14694-001	TX0128651	Elan Development, LP	Montgomery	0.18	4.29E+08

Table 6-5: Peach Creek Wasteload Allocations for TPDES-Permitted Facilities

TCEQ Permit Number	EPA Permit Number	Name	County	Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (cfu/day)
		Assessment Unit: 1011_01			
11143-001	TX0082511	Splendora ISD	Montgomery	0.04	9.54E+07
11143-002	TX0117463	Splendora ISD	Montgomery	0.04	9.54E+07
13389-001	TX0102512	City of Splendora	Montgomery	0.30	7.15E+08
		Assessment Unit: 1011_02			
11386-001	TX0078344	Montgomery Co MUD #16	Montgomery	0.18	4.22E+08
11993-001	TX0077241	City of Woodbranch Village	Montgomery	0.13	3.17E+08
13638-001	TX0093220	Roman Forest Consolidated MUD	Montgomery	0.32	7.68E+08
14311-001	TX0124583	East Montgomery Co MUD #4	Montgomery	0.75	1.79E+09
14536-001	TX0126853	Flying J Inc.	Montgomery	0.05	1.19E+08
14560-001	TX0127108	Whitestone Houston Land, Ltd.	Montgomery	0.90	2.15E+09

Municipal separate storm sewer system (MS4) discharges are also considered a point source and require wasteload allocation. Permitted MS4s within the Lake Houston Watershed include the City of Houston metropolitan area and The Woodlands metropolitan area. MS4 WLA is calculated by the percentage MS4 coverage of the watershed. Table 4-7 is repeated for convenience and summarizes the percentage MS4 coverage of each watershed. Remaining stormwater allocation constitutes the load allocation component of the TMDL.

Table 4-7: MS4 Areas within the TMDL Study Watersheds

Segment	Receiving Stream	Permit Number	Permitted Entity	MS4 Area (Acres)	MS4 Area (percent)
1004E	Stewarts Creek	WQ0004685000	Houston	0	0%
1008	Spring Creek	WQ0004685000	Houston	9,718	3%
1008	Spring Creek	TXR040256	The Woodlands	23,574	8%
1008H	Willow Creek	WQ0004685000	Houston	4,160	12%
1009	Cypress Creek	WQ0004685000	Houston	63,037	30%
1009C	Faulkey Gully	WQ0004685000	Houston	2,582	36%
1009D	Spring Gully	WQ0004685000	Houston	1,172	33%
1009E	Little Cypress Crk	WQ0004685000	Houston	2,852	8%
1010	Caney Creek	WQ0004685000	Houston	8,830	6%
1011	Peach Creek	WQ0004685000	Houston	0	0%

6.7 LOAD ALLOCATION (NONPOINT SOURCE)

Load allocations represent the maximum allowable contribution of nonpoint sources. Nonpoint sources can include both “wet weather” and “dry weather” sources. Wet weather sources include animal deposition and septic system failures that result in the buildup of bacteria at the land’s surface (which is subsequently available for washoff during rainfall events). Dry weather nonpoint sources include animals in streams, wastewater infrastructure leaking directly to streams, and failing septic systems leaking directly to streams.

The total load allocation (∑LA) can be determined from the TMDL equation described in Section 6.1. As shown below, the ∑LA equals the total maximum daily load (TMDL) minus the margin of safety (MOS) and total wasteload allocation (∑WLA).

$$TMDL = \sum WLA + \sum LA + MOS$$

$$\sum LA = TMDL - MOS - \sum WLA$$

6.8 FUTURE GROWTH

In many cases, future growth can conceivably impact TMDL allocation scenarios if associated with increased point source or nonpoint source loads. Point source loads can change from the addition of new or the expansion of existing point sources, such as new or expanding wastewater treatment plants to accommodate increased wastewater flows.

However, increases in point source discharges provide additional streamflow and therefore additional assimilative capacity that may allow for TMDL compliance. Future growth of point sources should not be limited by these TMDLs provided indicator bacteria concentrations do not exceed contact recreation criterion.

In the present analysis, future growth is accounted for through population projections. Current and projected population data was accessed from the Houston-Galveston Area Council (H-GAC). Projected population growth for each watershed was calculated between 2008 and 2035. Projected population percentage increase of each watershed was multiplied with corresponding WLA_{WWTF}, to calculate future WLA_{WWTF}. Population growth percentages are presented in Table 6-2 with future WWTF loads presented in the subsequent section.

Future growth also affects nonpoint sources as the watershed land use changes. As future growth occurs development and regulated MS4 area will expand. The expansion of MS4 redistributes pollutant load allocation, shifting from current LA to future WLA_{MS4}. However, increases in urban development and re-development lead to increased impervious cover and nonpoint source loads. Stormwater Best Management Practices (BMPs) should be used to mitigate nonpoint source load increase attributed to population growth, negating the need for increased future allocation.

Table 6-6: Population Projections per Subwatershed

Stream Name	Assessment Unit	2008	2035	Growth
Stewarts Creek	1004E	10,566	22,580	114%
Spring Creek	1008	263,370	521,082	98%
Willow Creek	1008H	32,840	90,498	176%
Cypress Creek	1009	289,117	576,108	99%
Faulkey Gulley	1009C	13,900	24,871	79%
Spring Gulley	1009D	8,298	17,896	116%
Little Cypress Crk	1009E	25,194	70,950	182%
Caney Creek	1010	58,022	139,977	141%
Peach Creek	1011	23,046	61,696	168%

6.9 TMDL CALCULATIONS

TMDL calculations were performed separately for each flow regime. All TMDL assessment units found Wet (high flow) conditions as the critical condition, as summarized in Table 6-1. For each assessment unit with multiple stations, the most downstream station was utilized for TMDL development. Downstream stations include all cumulative point sources, contributing drainage areas, and are thus representative of the assessment unit.

Required reductions and proposed TMDLs are calculated by the geometric mean criteria. Existing total loading for each flow regime is based on the geometric mean concentration and median flow for each flow regime. Tables 6-7 through 6-26 summarize existing and proposed loads along with percentage reduction goals for all TMDL study segments.

Table 6-27 summarizes pollutant allocations for all stations. This table includes current individual load and wasteload allocations along with projected future capacity from WWTFs. Assessment unit final TMDL allocations needed to comply with 40 CFR 130.7 are presented in Table 6-28. In this table WLA_{WWTF} incorporates future capacity.

Calculated TMDLs and available pollutant load allocation is limited by current TCEQ water quality criteria. Designated usage and water quality criterion are subject to change through TCEQ review and mandate. Appendix A illustrates how the TMDL and pollutant load allocation would fluctuate with hypothetical *E. coli* water quality criterion.

Table 6-7: *E. coli* TMDL Calculations for Stewarts Creek, Assessment Unit 1004E_02

Station 16626			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	15	5.3	3.0
Existing Load (10^9 cfu/day)	220	24	6.3
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	45	16	9
MOS (10^9 cfu/day)	2	0.8	0.5
Target Load (10^9 cfu/day)	43	16	9
Required Reduction	81%	36%	0%
Overall Reduction		47%	
TMDL (10^9 cfu/day)	45		

Table 6-8: *E. coli* TMDL Calculations for Spring Creek, Assessment Unit 1008_02

Station 11323			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	50	7	0.1
Existing Load (10^9 cfu/day)	1818	25	0.45
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	153	20	0.3
MOS (10^9 cfu/day)	8	1.0	0.0
Target Load (10^9 cfu/day)	145	19	0.3
Required Reduction	92%	22%	29%
Overall Reduction		64%	
TMDL (10^9 cfu/day)	154		

Table 6-9: *E. coli* TMDL Calculations for Spring Creek, Assessment Unit 1008_02

Station 11314			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	91	13	0.8
Existing Load (10^9 cfu/day)	2484	67	2.3
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	281	39	2.3
MOS (10^9 cfu/day)	14	1.9	0.1
Target Load (10^9 cfu/day)	267	37	2.2
Required Reduction	89%	45%	6%
Overall Reduction		71%	
TMDL (10^9 cfu/day)	287		

Table 6-10: *E. coli* TMDL Calculations for Spring Creek, Assessment Unit 1008_03

Station 17489			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	148	22	3.3
Existing Load (10^9 cfu/day)	3885	131	20
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	456	68	10
MOS (10^9 cfu/day)	23	3.4	0.5
Target Load (10^9 cfu/day)	433	65	9.7
Required Reduction	89%	50%	51%
Overall Reduction		70%	
TMDL (10^9 cfu/day)	487		

Table 6-11: *E. coli* TMDL Calculations for Spring Creek, Assessment Unit 1008_03

Station 11313			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	410	70	27
Existing Load (10^9 cfu/day)	8009	565	80
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	1265	216	83
MOS (10^9 cfu/day)	63.2	10.8	4.2
Target Load (10^9 cfu/day)	1201	205	79
Required Reduction	85%	64%	1%
Overall Reduction		64%	
TMDL (10^9 cfu/day)	1419		

Table 6-12: *E. coli* TMDL Calculations for Spring Creek, Assessment Unit 1008_04

Station 11312			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	426	75	30
Existing Load (10^9 cfu/day)	24737	439	129
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	1313	230	93
MOS (10^9 cfu/day)	65.6	11.5	4.7
Target Load (10^9 cfu/day)	1247	219	89
Required Reduction	95%	50%	31%
Overall Reduction		77%	
TMDL (10^9 cfu/day)	1514		

Table 6-13: *E. coli* TMDL Calculations for Willow Creek, Assessment Unit 1008H_01

Station 11185			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	38	7.0	3.2
Existing Load (10^9 cfu/day)	2914	26	23
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	117	22	10
MOS (10^9 cfu/day)	5.8	1.1	0.5
Target Load (10^9 cfu/day)	111	21	9
Required Reduction	96%	22%	59%
Overall Reduction		74%	
TMDL (10^9 cfu/day)	166		

Table 6-14: *E. coli* TMDL Calculations for Cypress Creek, Assessment Unit 1009_01

Station 11333			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	68	6.0	1.2
Existing Load (10^9 cfu/day)	1817	33	3.7
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	210	18	3.7
MOS (10^9 cfu/day)	10	0.9	0.2
Target Load (10^9 cfu/day)	199	18	3.5
Required Reduction	89%	47%	6%
Overall Reduction		62%	
TMDL (10^9 cfu/day)	227		

Table 6-15: *E. coli* TMDL Calculations for Cypress Creek, Assessment Unit 1009_02

Station 11332			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	146	16	7.0
Existing Load (10^9 cfu/day)	5737	77	20
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	450	49	21.6
MOS (10^9 cfu/day)	22	2.5	1.1
Target Load (10^9 cfu/day)	427	47	20.5
Required Reduction	93%	39%	0%
Overall Reduction		68%	
TMDL (10^9 cfu/day)	516		

Table 6-16: *E. coli* TMDL Calculations for Cypress Creek, Assessment Unit 1009_02

Station 11331			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	161	22	12
Existing Load (10^9 cfu/day)	6224	251	41
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	497	67	37.6
MOS (10^9 cfu/day)	25	3.4	1.9
Target Load (10^9 cfu/day)	472	64	35.7
Required Reduction	92%	75%	13%
Overall Reduction		80%	
TMDL (10^9 cfu/day)	615		

Table 6-17: *E. coli* TMDL Calculations for Cypress Creek, Assessment Unit 1009_03

Station 11330			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	179	30	20
Existing Load (10^9 cfu/day)	12428	349	229
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	552	92	60.1
MOS (10^9 cfu/day)	28	4.6	3.0
Target Load (10^9 cfu/day)	525	87	57.1
Required Reduction	96%	75%	75%
Overall Reduction		87%	
TMDL (10^9 cfu/day)	729		

Table 6-18: *E. coli* TMDL Calculations for Cypress Creek, Assessment Unit 1009_03

Station 11328			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	343	61	33
Existing Load (10^9 cfu/day)	17757	605	188
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	1057	188	102
MOS (10^9 cfu/day)	53	9	5.1
Target Load (10^9 cfu/day)	1004	179	96.7
Required Reduction	94%	70%	49%
Overall Reduction		81%	
TMDL (10^9 cfu/day)	1339		

Table 6-19: *E. coli* TMDL Calculations for Cypress Creek, Assessment Unit 1009_04

Station 11324			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	388	72	41
Existing Load (10^9 cfu/day)	22283	452	95
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	1195	223	127
MOS (10^9 cfu/day)	60	11	6
Target Load (10^9 cfu/day)	1136	212	120.7
Required Reduction	95%	53%	0%
Overall Reduction		74%	
TMDL (10^9 cfu/day)	1548		

Table 6-20: *E. coli* TMDL Calculations for Faulkey Gully, Assessment Unit 1009C_01

Station 17496			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	5.4	1.8	1.1
Existing Load (10^9 cfu/day)	203	27	7
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	17	6	3.4
MOS (10^9 cfu/day)	1	0.3	0.2
Target Load (10^9 cfu/day)	16	5	3.2
Required Reduction	92%	81%	57%
Overall Reduction		81%	
TMDL (10^9 cfu/day)	35		

Table 6-21: *E. coli* TMDL Calculations for Spring Gully, Assessment Unit 1009D_01

Station 17481			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	3.7	1.0	0.6
Existing Load (10^9 cfu/day)	186	7	10
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	12	3	1.8
MOS (10^9 cfu/day)	0.6	0.1	0.1
Target Load (10^9 cfu/day)	11	3	1.7
Required Reduction	94%	59%	83%
Overall Reduction		82%	
TMDL (10^9 cfu/day)	20		

Table 6-22: *E. coli* TMDL Calculations for Little Cypress Creek, Assessment Unit 1009E_01

Station 14159			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	20	2.6	1.5
Existing Load (10^9 cfu/day)	751	24	13
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	63	8	4.7
MOS (10^9 cfu/day)	3	0.4	0.2
Target Load (10^9 cfu/day)	60	8	4.5
Required Reduction	92%	68%	65%
Overall Reduction		78%	
TMDL (10^9 cfu/day)	91		

Table 6-23: *E. coli* TMDL Calculations for Caney Creek, Assessment Unit 1010_02

Station 14241			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	79	29	16
Existing Load (10^9 cfu/day)	1833	121	60
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	243	89	50
MOS (10^9 cfu/day)	12	4.5	2.5
Target Load (10^9 cfu/day)	231	85	48
Required Reduction	87%	30%	20%
Overall Reduction		59%	
TMDL (10^9 cfu/day)	245		

Table 6-24: *E. coli* TMDL Calculations for Caney Creek, Assessment Unit 1010_04

Station 11334			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	150	55	31
Existing Load (10^9 cfu/day)	2734	166	58
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	461	171	97
MOS (10^9 cfu/day)	23	9	5
Target Load (10^9 cfu/day)	438	162	92
Required Reduction	84%	2%	0%
Overall Reduction		41%	
TMDL (10^9 cfu/day)	493		

Table 6-25: *E. coli* TMDL Calculations for Peach Creek, Assessment Unit 1011_02

Station 11336			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	129	45	25
Existing Load (10^9 cfu/day)	1534	197	89
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	397	139	78
MOS (10^9 cfu/day)	20	7	3.9
Target Load (10^9 cfu/day)	377	132	74
Required Reduction	75%	33%	16%
Overall Reduction		51%	
TMDL (10^9 cfu/day)	420		

Table 6-26: *E. coli* TMDL Calculations for Peach Creek, Assessment Unit 1011_02

Station 17746			
Flow Regime	**Wet**	**Moderate**	**Dry**
Median Flow (cfs)	130	45	25
Existing Load (10^9 cfu/day)	1959	158	68
Target Conc. (cfu/dL)	120	120	120
Current Flow Load Capacity (10^9 cfu/day)	400	140	79
MOS (10^9 cfu/day)	20	7.0	3.9
Target Load (10^9 cfu/day)	380	133	75
Required Reduction	81%	16%	0%
Overall Reduction		53%	
TMDL (10^9 cfu/day)	422		

Table 6-27: *E. coli* TMDL Summary Calculations for Lake Houston Watershed Stations

Assessment Unit	Station #	Stream Name	TMDL (cfu/day)	MOS (cfu/day)	WLA_{WWTF} (cfu/day)	MS4 %	WLA_{MS4} (cfu/day)	$LA_{StormWater}$ (cfu/day)	$Future_{WWTF}$ (cfu/day)
1004E_02	16626	Stewarts Creek	4.49E+10	2.24E+09	0.00E+00	0.00	0.00E+00	4.26E+10	0.00E+00
1008_02	11323	Spring Creek	1.54E+11	7.70E+09	5.60E+08	0.12	1.72E+10	1.28E+11	5.48E+08
1008_02	11314		2.87E+11	1.44E+10	3.33E+09	0.12	3.14E+10	2.35E+11	3.25E+09
1008_03	17489		4.87E+11	2.44E+10	1.59E+10	0.12	5.10E+10	3.80E+11	1.56E+10
1008_03	11313		1.42E+12	7.09E+10	7.87E+10	0.12	1.41E+11	1.05E+12	7.70E+10
1008_04	11312		1.51E+12	7.57E+10	1.03E+11	0.12	1.46E+11	1.09E+12	1.01E+11
1008H_01	11185	Willow Creek	1.66E+11	8.28E+09	1.39E+10	0.12	1.49E+10	1.04E+11	2.44E+10
1009_01	11333	Cypress Creek	2.27E+11	1.13E+10	8.70E+09	0.30	5.99E+10	1.38E+11	8.64E+09
1009_02	11332		5.16E+11	2.58E+10	3.36E+10	0.30	1.28E+11	2.96E+11	3.34E+10
1009_02	11331		6.15E+11	3.08E+10	5.95E+10	0.30	1.41E+11	3.25E+11	5.90E+10
1009_03	11330		7.29E+11	3.64E+10	8.90E+10	0.30	1.56E+11	3.59E+11	8.83E+10
1009_03	11328		1.34E+12	6.70E+10	1.42E+11	0.30	2.99E+11	6.90E+11	1.41E+11
1009_04	11324		1.55E+12	7.74E+10	1.78E+11	0.30	3.38E+11	7.79E+11	1.76E+11
1009C_01	17496	Faulkey Gully	3.53E+10	1.76E+09	1.18E+10	0.36	4.42E+09	8.00E+09	9.31E+09
1009D_01	17481	Spring Gully	2.05E+10	1.02E+09	3.36E+09	0.33	4.09E+09	8.13E+09	3.89E+09
1009E_01	14159	Little Cypress Creek	9.11E+10	4.56E+09	7.82E+09	0.08	5.16E+09	5.94E+10	1.42E+10
1010_02	14241	Caney Creek	2.45E+11	1.22E+10	8.06E+08	0.06	1.48E+10	2.16E+11	1.14E+09
1010_04	11334		4.93E+11	2.46E+10	1.12E+10	0.06	2.82E+10	4.13E+11	1.58E+10
1011_02	11336	Peach Creek	4.19E+11	2.10E+10	6.47E+09	0.00	0.00E+00	3.81E+11	1.08E+10
1011_02	17746		4.22E+11	2.11E+10	6.47E+09	0.00	0.00E+00	3.83E+11	1.08E+10

Table 6-28: Final TMDL Allocations per Assessment Unit

Assessment Unit	Stream Name	TMDL (cfu/day)	MOS (cfu/day)	WLA_{WWTF} [a] (cfu/day)	WLA_{MS4} (cfu/day)	$LA_{StormWater}$ (cfu/day)
1004E_02	Stewarts Creek	4.49E+10	2.24E+09	0.00E+00	0.00E+00	4.26E+10
1008_02	Spring Creek	2.87E+11	1.44E+10	6.58E+09	3.14E+10	2.35E+11
1008_03		1.42E+12	7.09E+10	1.56E+11	1.41E+11	1.05E+12
1008_04		1.51E+12	7.44E+10	2.03E+11	1.46E+11	1.09E+12
1008H_01	Willow Creek	1.66E+11	8.28E+09	3.83E+10	1.49E+10	1.04E+11
1009_01	Cypress Creek	2.27E+11	1.13E+10	1.73E+10	5.99E+10	1.38E+11
1009_02		6.15E+11	3.08E+10	1.19E+11	1.41E+11	3.25E+11
1009_03		1.34E+12	6.70E+10	2.83E+11	2.99E+11	6.90E+11
1009_04		1.55E+12	7.71E+10	3.54E+11	3.38E+11	7.79E+11
1009C_01	Faulkey Gully	3.53E+10	1.76E+09	2.11E+10	4.42E+09	8.00E+09
1009D_01	Spring Gully	2.05E+10	1.02E+09	7.26E+09	4.09E+09	8.13E+09
1009E_01	Little Cypress Creek	9.11E+10	4.56E+09	2.20E+10	5.16E+09	5.94E+10
1010_02	Caney Creek	2.45E+11	1.22E+10	1.94E+09	1.48E+10	2.16E+11
1010_04		4.93E+11	2.40E+10	2.70E+10	2.82E+10	4.12E+11
1011_02	Peach Creek	4.22E+11	2.11E+10	1.73E+10	0.00E+00	3.83E+11

[a] $WLA_{WWTF} = WLA_{WWTF} + Future_{WWTF}$

7.0 REFERENCES

ASAE. 2003. Manure Production and Characteristics. D384.1.

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

Baxter-Potter, W.R. and M.W.Gilliland. 1988. Bacterial Pollution in Runoff from Agricultural Lands. J.of the Am Water Res Assoc. Vol 17, No. 1

Buckhouse, J.C. and G.F. Gifford. 1976. Water Quality Implications of Cattle Grazing on Semiarid Watershed in Southeastern Utah. J. Of Rangeland Man. Vol. 29, No. 2

Doran, J.W. and D.M. Linn. 1979. Bacteriological Quality of Runoff Water from Pastureland. Applied and Envir. Microb. May.

Drapcho, C.M and A.K.B. Hubbs. 2003. Fecal Coliform Concentration in Runoff from Fields with Applied Dairy Manure. La Water Resources Inst.

Edwards, D.R., B.T.Larson, and T.T.Lim. 2000. Runoff Nutrient and Fecal Coliform Content from Cattle Manure Application to Fescue Plots. J.of the Am Water Res Assoc. Vol 36, No. 4

Edwards, D.R., M.S.Coyne, P.F.Vendrell, T.C.Daniel, P.A.Moore, and J.F. Murdoch. 1997. Fecal Coliform and Streptococcus concentrations in Runoff from Grazed Pastures in Northwest Arkansas. J.of the Am Water Res. Assoc, Vol. 32, No. 2

EPA. 1986. Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality, EPA 440/5-87-001

EPA. 2000. Bacterial Indicator Tool: User's Guide. EPA-823-B-01-003. Office of Water. Washington, D.C.

EPA. 2003. Exfiltration in Sewer Systems. National Risk Management Research Laboratory. EPA/600/SR-1/034

EPA. 2007. Better Assessment Science Integrating Point and Nonpoint Sources. BASINS v4. EPA-823-C-07-001. Office of Water. Washington, D.C.

EPA. 2008. *Draft Handbook for Developing Watershed TMDLs*. Office of Water. Washington, D.C.

Glick. R. 2005. City of Austin Stormwater Data, 1984-2004, unpublished data. COA Watershed Protection Dept.

Inamdar, S.P., S. Mostaghimi, M.N. Cook, K.M. Brannan, and P.W. McClellan. 2002. A Long-Term, Watershed-Scale, Evaluation of the Impacts of Animal Waste BMPs. J.of the Am.Water Res Assoc, Vol.38, No.3.

JMA, 2007. *Monitoring Plan: Lake Houston Watershed Bacteria TMDLs Project.* Prepared for Texas Commission on Environmental Quality (TCEQ). Austin, Texas. James Miertschin & Associates, Inc. August 2007.

JMA, 2008. *Monitoring Results for Lake Houston Watershed Bacteria Impairments.* Prepared for Texas Commission on Environmental Quality (TCEQ). Austin, Texas. James Miertschin & Associates, Inc. October 2008.

JMA, 2009. *Monitoring Results for Spring Gully Outfalls (Segment 1009D).* Prepared for Texas Commission on Environmental Quality (TCEQ). Austin, Texas. James Miertschin & Associates, Inc. August 2009

Kress, M. And G.F. Gifford. 1984. Fecal Coliform Release from Cattle Fecal Deposits. Wat. Res. Bull. Vol. 20, No. 1.

Mau, D.P, and L.M. Pope. 1999. Occurrence of Fecal Coliform Bacteria in the Cheney Reservoir Watershed, South-Central Kansas, 1996-1998. USGS, Fact Sheet 170-99

Moore, J.A., J.D. Smyth, E.S. Baker, J.R. Miner, and D.C. Moffitt. 1989. Modeling Bacteria Movement in Livestock Manure Systems. ASAE. Vol. 32, No. 3.

MRLC, 2001. National Land Cover Database (NLCD) 2001. (website). Muli-Resolution Land Characteristics Consortium. http://www.mrlc.gov/nlcd.php

NRCS. 2007. *Soil Survey Geographic (SURGO) Database*. (Website.) Natural Resources Conservation Service. Accessed 2007. http://www.soils.usda.gov/survey/geography/ssurgo/

NWS. 2008. *2007 – Year in Review.* National Weather Service Houston/Galveston TX. 3 Jan 2008. http://www.srh.noaa.gov/hgx/climate/reviews/010308pns.txt

Ockerman, D.J. 2002. Hydrologic Conditions and Quality of Rainfall and Storm Runoff in Agricultural and Rangeland Areas in San Patricio County, Texas, 2000-2001. USGS, Open File Report 02-291

Ockerman, D.J., K. McNamara. 2003. Simulation of Streamflow and Estimation of Streamflow Constituent Loads in the San Antonio River Watershed, Bexar County, Texas, 1997-2001. USGS, Open File Report 03-4030

PBS&J. 2006. Existing and Ultimate Condition Data Layers – Final Deliverable. Transmittal letter to Mr. Nefi Garza (San Antonio River Authority). 23 May 2006. PBS&J Project #461052.01.

Reed Stowe and Yanke. 2001. Study to determine the magnitude of, and reasons for, chronically malfunctioning on-site sewage facility systems in Texas. Austin, Texas.

Robbins, J.W.D., D.H. Howells, and G.J. Kriz. 1972. Stream Pollution from Animal Production Units. J.WPCF. Vol. 44, No.8

SARA. 1992. Regional Assessment of Water Quality, San Antonio River Basin. San Antonio, Texas.

Selvakumar, A. And M. Borst. 2004. Land Use and Seasonal Effects on Urban Stormwater Runoff Microorganism Concentrations. ASCE, World Water Congress

Smith, J.H. and C.L. Douglas. 1973. Microbiological Quality of Surface Drainage Water from Three Small Irrigated Watersheds in southern Idaho. J.of Env.Qual. Vol 2, No. 1

TAC. 2006. Texas Association of Counties Website: County Profiles. http://www.txcip.org/tac/census/CountyProfiles.php

TCEQ. 2008a. *2008 Guidance for Assessing and Reporting Surface Water Quality in Texas* http://www.tceq.state.tx.us/assets/public/compliance/monops/water/08twqi/2008_guidance.pdf

TCEQ. 2008b. *2008 Texas Water Quality Inventory.* http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/08twqi/08_list.html

Thelin, R. And G.F. Gifford. 1983. Fecal Coliform Release Patterns from Fecal Material of Cattle. J.of Env. Qual., Vol. 12, No. 1

TNRCC. 1999. TMDL Guidance Document. TMDL Team, Water Quality Division.

TNRCC. 2001. Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data

TPWD. 2009. Texas Lake Finder (website). Texas Parks and Wildlife Department. Last accessed 2009. http://www.tpwd.state.tx.us/fishboat/fish/recreational/lakes/

TWDB. 2006. Water Resources Planning and Information: Population Projections Data (website). Texas Water Development Board. Projections last updated 2006. http://www.twdb.state.tx.us/wrpi/data/proj/popproj.htm

TSHA. 2001. The Handbook of Texas Online. Texas State Historical Association. http://www.tsha.utexas.edu/handbook/online/

US Census. 2009. Online census data for 1990, 2000. US Census Bureau.

USDA. 2007. Census of Agriculture. Volume 1, Chapter 2: Texas County Level Data. http://www.agcensus.usda.gov/Publications/2007/Full_Report/index.asp

Weidner, R.B., A.G. Christianson, S.R. Weibel, and G.G. Robeck. 1969. Rural Runoff as a Factor in Stream Pollution. J.WPCF, Vol. 41, No.3, Part 1

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

APPENDIX A – Equations for Calculating TMDL Allocations for Changed Contact Recreation Standards

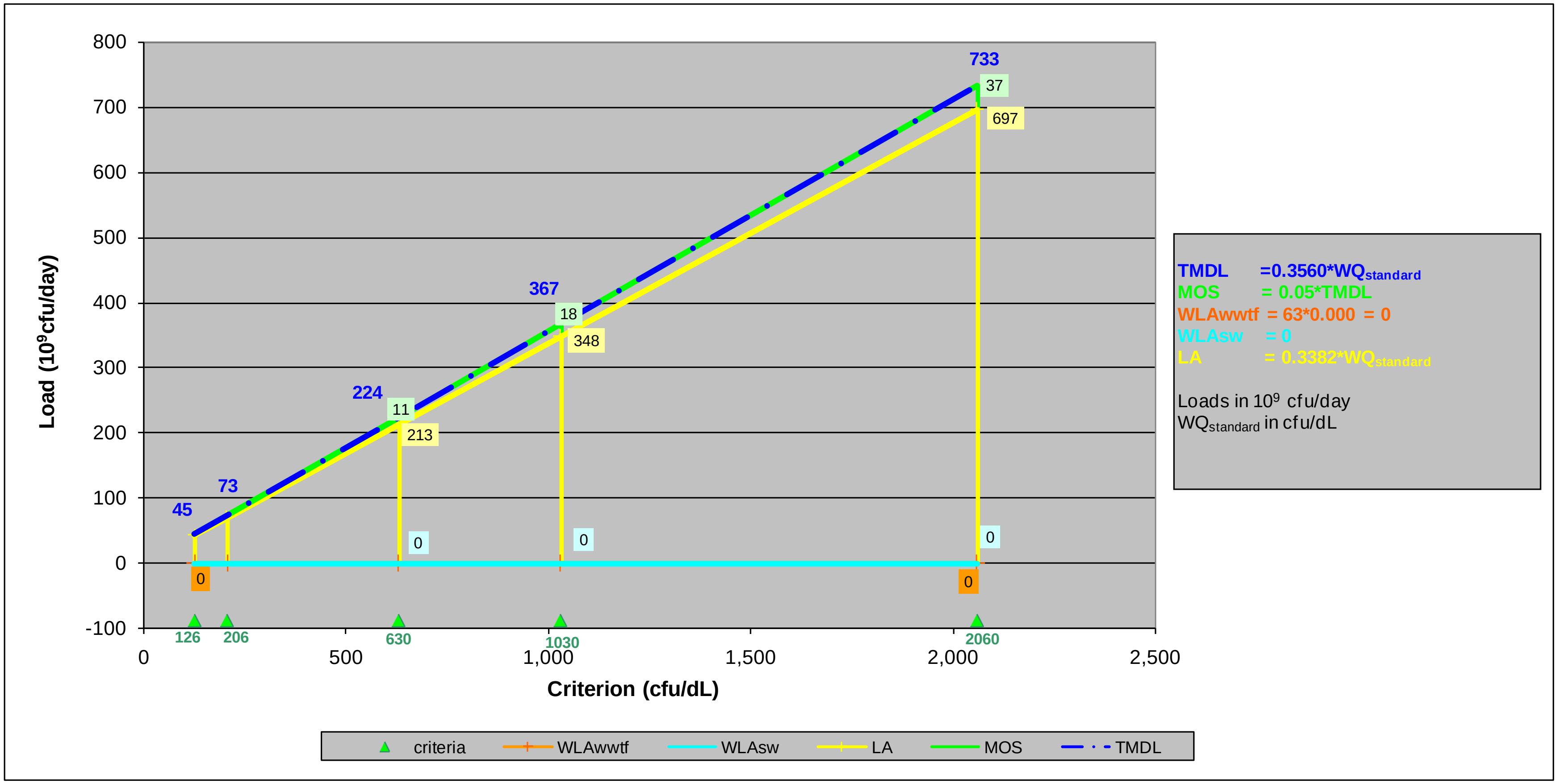

Figure A-1: Allocation Loads for AU 1004E_02 (16626) as a Function of WQ Criteria

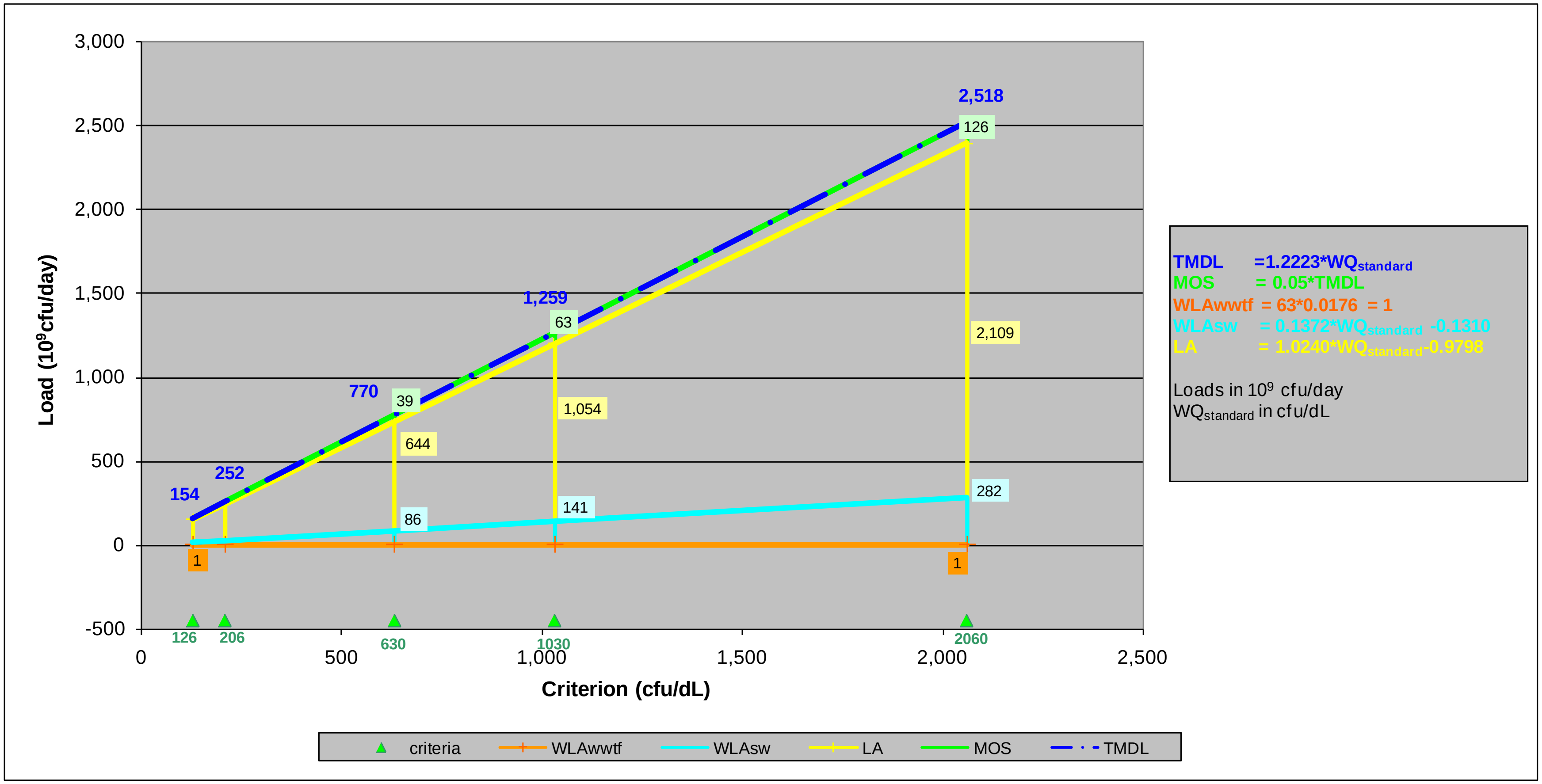

Figure A-2: Allocation Loads for AU 1008_02 (11323) as a Function of WQ Criteria

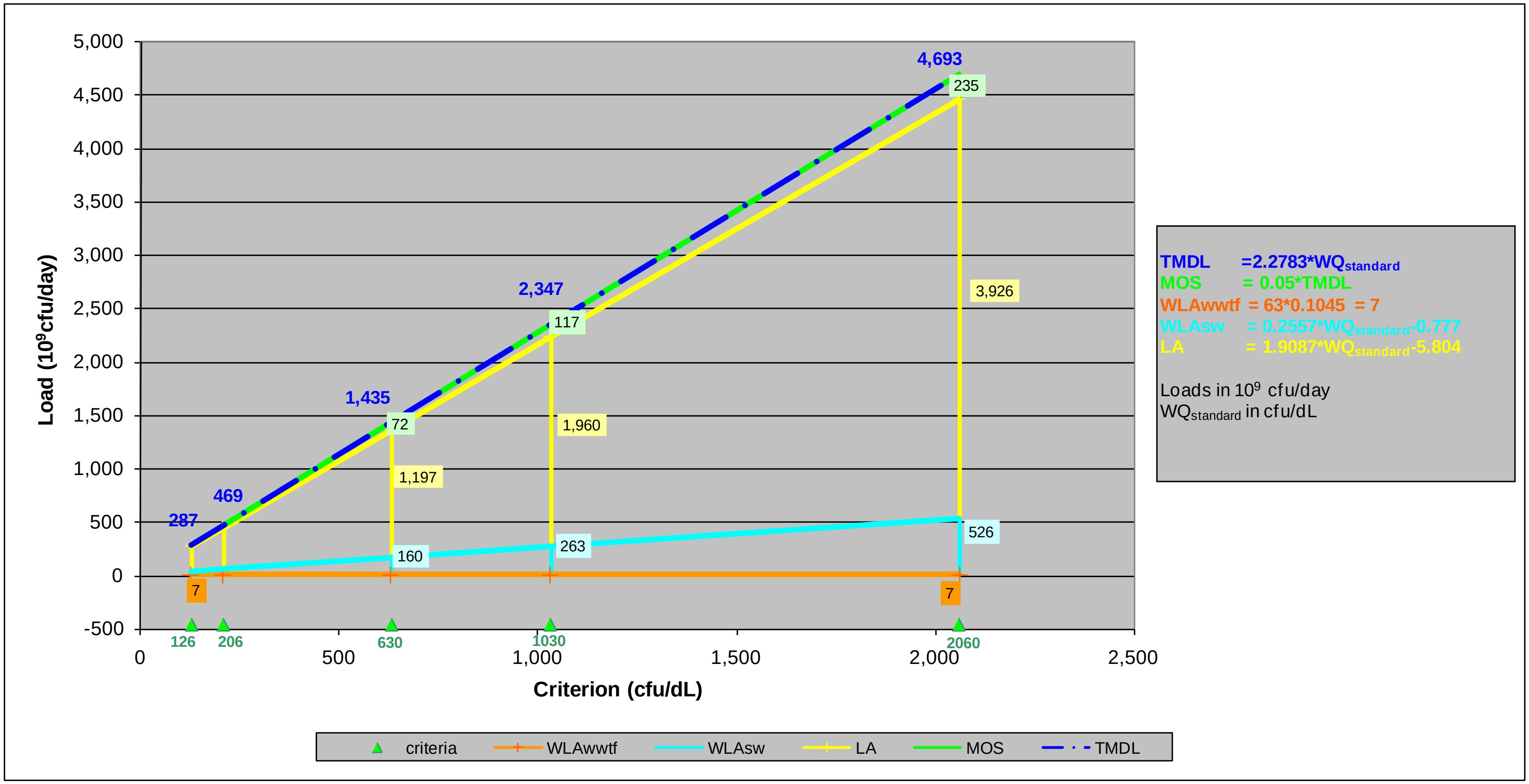

Figure A-3: Allocation Loads for AU 1008_02 (11314) as a Function of WQ Criteria

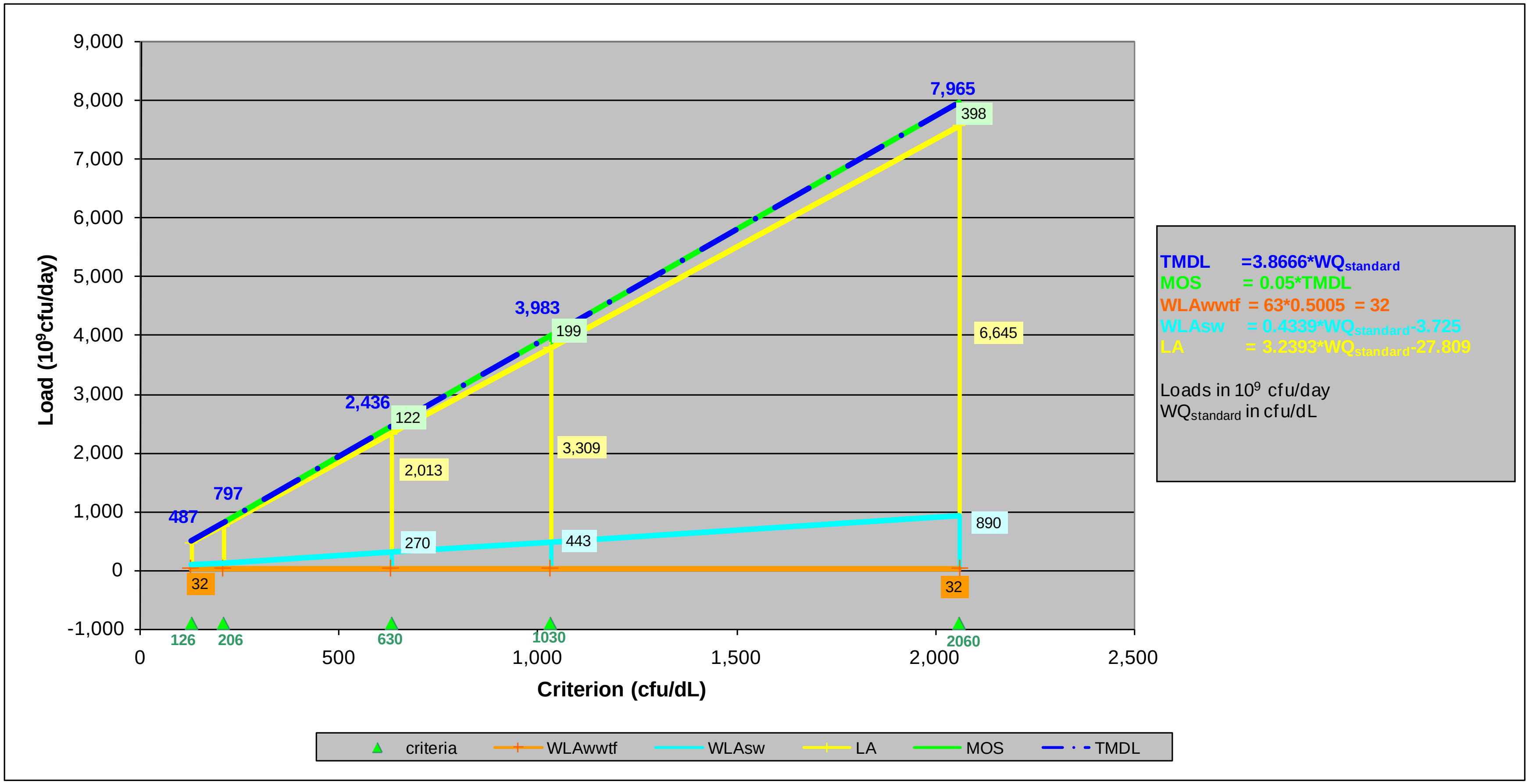

Figure A-4: Allocation Loads for AU 1008_03 (17489) as a Function of WQ Criteria

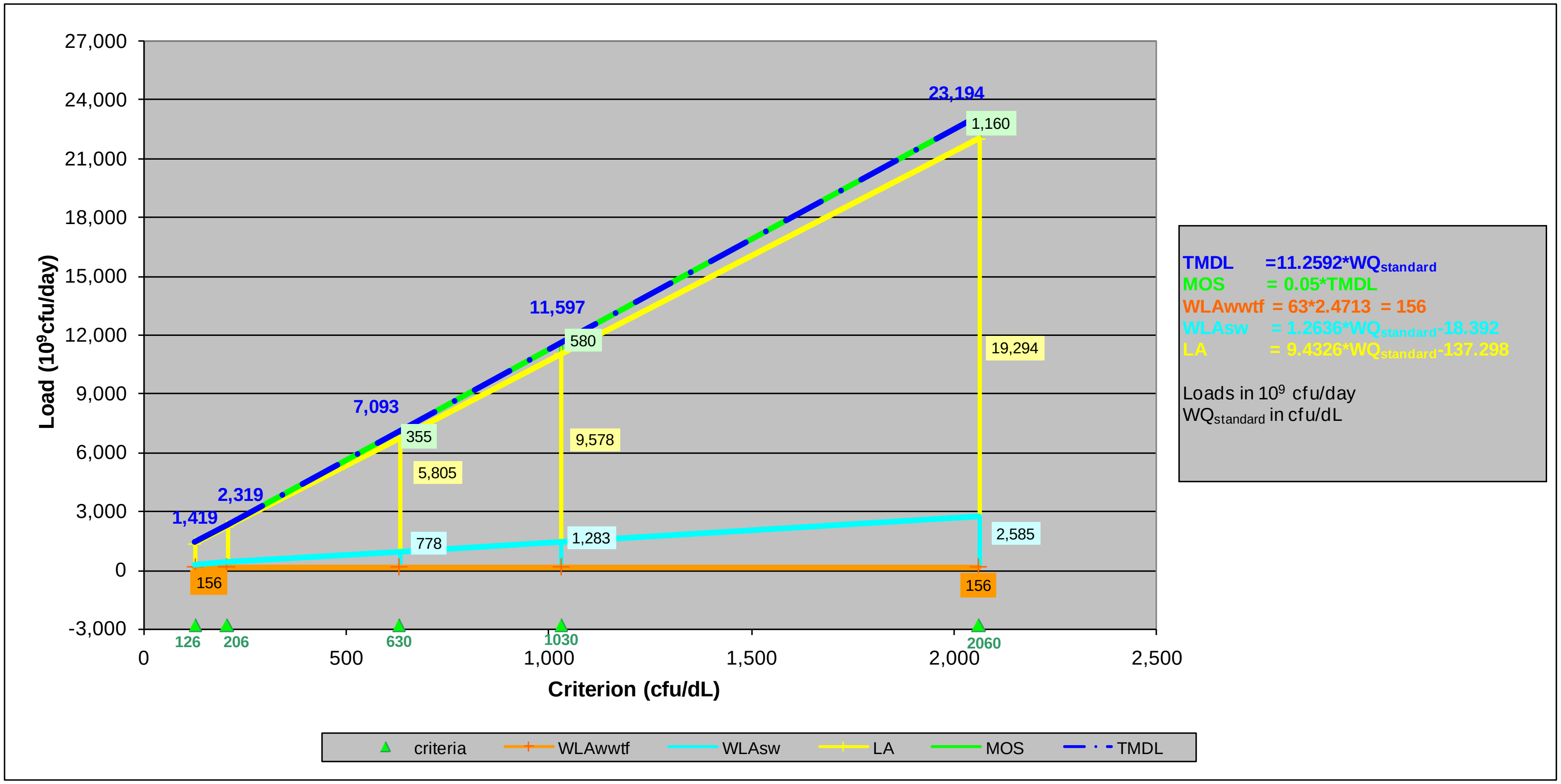

Figure A-5: Allocation Loads for AU 1008_03 (11313) as a Function of WQ Criteria

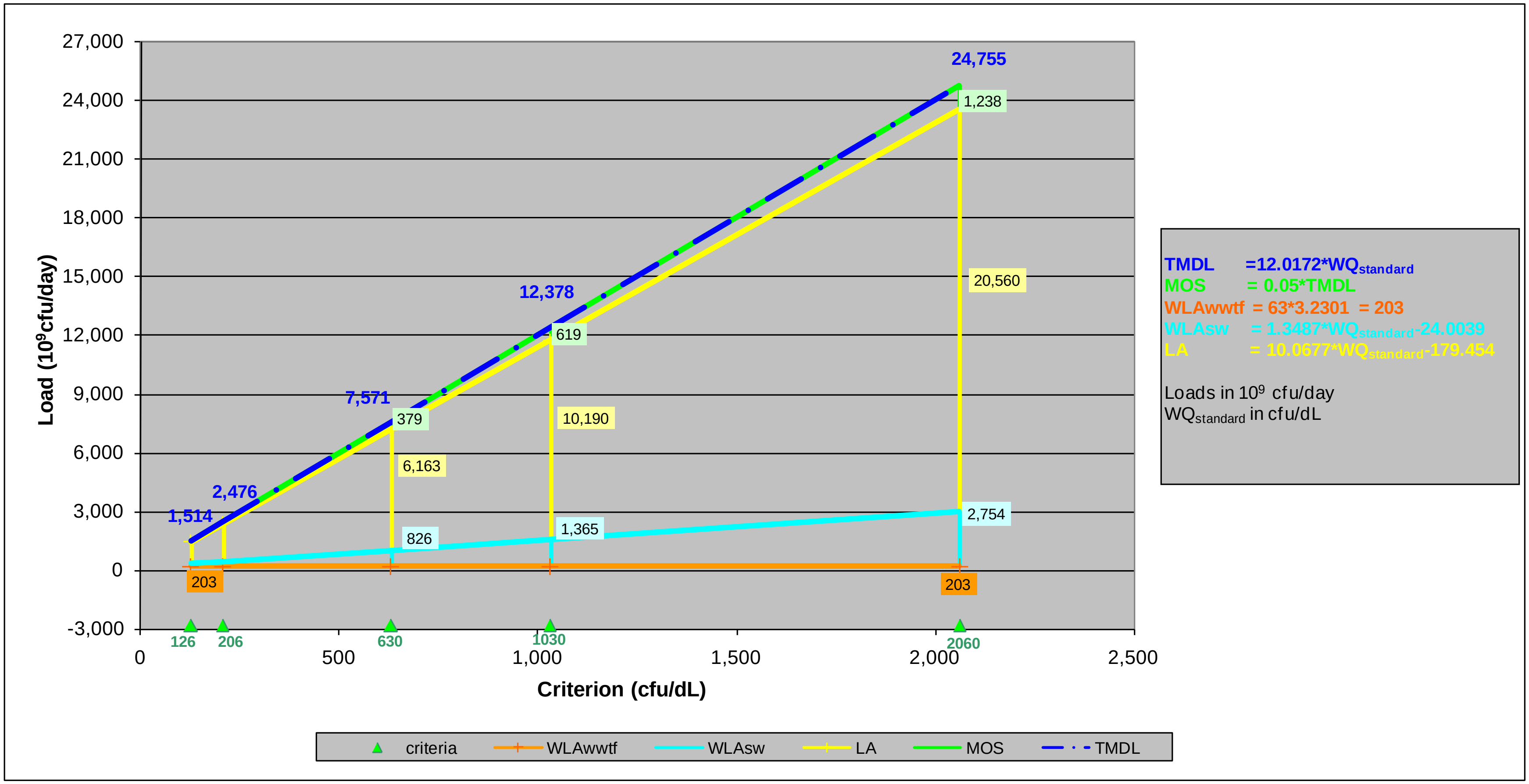

Figure A-6: Allocation Loads for AU 1008_04 (11312) as a Function of WQ Criteria

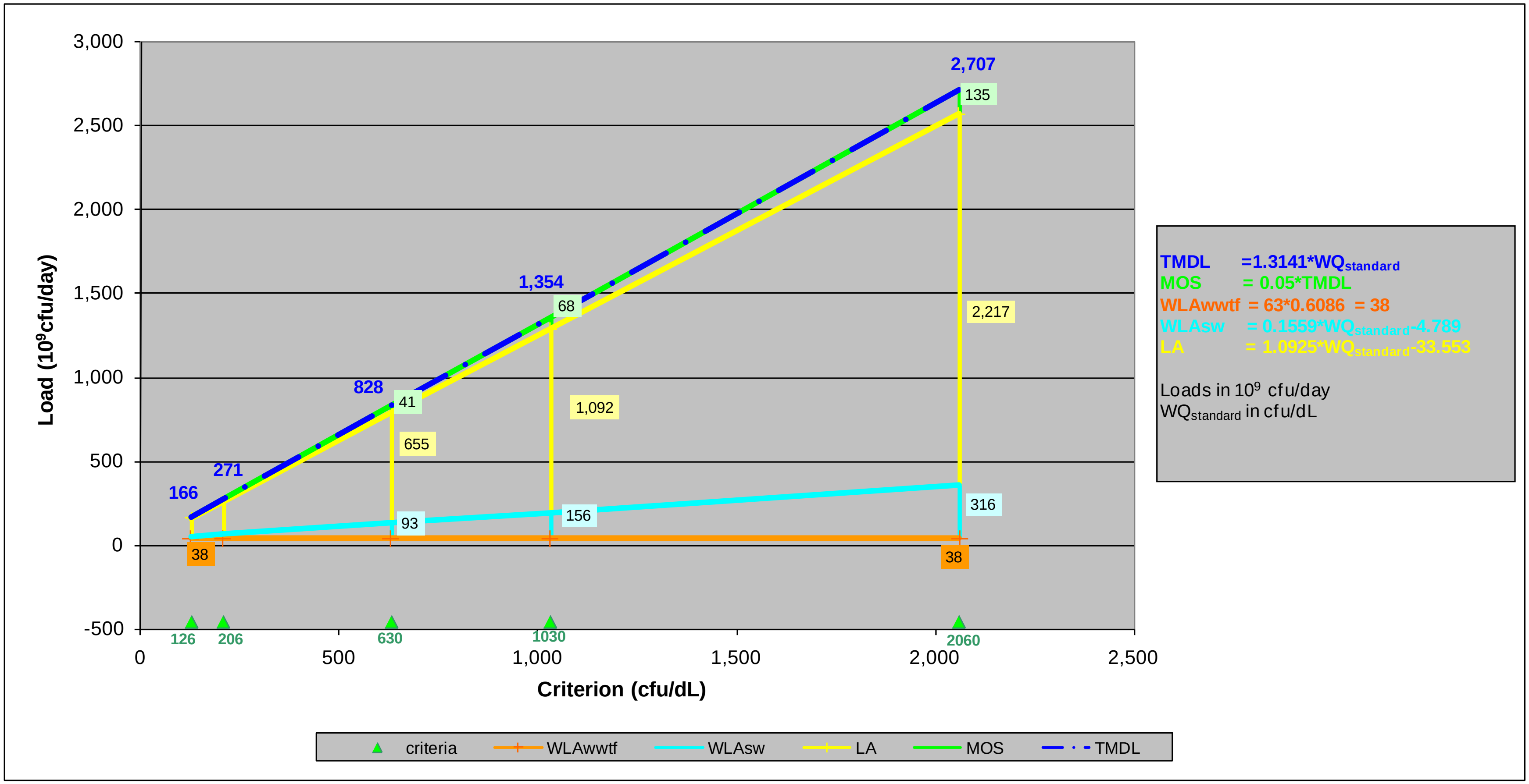

Figure A-7: Allocation Loads for AU 1008H_01 (11185) as a Function of WQ Criteria

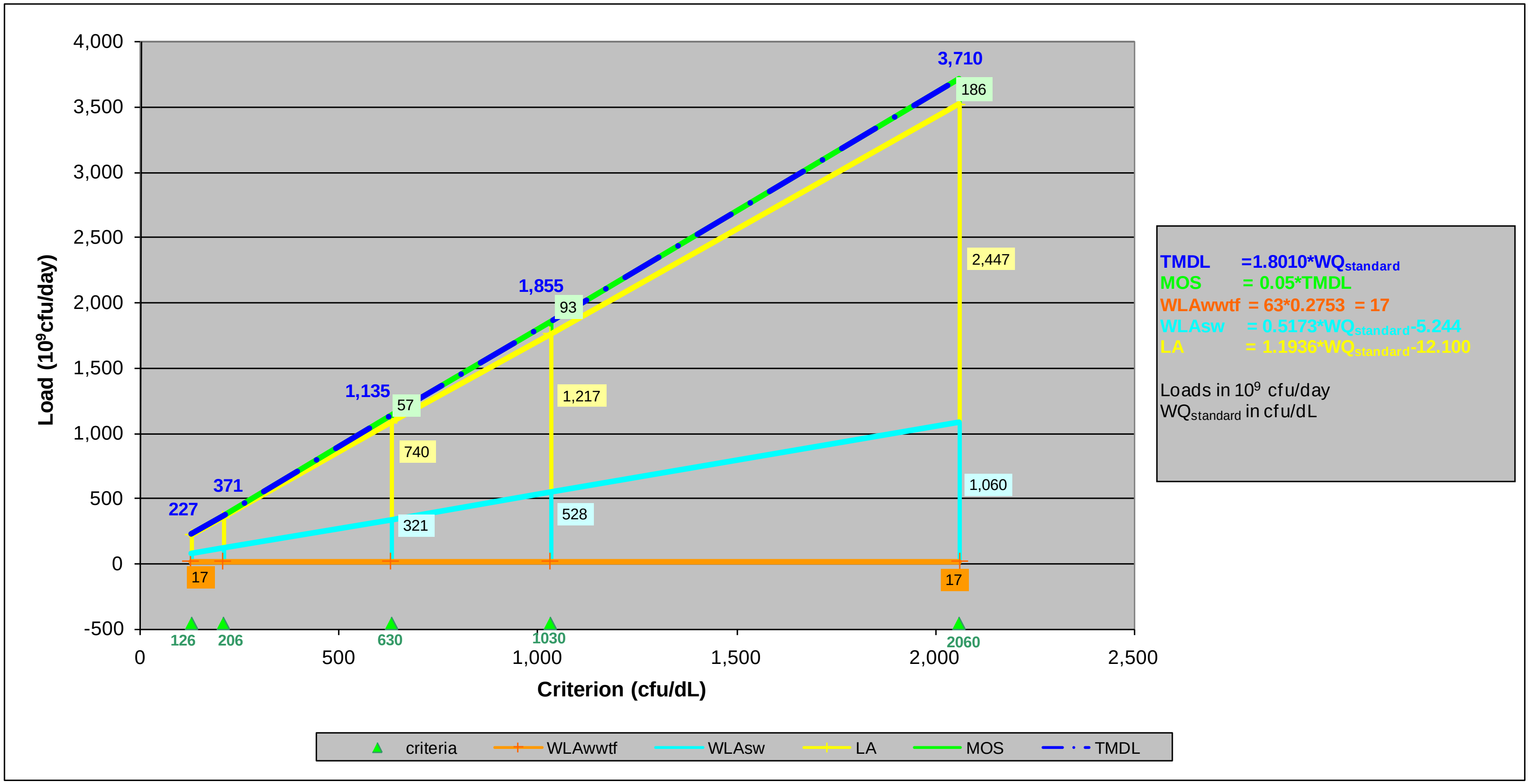

Figure A-8: Allocation Loads for AU 1009_01 (11333) as a Function of WQ Criteria

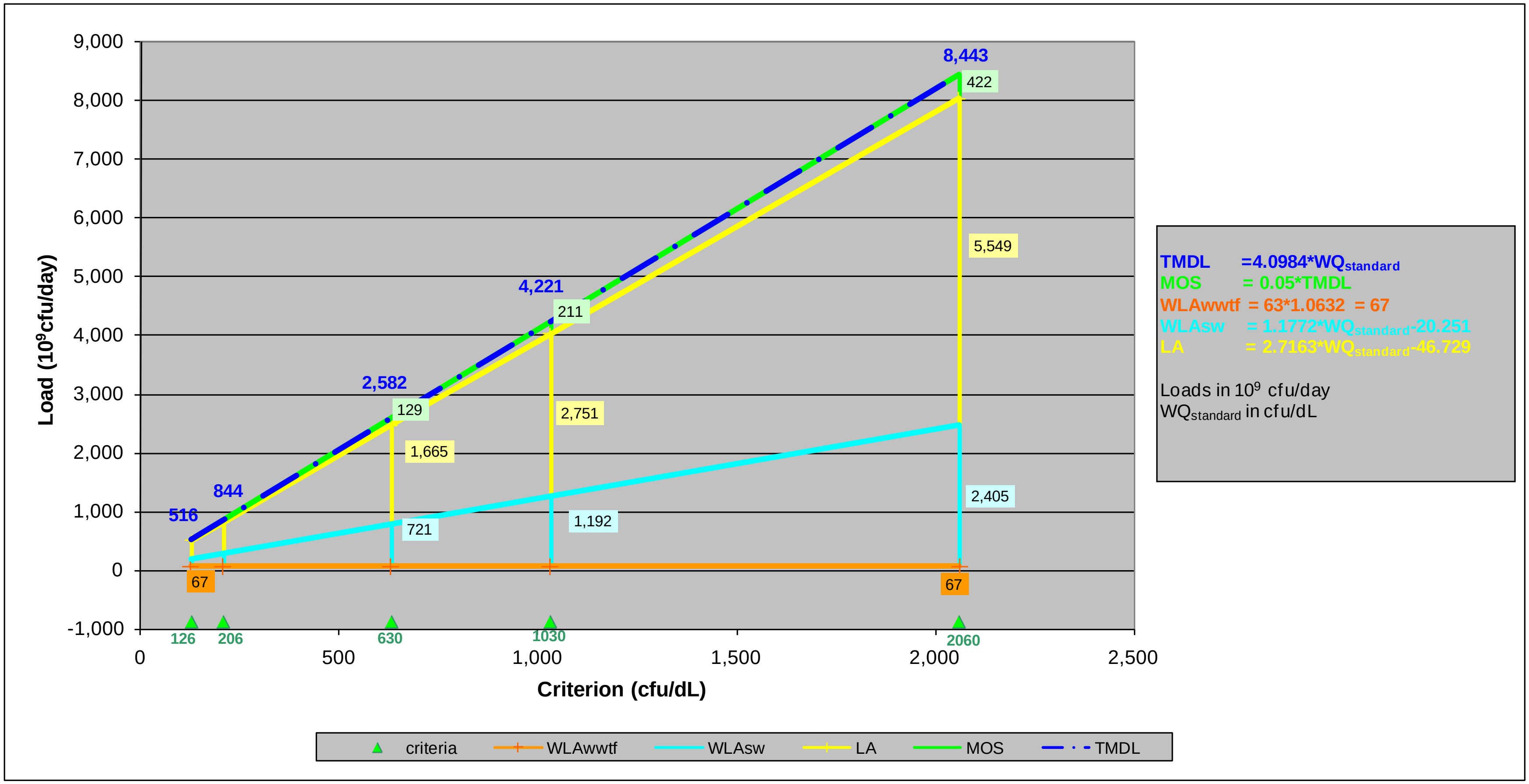

Figure A-9: Allocation Loads for AU 1009_02 (11332) as a Function of WQ Criteria

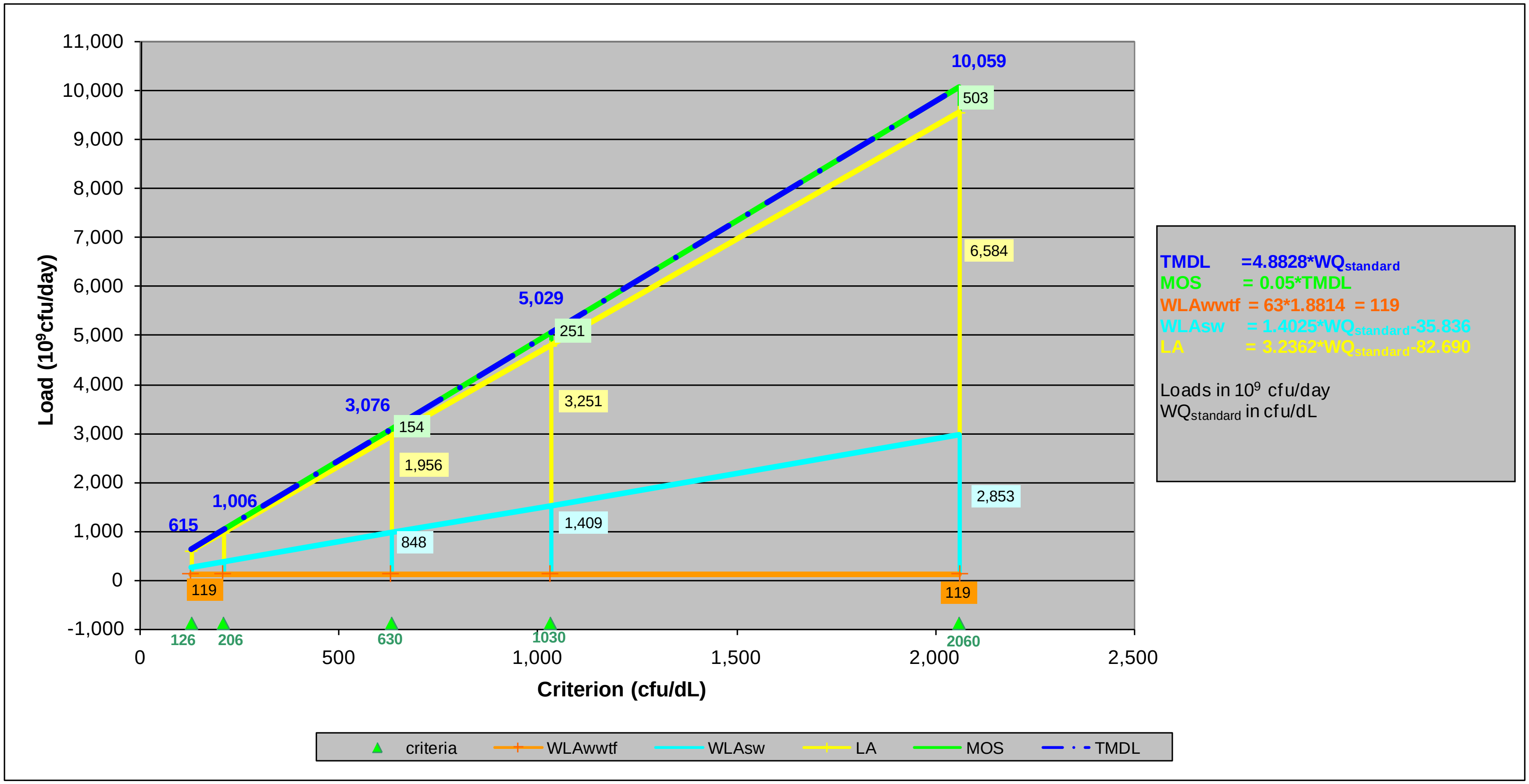

Figure A-10: Allocation Loads for AU 1009_02 (11331) as a Function of WQ Criteria

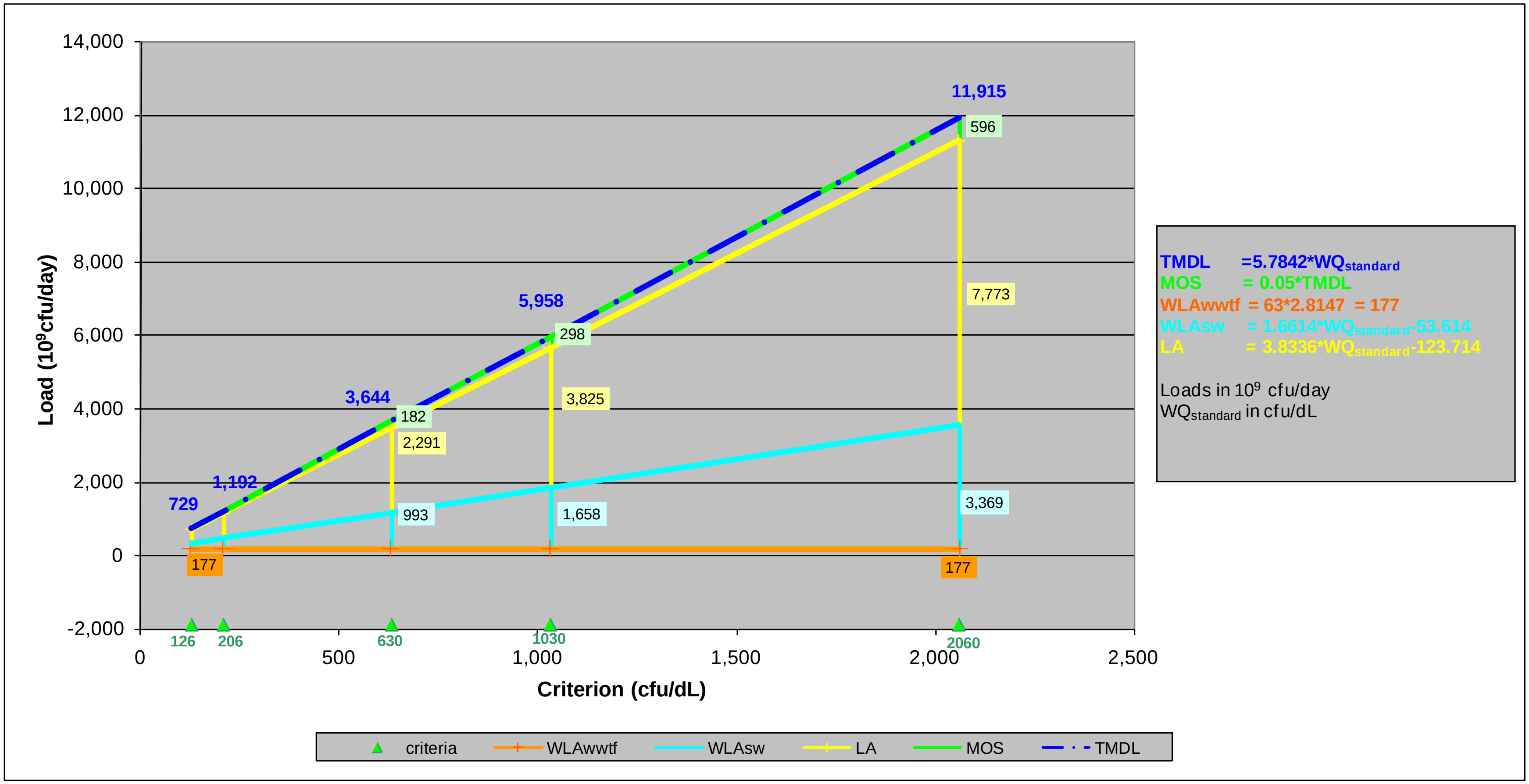

Figure A-11: Allocation Loads for AU 1009_03 (11330) as a Function of WQ Criteria

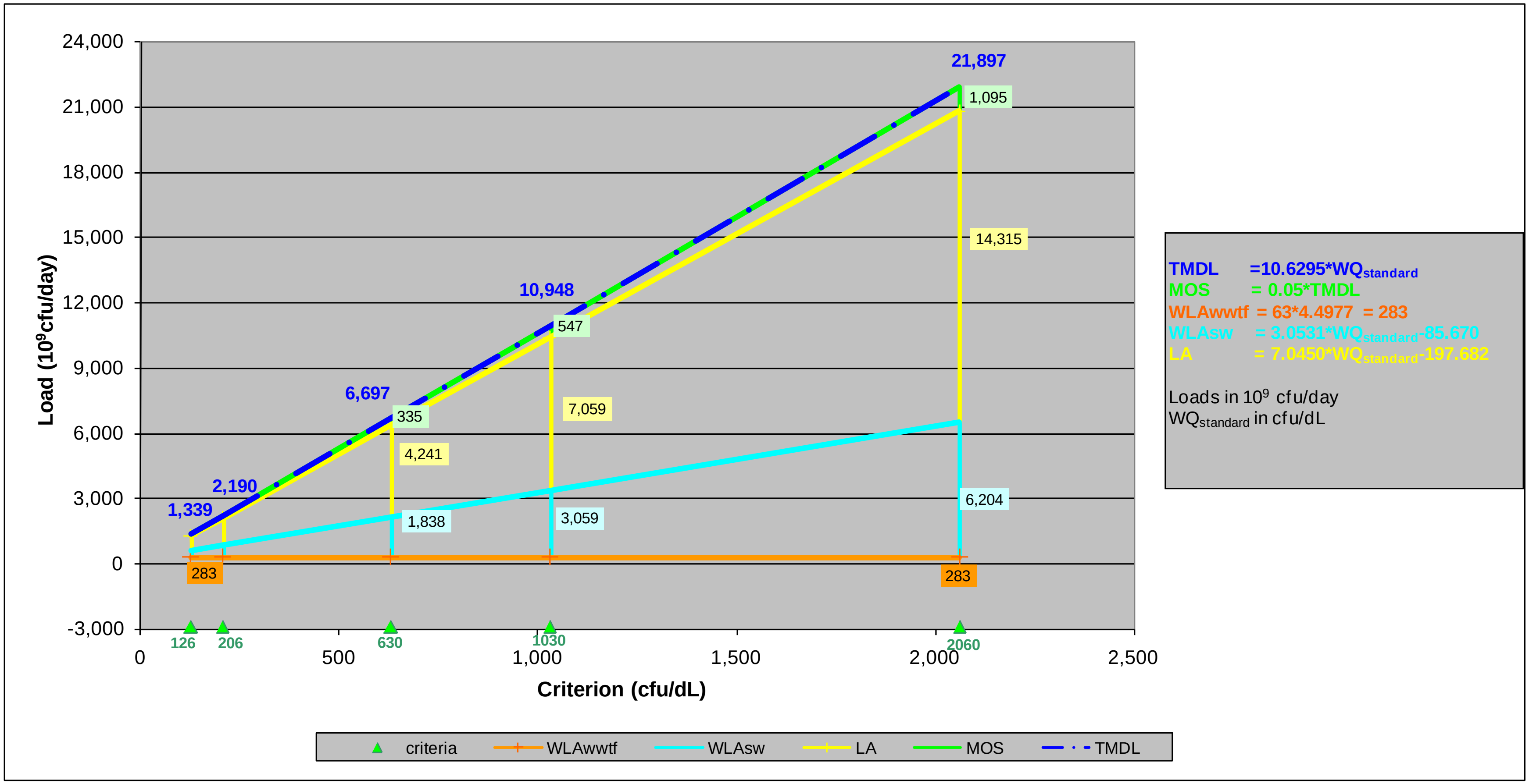

Figure A-12: Allocation Loads for AU 1009_03 (11328) as a Function of WQ Criteria

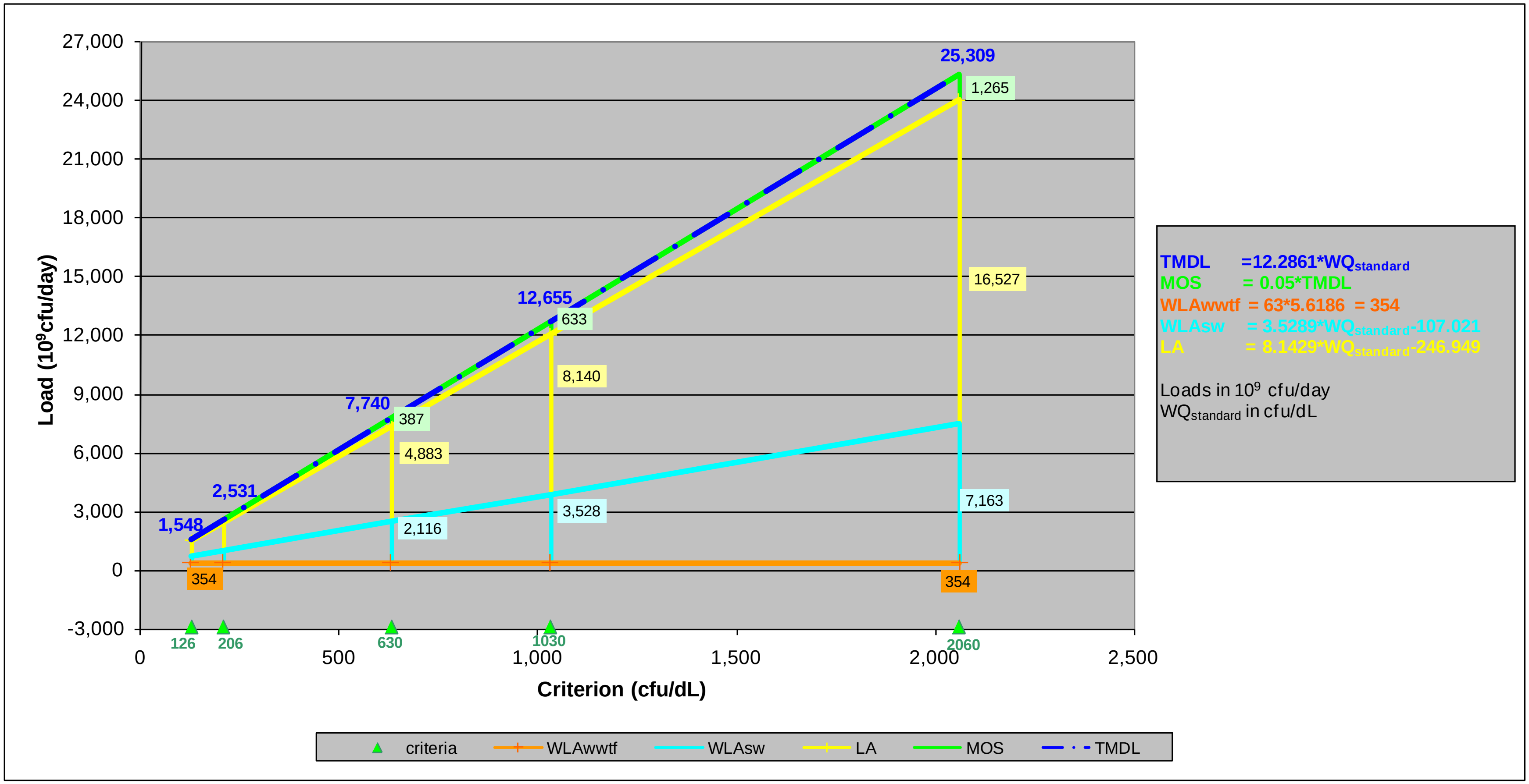

Figure A-13: Allocation Loads for AU 1009_04 (11324) as a Function of WQ Criteria

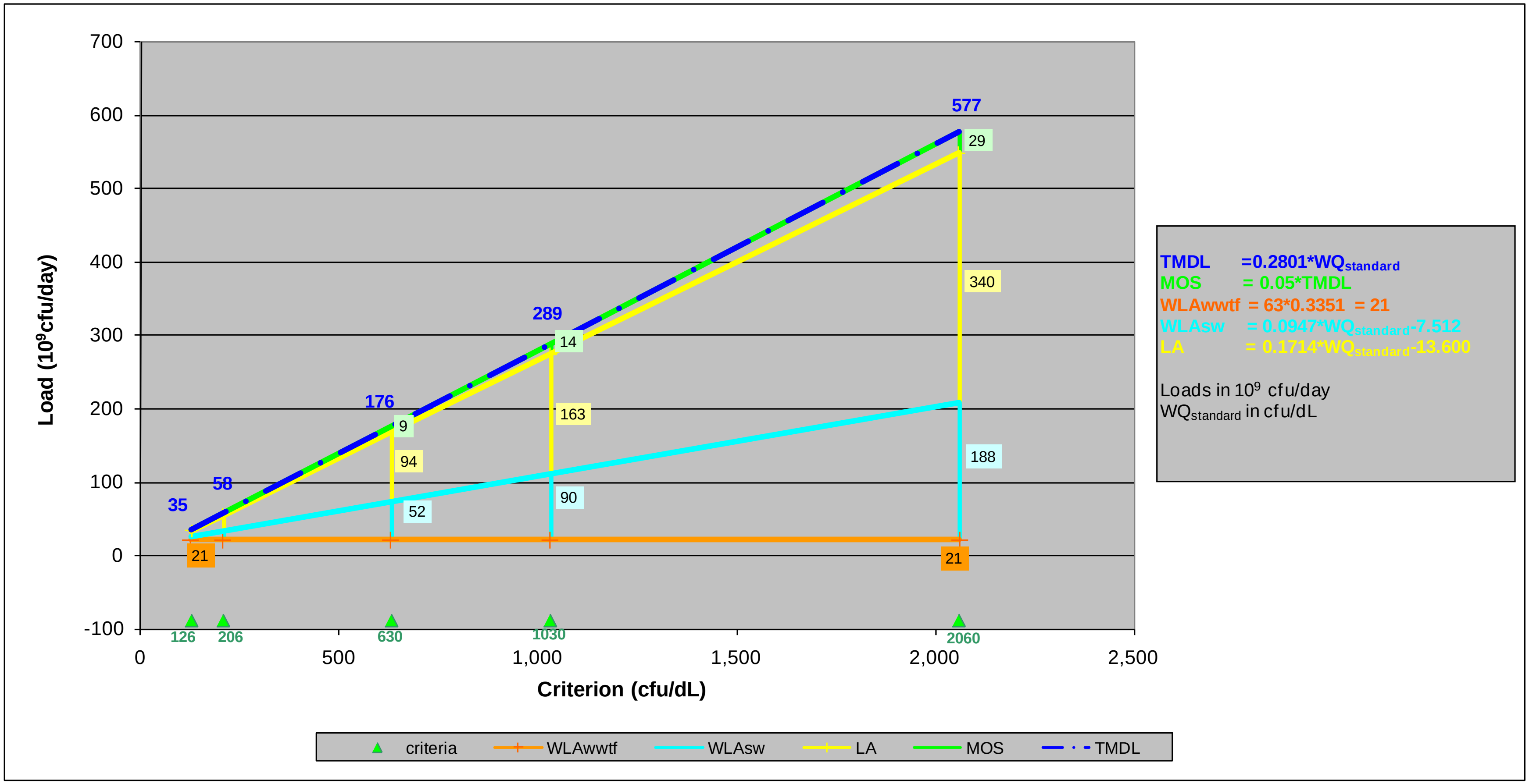

Figure A-14: Allocation Loads for AU 1009C_01 (17496) as a Function of WQ Criteria

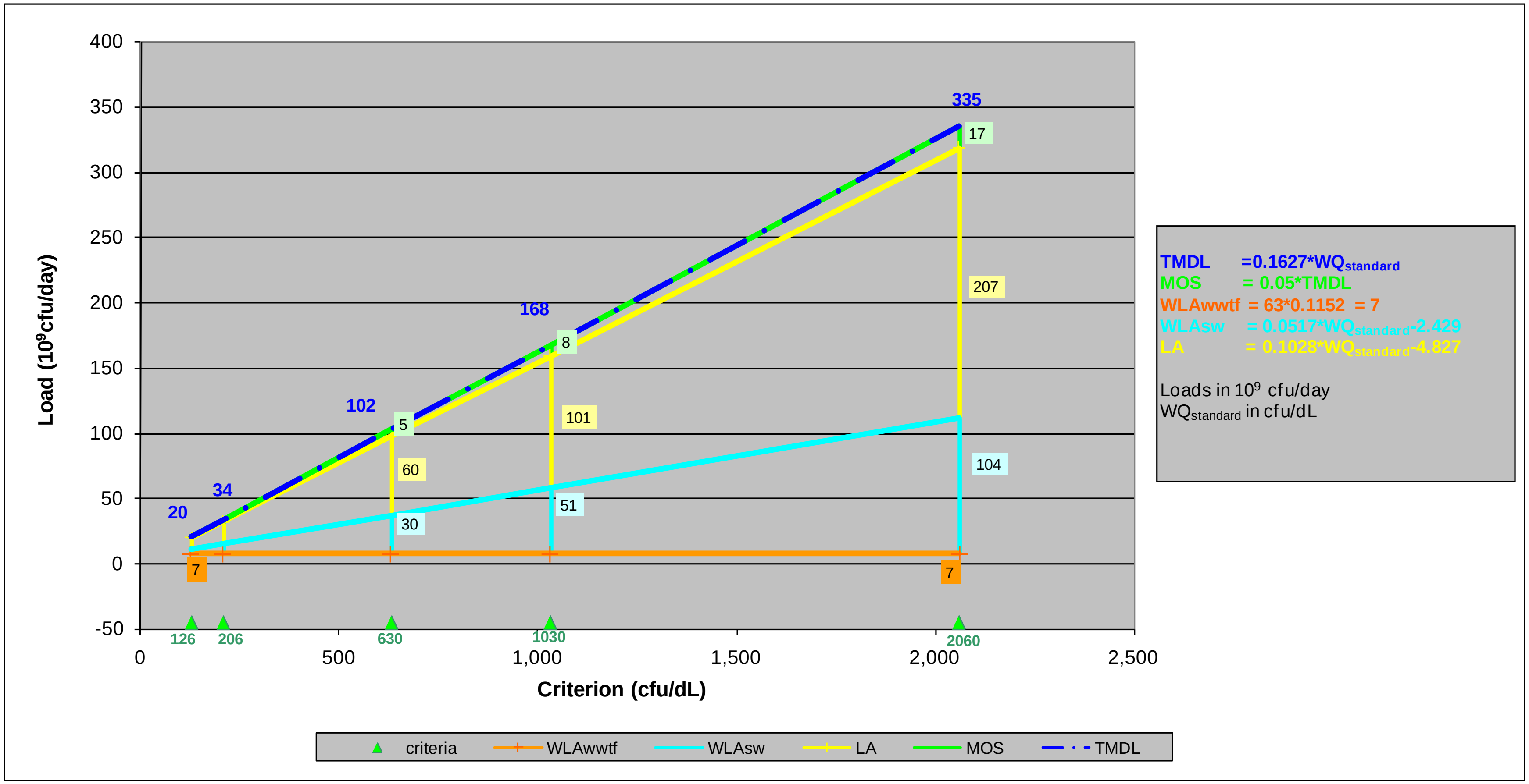

Figure A-15: Allocation Loads for AU 1009D_01 (17481) as a Function of WQ Criteria

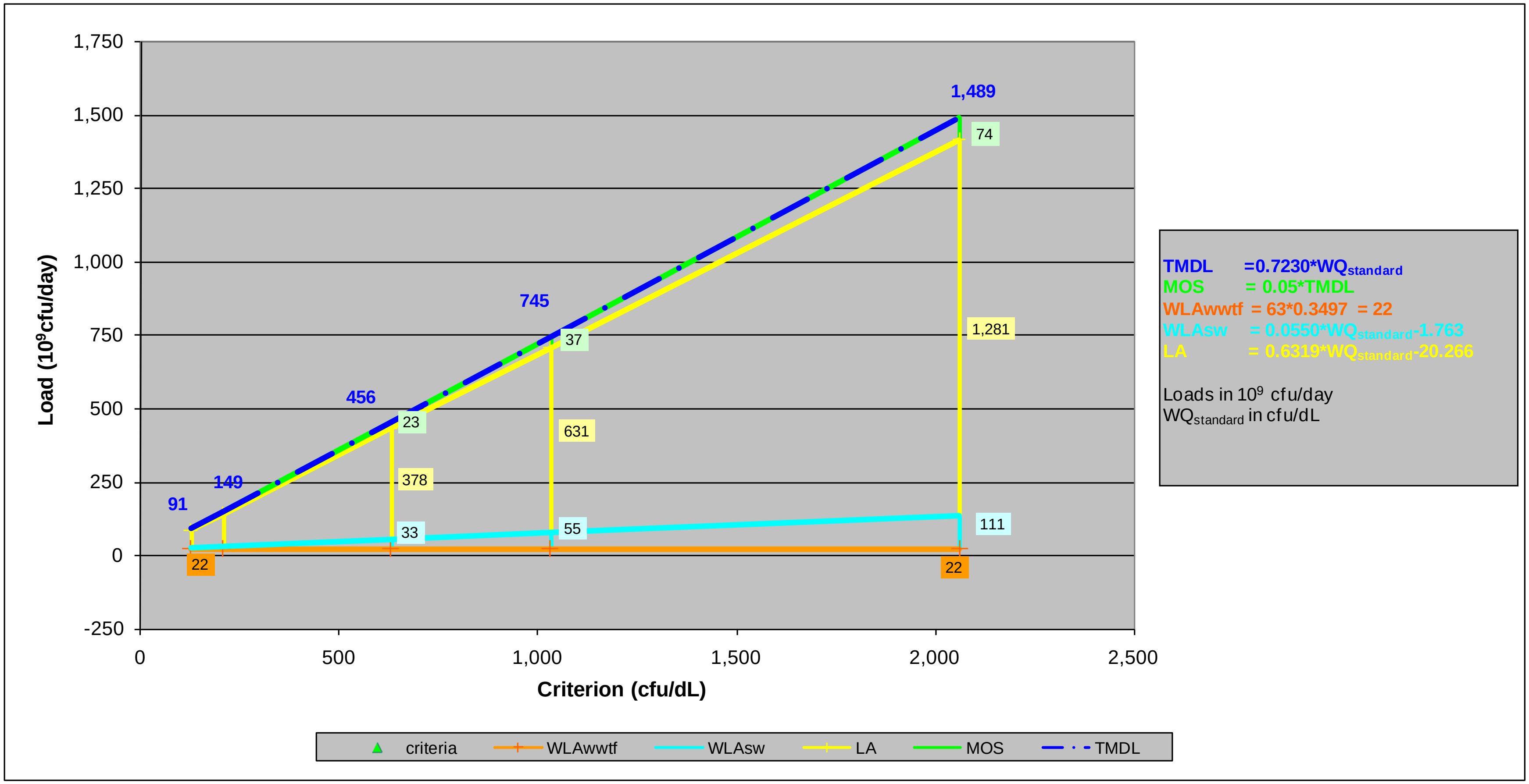

Figure A-16: Allocation Loads for AU 1009E_01 (14159) as a Function of WQ Criteria

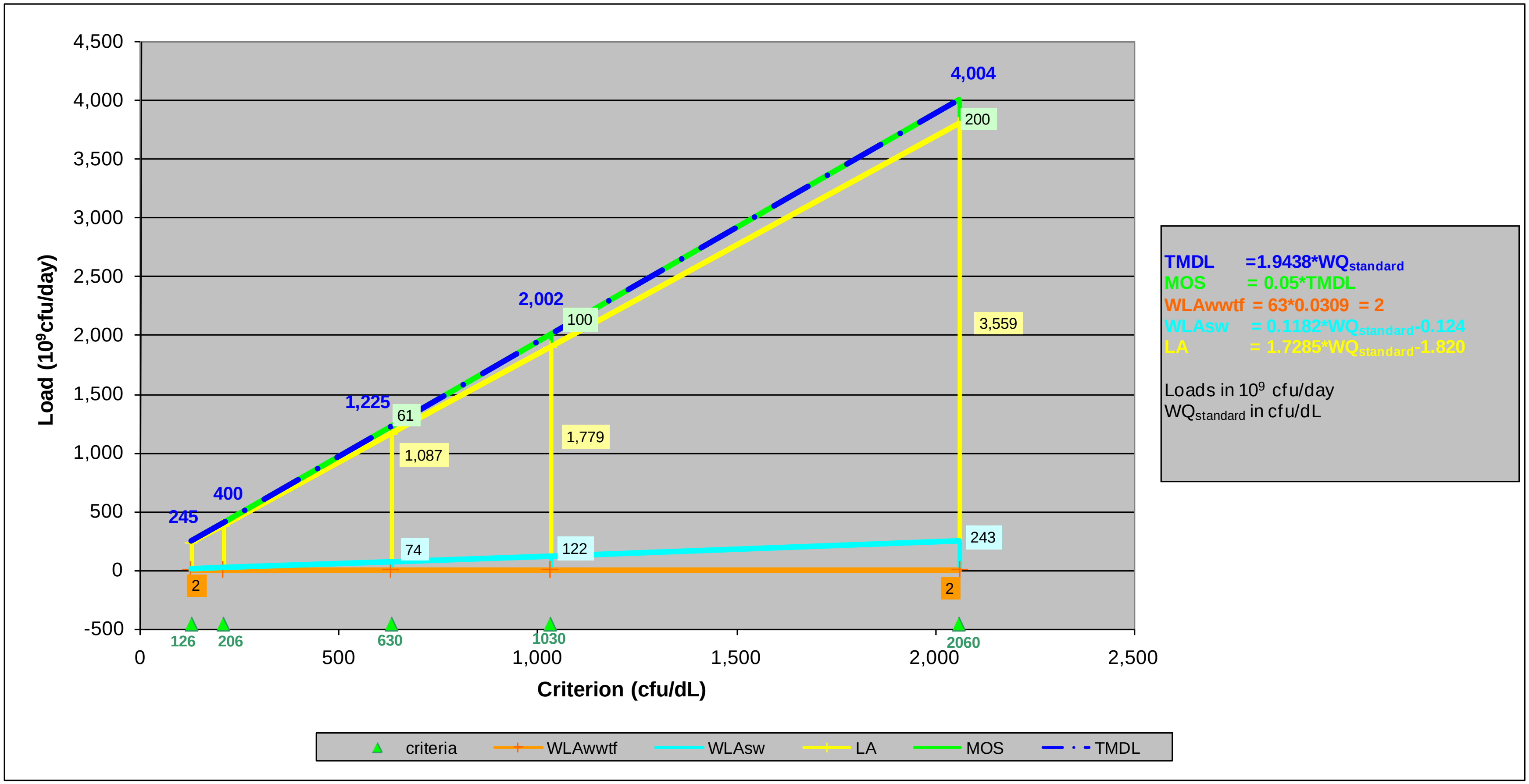

Figure A-17: Allocation Loads for AU 1010_02 (14241) as a Function of WQ Criteria

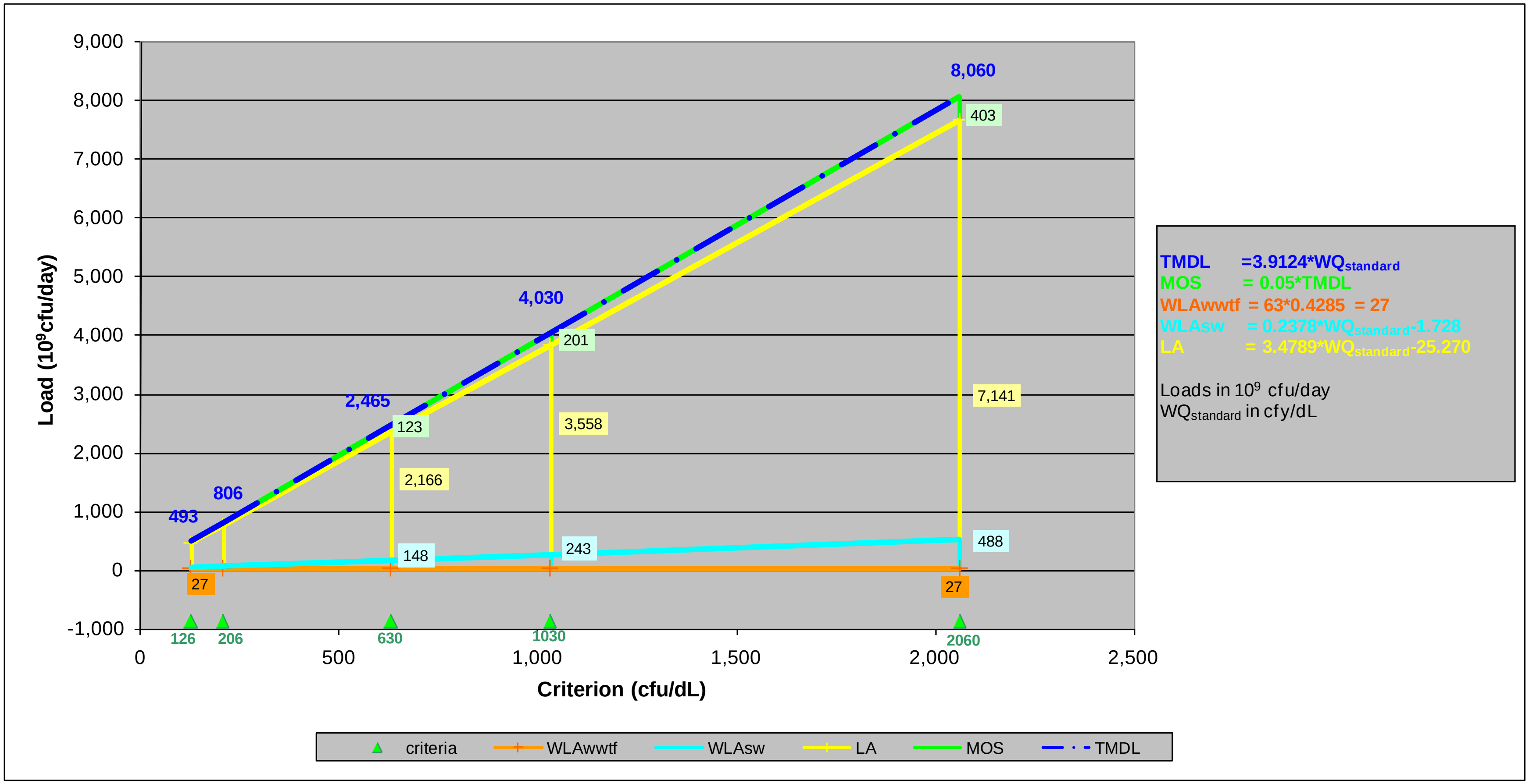

Figure A-18: Allocation Loads for AU 1010_04 (11334) as a Function of WQ Criteria

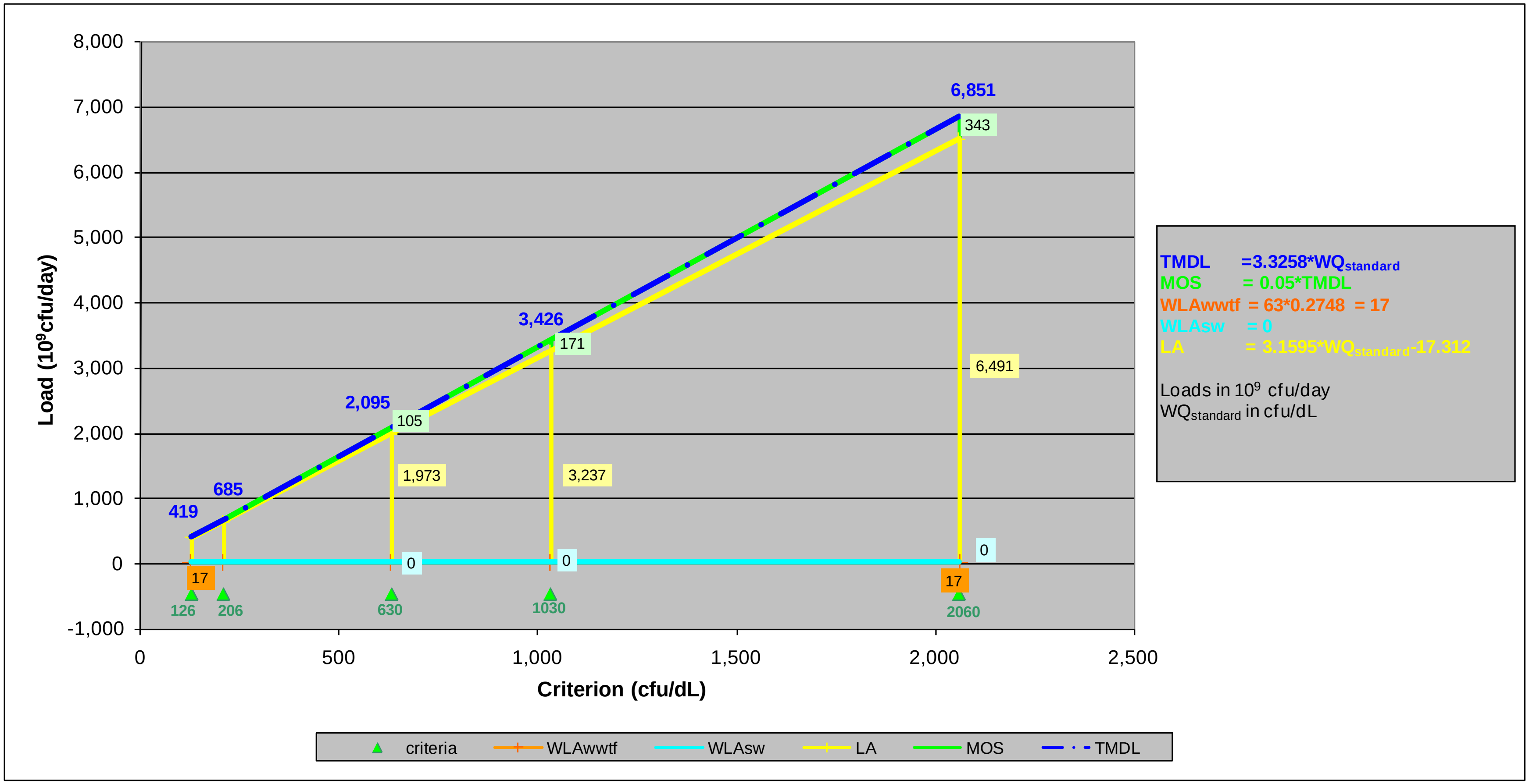

Figure A-19: Allocation Loads for AU 1011_02 (11336) as a Function of WQ Criteria

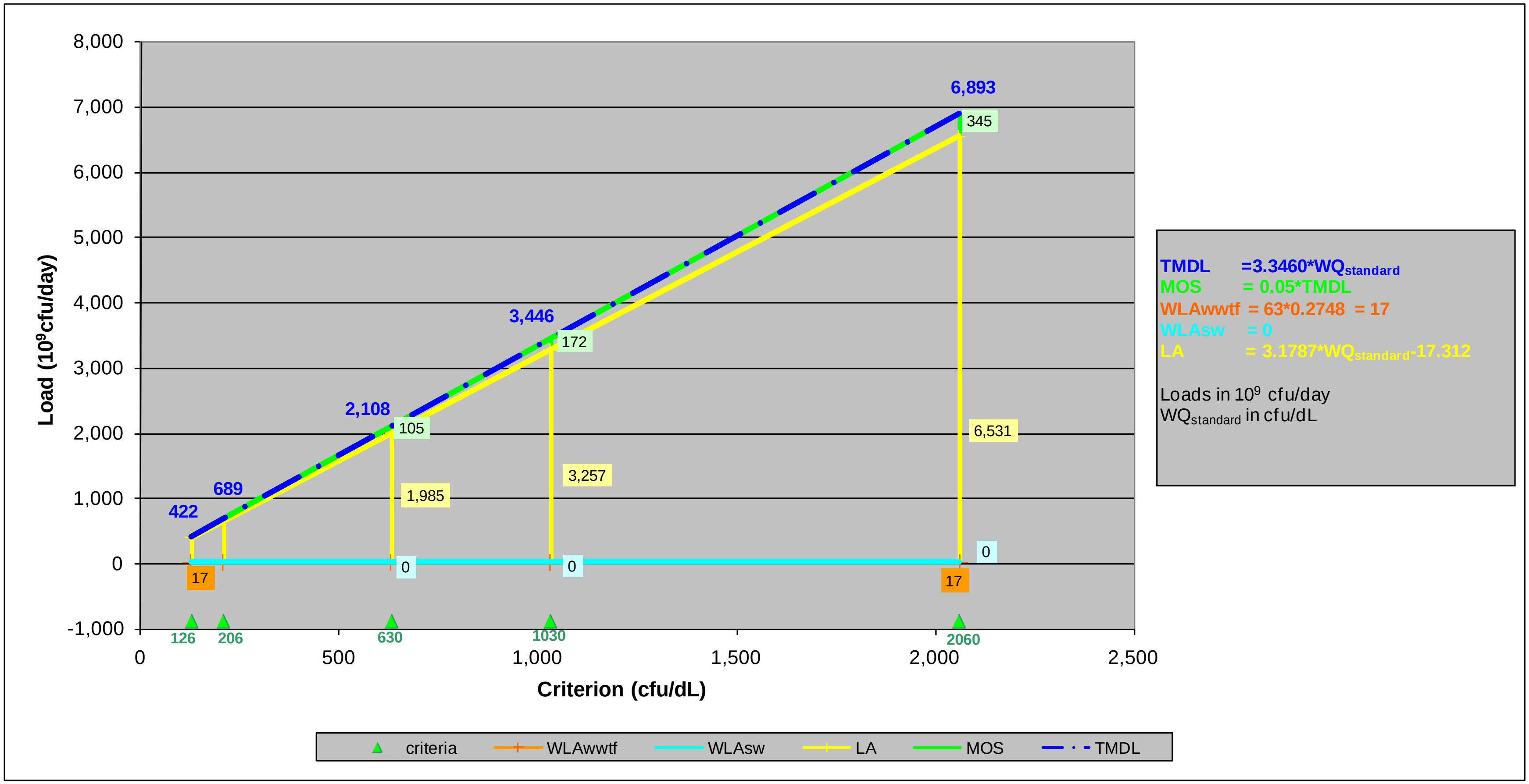

Figure A-20: Allocation Loads for AU 1011_02 (17746) as a Function of WQ Criteria