TECHNICAL SUPPORT DOCUMENT: INDICATOR BACTERIA TOTAL MAXIMUM DAILY LOADS FOR THE GREENS BAYOU WATERSHED, HOUSTON, TEXAS (1016_01, 1016_02, 1016_03, 1016A_02, 1016A_03, 1016B_01, 1016C_01, 1016D_01)

Prepared for:

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

TCEQ

Prepared by:

University of Houston

and

PARSONS

September 2009

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ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
ASAE	American Society of Agricultural Engineers
C-CAP	Coastal Change Analysis Program
CAFO	concentrated animal feeding operation
CFR	Code of Federal Regulations
cfs	Cubic feet per second
cfu	colony-forming unit
CN	curve number
dL	deciliter
DMR	discharge monitoring report
E. coli	Escherichia coli
FDC	flow duration curve
GIS	geographic information system
HCFCD	Harris County Flood Control District
HCOEM	Harris County Office of Homeland Security and Emergency Management
H-GAC	Houston-Galveston Area Council
LA	load allocations
LDC	load duration curve
mL	milliliter
MOS	margin of safety
MPN	most probable number
MS4	municipal separate storm sewer discharge
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NRCS	National Resources Conservation Service
OSSF	onsite sewage facility
SSO	sanitary sewer overflow
STATSGO	State Soil Geographic Database
SWQS	surface water quality standards
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TMDL	Total Maximum Daily Loads
TPDES	Texas Pollution Discharge Elimination System
TSARP	Tropical Storm Allison Recovery Project
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WLA	wasteload allocation
WQM	water quality monitoring
WWF	wet weather facility
WWTF	wastewater treatment facility

SECTION 1
INTRODUCTION

Twenty-seven segments in the general Houston Metropolitan Area are considered impaired water bodies for contact recreation because they do not meet indicator bacteria (*Escherichia coli* [*E. coli*]) water quality standards. These segments are in a number of watersheds in the San Jacinto River basin, including Greens Bayou Watershed, Halls Bayou Watershed, Hunting Bayou Watershed, Brays Bayou Watershed, Sims Bayou Watershed, and the general Houston Ship Channel Watershed.

For the purpose of total maximum daily load (TMDL) development, the project has been subdivided into five subprojects: Greens Bayou Watershed, Halls Bayou Watershed, Brays Bayou Watershed, Sims Bayou Watershed, and Eastern Houston Watersheds. The Eastern Houston Watersheds project includes all the bacteria-impaired segments in the Houston Ship Channel and Houston Ship Channel/Buffalo Bayou watersheds. All these segments are freshwater streams with contact recreation use that drain into the tidally influenced Houston Ship Channel and Houston Ship Channel/Buffalo Bayou segments with non-contact recreation use. This TMDL report will address the Greens Bayou Watershed.

1.1 Watershed Description

Greens Bayou is located in north central Harris County, about 10 miles north of the central business district of the City of Houston. The Greens Bayou non-tidal watershed drains an area of about 140 square miles and encompasses the cities of Houston and Humble. The non-tidal portion of the bayou flows across northern Harris County generally eastward from its headwaters near Farm-to-Market 1960 for about 23 miles, and then turns at its confluence with Garners Bayou and flows southward for about 7 miles to the confluence with Halls Bayou. The Harris County Flood Control District (HCFCD) has made channel improvements upstream of U.S. Highway 90 (U.S. Army Corps of Engineers [USACE], 2005).

Most of the watershed is highly developed, but some large areas between U.S. Highway 59 and I-10 remain undeveloped (HCFCD, 2008). There are about 200 miles of open streams within the watershed.

Subwatershed List

This report focuses on the following waterbodies that TCEQ placed in Category 5 [303(d) list] of the 2008 Integrated Report for nonsupport of contact recreation use:

- Greens Bayou above Tidal, Segment 1016 (Assessment Units 1016_01, 1016_02, and 1016_03)
- Garners Bayou, Segment 1016A (Assessment Units 1016A_02 and 1016A_03)
- Unnamed Tributary of Greens Bayou, Segment 1016B (Assessment Unit 1016B_01)
- Unnamed Tributary of Greens Bayou, Segment 1016C (Assessment Unit 1016C_01)
- Unnamed Tributary of Greens Bayou, Segment 1016D (Assessment Unit 1016D_01)

Figure 1-1 is a location map showing these Texas waterbodies and their contributing watersheds. The delineation of each subwatershed is derived from 2005 geographic information system (GIS) data files created for the Tropical Storm Allison Recovery Project (TSARP) provided by Harris County Flood Control District (HCFCD). Using the TSARP GIS file results in watershed delineations that are slightly different than the historic delineations based on Texas Commission on Environmental Quality (TCEQ) GIS files associated with classified segments (Segment 1016. These waterbodies and their surrounding watersheds are hereinafter referred to as the Study Area.

The climate of the region is subtropical humid, with very hot and humid summers and mild winters (USACE 1985). The average daytime temperature in the summer is 34 degrees Celsius (93 degrees Fahrenheit), while the temperature averages between 4 and 16 degrees Celsius (39 to 61 degrees Fahrenheit) during the winter. Summer rainfall is dominated by subtropical convection, winter rainfall by frontal storms, and fall and spring months by combinations of these two (Burian and Shepherd 2005). The 100-year floodplain encompasses about 22 percent of the drainage area of the watershed, approximately 31 square miles (HCFCD, 2008).

Table 1-1, derived from the 2000 U.S. census, summarizes the population for the cities on which the watershed lies (U.S. Census Bureau 2000). For comparison purposes, the 2010 estimated population from the Texas Water Development Board was included to show the population growth per city.

Table 1-1 City Population and Density

City Name	2000 U.S. Census	2000 Population Density (per square mile)	Texas Water Development Board Projections 2010[a]	2010 Population Density (per square mile)
Houston	1,953,631	3,371	2,240,974	3,867
Humble	14,579	1,477	16,862	1,708

[a] *Texas Water Development Board, 2005*

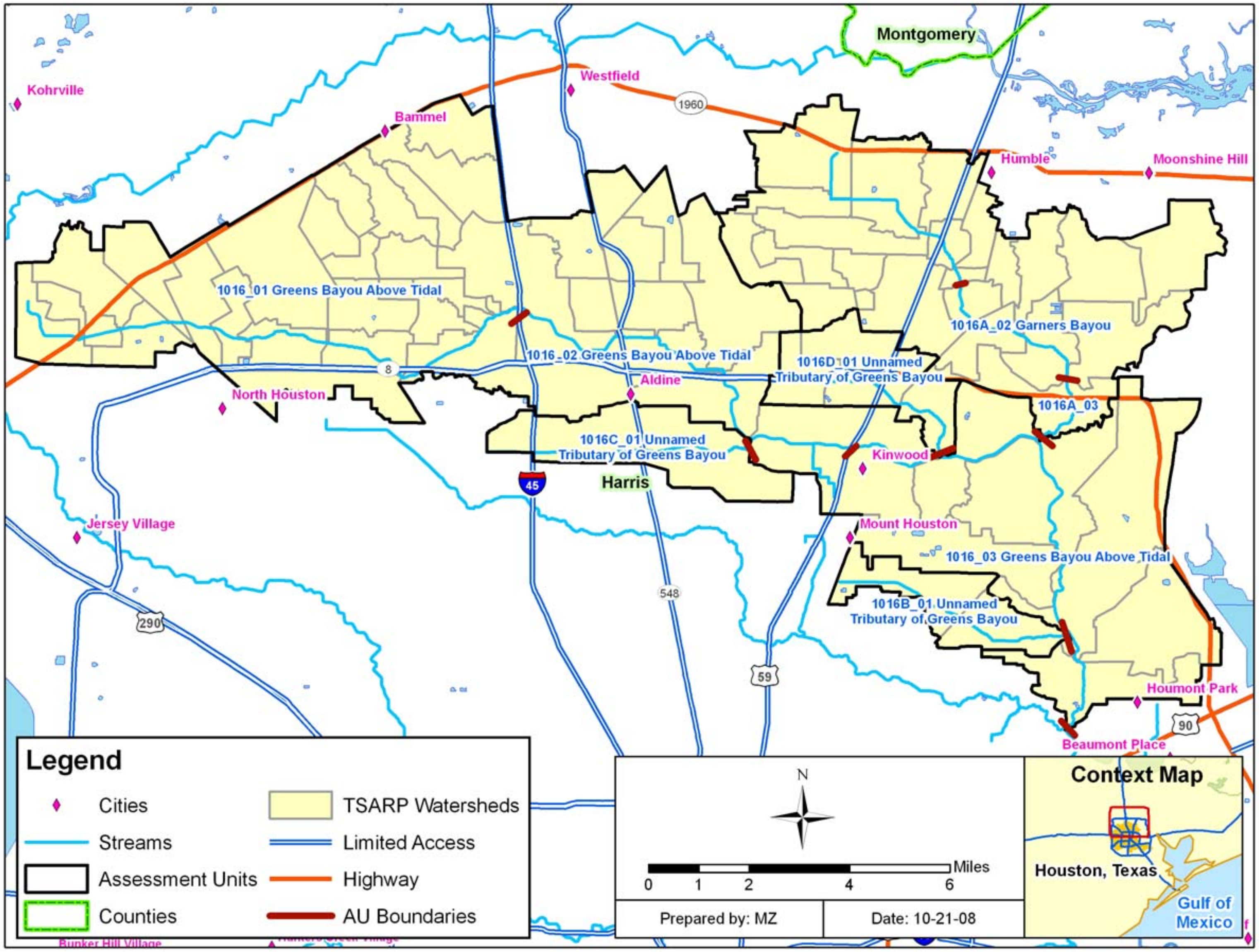

Figure 1-1 Location Map for Greens Bayou Watershed

1.2 Summary of Existing Data

The following subsections summarize existing data relevant to soil, land use, and precipitation throughout the watershed as well as the available ambient water quality and stream flow data for the Study Area.

1.2.1 Soil and Topography

The State Soil Geographic Database (STATSGO) (National Resources Conservation Service [NRCS] 1994) information was used to characterize soil in the Greens Bayou Watershed. As can be observed in Figure 1-2, the soil types that dominate the watershed are primarily from the Clodine, Aldine, and Wockley soil series. Table 1-2 lists the distribution and attributes of the three soil series found in the Study Area.

Table 1-2 Characteristics of Soil Types within Greens Bayou Watershed

NRCS Soil Type	Soil Series Name	Percent of Watershed Area	Surface Texture	Hydrologic Group	Soil Drainage Class	Min Water Capacity (in/in)	Max Water Capacity (in/in)	Min Bulk Density (g/cm3)
TX100	Clodine	64.3%	Loam	D	Poorly Drained	0.15	0.15	1.4
TX007	Aldine	16.8%	Fine Sandy Loam	D	Somewhat Poorly Drained	0.13	0.18	1.45
TX618	Wockley	13.3%	Fine Sandy Loam	C	Somewhat Poorly Drained	0.12	0.13	1.45
TX248	Katy	2.6%	Fine Sandy Loam	D	Somewhat Poorly Drained	0.12	0.16	1.4
TX068	Boy	1.2%	Loamy Fine Sand	B	Somewhat Poorly Drained	0.09	0.12	1.5
TX048	Bernard	0.9%	Clay Loam	D	Somewhat Poorly Drained	0.14	0.19	1.33
TX276	Lake Charles	0.9%	Clay	D	Somewhat Poorly Drained	0.12	0.17	1.33

Source: All data obtained/calculated from STATSGO database

The topography of the area is characteristic of the Texas Gulf Coastal Plains – flat and grassy. The streambed has an average slope of about 0.07 percent (3.7 feet per mile). Elevations in the watershed vary from about 123 feet near the headwaters to about 8 feet at the mouth of Greens Bayou (USACE 2005).

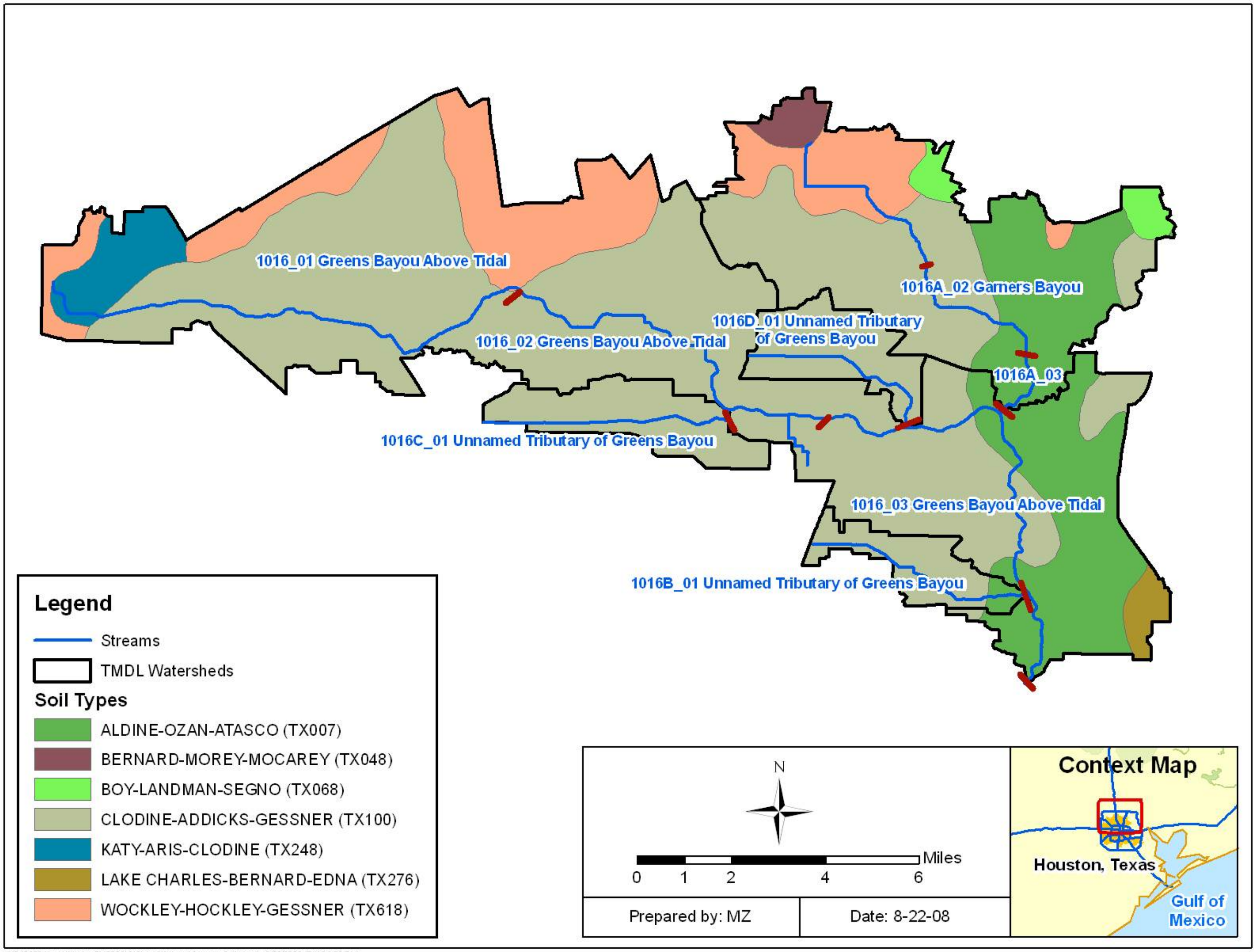

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Figure 1-2 Greens Bayou Watershed Soil Types

1.2.2 Land Use

Most of the Greens Bayou Watershed is highly developed, but some large areas between U.S. Highway 59 and I-10 remain undeveloped. Table 1-3 summarizes the acreages and the corresponding percentages of the land use categories for the contributing watershed associated with each respective segment in the Study Area. The land use/land cover data were derived from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Center. The specific land use/land cover data files were derived from the Coastal Change Analysis Program (C-CAP), Texas 2005 Land Cover Data (NOAA 2007). The land use categories are displayed in Figure 1-3. The total acreage of each segment in Table 1-3 corresponds to the watershed delineation in Figure 1-3. As mentioned before, the predominant land use category in this watershed is developed land (between 44% and 76%) followed by woody land (between 16% and 31%). Open water and bare/transitional land account for less than 2 percent of the subwatersheds.

Table 1-3 Aggregated Land Use Summaries by Segment

Aggregated Landuse Category	Segment/Assessment Unit ID				
	1016[a]	1016A[b]	1016B_01	1016C_01	1016D_01
Percent Developed	56	52	44	85	63
Percent Cultivated Land	0.0	0.0	0.0	0.0	0.0
Percent Pasture/Hay	3.0	3.2	1.2	1.9	0.4
Percent Grassland/Herbaceous	4.1	2.8	1.1	1.9	3.7
Percent Woody Land	25	31	26	10	23
Percent Open Water	0.3	0.4	0.1	0.0	0.1
Percent Wetland	10.6	9.7	28	1.8	9.0
Percent Bare/Transitional	1.1	0.6	0.1	0.1	0.3
Acres of Developed	32,852	11,284	1,180	3,426	2,256
Acres Cultivated Land	3.0	1	0	0	0
Acres Pasture/Hay	1752	698	33	76	13
Acres Grassland/Herbaceous	2381	597	30	79	133
Acres of Woody Land	14,417	6,795	697	387	820
Acres of Open Water	152	91	3.8	0	2.4
Acres of Wetland	6,204	2,096	755	73	322
Acres of Bare/Transitional	642	135	2	2	10
Watershed Area (acres)	58,404	21,697	2,698	4,043	3,556

[a] *Assessment Units 1016_01, 1016_02 and 1016_03*
[b] *Assessment 1016A_02 and 1016A_03*

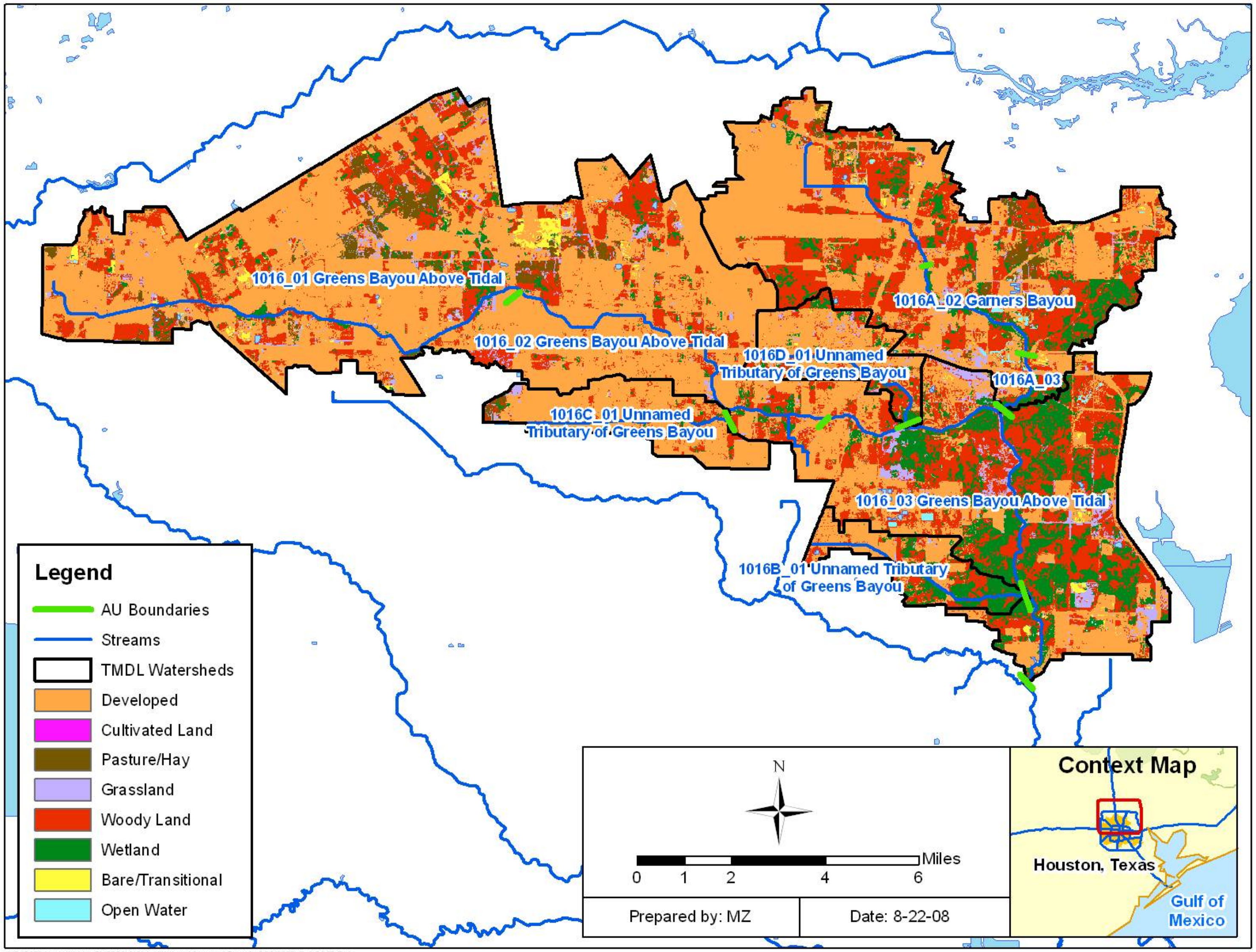


Figure 1-3 Land Use Map

1.2.3 Precipitation

There are 10 rain gauges located within the watershed (Figure 1-4). The gauges are maintained by the Harris County Office of Homeland Security and Emergency Management (HCOEM). Table 1-4 summarizes total annual rainfall for the 10 gauges for a 20-year period. The Study Area has high levels of humidity and receives annual precipitation ranging between 21 and 79 inches per year (Table 1-4). Based on data for the period 1988 to 2007, the watershed average is around 48.8 inches per year. Figure 1-4 shows average annual rainfall across the Study Area. This grid was obtained by kriging data from 148 HCOEM rain gauges located across Harris, Fort Bend, and Galveston Counties. Average values by subwatershed are summarized in Table 1-5. These average values were used to support the development of flow duration curves (Section 4).

Table 1-4 Annual Totals at Rainfall Gauges in Greens Bayou Watershed (in inches)

Segment	Gauge number	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1016	1645	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1016	1660	22.5	43.9	34.2	54.0	56.9	49.3	41.5	50.5	35.6	67.9
1016	1670	20.9	39.1	33.0	63.7	50.4	53.2	46.3	39.2	29.7	57.5
1016	1685	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1016	4310	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1016	1600	NA	NA	NA	NA	NA	31.5	66.4	NA	34.4	73.7
1016	1640	25.7	48.5	32.4	67.1	50.2	47.2	39.7	35.6	36.1	53.7
1016	1665	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1016	3520	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1016A	1630	25.9	52.4	35.2	60.6	61.5	58.7	45.4	42.6	33.6	58.0
Segment	**Gauge number**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
1016	1645	NA	35.1	48.1	75.8	52.8	43.5	63.8	37.1	56.4	63.6
1016	1660	NA	27.8	35.7	54.0	43.6	36.3	49.1	39.7	NA	70.8
1016	1670	52.8	32.4	36.3	68.8	49.8	37.7	58.9	39.2	51.7	59.5
1016	1685	NA	NA	NA	80.0	60.2	45.0	72.8	36.3	58.8	70.3
1016	4310	NA	NA	NA	NA	68.8	42.0	NA	29.5	40.3	51.0
1016	1600	38.6	23.1	21.7	NA	43.6	52.7	72.1	42.3	62.6	70.8
1016	1640	53.7	53.7	33.5	64.3	45.2	36.7	57.2	30.8	44.2	52.3
1016	1665	NA	32.2	43.7	73.1	55.0	43.1	58.3	38.3	53.2	59.7
1016	3520	NA	NA	34.2	65.9	NA	65.9	79.2	40.8	53.6	60.1
1016A	1630	45.1	30.6	NA	67.0	56.5	46.6	67.1	37.6	50.8	58.3

Average annual rainfall over period of 1988 to 2007 is 48.8 inches.

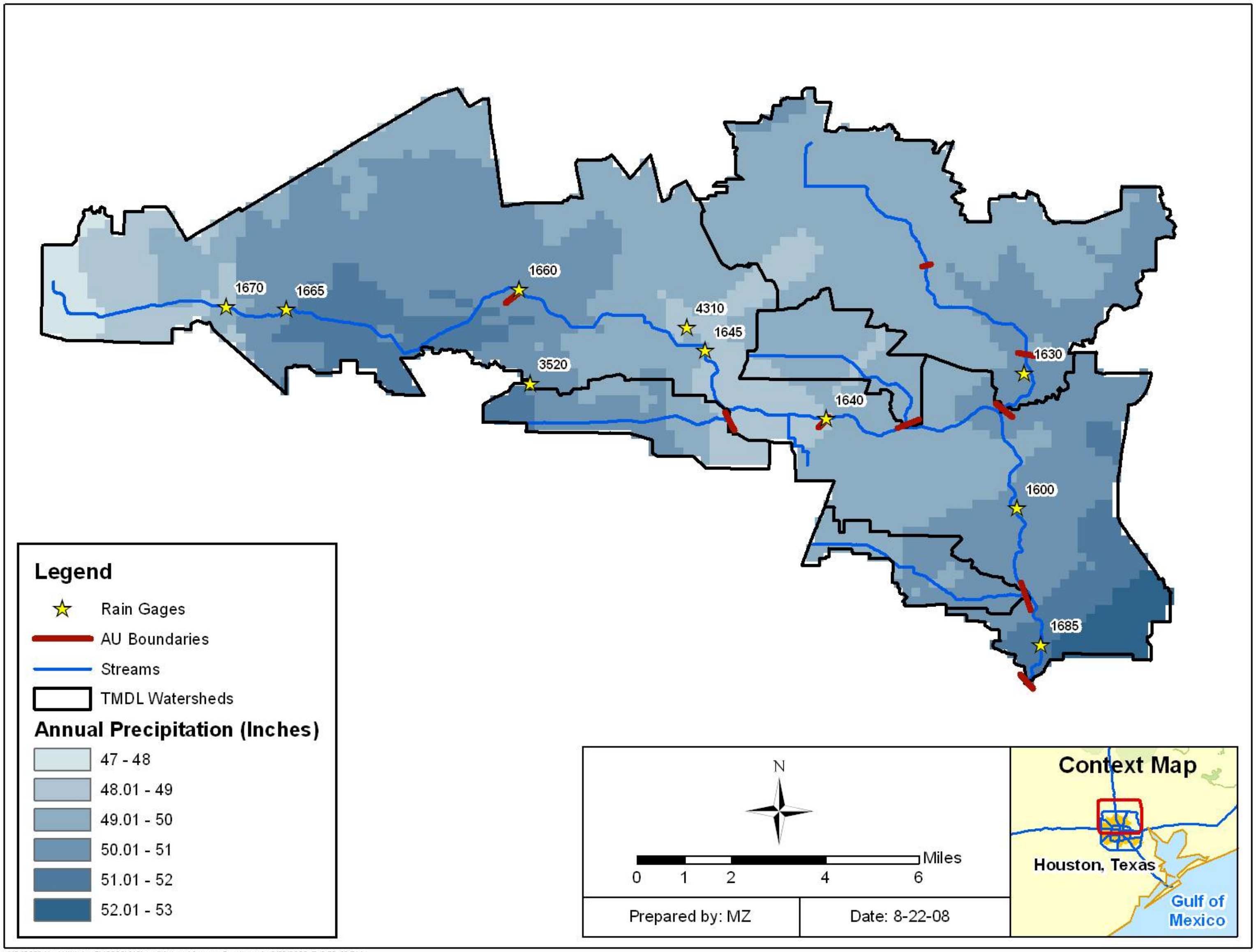


Figure 1-4 Precipitation Map

Table 1-5 Annual Average Precipitation in Greens Bayou Subwatersheds, 1988-2007 (in inches)

Segment/ Assessment Unit	Average Annual (inches)
1016_01, 1016_02, 1016_03	50.3
1016A_02, 1016A_3	49.1
1016B_01	54.6
1016C_01	51.8
1016D_01	49.1

1.2.4 Ambient Water Quality

Considerable amounts of ambient water quality data are available to support water quality assessment and development of TMDLs for segments in the Greens Bayou Watershed. Historical indicator bacteria data for the period 1992 to 2008 were obtained from the TCEQ SWQMIS database, which includes results from the sampling events conducted under this project in 2006. Fifty-six percent of the data correspond to *E. coli* concentrations (821 samples), while the remaining 44 percent correspond to fecal coliform concentrations (637 samples).

Table 1-6 summarizes the historical ambient water quality data for indicator bacteria (1992-2008) for select TCEQ Water Quality Monitoring (WQM) stations in the Greens Bayou Watershed. Data in Table 1-6 collected prior to 2001 correspond to fecal coliform concentrations, while data for 2001-2008 are primarily *E. coli* concentrations. Figure 1-5 shows the locations of the WQM locations with indicator bacteria data. The complete ambient water quality dataset for bacteria used to prepare Table 1-6 is provided in Appendix A. Table 1-6 presents the number of indicator bacteria samples, as well as the geometric mean of the concentrations for each indicator, and the number and percentage of single sample exceedances of the Texas SWQS. A more in-depth discussion of the analysis of this dataset is provided in Subsections 2.3 and 2.4.

Table 1-6 Historical Water Quality Data for TCEQ Stations from February 1992 to March 2008

Assessment Unit	WQM Station ID	Indicator Bacteria	Geometric Mean Criteria	Geometric Mean Concentration	Single Sample Criteria	Number of Samples	Number of Samples Exceeding Single Sample Criteria	% of Samples Exceeding
1016_03	11369	EC	126	399	394	95	43	45%
		FC	200	167	400	50	15	30%
	11370	EC	126	379	394	62	26	42%
		FC	200	107	400	49	10	20%
1016_02	11371	EC	126	1008	394	81	59	73%
		FC	200	423	400	89	45	51%
	11372	FC	200	6	400	8	0	0%
	11373	FC	200	8	400	8	1	13%
	13778	EC	126	1355	394	95	78	82%
		FC	126	1111	394	51	35	69%
1016_01	11376	EC	126	435	394	59	28	47%
		FC	200	12	400	9	1	11%
	11378	FC	200	265	400	1	0	0%
	17495	EC	126	243	394	59	17	29%
1016A_03	11125	EC	126	732	400	61	35	57%
		FC	200	553	400	79	38	48%
1016A_02	16589	EC	126	346	394	63	29	46%
		FC	200	1142	400	63	40	63%
1016B_01	16590	EC	126	622	394	62	36	58%
		FC	200	768	400	78	47	60%
	20024	EC	126	568	394	18	9	50%
1016C_01	11124	EC	126	1337	394	83	75	90%
		FC	200	1331	400	75	63	84%
1016D_01	16676	EC	126	2078	394	83	69	83%
		FC	200	882	400	77	43	56%

EC: E. coli in MPN/100mL, FC: Fecal Coliform in cfu/100mL

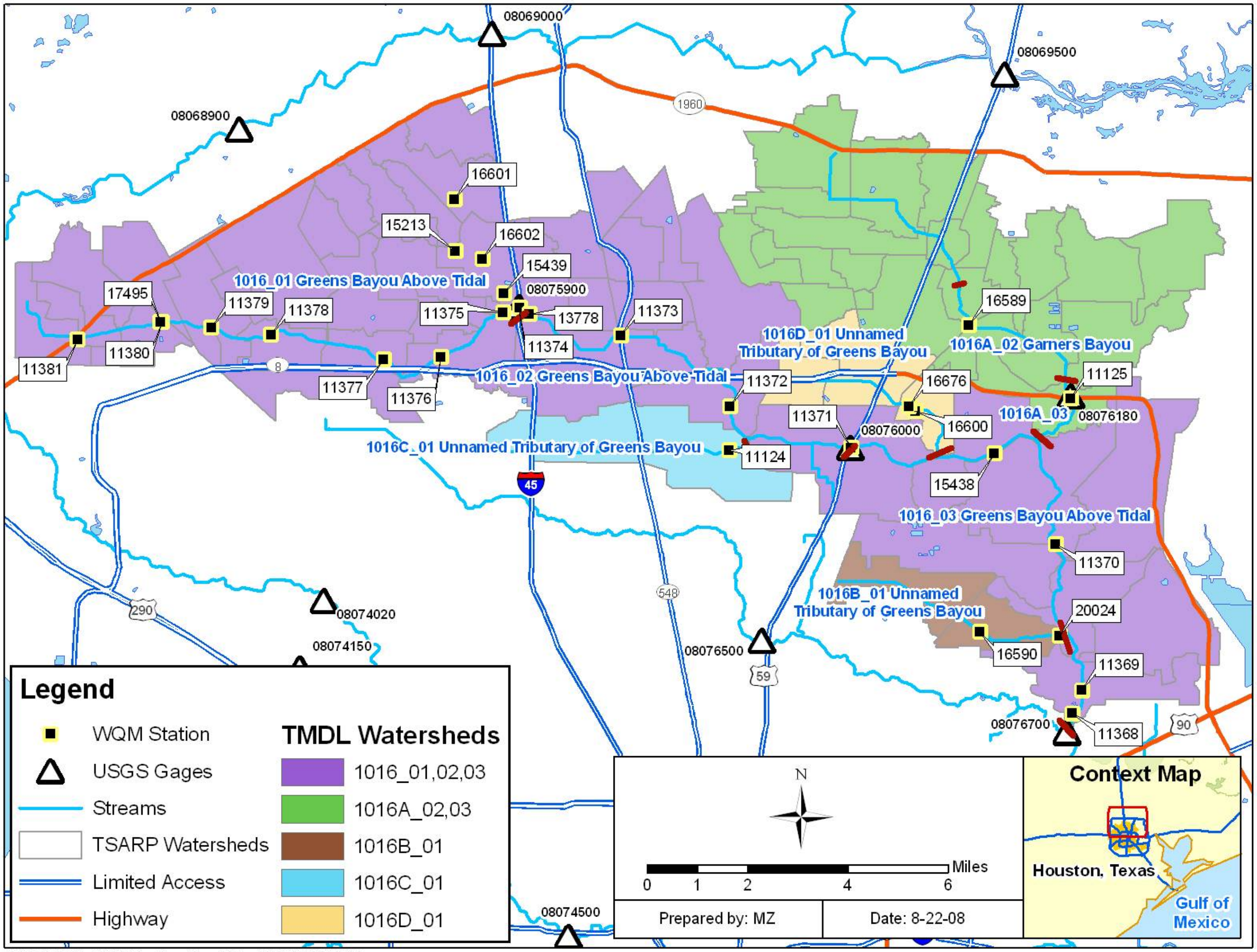


Figure 1-5 WQM and USGS Station Locations

1.2.5 Stream Flow Data

Stream flow data is key information when conducting water quality assessments such as TMDLs. The U.S. Geological Survey (USGS) operates flow gages at four locations along Greens Bayou to measure flow and elevations. The period of record and type of data collected at these gages are listed upstream to downstream in Table 1-7. The locations of these gage stations are shown on Figure 1-5. All gages in the watershed are currently active. The historical flow data available from these gages are included in Appendix B.

Table 1-7 USGS Gages in the Greens Bayou Watershed

USGS Gage Number	Name	Period of Record	Data Type
8075780	Greens Bayou at Cutter Rd	12/6/2003 - Present	Gage Height (ft)
8075900	Greens Bayou at U.S. Highway 75	8/3/1965 - Present	Discharge (cfs)
		4/17/1997 - Present	Gage Height (ft)
8076000	Greens Bayou at U.S. Highway 59 North of Houston	10/1/1952 - Present	Discharge (cfs)
		9/28/1952 - Present	Gage Height (ft)
8076180	Garners Bayou near Humble, Texas	2/25/1986 - Present	Discharge (cfs)
		2/13/1998 - Present	Gage Height (ft)

During intensive surveys conducted in the summer of 2006, instantaneous flow was measured at four WQM stations within the Study Area: 11371 (segment 1016), 20024 (segment 1016B), 11124 (segment 1016C), and 16676 (segment 1016D). The complete set of instantaneous flow data are also provided in Appendix B. No other historical flow data were available during water quality sample collection to assist in characterizing flows.

1.3 Greens Bayou Seasonality

Seasonal differences in indicator bacteria concentrations were assessed by comparing historical bacteria concentrations collected in the warmer months versus those collected during the cooler months. The monthly average temperatures for Houston obtained from NOAA (Table 1-8) and the following criteria: warm temperatures ranged from 24 – 32°C and cool temperatures ranged from 12 – 18°C were used to divide the data sets into warmer and cooler months. Based on this, November, December, January, and February were cooler months, and May, June, July, August, and September were warmer months.

Table 1-8 Average Monthly Temperatures for Houston Hobby AP, TX (1971-2000)

Month	Daily Max (°C)	Daily Min (°C)	Daily Mean (°C)	Classification
Jan	17.4	7.3	12.4	Cool
Feb	19.5	9	14.3	Cool
Mar	23.1	12.7	17.9	
Apr	26.3	15.9	21.1	
May	29.9	20.1	25	Warm
Jun	32.8	23.1	27.9	Warm
Jul	34.2	24.1	29.2	Warm
Aug	34.1	24.1	29.1	Warm
Sep	31.8	22	26.9	Warm
Oct	27.8	16.8	22.3	
Nov	22.5	11.9	17.2	Cool
Dec	18.6	8.2	13.4	Cool

Note: Temperature values from NOAA (degrees Fahrenheit) have been converted to degrees Celsius.
http://cdo.ncdc.noaa.gov/cgi-bin/climatenormals/climatenormals.pl

A t-test was conducted on log transformed data between the warmer months and cooler months for stations with 8 or more samples. Geometric means were also calculated for the warmer and cooler months. Table 1-9 shows that 5 out of 13 stations (38%) exhibited higher geometric means for colder months than for warmer months. However, fecal coliform levels were not found to be significantly higher (*p*-value<0.05) during cool months.

Table 1-9 Seasonal Differences for Fecal Coliform Concentrations

Assessment Unit	Station ID	Warm Months		Cool Months		*p*-value
		n	Geomean (cfu/100mL)	n	Geomean (cfu/100mL)	
1016_03	11369	22	96	13	200	0.226
	11370	22	73	12	82	0.861
1016_02	11371	35	373	32	386	0.944
	11372	8	6	0	-	NA
	11373	8	8	0	-	NA
	13778	25	541	12	2,453	0.065
1016_01	11376	8	8	1	-	NA
	11378	1	-	0	-	NA
1016A_03	11125	32	661	24	562	0.792
1016A_02	16589	24	1,722	19	1,462	0.808
1016B_01	16590	30	1,216	24	735	0.424
1016C_01	11124	29	1,738	23	985	0.158
1016D_01	16676	30	1,029	24	715	0.552

n = number of samples; ; NA = not available. Test could not be conducted because station does not have data for cool months.
Highlighted rows correspond to stations for which the warm and cold datasets are significantly different at a 95% confidence interval.
p-value is based on a t-test conducted at each station using single sample concentrations.
All concentrations are in cfu/100mL.

For *E. coli*, Table 1-10 shows that 75 percent of the stations (9 out of 12) exhibited higher geometric mean concentrations for the colder months than the warmer months. However, the warm and cool datasets are statistically different (*p*-value=0.05) in only two of the stations.

Overall this analysis of fecal coliform and *E. coli* data demonstrates that there is no significant difference in indicator bacteria between cool and warm weather seasons.

Table 1-10 Seasonal Differences for *E. coli* Concentrations

Assessment Unit	Station ID	Warm Months		Cool Months		*p*-value
		n	Geomean (MPN/100mL)	n	Geomean (MPN/100mL)	
1016_03	11369	36	265	35	653	0.053
	11370	22	310	25	505	0.363
1016_02	11371	40	780	26	1,912	0.035
	13778	36	1,198	36	1,884	0.144
1016_01	11376	22	767	22	352	0.105
	17495	22	291	22	251	0.787
1016A_03	11125	21	789	25	926	0.767
1016A_02	16589	22	341	26	427	0.661
1016B_01	16590	22	286	25	1,189	0.029
	20024	18	568	0	-	NA
1016C_01	11124	42	1,275	26	1,701	0.450
1016D_01	16676	42	2,291	26	2,533	0.812

n = number of samples; NA = not available. Test could not be conducted because station does not have data for cool months.
Highlighted rows correspond to stations for which the warm and cold datasets are significantly different at a 95% confidence interval.
p-value is based on a t-test conducted at each station using single sample concentrations.
All concentrations are in MPN/100mL.

SECTION 2
PROBLEM IDENTIFICATION AND WATER QUALITY TARGET

2.1 Pollutant of Concern: Characteristics of Bacterial Indicators

The contact recreation use is assigned to almost every designated water body in the State of Texas, although full support of the contact recreation use is not a guarantee that the water is completely safe of disease-causing organisms. The evolution of contact recreation criteria currently used by Texas began with criteria first published in 1968 based on general studies done on lakes in the Midwest and New York using fecal coliform bacteria as the indicator of the potential presence of fecal contamination (USEPA 1986). The USEPA-recommended criterion for recreational waters in 1976 included a geometric mean criterion: no more than 200 cfu/100mL based on five samples collected over a 30-day period, and an instantaneous criterion: no more than 10 percent of the individual grab samples could exceed 400 cfu/100mL (USEPA 1986). Shortly thereafter this recommended criterion was adopted by the State of Texas in its SWQS. These criteria, and the studies on which they were based, were heavily criticized by the USEPA in 1986 (USEPA 1986) following an extensive program of epidemiology testing. During that decade, USEPA studies found that fecal coliform was not a good predictor of the risk of disease and recommended new tests and criteria. As a result USEPA recommended new criteria for swimming areas, using *E. coli* as the new fecal indicator organism, and incorporating the idea of varying criteria with the level of swimming use. TCEQ then revised the WQS in 2000 to establish *E. coli* as the new indicator bacteria for assessment of contact recreation in all freshwater.

Thus in Texas both indicator bacteria - fecal coliform and *E. coli* - can be used to determine support of the contact recreation use in freshwater. However, it is expected that over time since only *E. coli* bacteria are measured through the statewide ambient monitoring program to determine the relative risk of contact recreation, reliance on fecal coliform data will diminish. The presence of *E. coli* indicates that associated pathogens from the waste of warm-blooded species (human or animal) may be present in a body of water. The standard associated with contact recreation use is designed to ensure that water is safe for swimming, wading by children, or other water sports that involve direct contact with the water, especially with the possibility of ingesting it. High concentrations of certain indicator bacteria in water indicate there may be a risk of becoming ill from recreational activities.

Texas WQSs for contact recreation allow exemptions for waterbodies where elevated bacteria concentrations frequently occur due to sources of pollution that cannot be reasonably controlled by the existing regulations, or where recreation is considered unsafe for other reasons, such as barge or ship traffic (*e.g.*, Houston Ship Channel), unrelated to water quality. This exemption and reclassification to less strict “noncontact recreation” standards have been applied to only a few waterbodies in Texas.

2.2 TCEQ Water Quality Standards for Contact Recreation

The TCEQ is responsible for administering provisions of the constitution and laws of the State of Texas to promote judicious use of and protection of the quality of waters in the state. Included in this responsibility is the continuous monitoring and assessment of water quality to evaluate compliance with SWQSs established within Texas Water Code, §26.023 and Title 30 Texas Administrative Code (TAC), §§307.1-307.10. Texas SWQS, 30 TAC 307.4 specify the designated uses and general criteria for all surface waters in the state.

This report focuses on the waterbodies within the Greens Bayou Watershed identified on the §303(d) list of the Texas Water Quality Inventory because they do not support contact recreation use (TCEQ 2008). Table 2-1 summarizes the designated uses and the applicable indicator bacteria used to assess the contact recreation use of each waterbody addressed in this report. Table 2-1 also identifies the year each waterbody was placed on the Texas §303(d) List for nonsupport of contact recreation use, the stream length in miles, and other designated uses for each waterbody. The TMDLs in this report only address the contact recreation use. TMDLs are a necessary step in the process to restore contact recreation use for each waterbody.

Table 2-1 Synopsis of Texas Integrated Report for Waterbodies in the Greens Bayou Watershed

Segment ID	Segment Name	Assessment Unit	Indicator Bacteria	Designated Use*				Year Placed on 303(d) List	Stream Length (miles)
				CR	AL	GU	FC		
1016	Greens Bayou above Tidal	1016_01	*E. coli* (or fecal coliform)	NS	S	S	NC	1996	4.9
		1016_02		NS	S	S	NC	1996	8.3
		1016_03		NS	S	S	NC	1996	10.7
1016A	Garners Bayou	1016A_02	*E. coli* (or fecal coliform)	NS	S	S	NC	2002	4.2
		1016A_03		NS	S	S	NC	2002	1.6
1016B	Unnamed Tributary of Greens Bayou	1016B_01	*E. coli* (or fecal coliform)	NS	S	S	NC	2002	5.1
1016C	Unnamed Tributary of Greens Bayou	1016C_01	*E. coli* (or fecal coliform)	NS	S	S	NC	2002	2.2
1016D	Unnamed Tributary of Greens Bayou	1016D_01	*E. coli* (or fecal coliform)	NS	S	S	NC	2002	2.8

**CR: Contact recreation; AL: Aquatic Life; GU: General Use; FC: Fish Consumption; NS: Nonsupport; S = Support; NC = No Concern; NA=not available, the 2006 Texas Water Quality Inventory does not state level of support for this designated use*

The excerpts below from Chapter 307, SWQS (TCEQ 2000) stipulate how water quality data were assessed to determine support of the contact recreation use as well as how the water quality targets are defined for each bacterial indicator. In addition to the specific requirements of §307.7 outlined below, the TMDLs for the Greens Bayou Watershed will also adhere to §307.5 of the SWQS which defines the antidegradation policy and procedures that apply to authorized wastewater discharges, TMDLs, wasteload evaluations, and any other miscellaneous actions, such as those related to man-induced nonpoint sources of pollution, which may impact the water in the state (TCEQ 2000).

§307.7. Site-specific Uses and Criteria.

(a) Uses and numerical criteria are established on a site-specific basis in Appendices A, D, and E of §307.10 of this title (relating to Appendices A - E). Site-specific uses and numerical criteria may also be applied to unclassified waters in accordance with §307.4(h) of this title (relating to General Criteria) and §307.5(c) of this title (relating to Antidegradation). Site-specific criteria apply specifically to substances attributed to waste discharges or the activities of man. Site-specific criteria do not apply to those instances in which surface waters exceed criteria due to natural phenomena. The application of site-specific uses and criteria is described in §307.8 of this title (relating to the Application of Standards) and §307.9 of this title (relating to the Determination of Standards Attainment).

(b) Appropriate uses and criteria for site-specific standards are defined as follows.

(1) Recreation. Recreational use consists of two categories - contact recreation waters and noncontact recreation waters. Classified segments are designated for contact recreation unless elevated concentrations of indicator bacteria frequently occur due to sources of pollution which cannot be reasonably controlled by existing regulations or contact recreation is considered unsafe for other reasons such as ship or barge traffic. In a classified segment where contact recreation is considered unsafe for reasons unrelated to water quality, a designated use of noncontact recreation may be assigned criteria normally associated with contact recreation. A designation of contact recreation is not a guarantee that the water so designated is completely free of disease-causing organisms. Indicator bacteria, although not generally pathogenic, are indicative of potential contamination by feces of warm blooded animals. The criteria for contact recreation are based on these indicator bacteria, rather than direct measurements of pathogens. Criteria are expressed as the number of "colony forming units" of bacteria per 100 milliliters (mL) of water. Even where the concentration of indicator bacteria is less than the criteria for contact recreation, there is still some risk of contracting waterborne diseases. Additional guidelines on minimum data requirements and procedures for evaluating standards attainment are specified in the latest approved version of the TNRCC Guidance for Screening and Assessing Texas Surface and Finished Drinking Water Quality Data.

(A) Freshwater

(i) Contact recreation. The geometric mean of E. coli should not exceed 126 per 100 mL. In addition, single samples of E. coli should not exceed 394 per 100 mL. Contact recreation applies to all bodies of freshwater except where specifically designated otherwise in §307.10 of this title (relating to Appendices A - E).

(ii) Noncontact recreation. The geometric mean of E. coli should not exceed 605 per 100 mL.

(B) Saltwater

(i) Contact recreation. The geometric mean of Enterococci should not exceed 35 per 100 mL. In addition, single samples of Enterococci should not exceed 89 per 100 mL. Contact recreation applies to all bodies of saltwater, except where specifically designated otherwise in §307.10 of this title.

(ii) Noncontact recreation. The geometric mean of Enterococci should not exceed 168 per 100 mL.

(C) Fecal coliform bacteria. Fecal coliform bacteria can be used as an alternative instream indicator of recreational suitability until sufficient data are available for E coli or Enterococci. For segments designated as oyster waters in §307.10 of this title, fecal coliform can continue to be used as an indicator of recreational suitability because fecal coliform is used as the indicator for suitability of oyster water use as described in paragraph (3)(B) of this subsection. Fecal coliform can also continue to be used as a surrogate indicator in effluent limits for wastewater discharges. Fecal coliform criteria are the same for both freshwater and saltwater, as follows.

(i) Contact recreation. The geometric mean of fecal coliform should not exceed 200 per 100 mL. In addition, single samples of fecal coliform should not exceed 400 per 100 mL.

(ii) Noncontact recreation. Fecal coliform shall not exceed 2,000 per 100 mL as a geometric mean. In addition, single samples of fecal coliform should not exceed 4,000 per 100 mL.

(D) Swimming advisory programs. For areas where local jurisdictions or private property owners voluntarily provide public notice or closure based on water quality, the use of any single sample or short-term indicators of recreational suitability are selected at the discretion of the local managers of aquatic recreation. Guidance for single-sample bacterial indicators is available in the EPA document entitled Ambient Water Quality Criteria for Bacteria - 1986. Other short-term indicators to assess water quality suitability for recreation -- such as measures of streamflow, turbidity, or rainfall -- may also be appropriate.

§307.10. Appendices A - E.

The indicator bacteria for recreation for freshwater is E. coli and for saltwater is Enterococci. Fecal coliform can still be used as an alternative indicator during the transition to the new indicator bacteria, as specified in §307.7 (b). The appropriate bacterial criteria and fecal coliform alternative are listed in the appendix under the Indicator Bacteria column. E. coli criteria of 126 colonies per 100 mL of water are applied as specified in §307.7(b)(1)(A)(i) and (ii) for contact recreation (relating to Site-specific Uses and Criteria). The criteria of 605 colonies per 100 mL of water are applied as specified in §307.7(b)(1)(A)(iii) for noncontact recreation. Enterococci criteria of 35 colonies per 100 mL are applied as specified in §307.7(b)(1)(B)(i) and (ii) for contact recreation, and 168 colonies per 100 mL for noncontact recreation. The indicator bacteria for suitability for oyster waters is fecal coliform. The fecal coliform criteria for oyster waters is 14 colonies per 100 mL as specified in §307.7(b)(3)(B).

As an alternative, fecal coliform criteria of 200 per 100 mL are applied as specified in §307.7(b)(1)(C)(i) and (ii). Fecal coliform criteria of 2,000 per 100 mL are applied as specified in §307.7(b)(1)(C)(iii).

As stipulated in Draft 2006 *Guidance for Assessing and Reporting Surface Water Quality in Texas* (TCEQ 2007), utilization of the geometric mean to determine compliance for any of the bacterial indicators depends on the collection of at least 10 samples over the most recent 10-year period.

Draft 2006 Guidance for Assessing and Reporting Surface Water Quality in Texas (TCEQ 2007):

- *Ten samples will also be required for listing and delisting water bodies for which the assessment method is based on an average. Larger sample sizes increase the state's confidence that impairments are not missed. Although we will use more than 10 samples, if available, it is not reasonable at this time to require more than 10 samples for a minimum data set, given the monitoring resources and currently available data.*
- *The 2006 assessment period of record for the last five years is December 1, 1999 through November 30, 2004. Samples from these five years are evaluated when available, if necessary, the most recent samples collected in the preceding five years (December 1, 1994 through November 30, 1999) can also be included to meet the requirements for minimum sample number.*

2.3 Problem Identification

Pursuant to §303(d) of the federal Clean Water Act, states must establish TMDLs for pollutants contributing to violations of WQSs. Table 2-2 identifies the waterbodies requiring TMDLs identified in Category 5 of the 2008 Texas Water Quality Inventory and §303(d) List (TCEQ 2008). Between 1996 and 2008 the TCEQ WQSs and water quality assessment method were modified and additional water quality data were collected throughout the Greens Bayou Watershed, other areas of impairment were added to the §303(d) list. All of the waterbodies listed in Table 2-2 are recognized as Category 5a and as such are considered high priority for TMDL development. Table 2-2 lists the TCEQ WQM stations from which ambient water quality data were summarized to support the decision to place these waterbodies on the TCEQ 303(d) list. The locations of these WQM stations are displayed in the map included as Figure 1-5. The waterbodies requiring the TMDLs were first listed in 2002 and 2004.

Table 2-2 Water Quality Monitoring Stations Used for 303(d) Listing Decision

Assessment Unit	Water Body	Description of Assessment Unit Not Supporting Contact Recreation Use	Monitoring Station IDs	Year Listed
1016_01 to 1016_03	Greens Bayou above Tidal	IH 45 to US 59	11371	2002
		US 59 to upstream Halls Bayou confluence	11369	2004
1016A_02 and 1016A_03	Garners Bayou	From Williams Gully confluence to confluence with Greens Bayou	11125	2002
1016B_01	Unnamed Tributary of Greens Bayou	Entire Stream	20024	2002
1016C_01	Unnamed Tributary of Greens Bayou	Entire Stream	11124	2002
1016D_01	Unnamed Tributary of Greens Bayou	Entire Stream	16676	2002

A number of changes have occurred in the past 10 years that warrant refinements in how indicator bacteria data are used to support water quality assessments and TMDL development in Texas. Some key factors that influence which indicator bacteria to use for water quality assessment and TMDL development and the period of record to use include:

- changes in land use and locations of Texas Pollution Discharge Elimination System (TPDES)-permitted facilities;
- changing the indicator bacteria in the 2000 TCEQ surface water quality standards (SWQS) from fecal coliform to *E. coli* for fresh water;
- TCEQ policy and procedures from other TCEQ/U.S. Environmental Protection Agency (USEPA)- approved bacteria TMDLs in Texas;
- refinements in the TCEQ surface water quality monitoring procedures; and
- changes in the TCEQ guidance, *Assessing and Reporting Surface Water Quality in Texas.*

As a result of these evolving factors in the water quality management arena associated with the protection and maintenance of contact recreation use, only a portion of the historical dataset was used to support the TMDLs in this report.

Table 2-3 summarizes the portion of the historical ambient water quality data set from the TCEQ WQM stations in each impaired assessment unit. Only indicator bacteria from 1999 to September 2006 were used in Table 2-3 for TMDL development to adhere to TCEQ assessment guidelines and to correspond to the available period of record used to estimate stream flow and existing flows of wastewater treatment facilities. From these data results in Table 2-3, key inferences can be made regarding the temporal and spatial extent of the contact recreation use impairment.

Table 2-3 Water Quality Data for TCEQ WQM Stations from 1999 to 2006

Assessment Unit	WQM Station ID	Indicator Bacteria	Geometric Mean Criteria	Geometric Mean Concentration	Single Sample Criteria	Number of Samples	Number of Samples Exceeding Single Sample Criteria	% of Samples Exceeding
1016_01	11376	EC	126	454	394	54	27	50%
		FC	200	5	400	7	0	0%
	17495	EC	126	252	394	54	16	30%
1016_02	11371	EC	126	979	394	74	54	73%
		FC	200	427	400	88	45	51%
	11372	FC	200	4	400	7	0	0%
	11373	FC	200	3	400	7	0	0%
	13778	EC	126	1,367	394	84	68	81%
		FC	126	1,165	394	47	33	70%
1016_03	11369	EC	126	386	394	78	33	42%
		FC	200	160	400	48	14	29%
	11370	EC	126	381	394	57	24	42%
		FC	200	110	400	48	10	21%
1016A_02	16589	EC	126	385	394	58	27	47%
		FC	200	1,142	400	63	40	63%
1016A_03	11125	EC	126	730	400	54	31	57%
		FC	200	558	400	78	38	49%
1016B_01	16590	EC	126	685	394	57	34	60%
		FC	200	768	400	78	47	60%
	20024	EC	126	568	394	18	9	50%
1016C_01	11124	EC	126	1,287	394	76	69	91%
		FC	200	1,331	400	75	63	84%
1016D_01	16676	EC	126	2,073	394	76	62	82%
		FC	200	882	400	77	43	56%

EC: E. coli in MPN/100mL, FC: Fecal Coliform in cfu/100mL
Highlight indicates downstream WQM station selected for TMDL development and indicator bacteria selected as target parameter.

Greens Bayou above Tidal (Assessment Units 1016_01, 1016_02, and 1016_03): At all the WQM stations with *E. coli* data (six total), more than 25 percent of the samples exceed the single sample criterion, and the geometric mean criterion for *E. coli* was also exceeded. Three of the eight WQM stations with fecal coliform data exceeded the single sample criterion more than 25 percent of the time, and the geometric mean criterion was exceeded at two stations. This indicates conditions of widespread and persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Garners Bayou (Assessment Units 1016A_02 and 1016A_03): At the two WQM stations, more than 25 percent of the samples exceed the *E. coli* and fecal coliform criteria, and the geometric mean criteria were also exceeded. This indicates conditions of widespread and persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Unnamed Tributary of Greens Bayou (Assessment Unit 1016B_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at the two WQM stations. Available data, thus, demonstrate persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Unnamed Tributary of Greens Bayou (Assessment Unit 1016C_01): Both the single sample and geometric mean criteria for *E. coli* and fecal coliform were exceeded at WQM station 11124, the only sampling location within this subwatershed. Given the small size of this subwatershed, this station adequately represents conditions of persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

Unnamed Tributary of Greens Bayou (Assessment Unit 1016D_01): At the only WQM station 16676, more than 25 percent of the samples exceed the *E. coli* and fecal coliform criteria established for this waterbody, and the geometric mean criteria were also exceeded. Given the small size of this subwatershed, this station adequately represents water quality conditions throughout the segment and the available data demonstrates persistent elevated levels of bacteria resulting in nonsupport of contact recreation use.

2.4 Water Quality Targets for Contact Recreation

The Code of Federal Regulations (40 CFR §130.7(c)(1)) states that, "TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numerical water quality standards." The Texas SWQSs (TCEQ 2000) provide numeric and narrative criteria to evaluate attainment of designated uses. The basis for water quality targets for all TMDLs developed in this report will be the numeric criteria for bacterial indicators from the 2000 Texas SWQSs as described in Subsection 2.2 above. *E. coli* is the preferred indicator bacteria for assessing contact recreation use in freshwater but fecal coliform bacteria may also be used since it was the preferred indicator in the past.

Several studies performed by the USEPA show a stronger link between the concentrations of *E. coli* and the concentrations of fecal pathogens than the previous standard, fecal coliform. The USEPA studies found that in freshwater streams, *E. coli* concentrations were the strongest predictor of illness following contact recreation. The TCEQ adopted the limit of 394 MPN/100mL for single samples of *E. coli* and a geometric mean limit of 126 MPN/100mL for waterbodies designated for contact recreation use. During the process of switching to the new standards, the USEPA recommended that fecal coliform concentrations (400 cfu/100mL in any single sample and 200 cfu/100mL for the geomean of all samples) be used until at least 10 data points have been collected for *E. coli* for each segment.

The water quality target for the TMDLs for freshwater segments is to maintain concentrations below the geometric mean criterion of 126 MPN/100mL for *E. coli* or if necessary, 200 cfu/100mL for fecal coliform. Maintaining the geometric mean criterion for each indicator bacteria is expected to be protective of the single sample criterion also, and therefore, will ultimately result in attainment of the contact recreation use.

The stations highlighted in Table 2-3 correspond to the specific WQM stations where TMDLs will be set for the Greens Bayou Watershed. The assessment units for which TMDLs will be developed are shown in Figure 2-1. For all the segments in the Study Area, *E. coli* is the selected indicator bacteria.

The water quality target for each waterbody will incorporate an explicit 5 percent margin of safety (MOS). Thus, for *E. coli* the single sample water quality target would be 374 MPN/100mL, 5 percent lower than the criterion value (394 MPN/100mL), and the geometric mean water quality target would be 120 MPN/100mL, 5 percent lower than the criterion value (126 MPN/100mL).

TMDLs must take into account that no more than 25 percent of the samples may exceed the single sample numeric criterion.

Each water quality target will be used to determine the allowable bacteria load derived by using the actual or estimated flow record multiplied by the instream criteria minus a 5 percent MOS. The line drawn through the allowable load data points is the water quality target that represents the maximum load for any given flow and still satisfies the WQS.

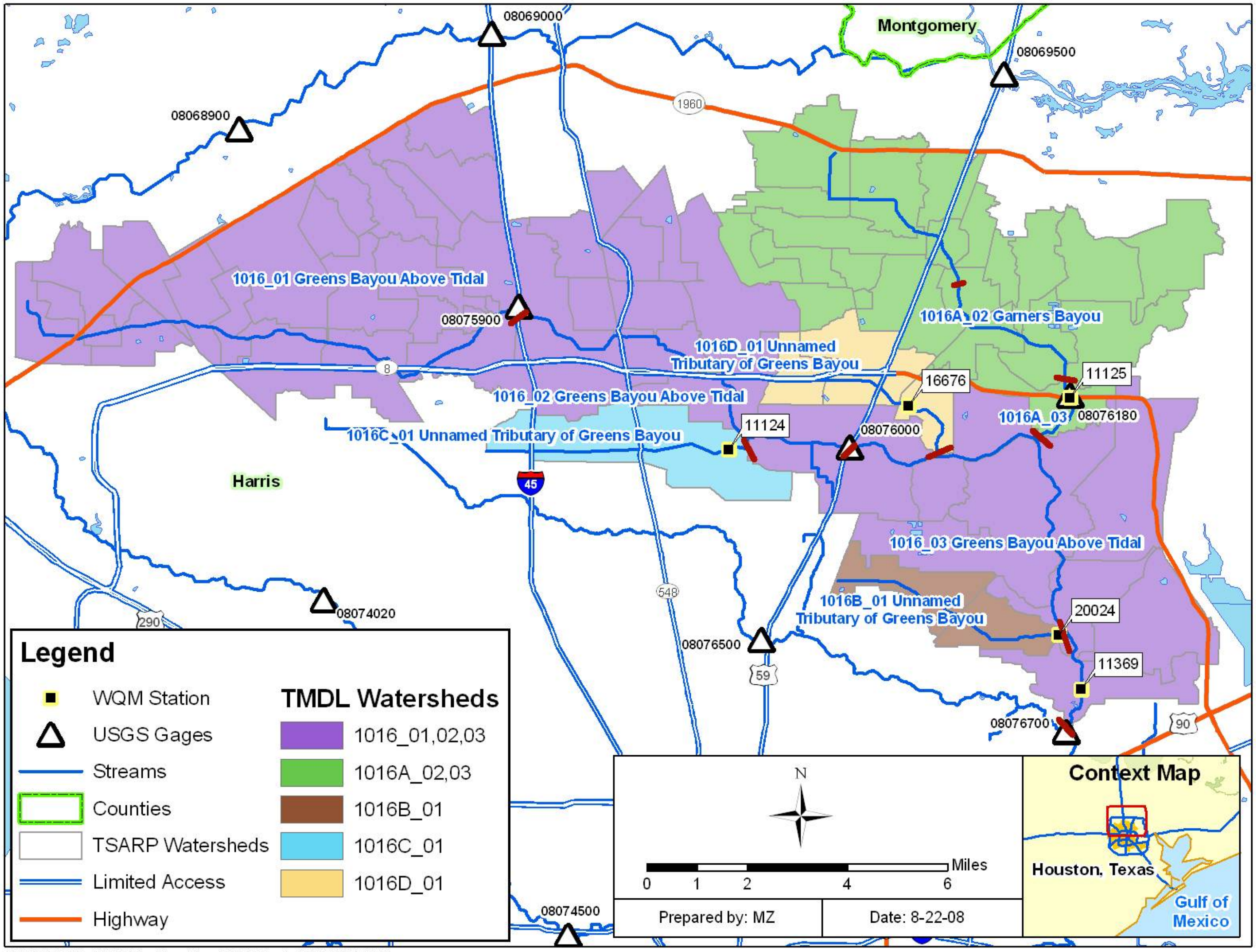


Figure 2-1 TMDL Station Locations

SECTION 3
POLLUTANT SOURCE ASSESSMENT

To support TMDL development, a pollutant source assessment attempts to characterize known and suspected sources of pollutant loading to impaired waterbodies. Pollutant sources within a watershed are categorized and quantified to the extent that information is available. Fecal bacteria such as *E. coli* originate in the intestines of warm-blooded species (human and animal), and sources of bacteria may be point (permitted) or nonpoint (non-permitted) in nature.

Point sources are permitted through the National Pollution Discharge Elimination System (NPDES) program. Some storm water runoff may be permitted through NPDES as construction, industrial and municipal storm sewer systems. Other non-permitted sources of storm water runoff that typically cannot be identified as entering a waterbody through a discrete conveyance at a single location are often referred to as nonpoint sources. For example, non-permitted sources include land activities that contribute bacteria to surface water as a result of rainfall runoff or on-site sewage system facilities. For the TMDLs in this report, all sources of pollutant loading not regulated by a NPDES-permit are considered nonpoint sources. The following discussion describes what is known regarding permitted and non-permitted sources of bacteria in the impaired watersheds.

3.1 Point Sources: NPDES/TPDES-Permitted Sources

Under 40 CFR, §122.2, a point source is described as a discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters. Under the Texas Water Code, TCEQ has adopted rules and procedures to issue permits to control the quantity and quality of discharges into or adjacent to waters of the state through the TPDES program. NPDES/TPDES-permitted facilities classified as point sources that may contribute bacteria loading to surface waters include:

- TPDES municipal wastewater treatment facilities (WWTF);
- TPDES industrial WWTF;
- TPDES municipal no-discharge WWTF;
- TPDES regulated storm water (construction, industrial and municipal storm sewer systems); and
- TPDES Concentrated Animal Feeding Operation (CAFO).

Continuous point source discharges such as WWTFs, could result in discharge of elevated concentrations of fecal bacteria if the disinfection unit is not properly maintained, is of poor design, or if flow rates exceed the disinfection capacity. Some industrial WWTF may contain fecal bacteria in their effluent. While no-discharge facilities do not discharge wastewater directly to a waterbody, it is possible that collection systems associated with these types of facilities may be a source of bacteria loading to surface waters. Permitted storm water runoff from TPDES regulated discharge areas called municipal separate storm sewer systems can also contain high fecal bacteria concentrations. CAFOs are recognized by USEPA as significant sources of pollution, and may have the potential to cause serious impacts to water quality if not properly managed.

Watersheds in the Study Area, including Greens Bayou above Tidal (1016), Garners Bayou (1016A), Unnamed Tributary of Greens Bayou (1016C), and Unnamed Tributary of Greens Bayou (1016D) have NPDES/TPDES-permitted sources. However, there are no NPDES/TPDES-permitted sources located within Unnamed Tributary of Greens Bayou (1016B). A significant portion of the Study Area (approximately 84%) is regulated under the TPDES storm water discharge permit jointly held by Harris County, HCFCD, City of Houston, and Texas Department of Transportation. There are no NPDES-permitted CAFOs within the Study Area.

3.1.1 Permitted Sources: Continuous Point Source Discharges

There are 109 permitted outfalls for WWTFs in the Study Area. The names and permit numbers of the TPDES-permitted facilities that continuously discharge wastewater to surface waters addressed in these TMDLs are listed in Table 3-1. Facility locations are displayed in Figure 3-1. A complete dataset of self-reported flows is included in Appendix C.

Not all TPDES-permitted facilities that discharge treated wastewater are required to monitor for fecal bacteria. In addition, while current instream water quality criteria are based on *E. coli* bacteria, permit limits are based on levels of fecal coliform, another measure of fecal bacteria of which *E. coli* is often the major constituent. Therefore, data on bacteria loads from WWTF outfalls are not available for all of the TPDES permitted dischargers in the Greens Bayou Watershed and only fecal coliform (not *E. coli*) concentrations are reported. Table 3-2 summarizes data from Discharge Monitoring Reports (DMR) available for 16 TPDES WWTFs that monitor their discharge for fecal coliform. The 90^{th} percentile of the monthly average load and the maximum monthly average loads are provided to estimate fecal coliform loads from these 16 TPDES WWTFs. The data used to generate Table 3-2 are provided in Appendix D. Table 3-2 also lists the number of reported monthly exceedances of the geometric mean concentration of 200 cfu/100mL, and the number of reported daily exceedances of the single sample standard of 400 cfu/100mL. As shown in Table 3-2, seven out of 16 permitted facilities exceeded fecal coliform permit limits during the monitoring time frame.

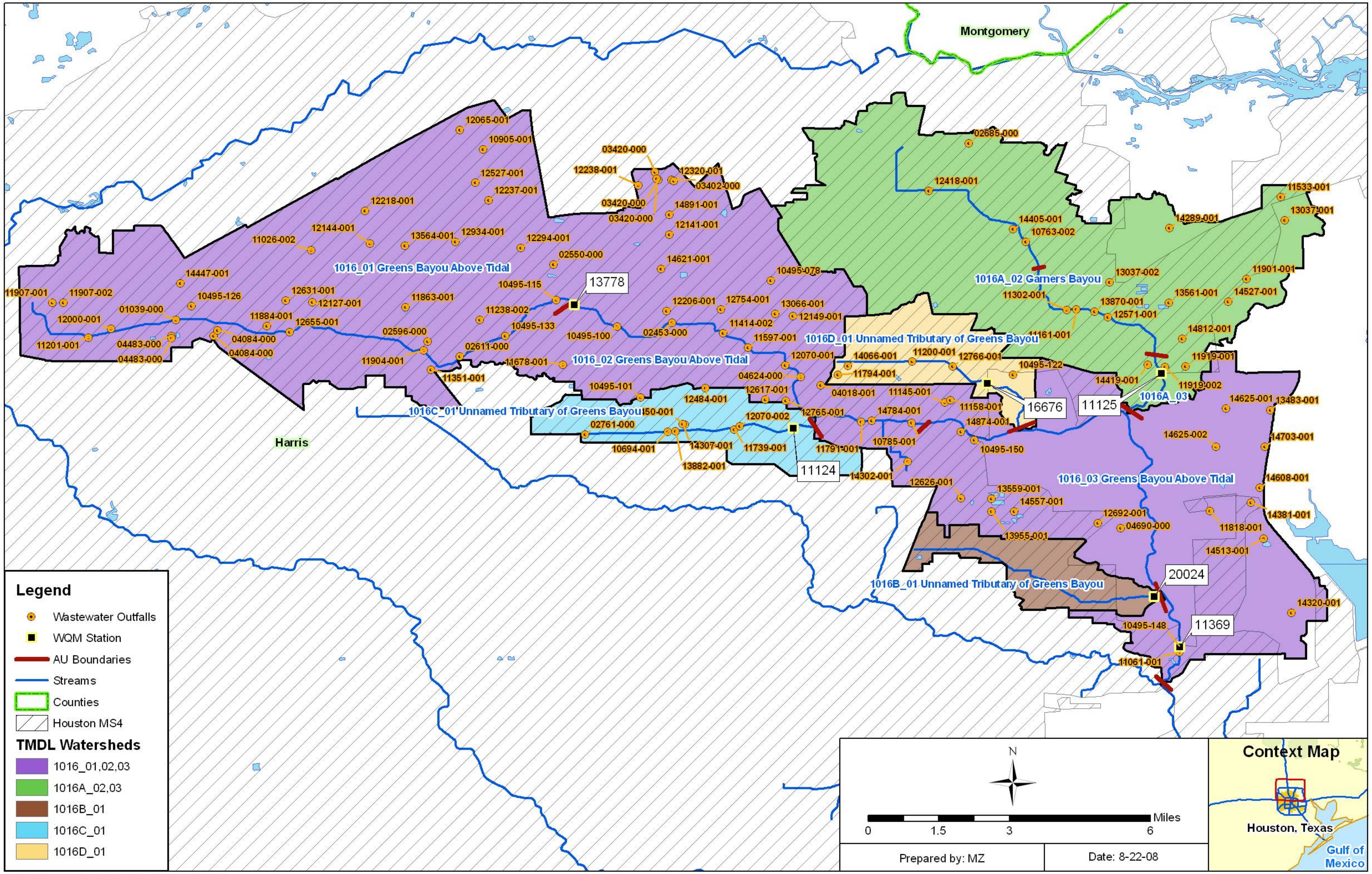
Table 3-1 TPDES-Permitted Facilities in the Study Area

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES Number	SIC CODE	Facility Type	Facility Name	DTYPE	County	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
1016	Greens Bayou above Tidal	1016_01	14446-001	TX0095265	NA	NA	1920 Interpark	NA	Harris	0.012	NA
		1016_01	11238-002	TX0026344	4952	Sewerage Systems	Harris Co.MUD 005	D	Harris	0.9	0.49
		1016_01	11201-001	TX0027324	4952	Sewerage Systems	Emerald Forest UD	W	Harris	1.5	0.46
		1016_01	11026-002	TX0033243	4952	Sewerage Systems	Harris Co.Wcid #109	W	Harris	3	1.42
		1016_01	10495-115	TX0054798	4952	Sewerage Systems	Houston-Northborough MUD	W	Harris	2	0.57
		1016_01	10905-001	TX0058424	4952	Sewerage Systems	North Forest MUD	D	Harris	0.3	0.13
		1016_01	04084-001	TX0063878	2899	Chemicals And Chemical Preparations, Not Elsewhere Classified	CSA Limited	D	Harris	0.004	0.0022
		1016_01	04084-002	TX0063878	2899	Chemicals And Chemical Preparations, Not Elsewhere Classified	CSA Limited	D	Harris	0.008	0.0022
		1016_01	11863-001	TX0072893	4952	Sewerage Systems	Harris Co.MUD 150	W	Harris	3	0.95
		1016_01	11884-001	TX0073407	4952	Sewerage Systems	Nw Harris Co.MUD 006	D	Harris	0.475	0.17
		1016_01	11904-001	TX0074136	4952	Sewerage Systems	Harris Co.MUD 033	W	Harris	3	0.83
		1016_01	11907-002	TX0075132	4952	Sewerage Systems	Mills Road MUD	D	Harris	0.9	0.33
		1016_01	02596-001	TX0076155	4911	Electric Services	Reliant Energy-Greensp	W	Harris	0.02	0.0025
		1016_01	12000-001	TX0077062	4952	Sewerage Systems	Moulding Specialists	D	Harris	0.005	0.0074
		1016_01	12065-001	TX0078824	4952	Sewerage Systems	Harris Co.MUD 086	D	Harris	0.95	0.22
		1016_01	12127-001	TX0079529	4952	Sewerage Systems	Harris Co.MUD 180	D	Harris	0.95	0.31
		1016_01	12144-001	TX0079821	4952	Sewerage Systems	Nw Harris Co.MUD 021	W	Harris	1.5	0.55
		1016_01	12218-001	TX0083429	6515	Operators Of Residential Mobile Home Sites	Cmh Parks	D	Harris	0.122	0.083
		1016_01	12237-001	TX0083712	4952	Sewerage Systems	Harris Co.MUD 189	D	Harris	1.25	0.52
		1016_01	10495-133	TX0084875	4952	Sewerage Systems	Houston-Hcmud #203	W	Harris	3	0.54
		1016_01	12294-001	TX0085413	4952	Sewerage Systems	Harris Co.MUD 200	W	Harris	1.44	0.76
		1016_01	04853-001	TX0088897	5511	Motor Vehicle Dealers (New And Used)	R & A Harris South	W	Harris	0.006	0.00011
		1016_01	12527-001	TX0090069	4952	Sewerage Systems	Movimex Co.	D	Harris	0.01	0.00061
		1016_01	14447-001	TX0090476	4952	Sewerage Systems	Harris Co. MUD #191	D	Harris	0.71	0.19
		1016_01	12631-001	TX0091901	4952	Sewerage Systems	Harris Co.MUD 202	D	Harris	0.725	0.078
		1016_01	12655-001	TX0092312	4952	Sewerage Systems	Nw Harris Co.MUD 024	D	Harris	0.5	0.084
		1016_01	12934-001	TX0097047	4952	Sewerage Systems	Rankin Rd West MUD	D	Harris	0.3	0.14
		1016_01	13564-001	TX0097225	4952	Sewerage Systems	Harris Co.MUD #304	D	Harris	0.65	0.17
		1016_01	04483-001	TX0102008	4911	Electric Services	Centerpoint Energy Houston	W	Harris	0.015	0.0026
		1016_01	11351-001	TX0111767	4952	Sewerage Systems	Harris Co.MUD 011	D	Harris	0.5	0.23
		1016_01	10495-126	TX0113131	4952	Sewerage Systems	Hou-Willowbrook Reg.	W	Harris	2	0.75
		1016_02	14882-001	NA	NA	NA	AMC Facilities Lp	D	Harris	0.025	NA
		1016_02	10495-101	TX0020478	4952	Sewerage Systems	Houston-Imperial Valley	W	Harris	4	1.44
		1016_02	10785-001	TX0021199	4952	Sewerage Systems	Sequoia Id	D	Harris	0.2	0.081
		1016_02	11414-002	TX0033189	6515	Operators Of Residential Mobile Home Sites	Sasson, Eli	D	Harris	0.099	0.048
		1016_02	10495-078	TX0034916	4952	Sewerage Systems	Houston-Intercont Air	W	Harris	8	1.14
		1016_02	10495-100	TX0055310	4952	Sewerage Systems	Houston-Northgate UD	W	Harris	3.71	2.03
		1016_02	11597-001	TX0058076	NA	NA	North Belt UD	D	Harris	1.5	0.17
		1016_02	11678-001	TX0064424	NA	NA	Yazdcorp Funds V LLC	D	Harris	0.05	0.031
		1016_02	11791-001	TX0071382	4952	Sewerage Systems	Sunbelt Fwsd	W	Harris	1.225	0.22

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES Number	SIC CODE	Facility Type	Facility Name	DTYPE	County	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
1016	Greens Bayou above Tidal	1016_02	04018-001	TX0078638	7041	Organization Hotels And Lodging Houses, On Membership Basis	Dresser Industries	W	Harris	0.07	0.032
		1016_02	12070-001	TX0078808	4952	Sewerage Systems	Aldine Isd	D	Harris	0.063	0.026
		1016_02	12149-001	TX0081388	NA	NA	Mlr Management	D	Harris	0.01	0.0027
		1016_02	12206-001	TX0083381	4952	Sewerage Systems	North Green MUD	D	Harris	0.6	0.25
		1016_02	03420-001	TX0084093	3498	Fabricated Pipe And Pipe Fittings	Vam Usa	W	Harris	0.02	0.0058
		1016_02	02453-001	TX0084298	3533	Oil And Gas Field Machinery And Equipment	Smith International	W	Harris	0.15	0.064
		1016_02	12320-001	TX0085901	4952	Sewerage Systems	Component Structures	D	Harris	0.002	NA
		1016_02	12484-001	TX0089281	4952	Sewerage Systems	Boring Specialties	D	Harris	0.005	0.0022
		1016_02	12617-001	TX0091651	7033	Recreational Vehicle Parks And Campsites	Goodwin, Sandra	D	Harris	0.035	0.0014
		1016_02	12754-001	TX0093475	4952	Sewerage Systems	Greens Parkway MUD	D	Harris	0.98	0.047
		1016_02	12765-001	TX0093556	3448	Prefabricated Metal Buildings And Components	United Structures	D	Harris	0.008	0.0033
		1016_02	13066-001	TX0097276	4952	Sewerage Systems	Hoajey, Ltd.	D	Harris	0.009	0.00011
		1016_02	03402-001	TX0103616	3081	Unsupported Plastics Film And Sheet	Gse Lining Technology	W	Harris	0.016	0.00095
		1016_02	14302-001	TX0124460	4952	Sewerage Systems	Rjr Realty, Ltd	D	Harris	0.003	NA
		1016_02	14621-001	TX0127957	4952	Sewerage Systems	Rankin Park Mainten & Util	D	Harris	0.05	NA
		1016_02	14784-001	TX0129445	4952	Sewerage Systems	Skymark Development	D	Harris	0.45	NA
		1016_02	14891-001	TX0131555	NA	NA	Lochinvar Golf Club	0	Harris	0.005	NA
		1016_03	14513-001	TX0126594	8661	Religious Organizations	Christian Tabernacle	D	Harris	0.019	NA
		1016_03	14633-001	TX0128066	4952	Sewerage Systems	South Central Water Company	D	Harris	0.45	NA
		1016_03	11061-001	TX0020800	4952	Sewerage Systems	Greenwood Utility District	D	Harris	0.95	0.42
		1016_03	10495-150	TX0025291	4952	Sewerage Systems	Houston-Wcid #76	D	Harris	0.7	0.42
		1016_03	11158-001	TX0032085	4952	Sewerage Systems	Champ's Water Co.	D	Harris	0.028	0.011
		1016_03	14874-001	TX0067539	4952	Sewerage Systems	BCWK Inc.	D	Harris	0.1	NA
		1016_03	11818-001	TX0071897	4952	Sewerage Systems	Harris Co.MUD 148	D	Harris	0.5	0.15
		1016_03	11818-003	TX0071897	4952	Sewerage Systems	Harris Co.MUD 148	D	Harris	0.95	0.15
		1016_03	14557-001	TX0087840	NA	NA	Mumtaz Builders	D	Harris	0.008	NA
		1016_03	12626-001	TX0091847	NA	NA	Thurber	D	Harris	0.019	0.0086
		1016_03	12692-001	TX0092711	4952	Sewerage Systems	Karbalai, Rita	D	Harris	0.05	0.019
		1016_03	13955-001	TX0094935	4952	Sewerage Systems	Murhaj, Kobra	D	Harris	0.025	0.0093
		1016_03	13559-001	TX0095761	4952	Sewerage Systems	Hinojosa Rene	D	Harris	0.015	0.0098
		1016_03	10495-148	TX0101460	4952	Sewerage Systems	Hou-Tidwell Timbers	D	Harris	0.488	0.13
		1016_03	13483-001	TX0104965	4952	Sewerage Systems	Harris Co.MUD	W	Harris	1	0.17
		1016_03	14320-001	TX0124702	4952	Sewerage Systems	Tidwell Wu, LLC	D	Harris	0.4	NA
		1016_03	14897-001	TX0125326	NA	NA	Holy Trinity Episcopal School	D	Harris	0.075	0.0012
		1016_03	14608-001	TX0127825	8661	Religious Organizations	Greens Bayou Assembly Of God	D	Harris	0.035	NA
		1016_03	14625-001	TX0127981	4952	Sewerage Systems	Marhaba Partners Limited Part	D	Harris	0.75	NA
		1016_03	14625-002	TX0127990	4952	Sewerage Systems	Marhaba Partners Limited Part	D	Harris	0.45	NA
		1016_03	14703-001	TX0128694	4952	Sewerage Systems	FRM/MRA Holdings #1	D	Harris	0.98	NA
1016A	Garners Bayou	1016A_02	10763-003	TX0073989	4952	Sewerage Systems	Humble-Timberwood	W	Harris	0.65	NA
		1016A_02	11161-001	TX0020320	6515	Operators Of Residential Mobile Home Sites	Clark, Harold	D	Harris	0.099	0.047
		1016A_02	11302-001	TX0025623	4952	Sewerage Systems	El Dorado UD	D	Harris	0.45	0.22
		1016A_02	10763-002	TX0034401	4952	Sewerage Systems	Humble-South	W	Harris	6.5	2.17

Segment	Stream Name	Assessment Unit	TPDES Number	NPDES Number	SIC CODE	Facility Type	Facility Name	DTYPE	County	2008 Permitted Flow (MGD)	Average Monthly Flow (MGD)
1016A	Garners Bayou	1016A_02	14405-001	TX0079570	4952	Sewerage Systems	International Airport Sq Inves	D	Harris	0.012	0.00056
		1016A_02	12418-001	TX0088111	4952	Sewerage Systems	Panalpina Inc.	D	Harris	0.007	0.00085
		1016A_02	12571-001	TX0090506	4952	Sewerage Systems	Champ's Water Co	D	Harris	0.1	0.059
		1016A_02	02685-001	TX0094196	NA	NA	Tiampo, Jamie	W	Harris	0.077	NA
		1016A_02	13870-001	TX0119067	4952	Sewerage Systems	Aquasource Developm	D	Harris	0.099	0.014
		1016A_02	13037-002	TX0127124	4952	Sewerage Systems	Harris Co.MUD 278	D	Harris	2.7	NA
		1016A_03	11533-001	TX0058963	4952	Sewerage Systems	Harris Co.MUD 109	W	Harris	9	3.80
		1016A_03	11901-001	TX0074021	4952	Sewerage Systems	Trail Of The Lakes MUD	W	Harris	1.75	0.40
		1016A_03	11919-001	TX0074268	4952	Sewerage Systems	Harris Co.MUD 049	D	Harris	0.2	0.083
		1016A_03	11919-002	TX0074446	4952	Sewerage Systems	Harris Co.MUD 049	D	Harris	1.5	0.059
		1016A_03	13037-001	TX0097071	4952	Sewerage Systems	Harris Co.MUD 278	D	Harris	0.4	0.13
		1016A_03	13561-001	TX0107301	9229	Public Order And Safety, Not Elsewhere Classified	Harris Co.-Detention Center	D	Harris	0.5	0.25
		1016A_03	14289-001	TX0124346	4952	Sewerage Systems	Austofield Partners #1	D	Harris	0.375	0.060
		1016A_03	14419-001	TX0125661	4952	Sewerage Systems	Land Tejas Park Lakes	W	Harris	1	0.035
		1016A_03	14527-001	TX0126756	4952	Sewerage Systems	Pine Development Ltd	D	Harris	0.64	NA
		1016A_03	14812-001	TX0129666	NA	NA	Land Tejas Park Lakes 1023	W	Harris	1	NA
1016C	Unnamed Tributary of Greens Bayou	1016C_01	10694-001	TX0027707	4952	Sewerage Systems	Southwest Utilities	D	Harris	0.1	0.077
		1016C_01	11739-001	TX0069582	4952	Sewerage Systems	Champ's Water Co.	D	Harris	0.025	0.0072
		1016C_01	13882-001	TX0070769	4952	Sewerage Systems	C&P Utilities	D	Harris	0.15	0.097
		1016C_01	12450-001	TX0088650	4952	Sewerage Systems	Darlene Ann Young	D	Harris	0.065	0.0073
		1016C_01	02761-001	TX0092037	4952	Sewerage Systems	West Road Wsc	W	Harris	0.013	0.0048
		1016C_01	14307-001	TX0124508	4952	Sewerage Systems	Metal Building Components	D	Harris	0.02	NA
1016D	Unnamed Tributary of Greens Bayou	1016D_01	11200-001	TX0031461	4952	Sewerage Systems	Douglas Utility Co.	D	Harris	0.38	0.27
		1016D_01	14066-001	TX0033430	7011	Hotels And Motels	Houston Airport Hospitality	D	Harris	0.125	0.052
		1016D_01	11794-001	TX0071251	3533	Oil And Gas Field Machinery And Equipment	Hydrill Co.	D	Harris	0.05	0.0087
		1016D_01	12766-001	TX0093548	7011	Hotels And Motels	Qbn Corp.	D	Harris	0.019	0.0019
		1016D_01	10495-122	TX0103721	4952	Sewerage Systems	Houston-Northbelt	W	Harris	5	1.63

Source: TCEQ Water Quality Assessment Team, May 2008
MGD - Millions of Gallons per Day
NA = data not available
TYPE
C = Cooling Water
D = Domestic <1 MGD
S = storm water
W = domestic >=1 MGD or industrial process water, including water treatment plant discharge



Source: The jurisdictional boundary of the Houston MS4 permit is derived from Urbanized Area Map Results for Texas *which can be found at the USEPA website* http://cfpub.epa.gov/npdes/stormwater/urbanmapresult.cfm?state=TX.

Figure 3-1 TPDES-Permitted Facilities in the Greens Bayou Watershed

Table 3-2 DMR Data for Permitted Wastewater Discharges (December 1998-September 2007)

NPDES Number	TPDES Number	Facility Name	Segment	Dates Monitored		# of Records	Number of MCMX Exceedances	Number of MCAV Exceedances	FC Daily Load (cfu)	
				Start	End				90 percentile Monthly Average	Maximum Monthly Average
TX0020800	11061-001	Greenwood Utility District	1016	03/31/1998	12/31/2000	12	0	0	4.29E+08	4.86E+08
TX0025291	10495-150	Houston-WCID #76	1016	12/31/1998	12/31/1999	5	0	0	1.02E+08	1.49E+08
TX0025623	11302-001	El Dorado UD	1016A	03/31/1998	09/30/2000	11	0	0	5.31E+07	9.73E+07
TX0026344	11238-002	Harris Co.MUD 005	1016	09/30/1998	06/30/2007	64	2	0	1.70E+09	4.94E+09
TX0031461	11200-001	Douglas Utility Co.	1016D	03/31/1998	03/31/2000	9	1	0	1.59E+09	2.17E+09
TX0033243	11026-002	Harris Co.WCID #109	1016	02/29/2000	06/30/2007	89	15	0	1.23E+10	1.84E+10
TX0034401	10763-002	Humble-South	1016A	01/31/1998	06/30/2007	110	11	0	1.69E+10	6.68E+10
TX0071897	11818-001	Harris Co.MUD 148	1016	01/31/1998	09/30/1999	10	1	0	5.21E+08	8.74E+08
TX0075132	11907-002	Mills Road MUD	1016	01/31/1998	10/31/1999	22	2	0	1.66E+08	5.31E+09
TX0083381	12206-001	North Green MUD	1016	01/31/1998	07/31/2002	15	1	0	1.50E+09	1.00E+10
TX0083429	12218-001	Cmh Parks	1016	09/30/1998	09/30/1999	5	0	0	6.24E+07	7.19E+07
TX0091901	12631-001	Harris Co.MUD 202	1016	09/30/1998	03/31/2000	7	0	0	4.90E+07	9.33E+07
TX0092711	12692-001	Karbalai, Rita	1016	09/30/1998	06/30/2000	7	0	0	7.86E+05	8.18E+05
TX0093475	12754-001	Greens Parkway MUD	1016	01/31/1998	03/31/2000	9	0	0	1.11E+06	1.32E+06
TX0097071	13037-001	Harris Co.MUD 278	1016A	06/30/1998	12/31/1999	6	0	0	1.40E+08	2.76E+08
TX0101460	10495-148	Hou-Tidwell Timbers	1016	12/31/1998	09/30/1999	4	0	0	2.22E+07	2.52E+07

Source: TCEQ, 2007
Notes: FC = Fecal Coliform
cfu = Colony Forming Unit
MCMX = Measurement: Concentration Maximum
MCAV = Measurement: Concentration Average

3.1.2 Permitted Sources: NPDES No-Discharge Facilities and Sanitary Sewer Overflows

There are no No-Discharge Facilities or land application sites located within the Study Area.

Sanitary sewer overflows (SSO) are permit violations that must be addressed by the responsible TPDES permittee. SSOs most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris or exceedances of capacity in the sanitary sewer conveyance system. The TCEQ maintains a database of SSO data collected from wastewater operators in the Greens Bayou Watershed. In 2007, the City of Houston provided the project team a database summarizing SSO reported. These data are included in Appendix E and summarized in Table 3-3. Analysis of the most current available data, as can be seen from Table 3-3, indicates there were approximately 67 sanitary sewer overflows reported in the Greens Bayou Watershed between February 2001 and December 2003. The reported SSOs averaged 4,477 gallons per event. The locations and magnitudes of all reported SSOs are displayed in Figure 3-2. The WWTF service area boundaries are also shown in Figure 3-2.

Table 3-3 Sanitary Sewer Overflow Summary

Facility Name	Facility ID	Receiving Water	Number of Occurrences	Date Range		Amount (Gallons)		
				From	To	Min	Max	Total Volume
FWSD 23*	10495-016	1016	4	1/13/2002	6/4/2002	116	7,036	12,947
FWSD 23*	10495-016	1016B	9	2/25/2001	10/3/2003	100	2,184	5,126
Houston-Northgate UD	10495-100	1016	10	2/16/2001	6/3/2003	148	69,825	113,492
Houston-Imperial Valley	10495-101	1016	8	3/22/2001	11/18/2003	39	23,172	35,689
Houston-Imperial Valley	10495-101	1016C	16	3/12/2001	10/24/2003	35	41,595	48,628
Houston-Northborough MUD	10495-115	1016	4	4/7/2001	2/5/2003	288	8,015	19,207
Houston-Northbelt	10495-122	1016A	3	2/26/2001	6/24/2003	52	10,675	12,143
Houston-Northbelt	10495-122	1016D	4	10/11/2001	5/9/2003	26	27,044	30,963
Hou-Willowbrook Reg.	10495-126	1016	1	6/29/2001	6/30/2001		5,196	5,196
Hou-Tidwell Timbers	10495-148	1016	4	2/7/2003	9/17/2003	82	8,740	13,553
Houston-WCID #76	10495-150	1016	4	1/27/2002	12/2/2003	200	2,360	3,010

**The wastewater service area for FWSD 23 covers portions of Segment 1016 and 1016B.*

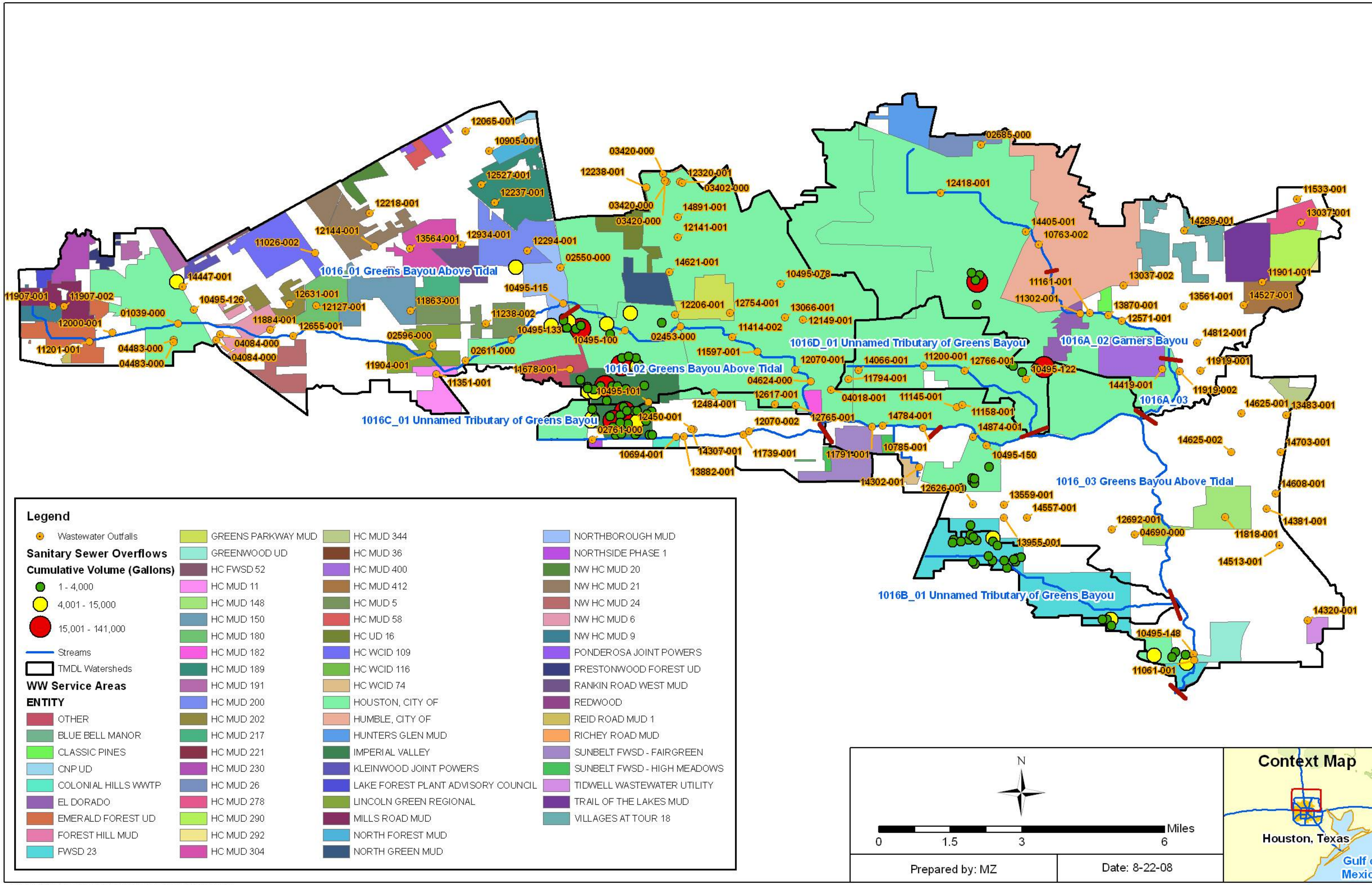


Figure 3-2 Sanitary Sewer Overflow Locations

3.1.3 Permitted Sources: TPDES Regulated Storm Water

In 1990, the USEPA developed rules establishing Phase I of the NPDES Storm Water Program, designed to prevent harmful nonpoint sources of pollutants from being washed by storm water runoff into municipal separate storm sewer systems and then discharged into local waterbodies (USEPA 2005). Phase I of the program required medium and large permitted dischargers (those generally serving populations of 100,000 or greater) to implement a storm water management program as a means to control polluted discharges. Approved storm water management programs for medium and large permitted discharges are required to address a variety of water quality-related issues, including roadway runoff management, municipal-owned operations, and hazardous waste treatment.

Phase II of the rule extends coverage of the NPDES Storm Water program to certain small MS4s Small MS4s are defined as any MS4 that is not a medium or large MS4 covered by Phase I of the NPDES Storm Water Program. Phase II requires operators of regulated small MS4s to obtain NPDES permits and develop a storm water management program. Programs are designed to reduce discharges of pollutants to the "maximum extent practicable," protect water quality, and satisfy appropriate water quality requirements of the Clean Water Act. Small MS4 storm water programs must address the following minimum control measures:

- Public Education and Outreach;
- Public Participation/Involvement;
- Illicit Discharge Detection and Elimination;
- Construction Site Runoff Control;
- Post- Construction Runoff Control; and
- Pollution Prevention/Good Housekeeping.

When evaluating pollutant loads originating from storm water runoff, a critical distinction must be made between storm water originating from an area under an NPDES/TPDES regulated discharge permit and storm water originating from areas not under an NPDES/TPDES regulated discharge permit. To characterize pollutant loads from storm water runoff, it is necessary to segregate storm water into two categories: 1) permitted storm water, which is storm water originating from an NPDES/TPDES-permitted Phase 1 or Phase 2 urbanized area; and 2) non-permitted storm water, which is storm water originating from any area outside an NPDES/TPDES-permitted Phase 1 or Phase 2 urbanized area. Considerable portions of each watershed in the Study Area are covered under the City of Houston/Harris County MS4 permit (TPDES Permit No. WQ0004685000). The jurisdictional boundary of the Houston MS4 permit is derived from *Urbanized Area Map Results for Texas,* which is based on the 2000 U.S. Census and can be found at the USEPA website http://cfpub.epa.gov/npdes/stormwater/urbanmapresult.cfm?state=TX. Figure 3-1 displays the portion of the watershed that contributes bacteria loads to the receiving waters from areas of permitted and non-permitted storm water.

Under the City of Houston/Harris County permitted discharge permit, Harris County, HCFCD, City of Houston, and Texas Department of Transportation are designated as copermittees. Table 3-4 lists the percentage of area within each watershed covered under the Houston MS4 permit.

Table 3-4 Percentage of Permitted Storm Water in Each Watershed

Assessment Unit	Stream Name	TPDES Number	Total Area (acres)	Area under MS4 Permit (Acres)	Percent of Assessment Unit under MS4 Jurisdiction
1016_01	Greens Bayou above Tidal	WQ0004685000	23,826	23,849	100%
1016_02		WQ0004685000	15,607	15,611	100%
1016_03		WQ0004685000	18,970	6,747	36%
1016A_02	Garners Bayou	WQ0004685000	15,406	14,795	96%
1016A_03		WQ0004685000	6,241	4,109	66%
1016B_01	Unnamed Tributary of Greens Bayou	WQ0004685000	2,691	2,347	87%
1016C_01	Unnamed Tributary of Greens Bayou	WQ0004685000	4,029	4,039	100%
1016D_01	Unnamed Tributary of Greens Bayou	WQ0004685000	3,560	3,010	85%

3.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from storm water can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. Dry-weather and illicit discharges are regulated under WWTF permits, and where applicable, under the provisions of an MS4. The term “illicit discharge” is defined in EPA’s Phase II storm water regulations as “any discharge to a municipal separate storm sewer that is not composed entirely of storm water, except discharges pursuant to an NPDES permit and discharges resulting from fire-fighting activities” (NEIWPCC 2003).

Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the *Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities* (NEIWPCC 2003) include

Direct illicit discharges:

- sanitary wastewater piping that is directly connected from a home to the storm sewer;
- materials (e.g., used motor oil) that have been dumped illegally into a storm drain catch basin;
- a shop floor drain that is connected to the storm sewer; and
- a cross-connection between the municipal sewer and storm sewer systems.

Indirect illicit discharges:

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

Various investigations have been conducted in localized areas of Houston. Data from neighboring watersheds (Buffalo and Whiteoak Bayous) demonstrate that illicit discharges are a source of significant indicator bacteria load**.** While the dry weather flows from the storm sewer network in Buffalo and Whiteoak Bayous were small relative to the other dry weather flows, the *E. coli* concentrations measured were at times very high (similar to the levels found in raw sewage). An outfall inventory survey has not been completed for Brays Bayou and dry weather discharges from the storm sewer network have not been sampled therefore, there is insufficient data to adequately quantify the magnitude of indicator bacteria loads from illicit discharges in the Brays Bayou watershed.

3.1.5 Concentrated Animal Feeding Operations

There are no CAFOs located within the Study Area.

3.2 Non-permitted Sources: Storm Water, On-site Sewage Facilities, and Direct Deposition

Non-permitted sources (nonpoint sources) include those sources that cannot be identified as entering the waterbody at a specific location. Bacteria originate from rural, suburban, and urban areas. The following section describes possible major nonpermitted sources contributing fecal coliform loading within the Study Area.

Nonpoint sources of bacteria can emanate from wildlife, various agricultural activities, and domesticated animals, land application fields, urban runoff, failing on-site sewage facilities (OSSF), and domestic pets. Bacteria associated with urban runoff can emanate from humans, wildlife, livestock, and domestic pets. Based on the ability of warm-blooded animals to harbor and shed human pathogens, the current USEPA policy establishes the position that it is inappropriate to conclude that livestock and wildlife sources present no risk to human health from waterborne pathogens. Consequently, states and authorized tribes should not use broad exemptions from the bacteriological criteria for waters designated for primary contact recreation based on the presumption that high levels of bacteria resulting from non-human fecal contamination present no risk to human health (USEPA 2002). Water quality data collected from streams draining urban communities often show existing concentrations of fecal coliform bacteria at levels greater than a state's instantaneous standards. A study under USEPA's National Urban Runoff Project indicated that the average fecal coliform concentration from 14 watersheds in different areas within the United States was approximately 15,000 cfu/100mL in storm water runoff (USEPA 1983). Non-permitted storm water can be a significant source of fecal bacteria.

3.2.1 Wildlife and Unmanaged Animal Contributions

Fecal coliform and *E. coli* bacteria are common inhabitants of the intestines of all warm-blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify the potential for bacteria contributions from wildlife by watershed. Wildlife is naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a waterbody. Fecal bacteria from wildlife is also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff. Typical of coastal watersheds, there is a significant population of avian species that frequent the watershed and the riparian corridors, in particular. However, currently there are insufficient data available to estimate populations and spatial distribution of wildlife and avian species by watershed. Consequently, it is difficult to assess the magnitude of bacteria contributions from wildlife species as a general category.

3.2.2 Non-Permitted Agricultural Activities and Domesticated Animals

There are a number of non-permitted agricultural activities that can also be sources of fecal bacteria loading. Given the fact that the Greens Bayou Watershed is highly urbanized, livestock and other domesticated animals are not found in these watersheds and therefore are not considered as a contributor of bacteria loads.

3.2.3 Failing On-site Sewage Facilities

On-site sewage facilities can be a source of bacteria loading to streams and rivers. Bacteria loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface ponding or through groundwater. Fecal coliform-contaminated groundwater can also be discharged to creeks through springs and seeps.

Over time, most OSSFs operating at full capacity will fail. OSSF failures are proportional to the adequacy of a state's minimum design criteria (Hall 2002). The 1995 American Housing Survey conducted by the U.S. Census Bureau estimates that, nationwide, 10 percent of occupied homes with OSSFs experience malfunctions during the year (U.S. Census Bureau 1995). A statewide study conducted by Reed, Stowe & Yanke, LLC (2001) reported that approximately 12 percent of the OSSFs in Harris County, which is part of Region 4, were chronically malfunctioning. Most studies estimate that the minimum lot size necessary to ensure against contamination is roughly one-half to one acre (Hall 2002). Some studies, however, found that lot sizes in this range or even larger could still cause contamination of ground or surface water (University of Florida 1987). It is estimated that areas with more than 40 OSSFs per square mile (6.25 septic systems per 100 acres) can be considered to have potential contamination problems (Canter and Knox 1985).

Only permitted OSSF systems are recorded by authorized county or city agents; therefore, it is difficult to estimate the exact number of OSSFs in use in the Study Area. Table 3-5 lists the OSSF totals based on the 1990 U.S. Census and the number of OSSF permits obtained by authorized county or city agents between 1992 -2007. Permits are obtained to install or replace systems. However, some permits are obtained when an older failing system needs repair (Houston-Galveston Area Council [H-GAC] 2005). It is assumed there are more OSSFs in each county installed prior to 1992 than listed in Table 3-5. Because the Greens Bayou Watershed covers only a portion of Harris County listed in Table 3-5, specific steps were taken to estimate the proportion of OSSFs that exist on the portion of the Study Area outside Harris County.

Table 3-5 Numbers of OSSF Permits Issued by Authorized County or City Agent

Year	Harris
1990 Census Totals	44,120
1992	243
1993	651
1994	881
1995	1,035
1996	1,327
1997	1,393
1998	1,301
1999	1,606
2000	1,422
2001	1,388
2002	1,397
2003	1,424
2004	1,174
2005	1,080
2006	1,039
2007*	498
Total	**61,979**

Note: Data obtained from TCEQ On-Site Activity Reporting System
** only data up to 8/8/2007 were available*

To estimate the potential magnitude of fecal bacteria loading from OSSFs, the number of OSSFs was estimated for each watershed. The estimate of OSSFs was derived by using data from the 1990 U.S. Census (U.S. Census Bureau 2000) and a GIS shapefile obtained from H-GAC showing all areas where wastewater service currently exists. Figure 3-3 displays unsewered areas that did not fall under the wastewater service areas. OSSFs were calculated using spatial GIS queries for areas not covered by wastewater service areas. OSSFs were assigned proportionally based on the percentage of the area falling outside a wastewater service area within each watershed. Finally, the OSSFs for each unsewered area were then totaled by TMDL watershed. This approach gives an estimate of OSSFs in the watershed. Table 3-6 shows the estimated number of OSSFs calculated using this GIS method.

Harris County provided a GIS shapefile showing the locations of potential OSSF violations from 2006-2007. Data are shown for areas not covered by wastewater service in Figure 3-3 and totaled for each subwatershed in Table 3-6.

For the purpose of estimating fecal coliform loading in watersheds, the OSSF failure rate of 12 percent from the Reed, Stowe & Yanke, LLC (2001) report for Texas Region 4 was used. Using this 12 percent failure rate, calculations were made to characterize fecal coliform loads in each watershed. Fecal coliform loads were estimated using the following equation (USEPA 2001):

$$\#\frac{counts}{day} = (\#\,Failing\_systems) \times \left(\frac{10^6\,counts}{100ml}\right) \times \left(\frac{70gal}{personday}\right) \times \left(\#\frac{person}{household}\right) \times \left(3785.2\frac{ml}{gal}\right)$$

The average of number of people per household was calculated to be 2.79 for Harris County (U.S. Census Bureau 2000). Approximately 70 gallons of wastewater were estimated to be produced on average per person per day (Metcalf and Eddy 1991). The fecal coliform concentration in septic tank effluent was estimated to be 10^6 per 100mL of effluent based on reported concentrations from a number of published reports (Metcalf and Eddy 1991; Canter and Knox 1985; Cogger and Carlile 1984). Using this information, the estimated load from potential violation septic systems within the watersheds was summarized below in Table 3-6. Based on these data, the estimated fecal coliform loading from OSSFs in the Study Area was found to be negligible.

Table 3-6 Estimated Number of OSSFs per Watershed and Fecal Coliform Load

Segment	Stream Name	OSSF Estimate using 1990 Census Method	# of Failing Septic Tanks[a]	Potential Violation Database[b]	Estimated Loads from Septic Tanks (x 10^9 counts/day)[c]
1016_01 to 1016_03	Greens Bayou above Tidal	1,710	205	110	1,517
1016A_02 and 1016A_03	Garners Bayou	128	15	1	114
1016B	Unnamed Tributary of Greens Bayou	26	3	0	23
1016C	Unnamed Tributary of Greens Bayou	1,027	123	54	911
1016D	Unnamed Tributary of Greens Bayou	2	0.2	0	2

[a] *A 12% failure rate was multiplied by the number of OSSFs estimated from the 1990 census.*
[b] *The Potential Violation Database was obtained from Harris County (2006-2007).*
[c] *Load estimate was based on literature values for fecal coliform concentrations since no E. coli concentration values were available. This calculation was based on the number of failing septic tanks.*

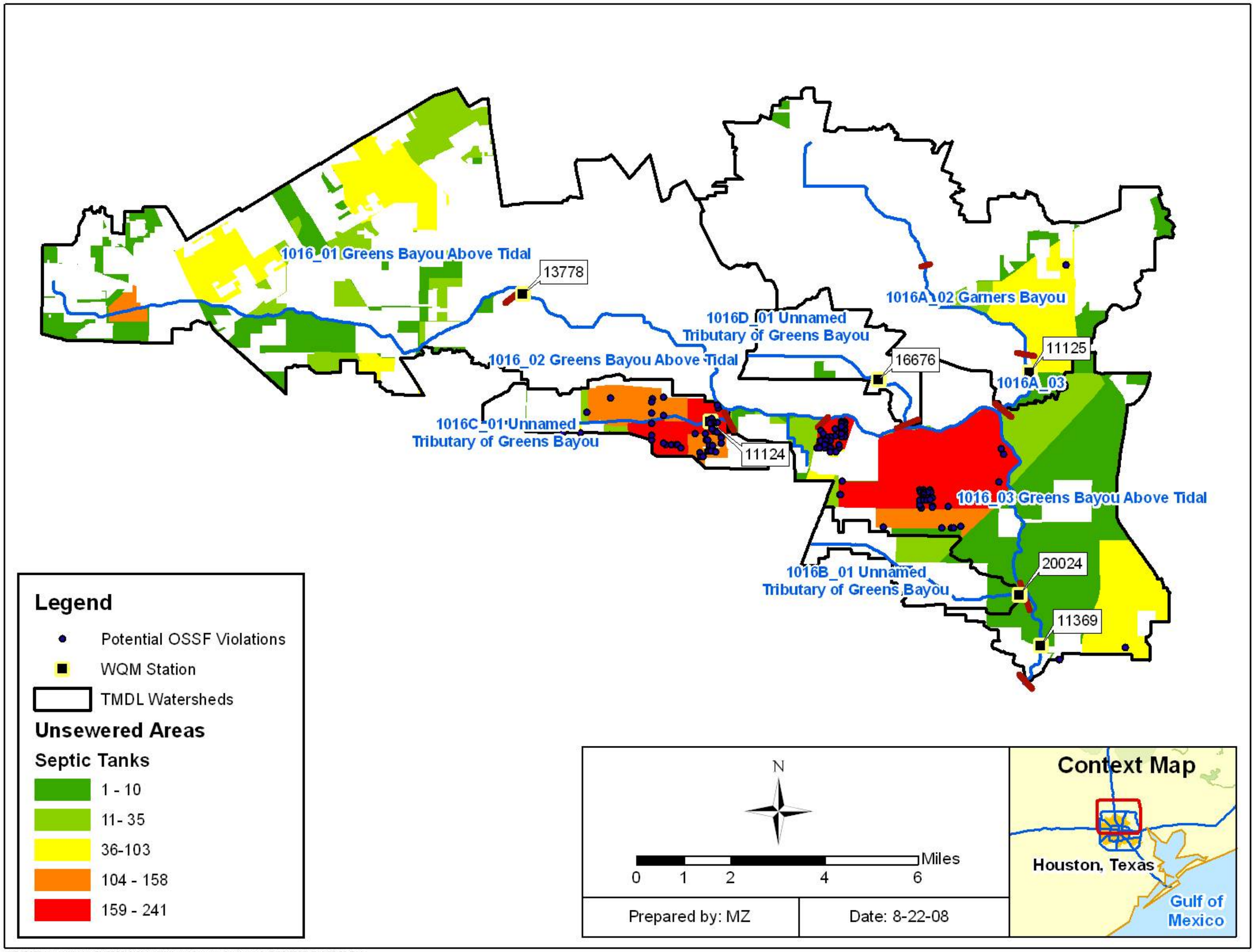


Figure 3-3 Unsewered Areas and Subdivisions with OSSF

3.2.4 Domestic Pets

Fecal matter from dogs and cats is transported to streams by runoff from urban and suburban areas and can be a potential source of bacteria loading. On average nationally, there are 0.58 dogs per household and 0.66 cats per household (American Veterinary Medical Association 2004). Using the U.S. Census data at the block level (U.S. Census Bureau 2000), dog and cat populations can be estimated for each watershed. Table 3-7 summarizes the estimated number of dogs and cats for the watersheds of the Study Area.

Table 3-7 Estimated Numbers of Pets

Segment	Stream Name	Dogs	Cats
1016_01 to 1016_03	Greens Bayou above Tidal	53,218	60,559
1016A_02 and 1016A_03	Garners Bayou	9,875	11,237
1016B	Unnamed Tributary of Greens Bayou	3,515	4,000
1016C	Unnamed Tributary of Greens Bayou	10,275	11,692
1016D	Unnamed Tributary of Greens Bayou	3,915	4,455

Table 3-8 provides an estimate of the fecal coliform load from pets. These estimates are based on estimated fecal coliform production rates of 5.4×10^8 per day for cats and 3.3×10^9 per day for dogs (Schueler 2000). Only a small portion of these loads is expected to reach waterbodies, through wash-off of land surfaces and conveyance in runoff.

Table 3-8 Estimated Fecal Coliform Daily Production by Pets (x 10^9)

Segment	Stream Name	Dogs	Cats	Total
1016_01 to 1016_03	Greens Bayou above Tidal	175,619	32,702	208,321
1016A_02 and 1016A_03	Garners Bayou	32,586	6,068	38,654
1016B	Unnamed Tributary of Greens Bayou	11,601	2,160	13,761
1016C	Unnamed Tributary of Greens Bayou	33,907	6,314	40,221
1016D	Unnamed Tributary of Greens Bayou	12,920	2,405	15,325

3.2.5 Bacteria Re-growth and Die-off

Bacteria are living organisms that grow and die. Certain enteric bacteria can regrow in organic materials if appropriate conditions prevail (*e.g.,* warm temperature). It is shown in the general literature that fecal organisms can regrow from improperly treated effluent during their transport in pipe networks, and they can regrow in organic rich materials such as compost and sludges. While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their regrowth is less well understood. Both processes (regrowth and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body.

SECTION 4
TECHNICAL APPROACH AND METHODS

The objective of a TMDL is to estimate allowable pollutant loads and to allocate these loads to the known pollutant sources in the watershed so appropriate control measures can be implemented and the standard for contact recreation achieved. A TMDL is expressed as the sum of three elements as described in the following mathematical equation:

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

The wasteload allocation (WLA) is the portion of the TMDL allocated to existing and future permitted (point) sources. The load allocation (LA) is the portion of the TMDL allocated to non-permitted (nonpoint) sources, including natural background sources. The MOS is intended to ensure that standard for contact recreation will be met. Thus, the allowable pollutant load that can be allocated to point and nonpoint sources can then be defined as the TMDL minus the MOS.

40 CFR, §130.2(1), states that TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli* bacteria, TMDLs are expressed as numbers per day, and represent the maximum one day load the stream can assimilate while still attaining the standard for contact recreation. For the Greens Bayou Watershed, to quantify allowable pollutant loads, percent reduction goals to achieve standard for contact recreation, and specific TMDL allocations for point and nonpoint sources using the load duration curve (LDC) method as described in this section.

4.1 Using Load Duration Curves to Develop TMDLs

The TMDL calculations for freshwater streams presented in this report are derived from LDCs. LDCs facilitate rapid development of TMDLs, and as a TMDL development tool, are effective at identifying whether impairments are associated with point or nonpoint sources. The technical approach for using LDCs for TMDL development includes the four following steps described in Subsections 4.2 through 4.4 below:

- preparing flow duration curves (FDC) for gaged and ungaged WQM stations;
- estimating existing bacteria loading in the receiving water using ambient water quality data;
- using LDCs to identify the critical condition that will dictate loading reductions necessary to attain the contact recreation standard; and
- interpreting LDCs to derive TMDL elements – WLA, LA, MOS, and percent reduction goal.

Historically, in developing WLAs for pollutants from point sources, it was customary to designate a critical low flow condition (*e.g.,* 7Q2) at which the maximum permissible loading was calculated. As water quality management efforts expanded in scope to quantitatively address nonpoint sources of pollution and types of pollutants, it became clear that this single critical low flow condition was inadequate to ensure adequate water quality across a range of flow conditions. Use of the LDC obviates the need to determine a design storm or selected flow recurrence interval with which to characterize the appropriate flow level for the assessment of critical conditions. For waterbodies impacted by both point and nonpoint sources, the "nonpoint source critical condition" would typically occur during high flows, when rainfall runoff would contribute the bulk of the pollutant load, while the "point source critical condition" would typically occur during low flows, when WWTF effluents would dominate the base flow of the impaired water.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by the water quality criterion. Using LDCs, a TMDL can be expressed as a continuous function of flow, equal to the line, or as a discrete value derived from a specific flow condition.

4.2 Development of Flow Duration Curves

Flow duration curves serve as the foundation of LDCs and are graphical representations of the flow characteristics of a stream at a given site. FDCs utilize the historical hydrologic record from stream gages to forecast future recurrence frequencies. While many WQM stations throughout Texas do not have long term flow data, there are various methods that can be used to estimate flow frequencies at ungaged stations or gaged stations missing flow data. The most basic method to estimate flows at an ungaged site involves 1) identifying an upstream or downstream flow gage; 2) calculating the contributing drainage areas of the ungaged sites and the flow gage; and 3) calculating daily flows at the ungaged site by using the flow from an acceptable nearby gaged site multiplied by the drainage area ratio. In developing the FDC presented in this report, a more complex approach was used that also considers watershed differences in rainfall, land use, WWTF discharges, and the hydrologic properties of soil that govern runoff and retention. More than one upstream flow gage may also be considered. A more detailed explanation of the methods for estimating flow at ungaged WQM stations is provided in Appendix F. Flow duration curves are a type of cumulative distribution function. The flow duration curve represents the fraction of flow observations that exceed a given flow at the site of interest. The observed flow values are first ranked from highest to lowest then, for each observation, the percentage of observations exceeding that flow is calculated. The flow value is read from the y-axis, which is typically on a logarithmic scale since the high flows would otherwise overwhelm the low flows. The flow exceedance frequency is read from the x-axis, which is numbered from 0 to 100 percent, and may or may not be logarithmic. The lowest measured flow occurs at an exceedance frequency of 100 percent indicating that flow has equaled or exceeded this value 100 percent of the time, while the highest measured flow is found at an exceedance frequency of 0 percent. The median flow occurs at a flow exceedance frequency of 50 percent.

While the number of observations required to develop a flow duration curve is not rigorously specified, a flow duration curve is usually based on more than 5-years of observations, and encompasses inter-annual and seasonal variation. Ideally, the drought of record and flood of record are included in the observations. For this purpose, the long-term flow gaging stations operated by the USGS are utilized. It was necessary to estimate flows within the Study Area since there is a lack of long-term flow data. Therefore, USGS gage station 08076000 (Greens Bayou near Houston, Texas), which is located inside the watershed, was chosen to conduct flow projections to establish estimated flows for each of these freshwater segments. The period of record for flow data used from this station was 1996 through 2006.

A typical semi-log flow duration curve exhibits a sigmoidal shape, bending upward near a flow exceedance frequency value of 0 percent and downward at a frequency near 100 percent, often with a relatively constant slope in between. For sites that on occasion exhibit no flow, the curve will intersect the x-axis at a frequency less than 100 percent. As the number of observations at a site increases, the line of the FDC tends to appear smoother. However, at extreme low and high flow values, flow duration curves may exhibit a "stair step" effect due to the USGS flow data rounding conventions near the limits of quantitation.

FDCs can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of flow and LDCs. The hydrologic classification scheme utilized for the Greens Bayou Watershed is outlined in Table 4-1.

Table 4-1 Hydrologic Classification Scheme

Assessment Unit	Hydrologic Condition Class		
	Highest Flows	Mid-range Flows	Lowest Flows
1016_01 to 1016_03	0-20	20-80	80-100
1016A_02 and 1016A_03	0-20	20-60	60-100
1016B_01	0-20	20-80	80-100
1016C_01	0-20	20-80	80-100
1016D_01	0-20	20-50	50-100

The low flow category was derived by calculating the percentage of bayou flows contributed by WWTFs using the long-term average reported flows. For example, the average flow discharged by WWTFs to Garnett Bayou (1016A) is 14.7 cubic feet per second (cfs) (41^{st} percentile of flows in the bayou); thus, flows between the 60 and 100 flow exceedance percentile are considered "low flows." Some instantaneous flow measurements were available from the intensive surveys collected for this project. These were not combined with the daily average flows or used in calculating flow percentiles, but were matched to bacteria grab measurements collected at the same site and time. When available, these instantaneous flow measurements were used in lieu of the daily average flow to calculate instantaneous bacteria loads.

Figures 4-1 through 4-6 present the FDCs developed for the downstream WQM station used for calculating the TMDLs of each 303(d) listed freshwater stream using the flow projection method outlined above and further described in Appendix F. The flow exceedance percentiles for each WQM station described below and presented in the figures are provided in Appendix G.

Figure 4-1 represents the FDC for Greens Bayou above Tidal, assessment units 1016_01 and 1016_02 at WQM station 11371. The curve was developed using data from USGS gage station 08076000 (Greens Bayou near Houston, Texas) which is co-located with the WQM station.

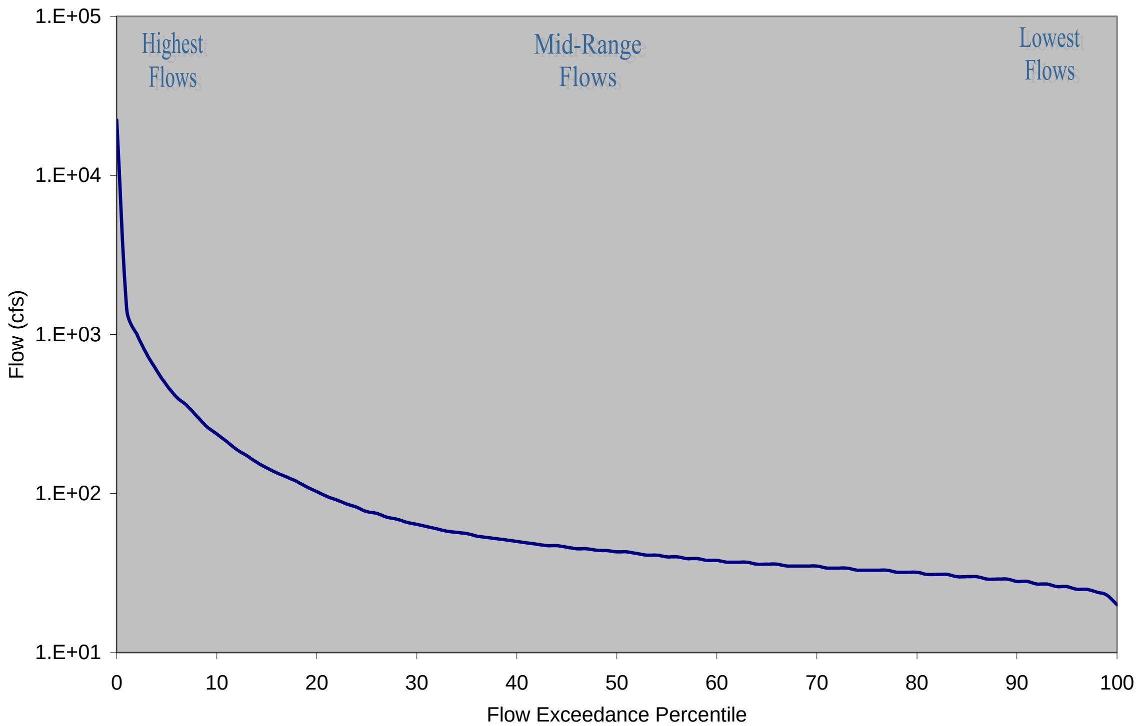


Figure 4-1 Flow Duration Curve for Greens Bayou above Tidal (1016_01, 1016_02)

Figure 4-2 represents the FDC for Greens Bayou above Tidal, assessment unit 1016_03 at WQM station 11369. Because WWTFs discharge to this assessment unit, average monthly WWTF flows obtained from DMRs were added to the projected flow. No DMR data were available for TX0127825, TX0124702 and TX0128694, located between USGS gage station 08076000 and WQM station 11369. Therefore, the self-reported flow was assumed equal to half of the permitted flow.

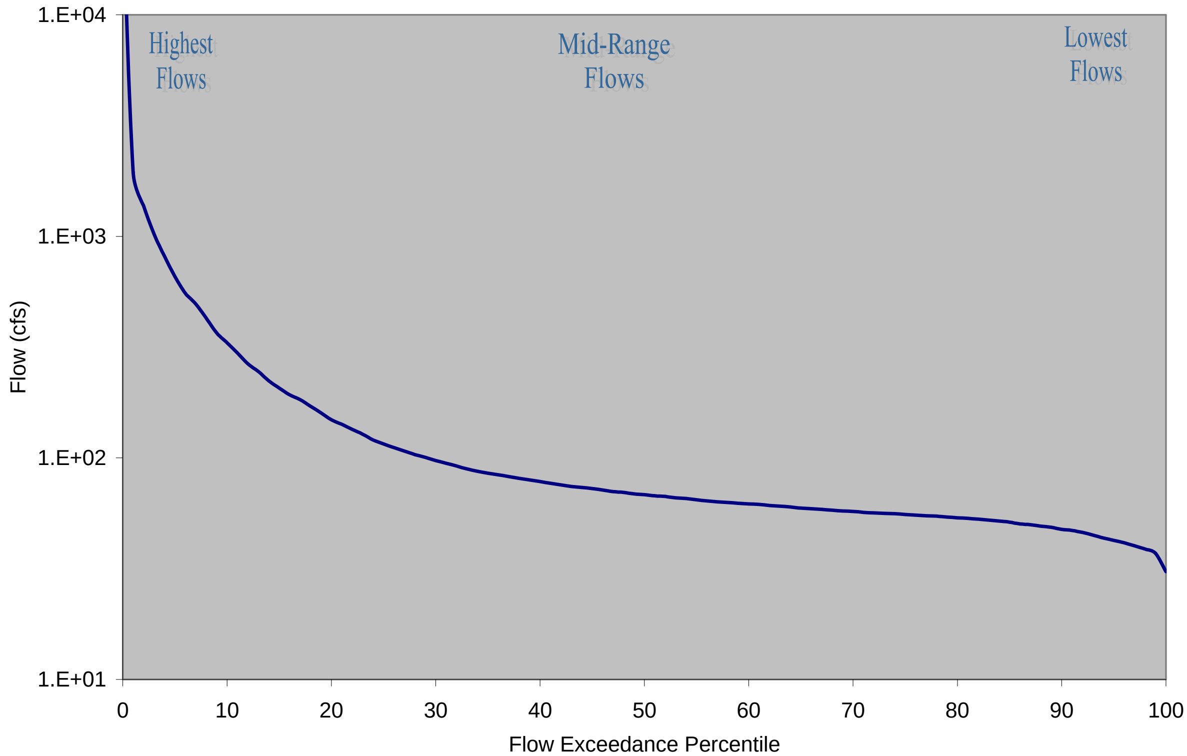


Figure 4-2 Flow Duration Curve for Greens Bayou above Tidal (1016_03)

Figure 4-3 represents the FDC for Garners Bayou, assessment units 1016A_02 and 1016A_03 at WQM station 11125. Daily flow data were available at USGS gage station 8076180 (Garners Bayou near Humble, Texas) for the time period 10/1/2000 to present. Therefore, the remainders of daily flows for the period of 1996 through 2006 used to develop the FDC were estimated from USGS gage station 08076000 (Greens Bayou near Houston, Texas). Because WWTF discharges occur in Garners Bayou, average monthly WWTF flows obtained from DMRs were added to the projected flow. No DMR data were available for TX0127124, TX0094196 and TX0129666. Therefore, half of the permitted flow for these facilities was added to the projected flow.

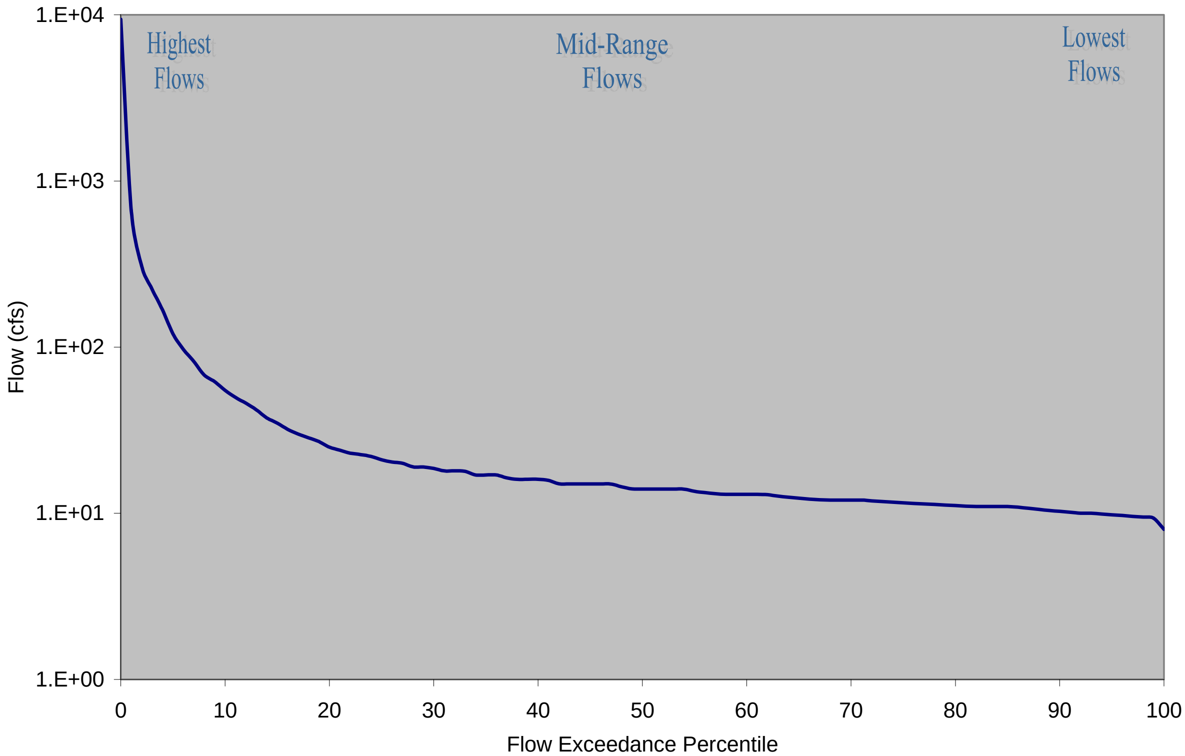


Figure 4-3 Flow Duration Curve for Garners Bayou (1016A_02, 1016A_03)

Figure 4-4 represents the FDC for Unnamed Tributary of Greens Bayou, assessment unit 1016B_01 at WQM station 20024. Since no WWTFs discharge to this assessment unit, the flows projected using the methods described in Appendix F were not modified.

Figure 4-5 represents the FDC for Unnamed Tributary of Greens Bayou, assessment unit 1016C_01 at WQM station 11124. Because WWTF discharges occur in Unnamed Tributary of Greens Bayou, average monthly WWTF flows obtained from DMRs were added to the projected flow.

Figure 4-6 represents the FDC for Unnamed Tributary of Greens Bayou, assessment unit 1016D_01 at WQM station 16676. Because WWTF discharges occur in Unnamed Tributary of Greens Bayou, average monthly WWTF flows obtained from DMRs were added to the projected flow. No DMR data was available for TX0124508. Therefore, half of the permitted flow was added to the projected flow.

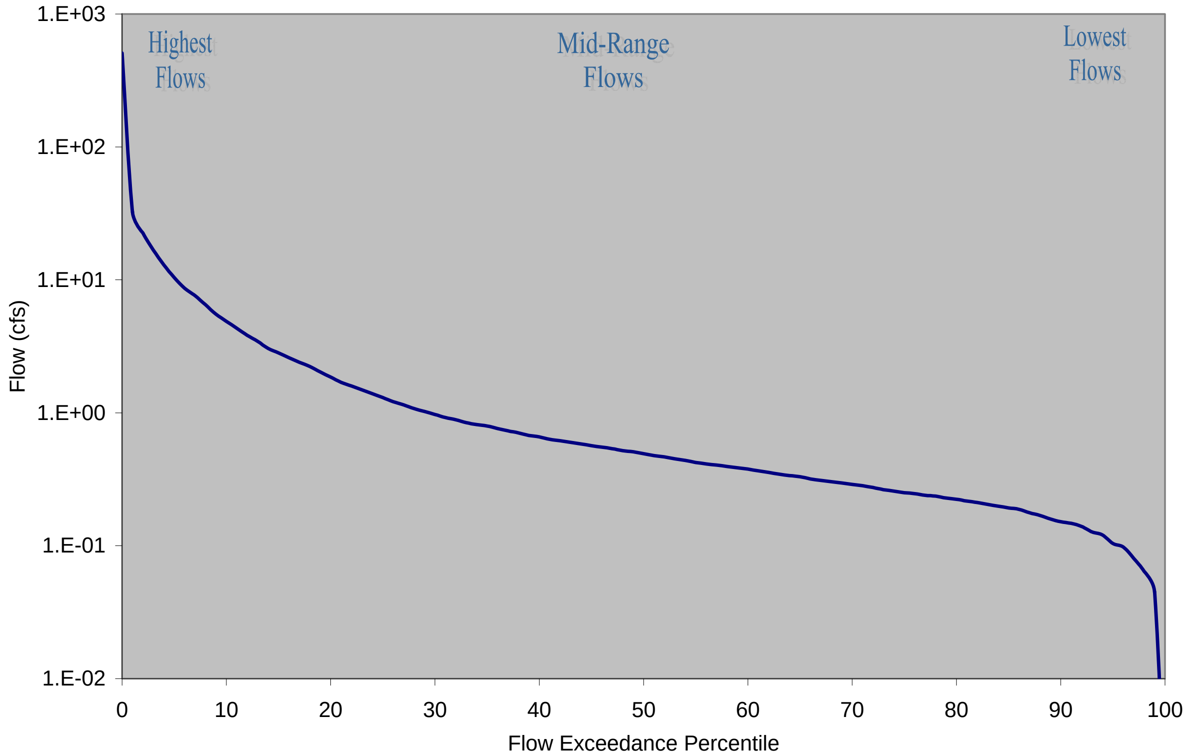


Figure 4-4 Flow Duration Curve for Unnamed Tributary of Greens Bayou (1016B_01)

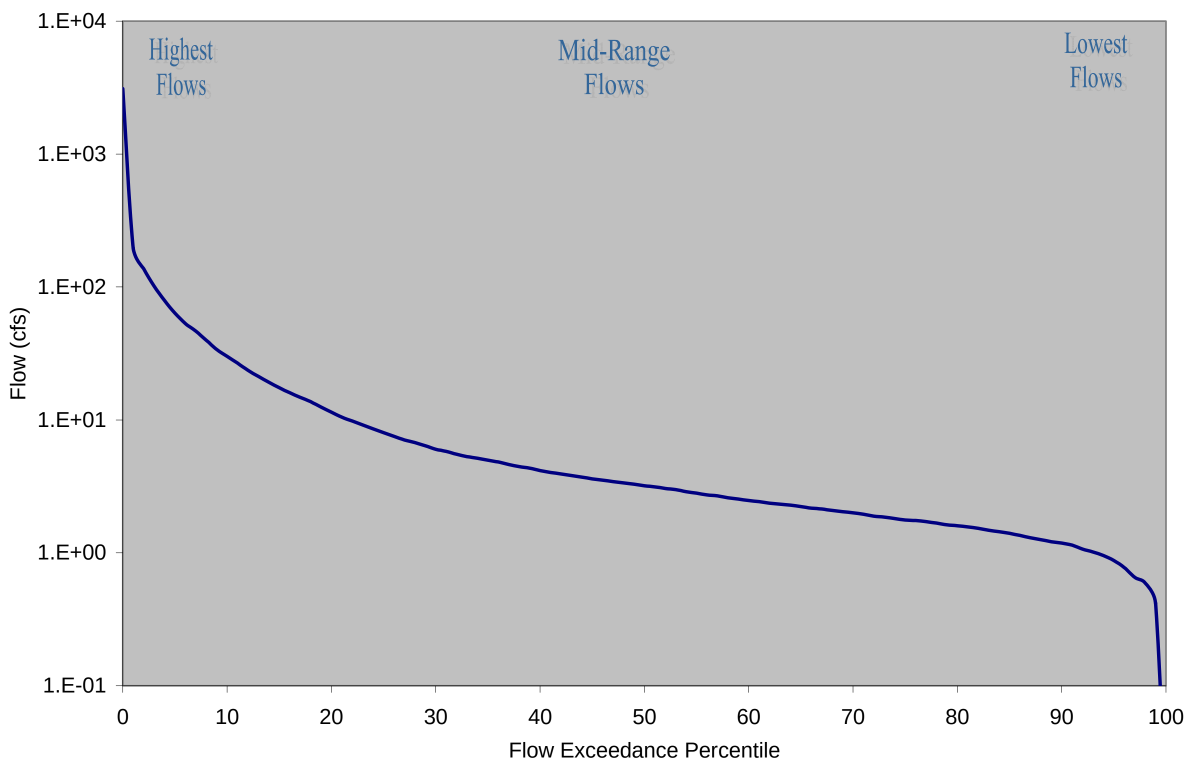


Figure 4-5 Flow Duration Curve for Unnamed Tributary of Greens Bayou (1016C_01)

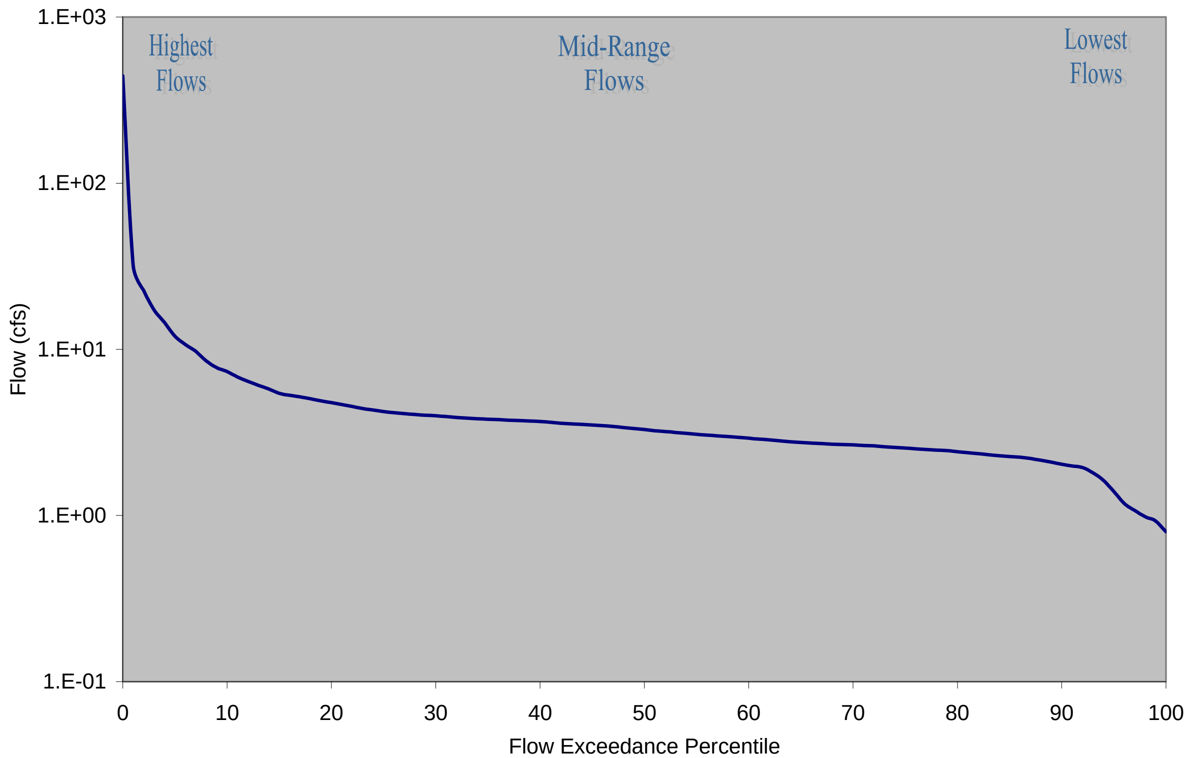


Figure 4-6 Flow Duration Curve for Unnamed Tributary of Greens Bayou (1016D_01)

4.3 Estimating Current Point and Nonpoint Loading and Identifying Critical Conditions from Load Duration Curves

Another key step in the use of LDCs for TMDL development is the estimation of existing bacteria loading from point and nonpoint sources and the display of this loading in relation to the TMDL. In Texas, WWTFs that discharge treated sanitary wastewater must meet the criteria for indicator bacteria at the point of discharge. However, for TMDL analysis it is necessary to understand the relative contribution of WWTFs to the overall pollutant load and its general compliance with required effluent limits. The monthly bacteria load for continuous point source dischargers is estimated by multiplying the monthly average flow rates by the monthly geometric mean bacteria concentration, with a volumetric conversion factor. Where available, fecal coliform data for this calculation were extracted from each point source's discharge monitoring reports from 1996 through 2006. The current pollutant loading from each permitted point source discharge is calculated using the equation below:

*Point Source Loading = monthly average flow rates (mgd) * geometric mean of corresponding fecal coliform concentration * unit conversion factor*

Where:

unit conversion factor = 37,854,120 dL/million gallons (mg)

It is difficult to estimate current nonpoint loading due to lack of specific water quality and flow information that would assist in estimating the relative proportion of non-specific sources within the watershed. Therefore, existing instream loads were used as a conservative surrogate for nonpoint loading. Existing instream loads were calculated using measured bacteria concentrations from WQM stations multiplied by the flow rate (estimated or instantaneous) under various flow conditions.

4.4 Development of Bacteria TMDLs for Freshwater Streams Using Load Duration Curves

The final step in the TMDL calculation process involves a group of additional computations derived from the preparation of LDCs. These computations are necessary to derive a percent reduction goal (one method of presenting how much bacteria loading must be reduced to meet the water quality criterion in an impaired watershed).

Step 1: Generate Bacteria LDCs. LDCs are similar in appearance to flow duration curves; however, the y-axis is expressed in terms of a bacteria load in counts/day. The curve represents the instantaneous water quality criterion for *E. coli* (394 MPN/100mL), expressed in terms of a load through multiplication by the continuum of flows historically observed at this site. Using the single sample water quality criterion to generate the LDC is necessary to display the allowable pollutant load in relation to the existing loads, which are represented by existing ambient water quality samples. The basic steps to generating an LDC involve:

- obtaining daily flow data for the WQM station of interest from the USGS;
- sorting the flow data and calculating flow exceedance percentiles for the time period and season of interest;
- obtaining the water quality data;
- matching the water quality observations with the flow data from the same date;
- displaying a curve on a plot that represents the allowable load multiply the actual or estimated flow by the SWQS for each respective indicator;
- multiplying the flow by the water quality parameter concentration to calculate daily loads; then
- plotting the flow exceedance percentiles and daily load observations in a load duration plot.

The culmination of these steps is expressed in the following formula, which is displayed on the LDC as the TMDL curve:

*TMDL (counts/day) = criterion * flow (cfs) * unit conversion factor*

Where: criterion = 394 MPN/100mL (E. coli) and

*unit conversion factor = 24,465,755 dL/ft3 * seconds/day*

The flow exceedance frequency (x-value of each point) is obtained by looking up the historical exceedance frequency of the measured or estimated flow; in other words, the percent of historical observations that equal or exceed the measured or estimated flow. Historical observations of bacteria concentration are paired with flow data and are plotted on the LDC. The indicator bacteria load (or the y-value of each point) is calculated by multiplying the indicator bacteria concentration (MPN/100mL) by the instantaneous flow (cfs) at the same site and time, with appropriate volumetric and time unit conversions. Indicator bacteria loads representing exceedance of water quality criterion fall above the water quality criterion line.

Figure 4-7 provides a schematic representation of where permitted and non-permitted sources of pollution occur throughout the entire hydrograph for a typical stream. This figure shows that runoff typically contributes pollutant loads during high flow to mid-ranged flow conditions. However, flows do not always correspond directly to runoff events. For instance, high flows may occur in dry weather and runoff influence may be observed with low or moderate flows. Wet weather influenced samples found during low flow conditions can be caused by an isolated rainfall event during dry conditions.

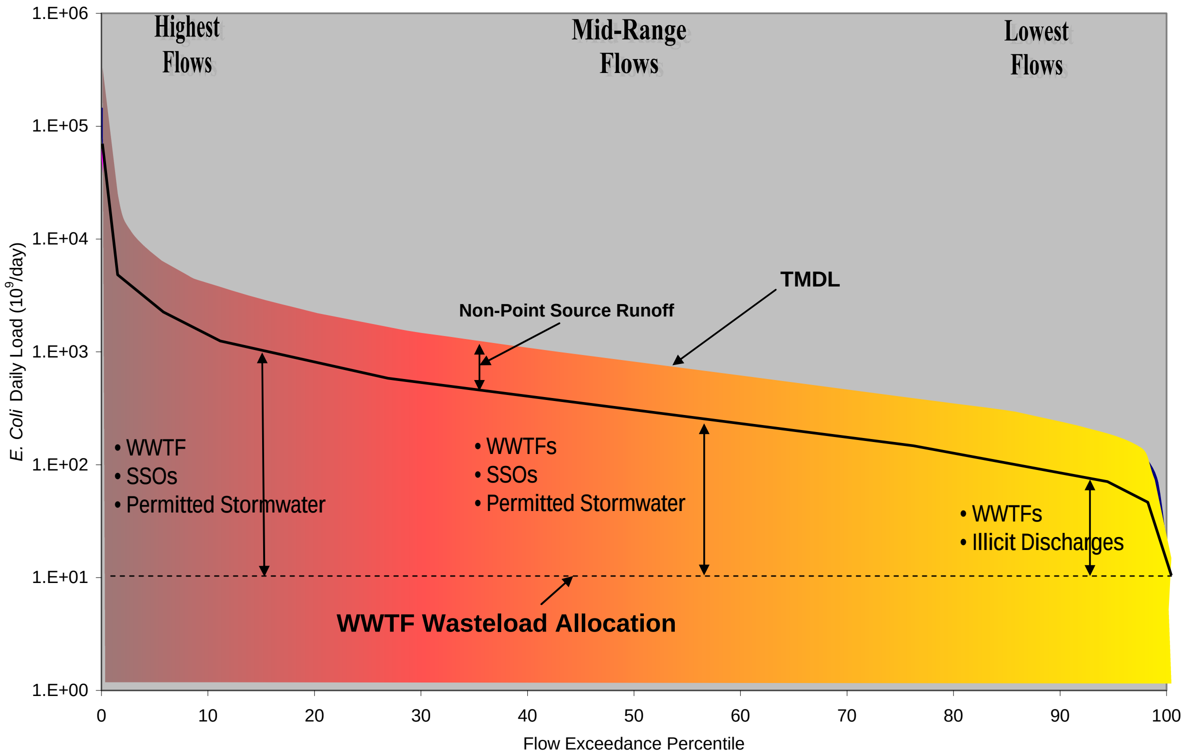


Figure 4-7 LDC Schematic Diagram – Interpreting Sources and Loads

To determine if a bacteria sample was influenced by runoff, rainfall data from the rain gage closest to a WQM station were evaluated. The potential maximum retention after runoff begins (S) was calculated to determine how much rainfall would be needed to produce runoff for each watershed. S is calculated using the formula below:

$$S = \frac{1000}{CN} - 10$$

Where: S = potential maximum retention after runoff begins (inches)

CN =average curve number for the watershed

Three-day rainfall totals were then calculated for each rain gage. These data were matched to the date the bacteria sample was collected. A bacteria sample was then considered a wet weather sample if the three-day rainfall total was greater than or equal to *S*. These bacteria samples were then plotted in the LDCs using a different symbol from those samples that were not considered wet weather influenced.

Step 2: Develop LDCs with MOS. The MOS may be defined explicitly or implicitly. A LDC depicting slightly lower estimates than the TMDL is typically developed to incorporate an MOS into the TMDL calculations. A typical explicit approach would reserve some fraction of the TMDL (*e.g.,* 5%) as the MOS. In an implicit MOS approach, conservative assumptions used in developing the TMDL are relied upon to provide an MOS to assure that water quality target for contact recreation is attained.

For the TMDLs for freshwater streams in this report, an explicit MOS of 5 percent of the TMDL value (5% of the instantaneous water quality criterion) has been selected to slightly reduce assimilative capacity in the watershed. The MOS at any given percent flow exceedance, therefore, is defined as the difference in loading between the TMDL and the TMDL with MOS.

Step 3: Calculate WLA. As previously stated, the pollutant load allocation for permitted (point) sources is defined by the WLA. A point source can be either a wastewater (continuous) or storm water permitted discharge. Storm water point sources are typically associated with urban and industrialized areas, and recent USEPA guidance includes NPDES-permitted storm water discharges as point source discharges and, therefore, part of the WLA.

The LDC approach recognizes that the assimilative capacity of a waterbody depends on the flow, and that maximum allowable loading will vary with flow condition. TMDLs can be expressed in terms of maximum allowable concentrations, or as different maximum loads allowable under different flow conditions, rather than single maximum load values. This concentration-based approach meets the requirements of 40 CFR, 130.2(i) for expressing TMDLs "in terms of mass per time, toxicity, or other appropriate measures" and is consistent with USEPA's Protocol for Developing Pathogen TMDLs (USEPA 2001).

WLA for WWTF. WLAs may be set to zero for watersheds with no existing or planned continuous permitted point sources. For watersheds with permitted point sources, WLAs may be derived from TPDES permit limits. A WLA may be calculated for each active TPDES wastewater discharger using a mass balance approach as shown in the equation below. The permitted average flow rate used for each point source discharge and the water quality criterion concentration are used to estimate the WLA for each wastewater facility. Through TPDES permits, WLAs for WWTFs are constant across all flow conditions and ensure that WQS will be attained (USEPA 2007). All WLA values for each TPDES wastewater discharger are then summed to represent the total WLA for the watershed.

*WLA = criterion/2 * flow * unit conversion factor (#/day)*

Where: criterion = 126 MPN/100mL (E. coli)

flow (mgd) = permitted flow

unit conversion factor = 37,854,120 dL/mgd

WLA for NPDES/TPDES Storm Water. Given the lack of data and the complexity of quantifying bacteria concentrations or loads associated with wet weather events, calculating the WLA for permitted storm water discharges must be derived in a manner similar to that used for all other non-permitted nonpoint sources. In other words it must be derived from the overall LA or the area under the TMDL curve and above the WLA established for WWTFs. Rather than one discrete value, which is practical for WWTF discharges, the WLA calculations for permitted storm water discharges must be expressed as different maximum loads allowable under different flow conditions. Therefore, the percentage of a watershed that is under MS4 jurisdiction is used to estimate the load that should be allocated as the permitted storm water load. For example, the area of the City of Houston/Harris County permitted MS4 discharge in the project area is estimated to be 46,039 acres, 81 percent of the Greens Bayou above Tidal (Segment 1007B) watershed.

Step 4: Calculate LA. LAs for non-permitted sources (nonpoint sources) can be calculated under different flow conditions as the water quality target load minus the sum of WLA for WWTFs (if any) and permitted storm water (or MS4). The LA is represented by the area under the LDC but above the WLA. The LA at any particular flow exceedance is calculated as shown in the equation below.

$$LA = TMDL – MOS - \Sigma WLA_{WWTF} – \Sigma WLA_{STORM\ WATER}$$

Where:

LA = allowable load from non-permitted sources
TMDL= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
$\Sigma WLA_{STORM\ WATER}$ = sum of all STORM WATER loads
MOS = margin of safety

Step 5: Estimate WLA Load Reduction. The WLA load reduction for TPDES-permitted WWTFs was not calculated since it was assumed that continuous dischargers are adequately regulated under existing permits and, therefore, no WLA reduction would be required. However, for permitted storm water the load reduction will be the same as the percent reduction goal established for the LA (nonpoint sources).

Step 6: Estimate LA Load Reduction. A percent reduction goal is derived for each WQM station on each segment for the geometric mean criterion. After existing loading estimates are computed for the indicator bacteria, nonpoint load reduction estimates for each sampling location are calculated by using the difference between estimated existing loading and the allowable load expressed by the LDC (TMDL-MOS). Existing loads were determined by using the median flow of each of the three flow regimes multiplied by the geometric mean concentration of the historical bacteria data within a given regime. For example, for the 0-20^{th} percentile flow range, the flow corresponding to the 10^{th} percentile was used. The geometric mean of the indicator bacteria samples within the 0-20^{th} flow percentile range was then multiplied by the flow corresponding to the 10^{th} exceedance percentile to determine the existing load. Overall, percent reduction goals were also calculated for the most-downstream station of each segment. The highest reduction determined for each segment is then applied as the percent reduction goal. In this case, all indicator bacteria data from flow exceedance percentiles of 0 through 100 were used to calculate the geometric mean and the percent reduction goal was derived using the following formula:

Percent Reduction Goal = (Geometric Mean of Indicator Bacteria Data – Water Quality Target) 100*

Figures 4-8 through 4-13 present the LDCs developed for the downstream WQM station used for calculating the TMDLs of each 303(d) listed freshwater segments.

Figure 4-8 represents the LDC for Greens Bayou above Tidal, assessment units 1006_01 and 1006_02 and is based on *E. coli* bacteria measurements at sampling location 11371 (Greens Bayou at US 59). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under high and mid-range flows. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions. Wet weather influenced samples found during low flow conditions can be caused by an isolated rainfall event during dry conditions.

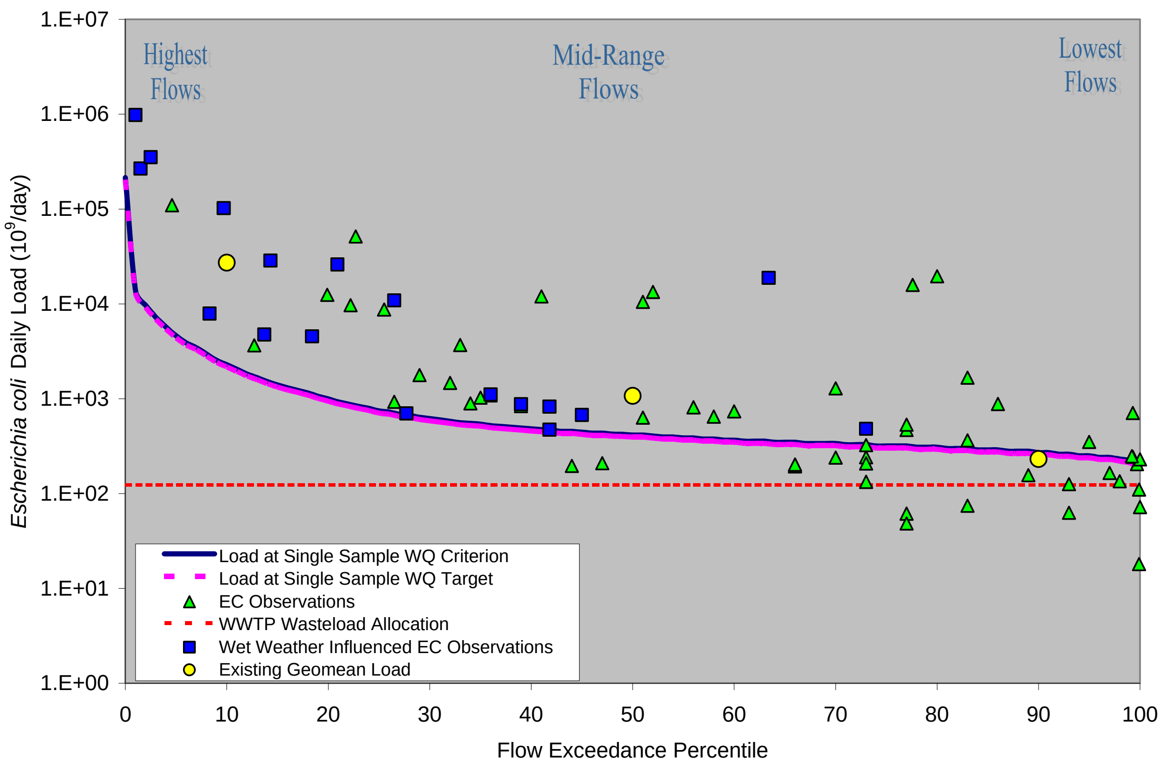


Figure 4-8 Load Duration Curve for Greens Bayou above Tidal (1016_01, 1016_02)

Figure 4-9 represents the LDC for Greens Bayou above Tidal, assessment unit 1006_03 and is based on *E. coli* bacteria measurements at sampling location 11369 (Greens Bayou at Tidwell Road). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under high flows. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions.

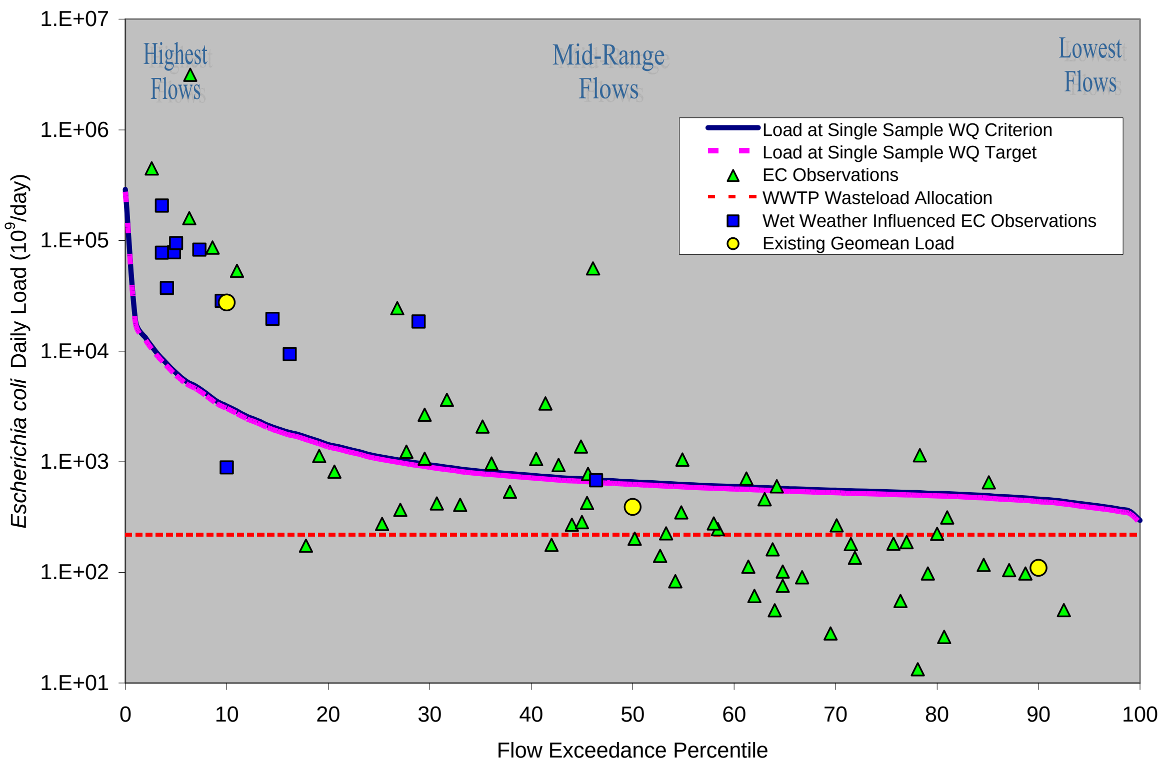


Figure 4-9 Load Duration Curve for Greens Bayou above Tidal (1016_03)

Figure 4-10 represents the LDC for Garners Bayou above Tidal, assessment units 1016A_02 and 1016A_03 and is based on *E. coli* bacteria measurements at sampling location 11125 (Garners Bayou at SH Loop 8). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criterion under high and mid-range flows. Wet weather influenced *E. coli* observations are found under high and mid-range flow conditions.

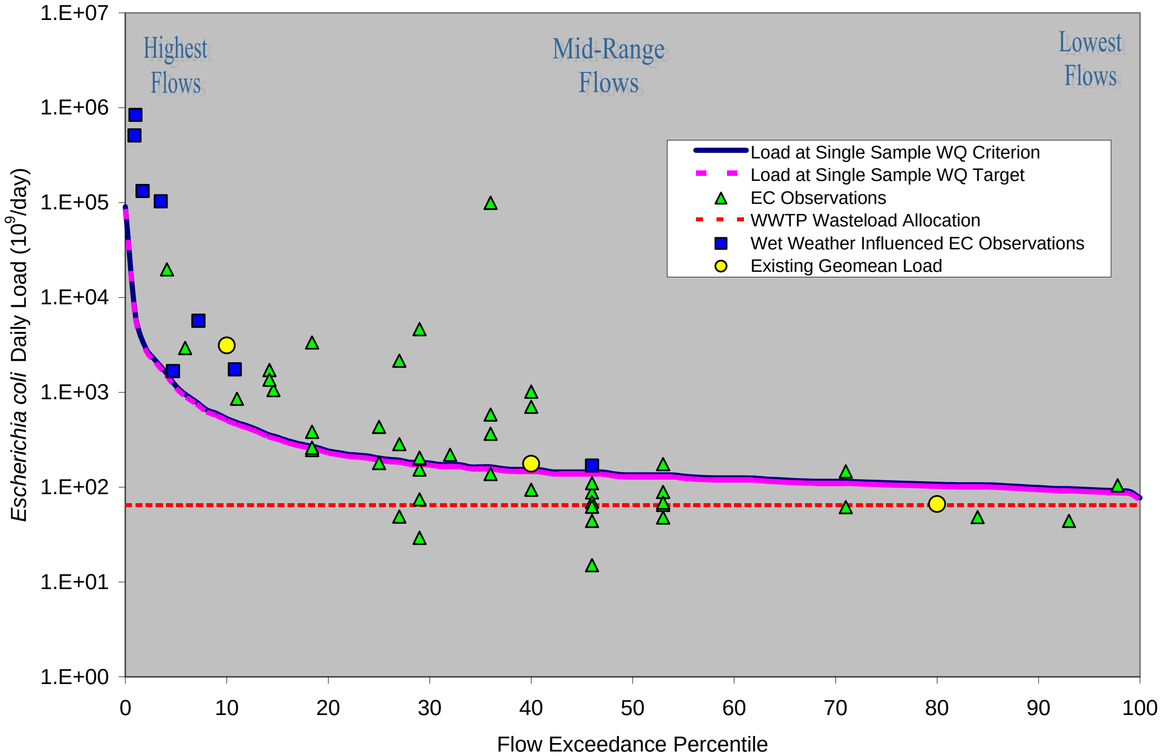


Figure 4-10 Load Duration Curve for Garners Bayou (1016A_02, 1016A_03)

Figure 4-11 represents the LDC for Unnamed Tributary of Greens Bayou, assessment unit 1016B_01 and is based on *E. coli* bacteria measurements at sampling location 20024 (Unnamed Tributary of Greens Bayou). The LDC indicates that *E. coli* levels exceed the instantaneous and geometric mean water quality criteria under high and mid range flow conditions. Wet weather influenced *E. coli* observations are found under high flow conditions.

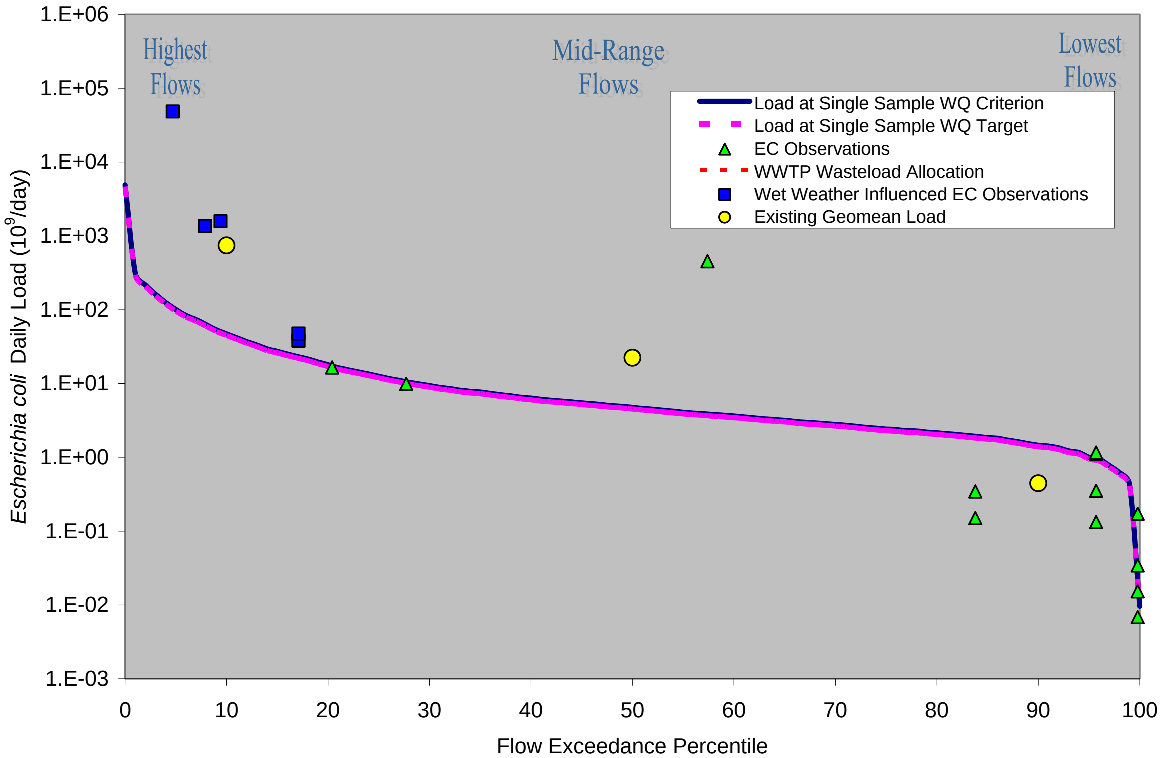


Figure 4-11 Load Duration Curve for Unnamed Tributary of Greens Bayou (1016B_01)

Figure 4-12 represents the LDC for Unnamed Tributary of Greens Bayou, assessment unit 1016C_01 and is based on *E. coli* bacteria measurements at sampling location 11124 (Unnamed Tributary of Greens Bayou). The LDC indicates that *E. coli* levels exceed both the instantaneous and geometric mean water quality criteria under all flow conditions. Wet weather influenced *E. coli* observations are found under high and mid range flow conditions.

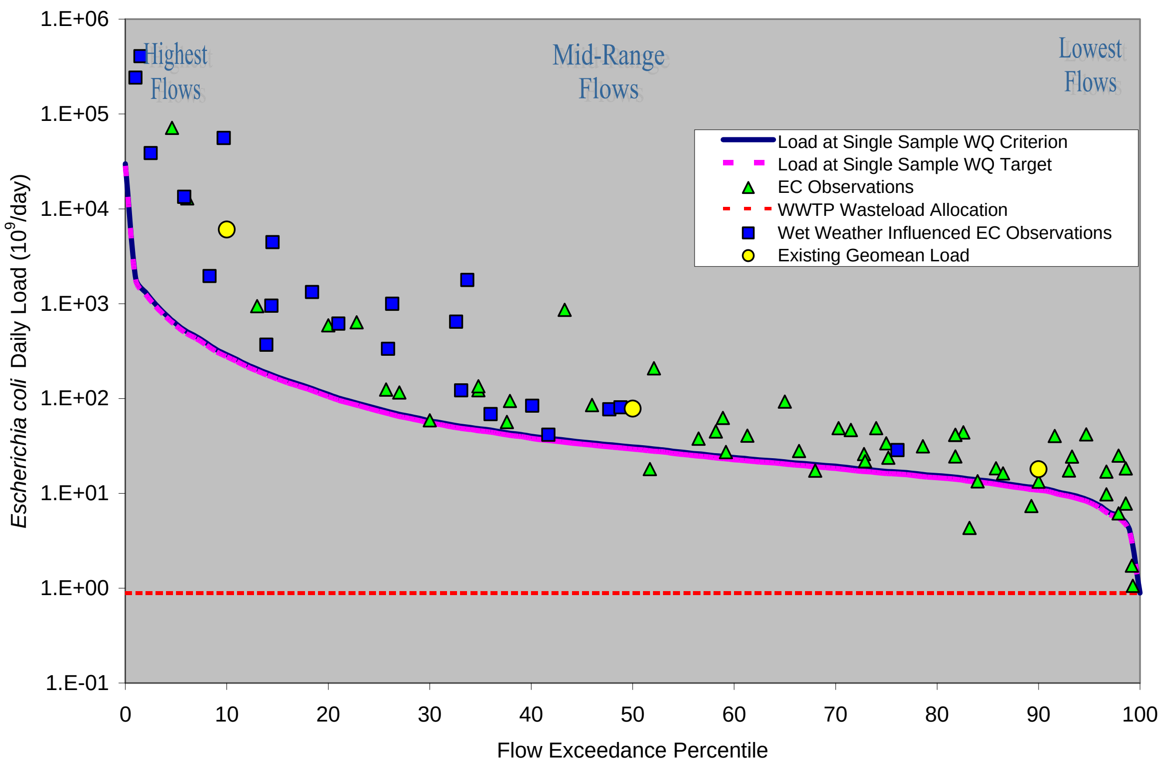


Figure 4-12 Load Duration Curve for Unnamed Tributary of Greens Bayou (1016C_01)

Figure 4-13 represents the LDC for Unnamed Tributary of Greens Bayou, assessment unit 1016D_01 and is based on *E. coli* bacteria measurements at sampling location 16676 (Unnamed Tributary of Greens Bayou). Wet weather influenced samples found during low flow conditions can be caused by an isolated rainfall event during dry conditions. The LDC indicates that *E. coli* levels exceed the instantaneous and geometric mean water quality criteria under all flow conditions. Wet weather influenced *E. coli* observations are found under all flow conditions. The last part of the curve, where the loads at WQ target are lower than the WWTF wasteload allocation, is assumed to be equal to the WLA-WWTF. This explains the difference of shape between the LDC and FDC at very low flows.

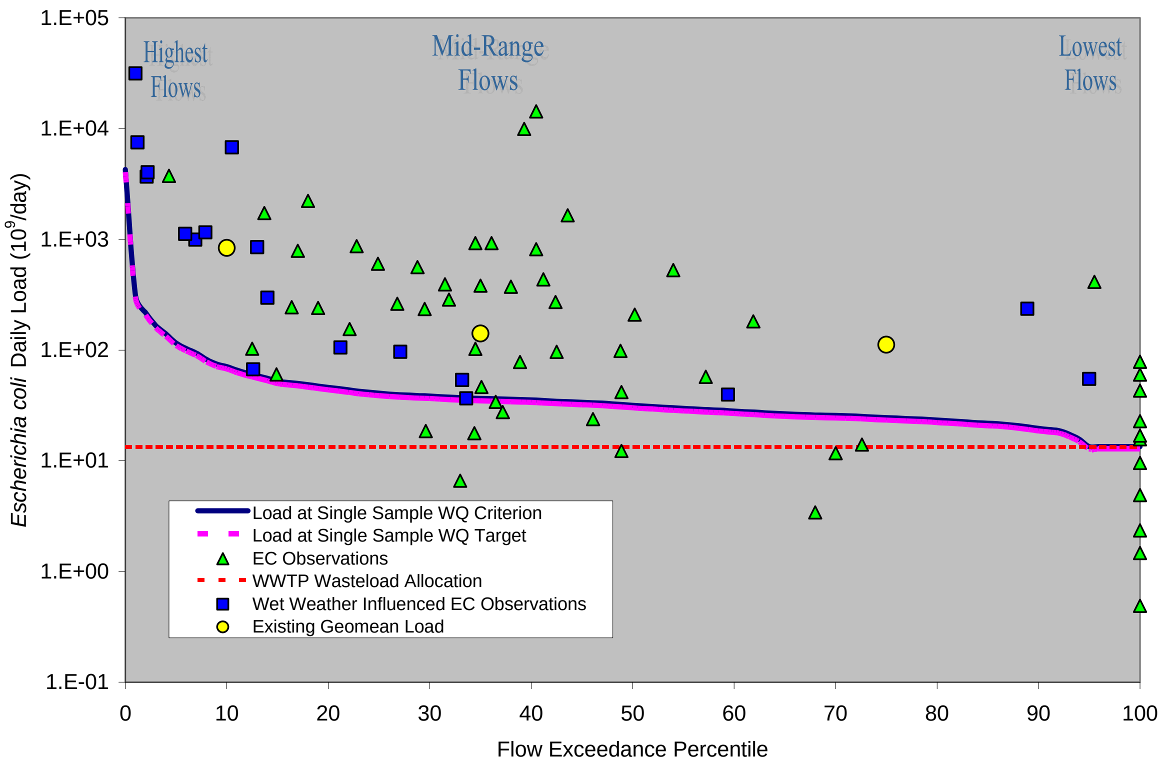


Figure 4-13 Load Duration Curve for Unnamed Tributary of Greens Bayou (1016D_01)

4.5 Estimated Loading and Critical Conditions

USEPA regulations at 40 CFR 130.7(c) (1) require TMDLs to take into account critical conditions for stream flow, loading, and all applicable water quality standards. To accomplish this, available instream WQM data were evaluated with respect to stream flows and the magnitude of water quality criteria exceedance. TMDLs are derived for indicator bacteria in 303(d) listed water bodies at specific WQM stations based on LDCs for freshwater streams.

To calculate the bacteria load at the criterion for freshwater segments, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (*24,465,755 dL/ft3 * seconds/day*) and the criterion specific to each indicator bacteria. This calculation produces the maximum bacteria load in the stream without exceeding the instantaneous standard over the range of flow conditions. In the case of *E. coli* for freshwater streams, the allowable geometric mean concentrations defined in the SWQS are the TMDL. *E. coli* is plotted versus flow exceedance percentiles as a LDC. The x-axis indicates the flow exceedance percentile, while the y-axis is expressed in terms of a bacteria load.

To estimate existing loading, bacteria observations from 2000 to 2006 are paired with the flows measured or estimated in that segment on the same date. Pollutant loads are then calculated by multiplying the measured bacteria concentration by the flow rate and a unit conversion factor of *24,465,755 dL/ft3 * seconds/day*. The associated flow exceedance percentile is then matched with the measured flow from the tables provided in Appendix G. The observed bacteria loads are then added to the LDC plot as points. These points represent individual ambient water quality samples of bacteria. Points above the LDC indicate the bacteria instantaneous standard was exceeded at the time of sampling. Conversely, points under the LDC indicate the sample met the criterion.

The LDC approach recognizes that the assimilative capacity of a waterbody depends on the flow, and that maximum allowable loading varies with flow condition. Existing loading, and load reductions required to meet the TMDL water quality target can also be calculated under different flow conditions. The difference between existing loading and the water quality target is used to calculate the loading reductions required.

Table 4-2 presents the percent reduction goals necessary to achieve the contact recreation standard for select indicator bacteria for each 303(d) listed freshwater stream in the Study Area, as derived from the LDCs. Percent reduction goals for each 303(d)-listed freshwater stream in the Study Area are based on data analysis using the geometric mean criterion since it is anticipated that achieving the geometric mean over an extended period of time will likely ensure that the single sample criterion will also be achieved. Because the geometric mean criterion is considered more stringent, the TMDL for each of these sampling locations is determined by selecting the highest percent reduction goal calculated for the geometric mean criterion.

The sampling location requiring the highest percent reduction based on the geometric mean criterion was chosen for each stream. The most-downstream stations were found to require the highest percent reductions for all the segments within the Study Area. The TMDL percent reduction goals are based on the geometric mean criterion for *E. coli*.

The highest percent reductions for each stream are found in Table 4-2. The pollutant load allocations and percent reduction goals for each flow regime are summarized in Section 5.6. The highest percent reduction goals for each segment were all found to occur in the flow regime with the highest flows. The percent reduction goals for individual flow intervals range from 87 to 98 percent. However, the overall percent reduction goal, which is calculated as the reduction required for the geometric mean of all the observed data to reach the geometric mean criterion, ranges from 70 to 94 percent.

Table 4-2 TMDL Percent Reductions Required to Meet Contact Recreation Standards in the Greens Bayou Watershed

Assessment Unit	Sampling Location	Stream Name	Indicator Bacteria Species	Highest Reduction		Overall Reduction
				Percent Reduction	Corresponding Flow Regime	
1016_03	11369	Greens Bayou above Tidal	*E.coli*	96%	Highest flows	69%
1016_01 and 1016_02	11371		*E. coli*	97%	Highest flows	88%
1016A_02 and 1016A_03	11125	Garners Bayou	*E.coli*	95%	Highest flows	84%
1016B_01	20024	Unnamed Tributary of Greens Bayou	*E.coli*	98%	Highest flows	79%
1016C_01	11124	Unnamed Tributary of Greens Bayou	*E.coli*	98%	Highest flows	91%
1016D_01	16676	Unnamed Tributary of Greens Bayou	*E.coli*	97%	Highest flows	94%

SECTION 5
TMDL CALCULATIONS

5.1 Wasteload Allocation

TPDES-permitted facilities are allocated a daily wasteload calculated as their permitted discharge flow rate multiplied by one half of the instream geometric mean water quality criterion. Table 5-1 summarizes the WLA for the TPDES-permitted facilities within the Study Area. The WWTFs will not be subject to all listed indicator bacteria. The WLA for each facility (WLA_{WWTF}) is derived from the following equation:

WLA_{WWTF} = *criterion/2 * flow * unit conversion factor (#/day)*

Where:

criterion = 126 MPN/100mL for E. coli

flow (10^6 gal/day) = permitted flow

unit conversion factor = 37,854,120-10^6gal/day

When multiple TPDES facilities occur within a watershed, loads from individual WWTFs are summed and the total load for continuous point sources is included as part of the WLA_{WWTF} component of the TMDL calculation for the corresponding segment. When there are no TPDES WWTFs discharging into the contributing watershed of a WQM station, then WWTF WLA is zero. Compliance with the WLA_{WWTF} will be achieved by adhering to the fecal coliform discharge limits and disinfection requirements of TPDES permits.

Storm water discharges from MS4 areas are considered permitted point sources. Therefore, the WLA calculations must also include an allocation for permitted storm water discharges. Given the limited amount of data available and the complexities associated with simulating rainfall runoff and the variability of storm water loading, a simplified approach for estimating the WLA_{MS4} areas was used in the development of these TMDLs. For the LDC method, the percentage of each watershed that is under a TPDES MS4 permit is used to estimate the amount of the overall runoff load that should be dedicated as the permitted storm water contribution in the $WLA_{STORM\ WATER}$ component of the TMDL. The difference between the total storm water runoff load and the portion allocated to $WLA_{STORM\ WATER}$ constitutes the LA component of the TMDL (direct nonpoint runoff).

Table 5-1 Wasteload Allocations for TPDES-Permitted Facilities

Receiving Water	Assessment Unit	TPDES Number	NPDES Number	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (MPN/day)
Greens Bayou above Tidal (1016)	1016_01	04853-001	TX0088897	R & A Harris South	0.006	1.43E+07
		02596-001	TX0076155	Reliant Energy-Greensp	0.02	4.77E+07
		04084-001	TX0063878	CSA Limited	0.004	9.54E+06
		04084-002	TX0063878	CSA Limited	0.008	1.91E+07
		04483-001	TX0102008	Centerpoint Energy Houston	0.015	3.58E+07
		10495-115	TX0054798	Houston-Northborough MUD	2	4.77E+09
		10495-126	TX0113131	Hou-Willowbrook Reg.	2	4.77E+09
		10495-133	TX0084875	Houston-HCMUD #203	3	7.15E+09
		10905-001	TX0058424	North Forest MUD	0.3	7.15E+08
		11026-002	TX0033243	Harris Co.WCID #109	3	7.15E+09
		11201-001	TX0027324	Emerald Forest UD	1.5	3.58E+09
		11238-002	TX0026344	Harris Co.MUD 005	0.9	2.15E+09
		11351-001	TX0111767	Harris Co.MUD 011	0.5	1.19E+09
		11863-001	TX0072893	Harris Co.MUD 150	3	7.15E+09
		11884-001	TX0073407	Nw Harris Co.MUD 006	0.475	1.13E+09
		11904-001	TX0074136	Harris Co.MUD 033	3	7.15E+09
		11907-002	TX0075132	Mills Road MUD	0.9	2.15E+09
		12000-001	TX0077062	Moulding Specialists	0.005	1.19E+07
		12065-001	TX0078824	Harris Co.MUD 086	0.95	2.27E+09
		12127-001	TX0079529	Harris Co.MUD 180	0.95	2.27E+09
		12144-001	TX0079821	Nw Harris Co.MUD 021	1.5	3.58E+09
		12218-001	TX0083429	Cmh Parks	0.122	2.91E+08
		12237-001	TX0083712	Harris Co.MUD 189	1.25	2.98E+09
		12294-001	TX0085413	Harris Co.MUD 200	1.44	3.43E+09
		12527-001	TX0090069	Movimex Co.	0.01	2.38E+07
		12631-001	TX0091901	Harris Co.MUD 202	0.725	1.73E+09
		12655-001	TX0092312	Nw Harris Co.MUD 024	0.5	1.19E+09
		12934-001	TX0097047	Rankin Rd West MUD	0.3	7.15E+08
		13564-001	TX0097225	Harris Co.MUD #304	0.65	1.55E+09
		14446-001	TX0095265	1920 Interpark	0.012	2.86E+07
		14447-001	TX0090476	Harris Co. MUD #191	0.71	1.69E+09

Receiving Water	Assessment Unit	TPDES Number	NPDES Number	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (MPN/day)
Greens Bayou above Tidal (1016)	1016_02	02453-001	TX0084298	Smith International	0.15	3.58E+08
		03402-001	TX0103616	Gse Lining Technology	0.016	3.82E+07
		03420-001	TX0084093	Vam Usa	0.02	4.77E+07
		04018-001	TX0078638	Dresser Industries	0.07	1.67E+08
		10495-078	TX0034916	Houston-Intercont Air	8	1.91E+10
		10495-100	TX0055310	Houston-Northgate UD	3.71	8.85E+09
		10495-101	TX0020478	Houston-Imperial Valley	4	9.54E+09
		10785-001	TX0021199	Sequoia Id	0.2	4.77E+08
		11414-002	TX0033189	Sasson, Eli	0.099	2.36E+08
		11597-001	TX0058076	North Belt UD	1.5	3.58E+09
		11678-001	TX0064424	Yazdcorp Funds V LLC	0.05	1.19E+08
		11791-001	TX0071382	Sunbelt FWSD	1.225	2.92E+09
		12070-001	TX0078808	Aldine ISD	0.063	1.50E+08
		12149-001	TX0081388	Mlr Management	0.01	2.38E+07
		12206-001	TX0083381	North Green MUD	0.6	1.43E+09
		12320-001	TX0085901	Component Structures	0.002	4.77E+06
		12484-001	TX0089281	Boring Specialties	0.005	1.19E+07
		12617-001	TX0091651	Goodwin, Sandra	0.035	8.35E+07
		12754-001	TX0093475	Greens Parkway MUD	0.98	2.34E+09
		12765-001	TX0093556	United Structures	0.008	1.91E+07
		13066-001	TX0097276	Hoajey, Ltd.	0.009	2.15E+07
		14302-001	TX0124460	Rjr Realty, Ltd	0.003	7.15E+06
		14621-001	TX0127957	Rankin Park Mainten & Util	0.05	1.19E+08
		14784-001	TX0129445	Skymark Development	0.45	1.07E+09
		14882-001	NA	AMC Facilities LP	0.025	5.96E+07
		14891-001	TX0131555	Lochinvar Golf Club	0.005	1.19E+07
	1016_03	10495-148	TX0101460	Hou-Tidwell Timbers	0.488	1.16E+09
		10495-150	TX0025291	Houston-WCID #76	0.7	1.67E+09
		11061-001	TX0020800	Greenwood Utility District	0.95	2.27E+09
		11158-001	TX0032085	Champ's Water Co.	0.028	6.68E+07
		11818-001	TX0071897	Harris Co.MUD 148	0.5	1.19E+09
		11818-003	TX0071897	Harris Co.MUD 148	0.95	2.27E+09

Receiving Water	Assessment Unit	TPDES Number	NPDES Number	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (MPN/day)
Greens Bayou above Tidal (1016)	1016_03	12626-001	TX0091847	Thurber	0.019	4.53E+07
		12692-001	TX0092711	Karbalai, Rita	0.05	1.19E+08
		13483-001	TX0104965	Harris Co.MUD	1	2.38E+09
		13559-001	TX0095761	Hinojosa Rene	0.015	3.58E+07
		13955-001	TX0094935	Murhaj, Kobra	0.025	5.96E+07
		14320-001	TX0124702	Tidwell Wu, LLC	0.4	9.54E+08
		14897-001	TX0125326	Holy Trinity Episcopal School	0.075	1.79E+08
		14513-001	TX0126594	Christian Tabernacle	0.019	4.53E+07
		14557-001	TX0087840	Mumtaz Builders	0.008	1.91E+07
		14608-001	TX0127825	Greens Bayou Assembly Of God	0.035	8.35E+07
		14625-001	TX0127981	Marhaba Partners Limited Part	0.75	1.79E+09
		14625-002	TX0127990	Marhaba Partners Limited Part	0.45	1.07E+09
		14633-001	TX0128066	South Central Water Company	0.45	1.07E+09
		14703-001	TX0128694	FRM/MRA Holdings #1	0.98	2.34E+09
		14874-001	TX0067539	BCWK Inc.	0.1	2.38E+08
Garners Bayou (1016A)	1016A_02	10763-003	TX0073989	Humble-Timberwood	0.65	1.55E+09
		11161-001	TX0020320	Clark, Harold	0.099	2.36E+08
		11302-001	TX0025623	El Dorado UD	0.45	1.07E+09
		10763-002	TX0034401	Humble-South	6.5	1.55E+10
		14405-001	TX0079570	International Airport Sq Inves	0.012	2.86E+07
		12418-001	TX0088111	Panalpina Inc.	0.007	1.67E+07
		12571-001	TX0090506	Champ's Water Co	0.1	2.38E+08
		02685-001	TX0094196	Tiampo, Jamie	0.077	1.84E+08
		13870-001	TX0119067	Aquasource Developm	0.099	2.36E+08
		13037-002	TX0127124	Harris Co.MUD 278	2.7	6.44E+09
	1016A_03	11533-001	TX0058963	Harris Co.MUD 109	9	2.15E+10
		11901-001	TX0074021	Trail Of The Lakes MUD	1.75	4.17E+09
		11919-001	TX0074268	Harris Co.MUD 049	0.2	4.77E+08
		11919-002	TX0074446	Harris Co.MUD 049	1.5	3.58E+09

Receiving Water	Assessment Unit	TPDES Number	NPDES Number	Facility Name	Final Permitted Flow (MGD)	*E. coli* WLA_{WWTF} (MPN/day)
Garners Bayou (1016A)	1016A_03	13037-001	TX0097071	Harris Co.MUD 278	0.4	9.54E+08
		13561-001	TX0107301	Harris Co.-Detention Center	0.5	1.19E+09
		14289-001	TX0124346	Austofield Partners #1	0.375	8.94E+08
		14419-001	TX0125661	Land Tejas Park Lakes	1	2.38E+09
		14527-001	TX0126756	Pine Development Ltd	0.64	1.53E+09
		14812-001	TX0129666	Land Tejas Park Lakes 1023	1	2.38E+09
Unnamed Tributary of Greens Bayou (1016C)	1016C_01	10694-001	TX0027707	Southwest Utilities	0.1	2.38E+08
		11739-001	TX0069582	Champ's Water Co.	0.025	5.96E+07
		13882-001	TX0070769	C&P Utilities	0.15	3.58E+08
		12450-001	TX0088650	Darlene Ann Young	0.065	1.55E+08
		02761-001	TX0092037	West Road WSC	0.013	3.10E+07
		14307-001	TX0124508	Metal Building Components	0.02	4.77E+07
Unnamed Tributary of Greens Bayou (1016D)	1016D_01	11200-001	TX0031461	Douglas Utility Co.	0.38	9.06E+08
		14066-001	TX0033430	Houston Airport Hospitality	0.125	2.98E+08
		11794-001	TX0071251	Hydrill Co.	0.05	1.19E+08
		12766-001	TX0093548	Qbn Corp.	0.019	4.53E+07
		10495-122	TX0103721	Houston-Northbelt	5	1.19E+10

5.2 Load Allocation

As discussed in Section 3, non-permitted sources of bacteria loading to the receiving streams of each waterbody emanate from a number of different sources. The data analyses demonstrate that exceedances at the WQM stations are the result of a variety of nonpoint source loading. The LAs for each stream segment are calculated as the difference between the TMDL, MOS, WLA, and WLA for storm water as follows:

$$LA = TMDL - \sum WLA_{WWTF} - \sum WLA_{STORM\ WATER} - MOS$$

Where:

LA = allowable load from non-permitted sources
TMDL= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
$\Sigma WLA_{STORM\ WATER}$ = sum of all Storm Water loads
MOS = margin of safety

5.3 Allocations for Future Growth

Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. It is assumed that the assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation criterion. The addition of any future wastewater discharge facilities will be evaluated on a case-by-case basis. To account for the probability that new additional flows from WWTF may occur in any of the segments, a provision for future growth was included in the TMDL calculations by estimating permitted flows to year 2035 using population projections completed by HGAC (HGAC 2007).

Table 5-2 shows the population increases in each of the eight TMDL assessment units based on the population projections from the H-GAC report. The population increases range from 27 percent to 170 percent. The permitted flows were increased by the expected population growth per assessment unit between 2005 and 2035 to determine the estimated future flows. Future WWTF flows were calculated by multiplying the permitted flow by the increase in population estimated for each assessment unit. The future WWTF flows for each assessment unit were added to the flows from runoff to calculate the TMDL. The allocation for future population growth is the difference between the WWTF loads calculated using estimated future flows and permitted flows.

Table 5-2 Population Projection per Subwatershed

Stream Name	Assessment Unit	2005	2035	Increase
Greens Bayou above Tidal	1016_01	122,837	156,222	27%
	1016_02	48,239	87,338	81%
	1016_03	27,189	56,546	108%
Garners Bayou	1016A_02	20,226	54,531	170%
	1016A_03	3,048	6,614	117%
Unnamed Tributary of Greens Bayou	1016B_01	7,626	10,860	42%
	1016C_01	20,839	28,288	36%
	1016D_01	4,556	11,437	151%

5.4 Margin of Safety

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs include an MOS. The MOS is a conservative measure incorporated into the TMDL equation that accounts for the uncertainty associated with calculating the allowable pollutant loading to ensure geometric mean criterion are attained. USEPA guidance allows for use of implicit or explicit expressions of the MOS, or both. When conservative assumptions are used in development of the TMDL, or conservative factors are used in the calculations, the MOS is implicit. When a specific percentage of the TMDL is set aside to account for uncertainty, then the MOS is considered explicit.

These TMDLs incorporate an explicit MOS by setting a more stringent target for indicator bacteria loads 5 percent lower than the single sample criterion. The explicit MOS was used because of the limited amount of data for some of the sampling locations. For contact recreation, this equates to a single sample target of 374 MPN/100mL for *E. coli*. and a geometric mean target of 120 MPN/100mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each waterbody is slightly reduced. The TMDLs for the freshwater streams in this report incorporate an explicit MOS in each LDC by using 95 percent of the single sample criterion.

5.5 Seasonal Variability

Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. Seasonal variation was accounted for in these TMDLs by using more than 5 years of water quality data and by using the longest period of USGS flow records when developing flow exceedance percentiles.

Seasonality analyses of *E. coli* datasets showed that while 75 percent of the stations (9 out of 12) exhibited higher geometric mean concentrations for the cooler months than the warmer months, there is no significant difference in indicator bacteria between cool and warm weather seasons.

5.6 TMDL Calculations

The bacteria TMDLs for the 303(d)-listed WQM stations covered in this report were derived using LDCs. A TMDL is expressed as the sum of all WLAs (point source loads), LAs (nonpoint source loads), and an appropriate MOS, which attempts to account for uncertainty concerning the relationship between effluent limitations and water quality.

This definition can be expressed by the following equation:

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

Tables 5-3 through 5-8 summarize the pollutant load allocations and percent reduction goals, for the median flow exceedance percentile of each of the three hydrologic classification categories. The percent reduction goals provided in the tables are derived from calculations using the geometric mean criterion not the single sample criterion. The estimated maximum allowable load of *E. coli* for each freshwater segment was determined as that corresponding to the flow regime requiring the highest load reduction (Tables 5-3 to 5-8).

Table 5-3 *E. coli* TMDL Calculations for Greens Bayou above Tidal (1016_01 and 1016_02)

Station 11371			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	236.5	43.0	28.0
Existing Load (10^9 org/day)	2.72E+04	1.07E+03	2.31E+02
Load Capacity at Current Flow (Q*126 org/dL)(10^9 org/day)	7.29E+02	1.33E+02	8.63E+01
MOS (Load Capacity*0.05) (10^9 org/day)	3.65E+01	6.63E+00	4.32E+00
Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)	6.93E+02	1.26E+02	8.20E+01
Load Reduction (10^9 org/day)	2.66E+04	9.48E+02	1.49E+02
Load Reduction (%)	**97.5%**	88.3%	64.6%
Overall Load Reduction (%)	88%		
TMDL for 1016_02 and 1016_01 (Q_{future}*WQS) (10^9 org/day)	1.02E+03		

Table 5-4 *E. coli* TMDL Calculations for Greens Bayou above Tidal (1016_03)

Station 11369			
Flow Regime %	**0%-20%**	**20%-80%**	**80%-100%**
Median Flow, Q (cfs)	330.8	68.3	47.6
Existing Load (10^9 org/day)	2.75E+04	3.90E+02	1.10E+02
Load Capacity at Current Flow (Q*126 org/dL)(10^9 org/day)	1.02E+03	2.10E+02	1.47E+02
MOS (Load Capacity*0.05) (10^9 org/day)	5.10E+01	1.05E+01	7.33E+00
Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)	9.69E+02	2.00E+02	1.39E+02
Load Reduction (10^9 org/day)	2.65E+04	1.90E+02	0
Load Reduction (%)	**96.5%**	48.7%	0
Overall Load Reduction (%)	69%		
TMDL (Q_{future}*WQS) (10^9 org/day)	1.78E+03		

Table 5-5 *E. coli* TMDL Calculations for Garners Bayou (1016A_02 and 1016A_03)

Station 11125			
Flow Regime %	**0%-20%**	**20%-60%**	**60%-100%**
Median Flow, Q (cfs)	55.0	16.0	11.1
Existing Load (10^9 org/day)	3.13E+03	1.76E+02	6.65E+01
Load Capacity at Current Flow (Q*126 org/dL)(10^9 org/day)	1.70E+02	4.93E+01	3.43E+01
MOS (Load Capacity*0.05) (10^9 org/day)	8.48E+00	2.47E+00	1.71E+00
Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)	1.61E+02	4.69E+01	3.26E+01
Load Reduction (10^9 org/day)	2.97E+03	1.30E+02	3.39E+01
Load Reduction (%)	**94.8%**	73.4%	51.0%
Overall Load Reduction (%)	84%		
TMDL (Q_{future}*WQS) (10^9 org/day)	4.19E+02		

Table 5-6 *E. coli* TMDL Calculations for Unnamed Tributary of Greens Bayou (1016B_01)

Station 20024			
Flow Regime %	**0%-20%**	**20%-80%**	**80%-100%**
Median Flow, Q (cfs)	4.9	0.49	0.15
Existing Load (10^9 org/day)	7.42E+02	2.24E+01	4.46E-01
Load Capacity at Current Flow (Q*126 org/dL)(10^9 org/day)	1.50E+01	1.52E+00	4.67E-01
MOS (Load Capacity*0.05) (10^9 org/day)	7.51E-01	7.59E-02	2.34E-02
Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)	1.43E+01	1.44E+00	4.44E-01
Load Reduction (10^9 org/day)	7.28E+02	2.09E+01	2.01E-03
Load Reduction (%)	**98.1%**	93.6%	0.5%
Overall Load Reduction (%)	79%		
TMDL (Q_{future}*WQS) (10^9 org/day)	1.50E+01		

Table 5-7 *E. coli* TMDL Calculations for Unnamed Tributary of Greens Bayou (1016C_01)

Station 11124			
Flow Regime %	**0%-20%**	**20%-80%**	**80%-100%**
Median Flow, Q (cfs)	30.1	3.2	1.2
Existing Load (10^9 org/day)	6.06E+03	7.84E+01	1.80E+01
TMDL (Q*C) (10^9 org/day)	9.27E+01	9.85E+00	3.65E+00
MOS (Load Capacity*0.05) (10^9 org/day)	4.64E+00	4.93E-01	1.82E-01
Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)	8.81E+01	9.36E+00	3.47E+00
Load Reduction (10^9 org/day)	5.97E+03	6.90E+01	1.46E+01
Load Reduction (%)	**98.5%**	88.1%	80.8%
Overall Load Reduction* (%)	91%		
TMDL (Q_{future}*WQS) (10^9 org/day)	9.41E+01		

Table 5-8 *E. coli* TMDL Calculations for Unnamed Tributary of Greens Bayou (1016D_01)

Station 16676			
Flow Regime %	**0%-20%**	**20%-50%**	**50%-100%**
Median Flow, Q (cfs)	7.4	3.8	2.6
Existing Load (10^9 org/day)	8.37E+02	1.41E+02	1.12E+02
Load Capacity at Current Flow (Q*126 org/dL)(10^9 org/day)	2.27E+01	1.17E+01	7.85E+00
MOS (Load Capacity*0.05) (10^9 org/day)	1.13E+00	5.86E-01	3.92E-01
Allowable Load at Water Quality Target and Current Flow (Load Capacity-MOS) (10^9 org/day)	2.15E+01	1.11E+01	7.46E+00
Load Reduction (10^9 org/day)	8.15E+02	1.30E+02	1.04E+02
Load Reduction (%)	**97.4%**	92.1%	93.3%
Overall Load Reduction (%)	94%		
TMDL (Q_{future}*WQS) (10^9 org/day)	7.97E+01		

Because Greens Bayou above Tidal at WQM station 11371 and Garners Bayou at WQM station 11125 each encompasses two assessment units, the calculated TMDLs for the entire areas (Tables 5-3 and 5-5) were proportioned using three ratios: (i) assessment unit length to total stream length to proportion WLA, MS4 and LA, (ii) ratio of WWTF flows discharging to each assessment unit to the total WWTF in the watershed to proportion WLA-WWTF and (iii) ratio of projected increase in WWTF flows for each assessment unit to the total increase in WWTF flows in the watershed to proportion Future Growth. Ratios are summarized in Table 5-9.

Table 5-9 Ratios for Proportioning of Greens Bayou at 11371 and Garners Bayou at 11125 by Assessment Unit

Assessment Unit	Segment ID	Length of Segment (mi)	Length of AU (mi)	AU/ Segment Length Ratio[a]	Total Current WWTF Permitted Flow for Segment (MGD)	Current WWTF Permitted Flow (MGD)	AU/ Segment Flow Ratio[b]	Total Projected Increase in Permitted Flow for Segment (MGD)	Projected Increase WWTF Permitted Flow (MGD)	AU/ Segment Flow Ratio[c]
1016C_01	1016_02 and upstream AU's	13.2	-	-	51.4	0.37	0.01	25.5	0.13	0.01
1016_01			4.9	0.37		29.8	0.58		8.1	0.32
1016_02			8.3	0.63		21.3	0.41		17.3	0.68
1016A_02	1016A	5.8	4.2	0.72	27.1	10.7	0.40	37.3	18.1	0.49
1016A_03			1.6	0.28		16.4	0.60		19.1	0.51

[a] *To proportion WLA-MS4 and LA*
[b] *To proportion WLA-WWTF*
[c] *To proportion Future growth*

Once the LA, WLA, and Future Growth for each assessment unit were calculated using the above listed ratios and the percent of the drainage areas within an MS4 (Table 3-4), they were added. The sums were then divided by 0.95 (to account for the 5% MOS) to obtain the proportioned TMDLs. These correspond to the TMDLs for assessment units 1016_01 and 1016_02 in Greens Bayou above US-59 and the two assessment units included in Garners Bayou at SH Loop 8 (1016A_02 to 1016A_03).

The final TMDLs for the eight assessment units included in this project are summarized in Table 5-10. The TMDLs were calculated based on the median flow in the 0-20 flow exceedance percentile range, which corresponds to the range requiring the highest percent reductions.

The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 are presented in Table 5-11. In this table the future capacity for WWTF has been added to the WLA_{WWTF}.

TMDL values and allocations in Table 5-11 are derived from calculations using the existing water quality criterion for *E. coli* and a critical flow condition (median flow of the hydrologic range requiring the greatest pollutant load reduction). However, designated uses and water quality criteria for these water bodies are subject to change through the TCEQ standards revision process. Figures 5-1 through 5-8 were developed to demonstrate how assimilative capacity, TMDL calculations and pollutant load allocations change in relation to a number of hypothetical water quality criteria for *E. coli*. The equations provided along with Figures 5-1 through 5-5 allow calculating new TMDLs and pollutant load allocations based on any potential new water quality criterion for *E. coli*.

Table 5-10 *E. coli* TMDL Summary Calculations for Greens Bayou Segments

Assessment Unit	Sampling Location	Stream Name	TMDL[a] (MPN/day)	WLA_{WWTF}[b] (MPN/day)	$WLA_{STORM\ WATER}$[f] (MPN/day)	LA[g] (MPN/day)	MOS[h] (MPN/day)	Future Growth[i] (MPN/day)
1016_01	11371	Greens Bayou above Tidal	4.03E+11	7.09E+10	2.93E+11	0	2.02E+10	1.93E+10
1016_02			1.02E+12	1.23E+11	7.89E+11	0	5.12E+10	6.07E+10
1016_03	11369		1.78E+12	2.19E+11	1.05E+12	2.31E+11	8.90E+10	1.90E+11
1016A_02	11125	Garners Bayou	1.97E+11	2.55E+10	1.38E+11	5.69E+09	9.84E+09	1.80E+10
1016A_03			4.19E+11	6.45E+10	2.14E+11	3.10E+10	2.10E+10	8.89E+10
1016B_01	20024	Unnamed Tributary of Greens Bayou	1.50E+10	0	1.24E+10	1.86E+09	7.51E+08	0
1016C_01	11124	Unnamed Tributary of Greens Bayou	9.41E+10	8.90E+08	8.82E+10	0	4.70E+09	3.20E+08
1016D_01	16676	Unnamed Tributary of Greens Bayou	7.97E+10	1.33E+10	3.58E+10	6.51E+09	3.99E+09	2.01E+10

[a] Maximum allowable load for the flow range requiring the highest percent reduction (Tables 5-3 to 5-8)
*[b] Sum of loads from the WWTF discharging to the segment. Individual loads are calculated as permitted flow * 126/2 (E. coli) MPN/100mL*conversion factor (Table 5-1)*
[c] The WLA_{WWTF} for 1016_02 includes all the facilities discharging upstream of station 11371 and, thus, it includes WWTF that discharge to AU 1016_01
[d] The WLA_{WWTF} for 1016_03 includes all the facilities discharging upstream of station 11369 and, thus, it includes WWTF that discharge to all other AUs
[e] The WLA_{WWTF} for 1016A_03 includes all the facilities discharging upstream of station 11125 and, thus, it includes WWTF that discharge to AU 1016A__02
[f] $WLA_{STORM\ WATER}$ = (TMDL – MOS –WLA_{WWTF})(percent of drainage area covered by storm water permits)*
[g] LA = TMDL – MOS –WLA_{WWTF} –$WLA_{STORM\ WATER}$-Future growth
[h] MOS = TMDL x 0.05
*[i] Projected increase in WWTF permitted flows*126/2*conversion factor*

Table 5-11 Final TMDL Allocations

Assessment Unit	TMDL (MPN/day)	WLA_{WWTF}[a] (MPN/day)	$WLA_{STORM\ WATER}$ (MPN/day)	LA (MPN/day)	MOS (MPN/day)
1016_01	4.03E+11	9.02E+10	2.93E+11	0	2.02E+10
1016_02	1.02E+12	1.83E+11	7.89E+11	0	5.12E+10
1016_03	1.78E+12	4.10E+11	1.05E+12	2.31E+11	8.90E+10
1016A_02	1.97E+11	4.35E+10	1.38E+11	5.69E+09	9.84E+09
1016A_03	4.19E+11	1.53E+11	2.14E+11	3.10E+10	2.10E+10
1016B_01	1.50E+10	0	1.24E+10	1.86E+09	7.51E+08
1016C_01	9.41E+10	1.21E+09	8.82E+10	0	4.70E+09
1016D_01	7.97E+10	3.34E+10	3.58E+10	6.51E+09	3.99E+09

[a] $WLA_{WWTF} = WLA_{WWTF\ (Table\ 5\text{-}10)}$ + Future $Growth_{(Table\ 5\text{-}10)}$

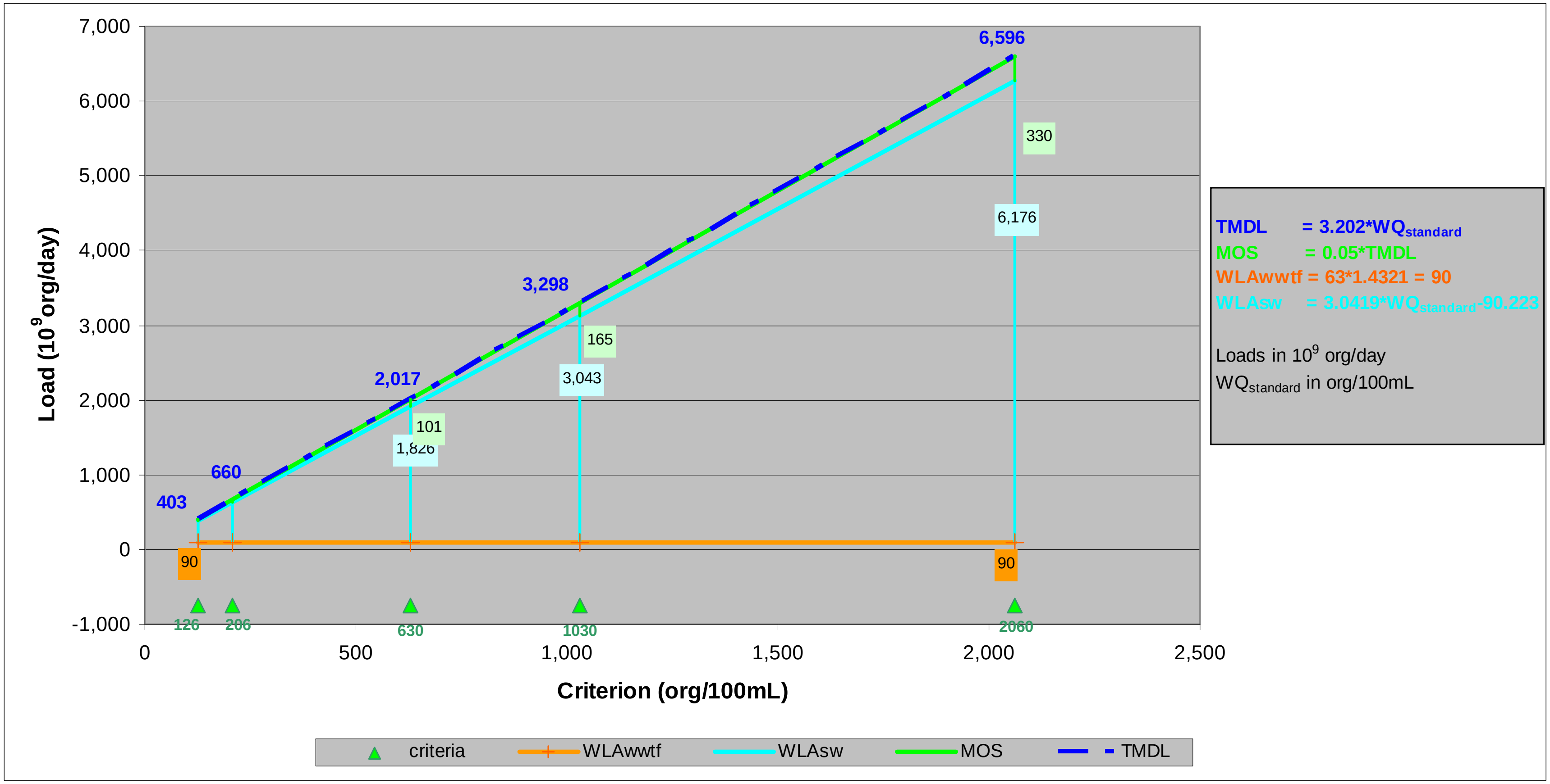


Figure 5-1 Allocation Loads for AU 1016_01 as a Function of WQ Criteria

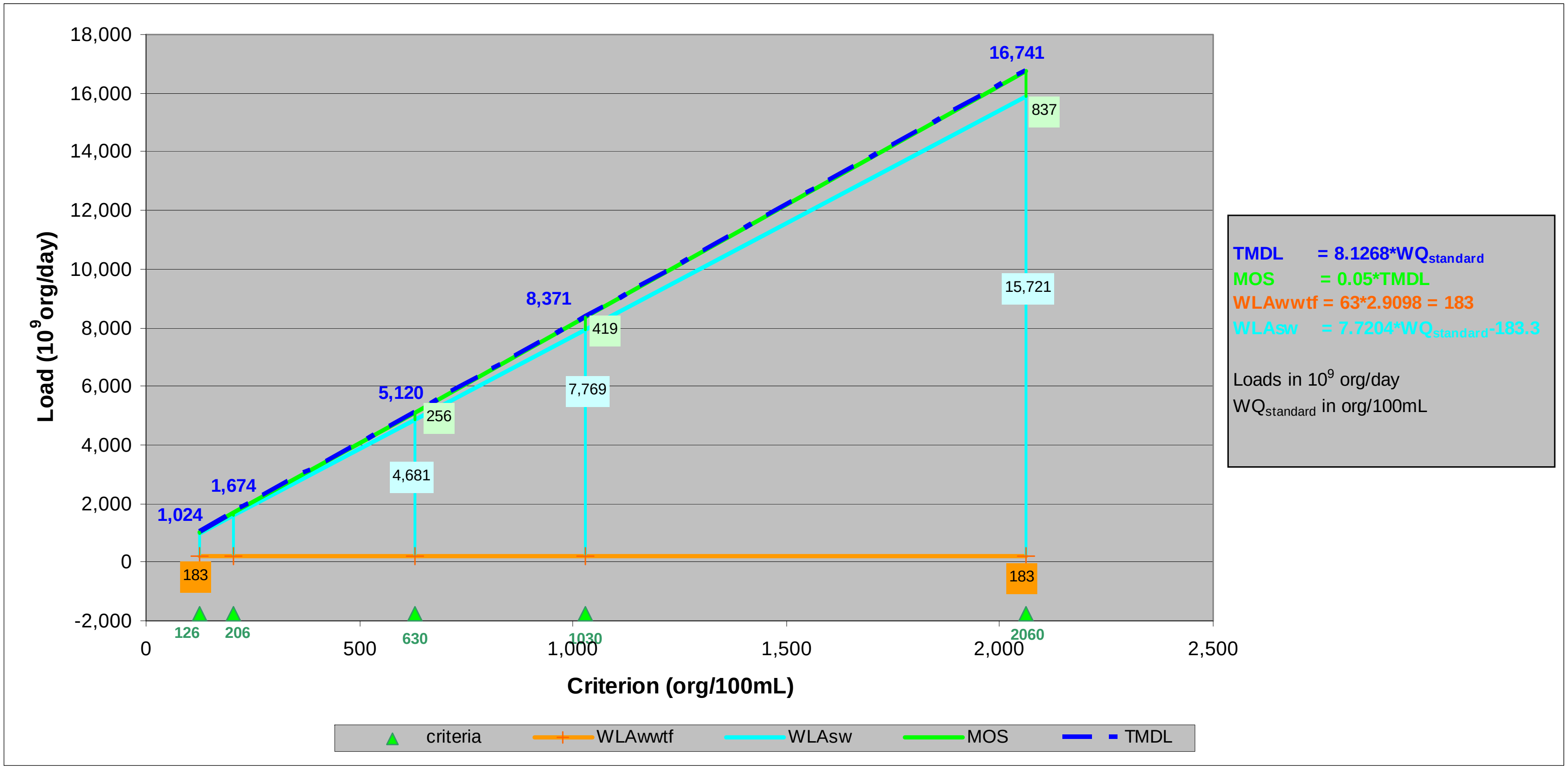


Figure 5-2 Allocation Loads for AU 1016_02 as a Function of WQ Criteria

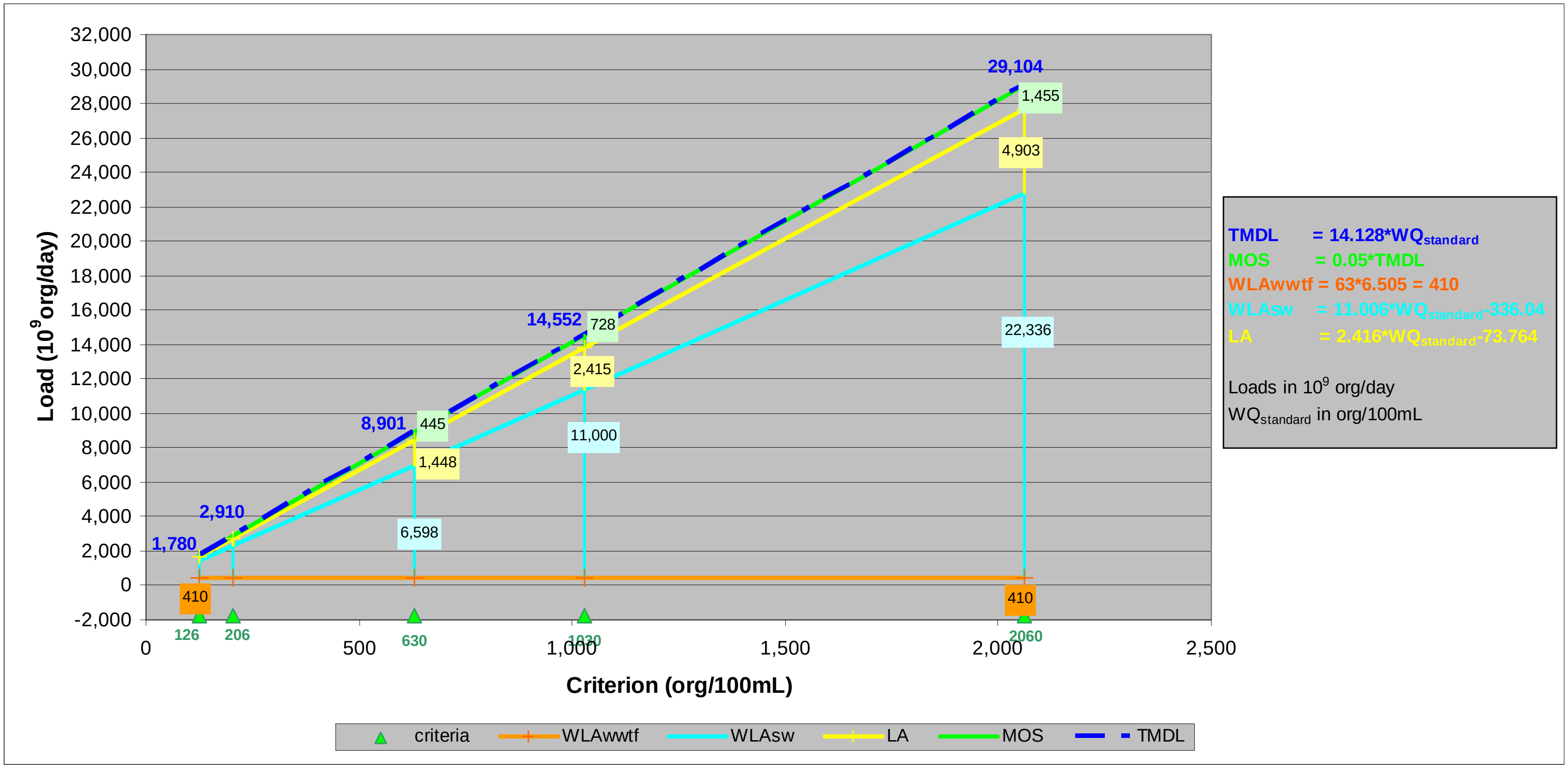


Figure 5-3 Allocation Loads for AU 1016_03 as a Function of WQ Criteria

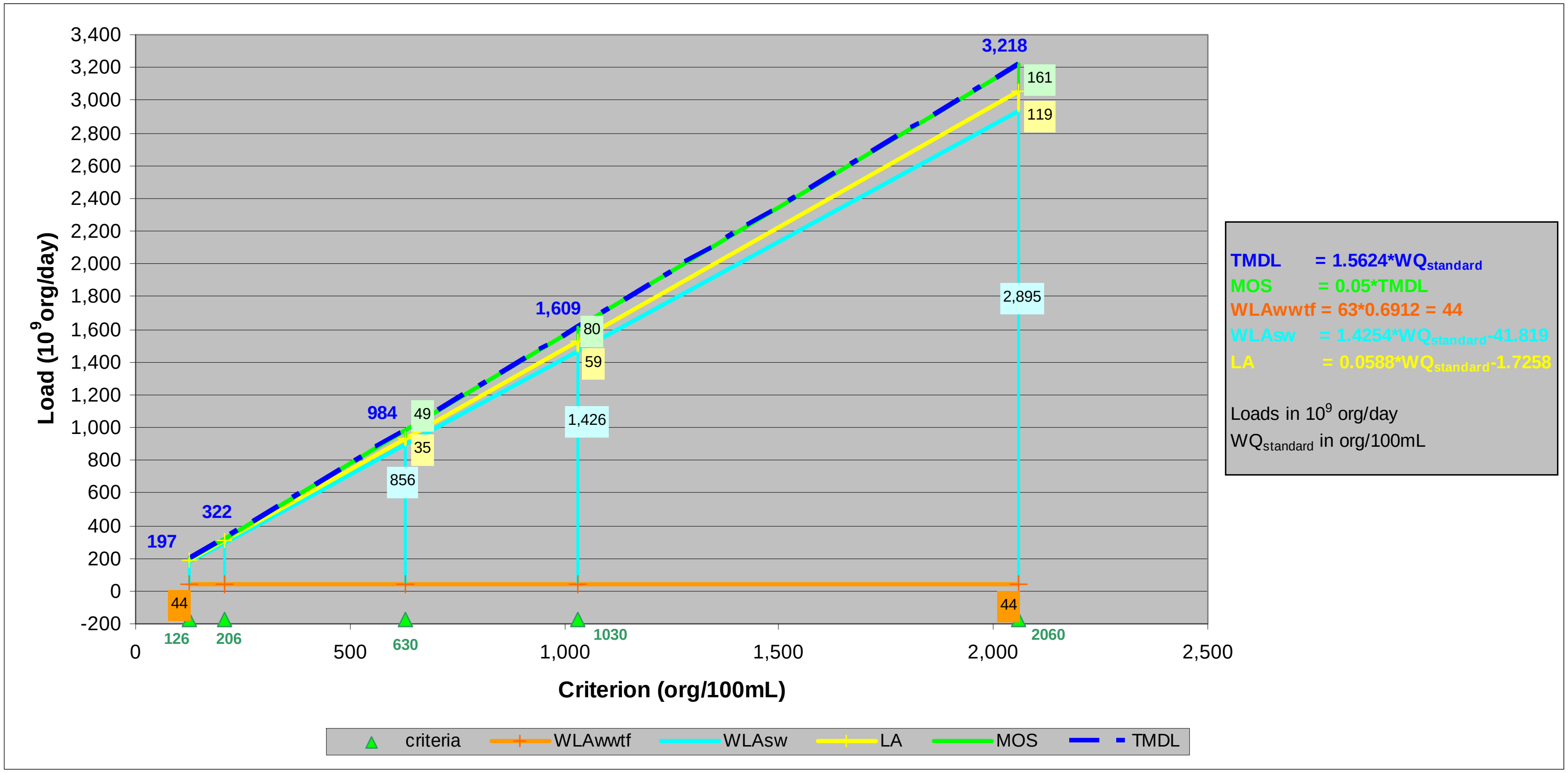


Figure 5-4 Allocation Loads for AU 1016A_02 as a Function of WQ Criteria

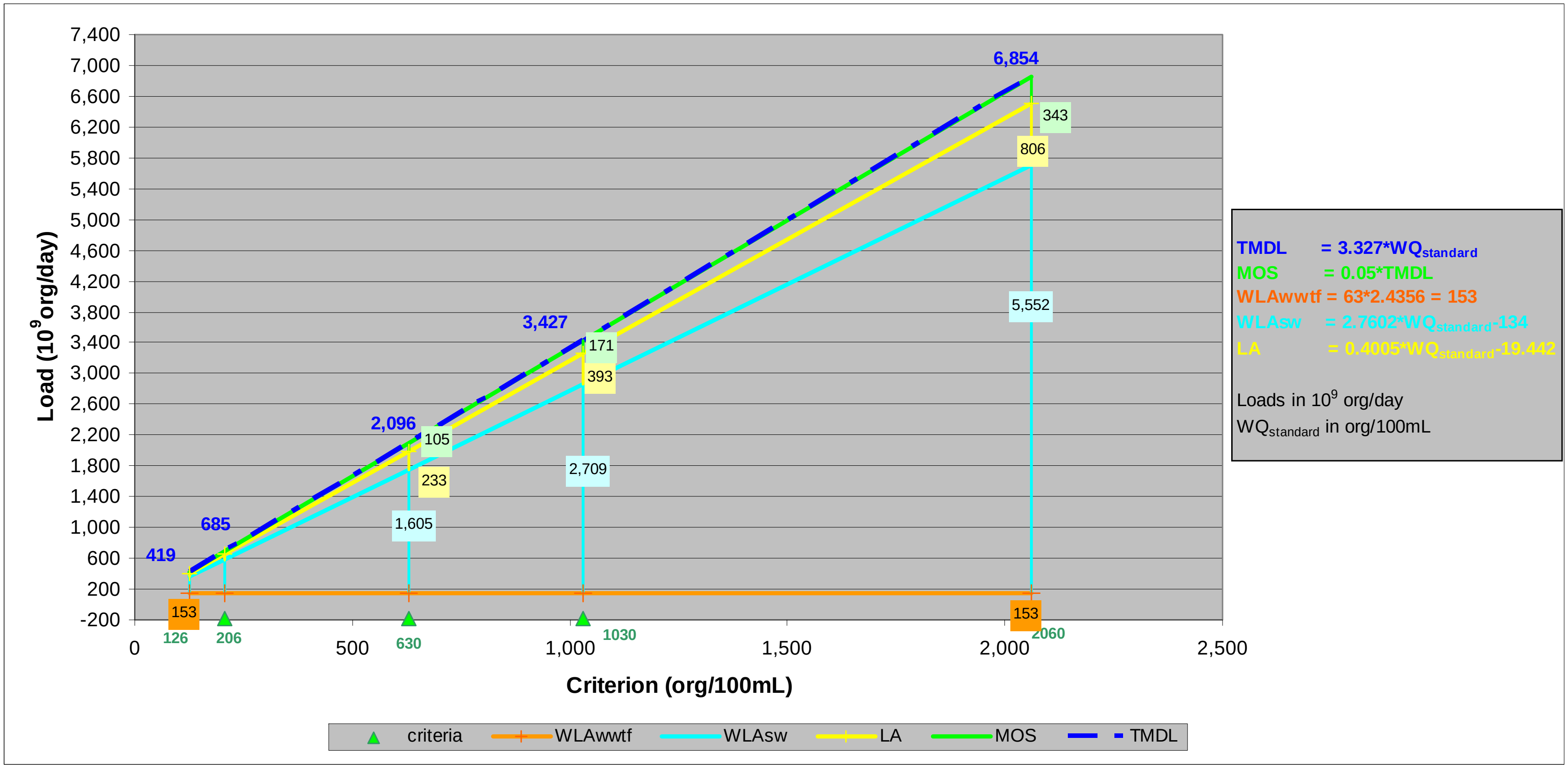


Figure 5-5 Allocation Loads for AU 1016A_03 as a Function of WQ Criteria

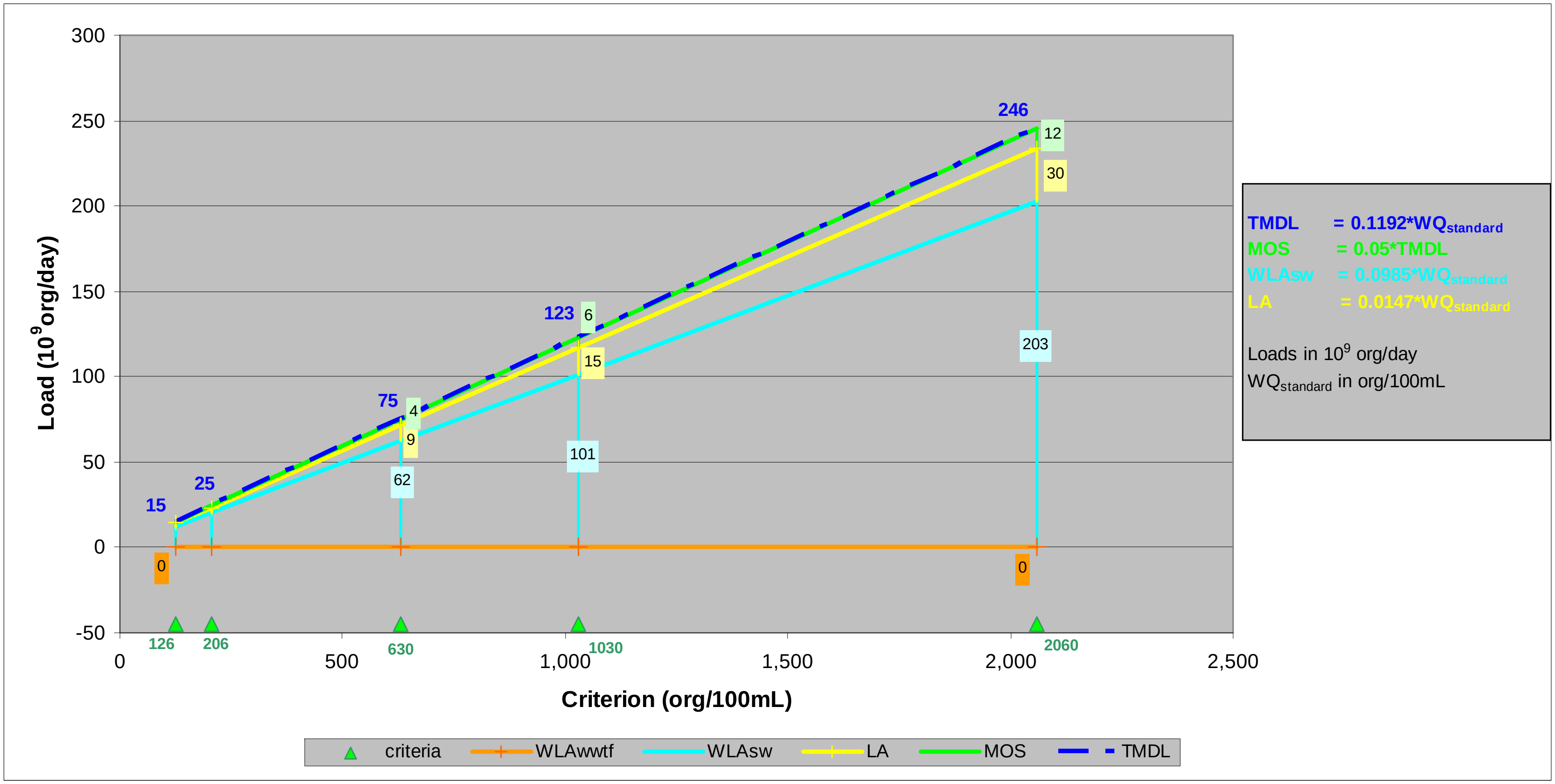


Figure 5-6 Allocation Loads for AU 1016B_01 as a Function of WQ Criteria

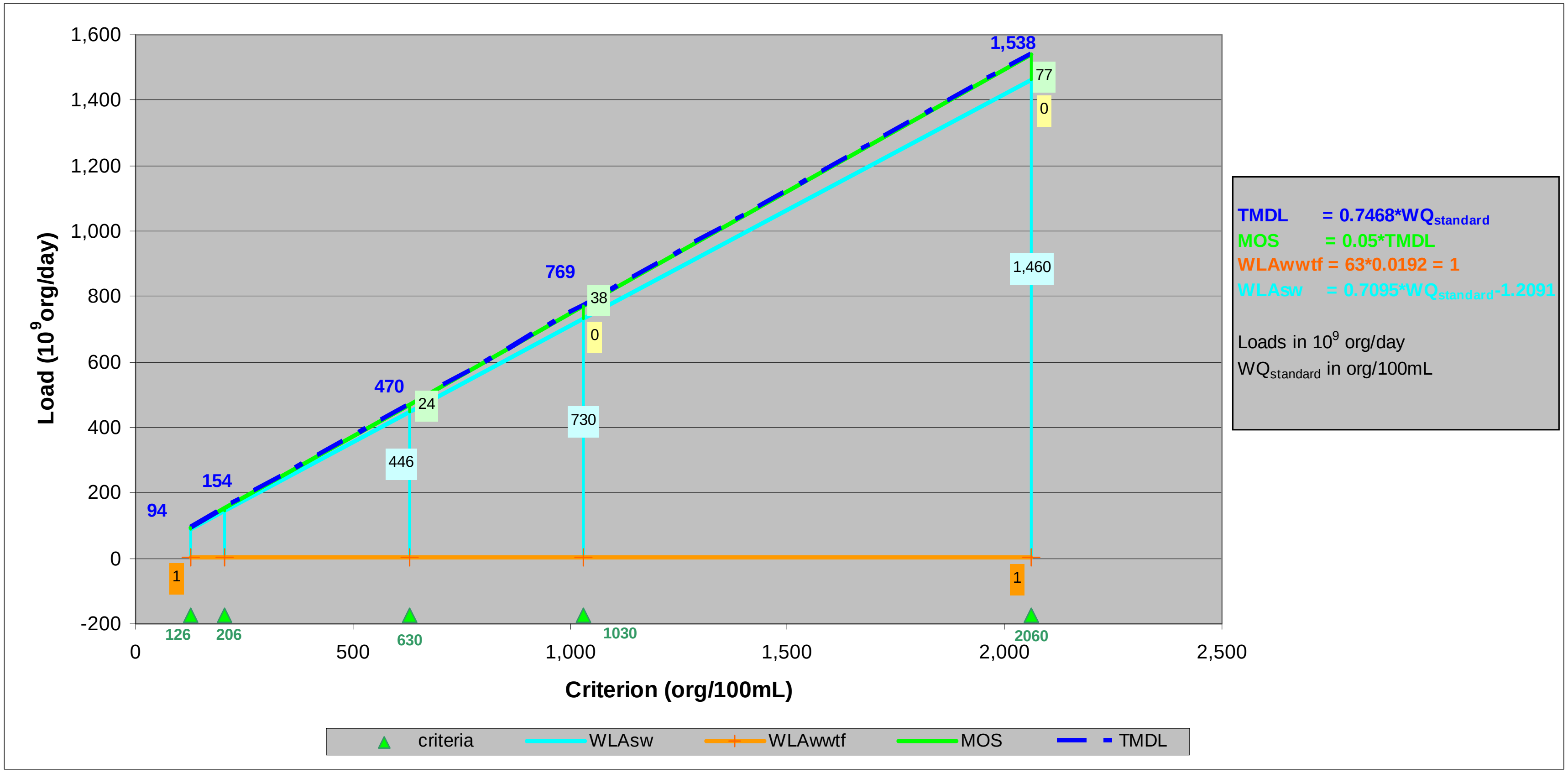


Figure 5-7 Allocation Loads for AU 1016C_01 as a Function of WQ Criteria

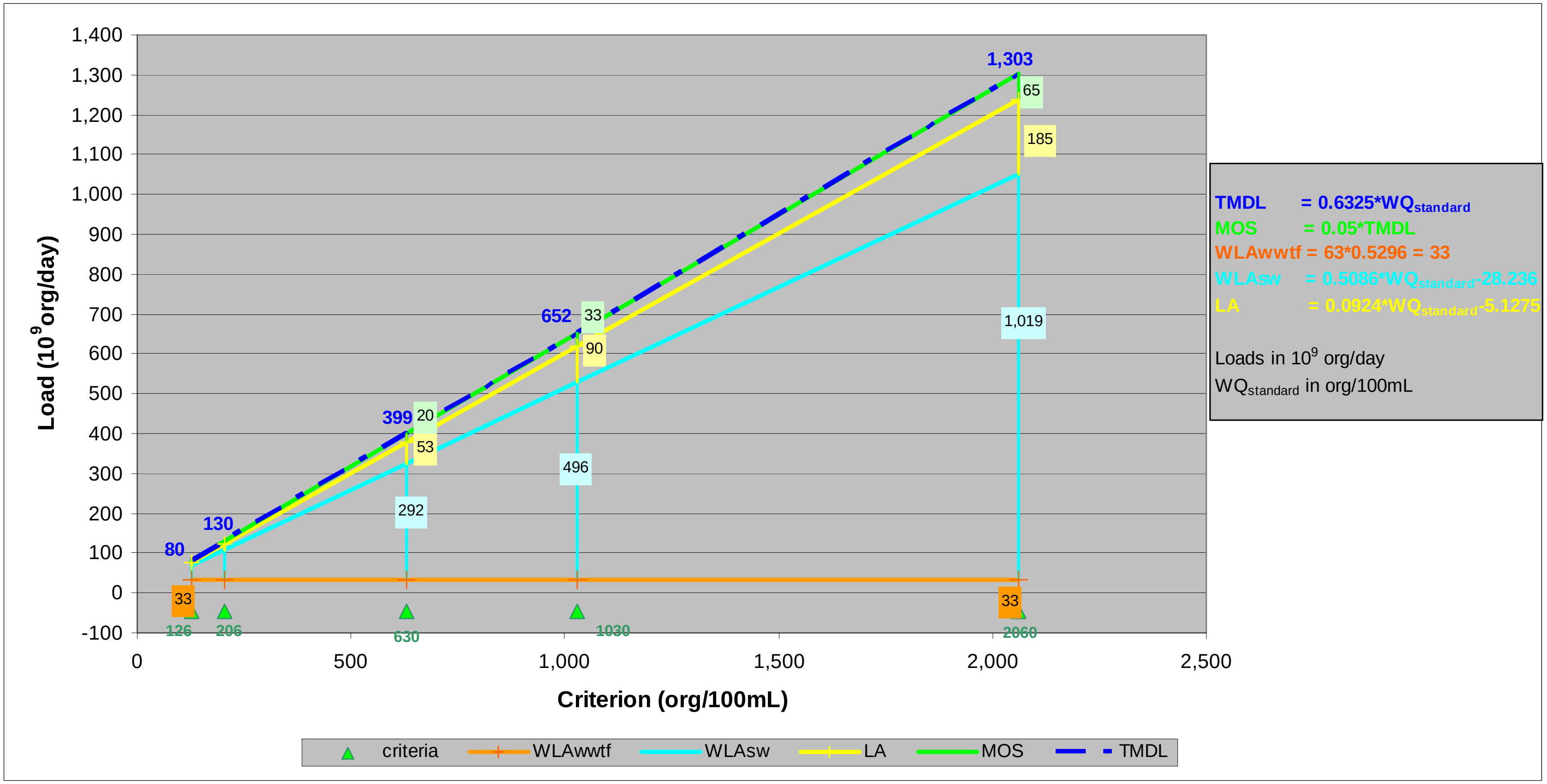


Figure 5-8 Allocation Loads for AU 1016D_01 as a Function of WQ Criteria

SECTION 6
PUBLIC PARTICIPATION

The Houston-Galveston Area Council is providing coordination for public participation in this project. To obtain public input on the Greens Bayou Bacteria TMDL and the implementation phase, public meetings were held on November 5, 2007 and November 6, 2008. The meetings introduced the TMDL process, identified the impaired segments and the reason for the impairment, reviewed historical data, described potential sources of bacteria within the watershed, and presented preliminary load allocations. In addition, the meetings gave TCEQ the opportunity to solicit input from all interested parties within the Study Area.

SECTION 7
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APPENDIX A
AMBIENT WATER QUALITY BACTERIA DATA – 1992 TO 2008

(Electronic)

APPENDIX B
FLOW DATA

(Electronic)

APPENDIX C
DISCHARGE MONITORING REPORTS FOR FLOW – 1997 TO 2007

(Electronic)

APPENDIX D
DISCHARGE MONITORING REPORTS FOR FECAL COLIFORM – 1998 TO 2007

(Electronic)

APPENDIX E
SANITARY SEWER OVERFLOWS DATA SUMMARY – 2001 TO 2003

(Electronic)

APPENDIX F
GENERAL METHODS FOR ESTIMATING FLOW AT WQM STATIONS

Appendix F
General Methods for Estimating Flow at WQM Stations

Flow duration curve analysis looks at the cumulative frequency of historic flow data over a specified period (USEPA 2007). Because stream flow conditions on any given day can be highly variable, depending on watershed characteristics and weather patterns, flow duration curves are a useful tool for characterizing the percentage of days in a year when given flows occur (USEPA 2007). To support the development of bacteria TMDLs, flow duration curves can be developed using existing USGS measured flow where the data exist at the same location as the WQM station, or by estimating flow for WQM stations with no corresponding flow record. Flow data are derived and synthesized to support preparation of flow duration curves and load duration curves for each WQM station in this report in the following priority.

USGS Gage Coincides with WQM Station

In cases where a USGS flow gage coincides with, or occurs within one-half mile upstream or downstream of the WQM station the following protocols will be employed:

a. If simultaneous daily flow data matching the water quality sample date are available, these flow measurements will be used to prepare flow exceedance percentiles.
b. If flow measurements at the coincident gage are missing for some dates on which water quality samples were collected, the gaps in the flow record will be filled, or the record will be extended, by estimating flow based on measured streamflows at a nearby gages. First, the most appropriate nearby stream gages are identified as those within a 150 km radius that have at least 300 coincident daily flow measurements. For all identified gages, four regression equations are calculated on the coincident data. The calculated regressions include a linear regression, log-linear regression, logarithmic regression and a power curve regression. For each regression, the root mean square error (RMSE) is calculated and the equation with the best fit or lowest RMSE is chosen to represent that gage. The gages are ranked in order of best fit or increasing RMSE. As many data points requiring filling as possible are filled with the best fit gage (lowest RMSE). If dates remain to be filled, the process is repeated in an iterative fashion with the second best fit gage and so forth until all dates requiring filling have been filled.

No USGS Gage Coincides with WQM Station

Where no coincident flow data are available for a WQM station, but flow gage(s) are present upstream and/or downstream, flows will be estimated for the WQM station from an upstream or downstream gage using a watershed area ratio method that includes a modification utilizing the NRCS Curve number (CN) to account for differences in watersheds (Wurbs & Sisson, 1999; Wurbs 2006). In coastal watersheds, where the choice of using an upstream or downstream station may be severely limited, it may be necessary to use a gage station from an adjacent watershed that has similar characteristics. These recent studies have demonstrated that, while flow predictions for a specific time with any flow distribution method are not highly accurate, RMSE, means and others flow characteristics can be estimated with an acceptable degree of accuracy. Since many of the flow frequencies important to a load duration curve involve the low end of the frequency range and the NRCS Curve method involves inherent limitations as flows approach the initial abstraction limit, another modification was applied to this method.

The Furness method (Furness 1959) employed by the USGS in Kansas (Studley 2000) estimates flow duration curves by estimating several descriptive statistics that describe the curve. The adaptation was included to utilize the existing period of record to calculate the flow frequency curve for an individual USGS gage, which completely describes the shape of the curve. The mean flow is then projected to the ungaged location utilizing the modified NRCS Curve method, which operates best around the mean of a distribution. Individual flow measurements and flow frequencies can then be projected to the ungaged location by normalizing them to the percent of the mean flow and multiplying the result by the newly projected mean flow for the ungaged location.

Drainage subbasins will first be delineated for all impaired 303(d)-listed WQM stations, along with all USGS flow stations located in the 8-digit HUCs with impaired streams. All the USGS gage stations will be identified that have a continuous period of record upstream and downstream of the subwatersheds with 303(d) listed WQM stations.

a. Watershed delineations are performed using ESRI Arc Hydro with a 30 m resolution National Elevation Dataset (NED) digital elevation model, and National Hydrography Dataset (NHD) streams. The area of each watershed will be calculated following watershed delineation.
b. The watershed average curve number is calculated from soil properties and land cover as described in the U.S. Department of Agriculture (USDA) Publication TR-55: Urban Hydrology for Small Watersheds. The soil hydrologic group is extracted from NRCS STATSGO soil data, and land use category from the NOAA Coastal Change Analysis Program (C-CAP). Based on land use and the hydrologic soil group, SCS curve numbers are estimated at the 30-meter resolution of the C-CAP grid as shown in Table F-1.
c. The average curve number is then calculated from all the grid cells within the delineated watershed.
d. The average rainfall is calculated for each watershed from average annual precipitation datasets for the period 1988-2007 from rainfall data obtained from Harris County Office of Emergency Management.

Table F-1 Runoff Curve Numbers for Various Land Use Categories and Hydrologic Soil Groups

C-CAP Value	C-CAP Class	Group A	Group B	Group C	Group D
2	High-Intensity Developed	89	92	94	95
3	Medium-Intensity Developed	77	85	90	92
4	Low-Intensity Developed	61	75	83	87
5	Open-Space Developed	39	61	74	80
6	Cultivated Land	67	78	85	89
7	Pasture/Hay	35	56	70	77
8	Grassland/Herbaceous	39	61	74	80
9	Deciduous Forest	30	55	70	77
10	Evergreen Forest	30	55	70	77
11	Mixed Forest	30	55	70	77
12	Scrub/Shrub	30	48	65	73
13	Palustrine Forested Wetland	0	0	0	0
14	Palustrine Scrub/Shrub Wetland	0	0	0	0
15	Palustrine Emergent Wetland	0	0	0	0
16	Estuarine Forested Wetland	0	0	0	0
17	Estuarine Scrub/Shrub Wetland	0	0	0	0
18	Estuarine Emergent Wetland	0	0	0	0
19	Unconsolidated Shore	0	0	0	0
20	Bare Land	77	86	91	94
21	Water	0	0	0	0
22	Palustrine Aquatic Bed	0	0	0	0
23	Estuarine Aquatic Bed	0	0	0	0

e. The mean flow at the ungaged site is calculated from the gaged site utilizing the modified NRCS Curve Number method (Wurbs & Sisson, 1999). The NRCS runoff curve number equation is:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

where:

Q = runoff (inches)

P = rainfall (inches)

S = potential maximum retention after runoff begins (inches)

I_a = initial abstraction (inches)

If P < 0.2, Q = 0. Initial abstraction has been found to be empirically related to S by the equation:

$$I_a = 0.2*S \qquad (2)$$

Thus, the runoff curve number equation can be rewritten:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (3)$$

S is related to the curve number (CN) by:

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

f. First, S is calculated from the average curve number for the gaged watershed. Next, the historic mean flow at the gage is converted to depth basis (as used in equations 1 and 3) by dividing by its drainage area, then converted to inches. Equation 3 is then solved for daily precipitation depth of the gaged site, P_{gaged}. The daily precipitation depth for the ungaged site is then calculated as the precipitation depth of the gaged site multiplied by the ratio of the long-term average precipitation in the watersheds of the ungaged and gaged sites:

$$P_{ungaged} = P_{gaged}\left(\frac{M_{ungaged}}{M_{gaged}}\right) \qquad (5)$$

where M is the mean annual precipitation of the watershed in inches. The daily precipitation depth for the ungaged watershed, along with the average curve number of the ungaged watershed, are then used to calculate the depth equivalent daily flow Q of the ungaged site. Finally, the volumetric flow rate at the ungaged site is calculated by multiplying by the area of the watershed of the ungaged site and converting the value to cubic feet.

g. If wastewater treatment facilities (WWTF) are located within the drainage area of the USGS gage, a base flow for the USGS gage should be calculated before projecting flow to an ungaged site. The base flow for the USGS gage is calculated by deducting the sum of the Average Monthly WWTF flow for all outfalls in the drainage area from the measured USGS flow record. The Average Monthly WWTF flows are applied for each day (1-31) of a given month.

$$Q_{baseflow} = Q_{USGSgage} - \sum_{\#wwtf}^{1} Q_{Avg.MonthlyWWTF}$$

If the base flow results in a negative value, that value is then set to zero.

h. After flow has been estimated for the ungaged site, average monthly flows from WWTFs that drain into the ungaged watershed are then added to the flow estimates.

In the rare case where no coincident flow data are available for a WQM station and no gages are present upstream or downstream, flows will be estimated for the WQM station from a gage on an adjacent watershed of similar size and properties, via the same procedure described above for upstream or downstream gages.

Furness, L.W. 1959. Kansas streamflow characteristics- part 1, Flow duration: Kansas Water Resources Board Technical Report No. 1, 213 p.

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USEPA 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006 August 2007. http://www.epa.gov/owow/tmdl/techsupp.html

Wurbs, R. A. 2006. Methods for Developing Naturalized Monthly Flows at Gaged and Ungaged Sites. Journal of Hydrologic Engineering, Vol. 11, No. 1, January 1, 2006.

Wurbs, R.A. and E. Sisson. 1999. Comparative Evaluation of Methods for Distributing Naturalized Streamflows from Gauge to Ungauged Sites. Texas Water Resources Institute, Texas A&M University, TR-179 August 1999.

APPENDIX G
FLOW EXCEEDANCE PERCENTILES FOR TMDL WQM STATIONS

(Electronic)