TECHNICAL SUPPORT DOCUMENT: BACTERIA TOTAL MAXIMUM DAILY LOADS FOR THE CLEAR CREEK WATERSHED, HOUSTON, TEXAS (1101A_01, 1101C_01, 1101E_01, AND 1102G_01)

Prepared for:

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

TCEQ

Prepared by:

University of Houston

FEBRUARY 2012

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ACRONYMS AND ABBREVIATIONS

ASAE	American Society of Agricultural Engineers
COH	City of Houston
C-CAP	Coastal Change Analysis Program
CAFO	concentrated animal feeding operation
CFR	Code of Federal Regulations
cfs	cubic feet per second
counts	colony forming unit
CN	curve number
dL	deciliter
DMR	discharge monitoring report
E. coli	Escherichia coli
EMC	event mean concentration
FDC	flow duration curve
GCHD	Galveston County Health District
GIS	geographic information system
GPS	global positioning system
HCFCD	Harris County Flood Control District
HCOEM	Harris County Office of Emergency Management
H-GAC	Houston-Galveston Area Council
LA	load allocation
LDC	load duration curve
mL	milliliter
MOS	margin of safety
MS4	municipal separate storm sewer system
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NRCS	National Resources Conservation Service
OSSF	on-site sewage facility
RMSE	root mean square error
SSO	sanitary sewer overflow
SWQS	surface water quality standards
SWQMIS	Surface Water Quality Information System
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TCOON	Texas Coastal Ocean Observation Network
TMDL	Total Maximum Daily Loads

TPDES	Texas Pollution Discharge Elimination System
TSARP	Tropical Storm Allison Recovery Project
TWDB	Texas Water Development Board
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	waste load allocation
WQM	water quality monitoring
WQS	water quality standard
WWTF	wastewater treatment facility

CHAPTER 1
INTRODUCTION

1.1 Watershed Description

The Clear Creek Watershed encompasses approximately 180 square miles of land located just southeast of the City of Houston, Texas. The Clear Creek Watershed is part of the San Jacinto-Brazos Coastal Basin. Clear Creek flows into Clear Lake (Segment 2425) which, in turn, feeds into Upper Galveston Bay (Segment 2421). Approximately 40 percent of the watershed lies within Brazoria County, 35 percent lies within Harris County, 20 percent is within Galveston County, and 5 percent of the watershed lies within Fort Bend County. These counties are part of the Northern Humid Gulf Coastal Prairies ecoregion. The eastern and central portions of the watershed are primarily urban and residential, with some commercial and industrial uses. The western and southern parts of the watershed include rural and agricultural land uses which continue to transition over time from cultivated and woody land to developed land.

Clear Creek and its tributaries have both freshwater segments and tidally influenced mixed segments. The Texas Commission on Environmental Quality (TCEQ) classified Clear Creek as two separate waterbodies, Clear Creek Tidal, Segment 1101 and Clear Creek above Tidal, Segment 1102. Unclassified waterbodies that are tributaries to Clear Creek Tidal (Segment 1101) include Robinson Bayou (Segment 1101D), which is tidally influenced, and Chigger Creek (Segment 1101B), which is not. The tidal influence within Clear Creek creates a median high tide level of 2.0 feet and an average annual peak tide of 3.3 feet above mean sea level (USACE 1985). Unclassified waterbodies that are tributaries to Clear Creek above Tidal (Segment 1102) include Cowart Creek (Segment 1102A), Mary's Creek (Segment 1102B), Hickory Slough (Segment 1102C), Turkey Creek (Segment 1102D), and Mud Gully (Segment 1102E). All the tributaries to Clear Creek above Tidal are freshwater streams.

Subwatershed List

In 2008, total maximum daily loads (TMDLs) were developed for the nine aforementioned segments in the Clear Creek Watershed. This report focuses on the following additional waterbodies that TCEQ placed in Category 5 [303(d) list] of the Draft 2010 Integrated Report for nonsupport of contact recreation use:

Magnolia Creek (1101A_01)

Cow Bayou (1101C_01)

Unnamed Tributary of Clear Creek Tidal (1101E_01)

Unnamed Tributary of Mary's Creek (1102G_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 produces watershed delineations that are slightly different than the historic delineations based on TCEQ GIS files associated with classified segments (Segments 1101 and 1102). The importance of the watershed delineations based on the TSARP subwatershed delineations and their influence on the calculation method used for establishing TMDLs, will be discussed in more detail in Section 2.4 of this report. 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 maximum daytime temperature 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 sub-tropical convection, winter rainfall by frontal storms, and fall and spring months by combinations of these two (Burian 2005). The floodplain encompasses about 10 percent of the drainage area of the watershed, approximately 12,800 acres (20 square miles) (Dunbar 1998).

Table 1-1, derived from the 2000 and 2010 U.S. Census, demonstrates that the counties in which these watersheds are located are very densely populated and shows the population growth per county (U.S. Census Bureau 2010).

Table 1-1 County Population and Density

County Name	2000 U.S. Census	2000 Population Density (per square mile)	2010 U.S. Census	2010 Population Density (per square mile)
Harris	3,400,578	1,967	4,092,459	2,367
Galveston	250,158	629	291,309	732
Brazoria	241,767	174	313,166	226
Fort Bend	354,452	405	585,375	669

The six largest cities within the Clear Creek Watershed are expected to increase in population by an average of 60.5 percent from 2000 to 2020, according to the Texas Water Development Board (TWDB) (Montgomery Watson America, Inc. 2000). Table 1-2 lists TWDB population growth estimates for these six cities from 2000 to 2020.

Table 1-2 Clear Creek Watershed Population Increases by City, 2000 to 2020

City	2000 Census Population	2010 Population	2020 Population	Growth Rate (2000-2020)
Brookside Village	1,960	2,282	2,618	34%
Friendswood	29,037	32,353	35,215	21%
League City	45,444	53,583	60,577	33%
Nassau Bay *	4,170	4,170	4,170	0%
Pearland	37,640	85,877	108,518	188%
Webster	9,083	13,076	16,946	87%

Source:http//www.twdb.state.tx.us/data/data.asp (Dec. 2011).
Projections last updated 07/22/2010.
* Possible error since projected populations are all the same.

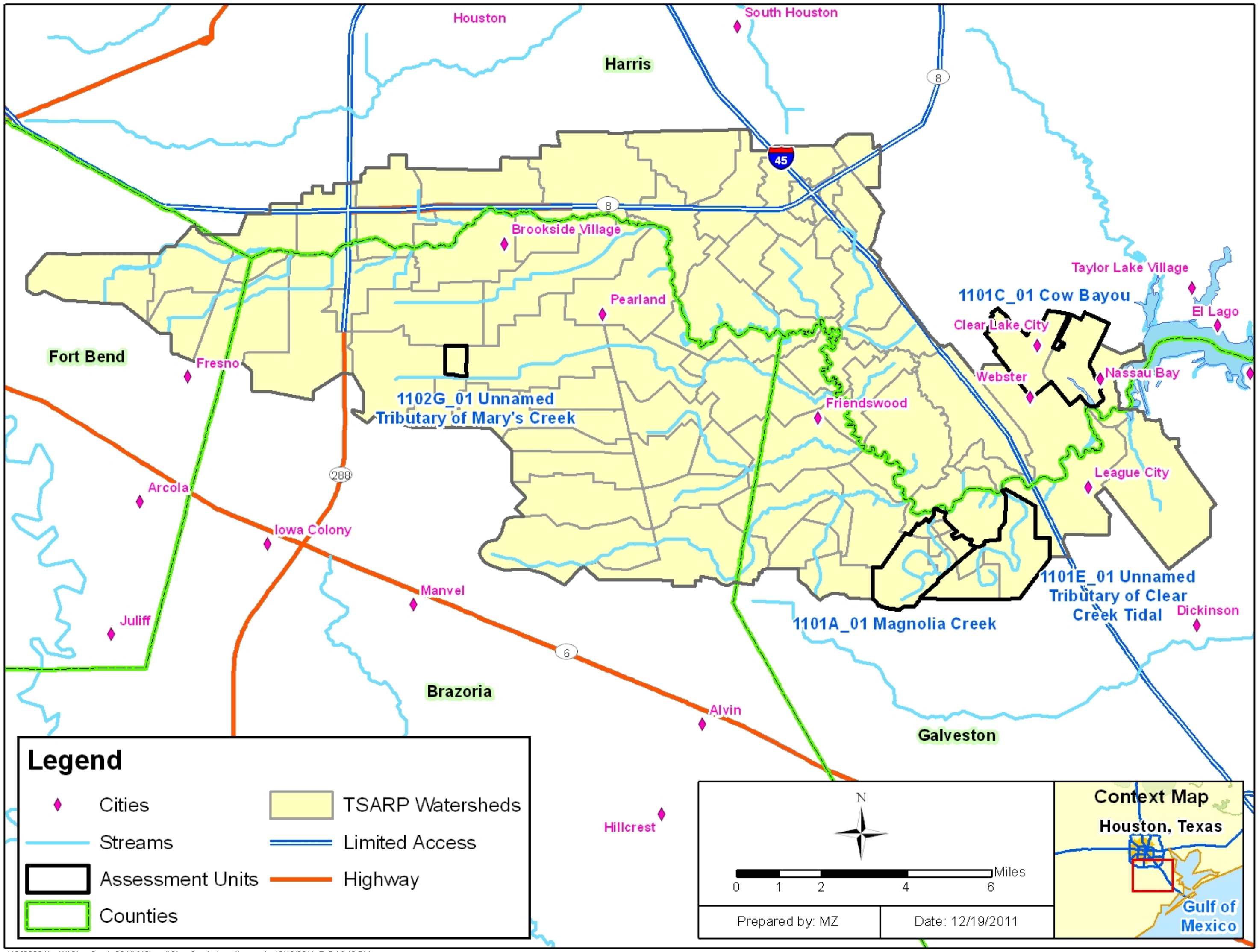

Figure 1-1 Location Map for Clear Creek Watershed

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 chemical and physical characteristics of the waterbodies using ambient water quality, stream flow, tide, and conductivity data.

1.2.1 Soil

The geology of the Clear Creek Watershed comprises unconsolidated clay, clay shale, and poorly cemented sand that extend several miles in depth (TCEQ 2005). The soil has a low water-bearing capacity, high moisture content, low permeability, and a high shrink-swell potential. The State Soil Geographic Database (STATSGO) (National Resources Conservation Service [NRCS] 1994) information was used to characterize soil in the Study Area. As can be observed in Figure 1-2, the soil types that dominate the watershed are from the Edna and Lake Charles soil series, with a very small portion composed of Mocarey soil. Table-1-3 lists the distribution and attributes of the three soil series found in the Study Area.

Table 1-3 Characteristics of Soil Types within the Clear Creek Watershed

NRCS Soil Type	Surface Texture	Soil Series Name	Hydro-logic Soil Group	Watershed	Percent of Watershed Area	Soil Drainage Class	Min Water Capacity (in/in)	Max Water Capacity (in/in)	Min Bulk Density (g/cm3)
TX162	Fine Sandy Loam	Edna-Aris-Kemah	D	Magnolia Creek (1101A_01)	36%	Somewhat Poorly Drained	0.1	0.15	1.5
				Unnamed Tributary of Clear Creek Tidal (1101E_01)	15%				
TX163	Fine Sandy Loam	Edna-Bernard-Verland	D	Magnolia Creek (1101A_01)	52%	Somewhat Poorly Drained	0.1	0.15	1.4
				Cow Bayou (1101C_01)	63%				
				Unnamed Tributary of Clear Creek Tidal (1101E_01)	13%				
TX276	Clay	Lake Charles-Bernard-Edna	D	Magnolia Creek (1101A_01)	12%	Somewhat Poorly Drained	0.15	0.2	1.2
				Unnamed Tributary of Clear Creek Tidal (1101E_01)	39%				
				Unnamed Tributary of Mary's Creek (1102G_01)	100%				
				Cow Bayou (1101C_01)	37%				
TX346	Silt Loam	Mocarey-Leton-Algoa	D	Unnamed Tributary of Clear Creek Tidal (1101E_01)	34%	Somewhat Poorly Drained	0.14	0.24	1.4

All information derived from STATSGO data
Weighted Avg Water capacity is in units of (inches of water/inch of soil)

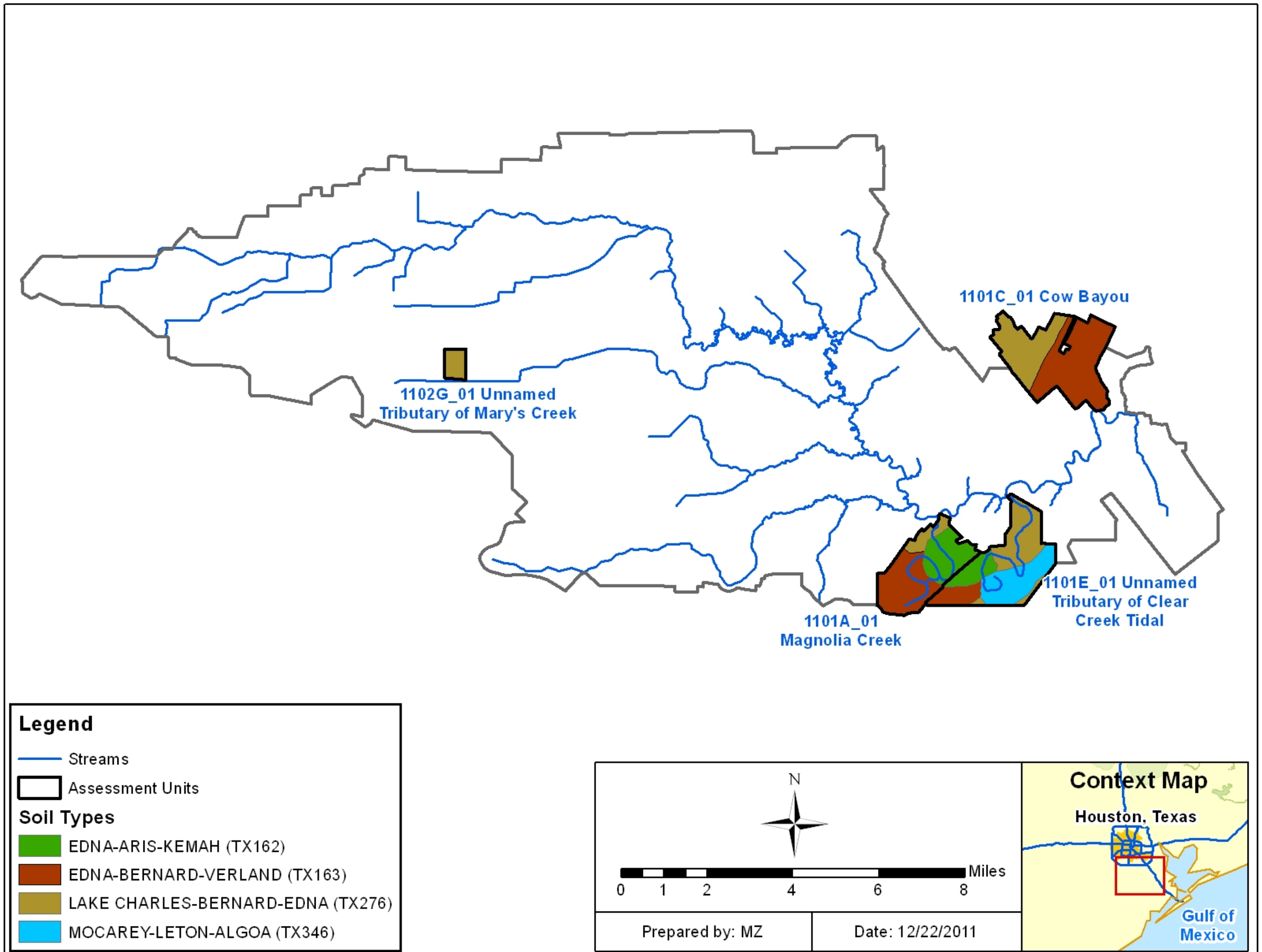

Figure 1-2 Clear Creek Region Soil Types

1.2.2 Land Use

Table 1-4 summarizes the acreages and the corresponding percentages of the land use categories for the contributing watershed associated with each subwatershed in the Clear Creek Watershed. The land use/land cover data were retrieved 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 total acreage of each segment in Table 1-4 corresponds to the watershed delineation in Figure 1-3. The predominant land use category in this watershed is developed land (between 54% and 99%) followed by pasture/hay (between 0% and 25%) and woody land (between 0% and 13%). Open water and bare/transitional land account for less than 3 percent of the assessment units.

Table 1-4 Aggregated Land Use Summaries by Segment

Aggregated Landuse Category	Segment Name and ID			
	Magnolia Creek	Cow Bayou	Unnamed Tributary of Clear Creek Tidal	Unnamed Tributary of Mary's Creek
Segment ID	1101A_01	1101C_01	1101E_01	1102G_01
Acres of Developed	1,018	2,030	1,873	222
Acres Cultivated Land	88	0	5	0
Acres Pasture/Hay	464	392	60	0
Acres Grassland/Herbaceous	48	70	80	1
Acres of Woody Land	254	92	229	0
Acres of Open Water	9	25	25	0
Acres of Wetland	13	3	67	0
Acres of Bare/Transitional	0	3	1	0
Watershed Area (acres)	**1,894**	**2,614**	**2,340**	**224**
Percent Developed	54%	78%	80%	99%
Percent Cultivated Land	5%	0%	0%	0%
Percent Pasture/Hay	25%	15%	3%	0%
Percent Grassland/Herbaceous	3%	3%	3%	0%
Percent Woody Land	13%	4%	10%	0%
Percent Open Water	0%	1%	1%	0%
Percent Wetland	1%	0%	3%	0%
Percent Bare/Transitional	0%	0%	0%	0%

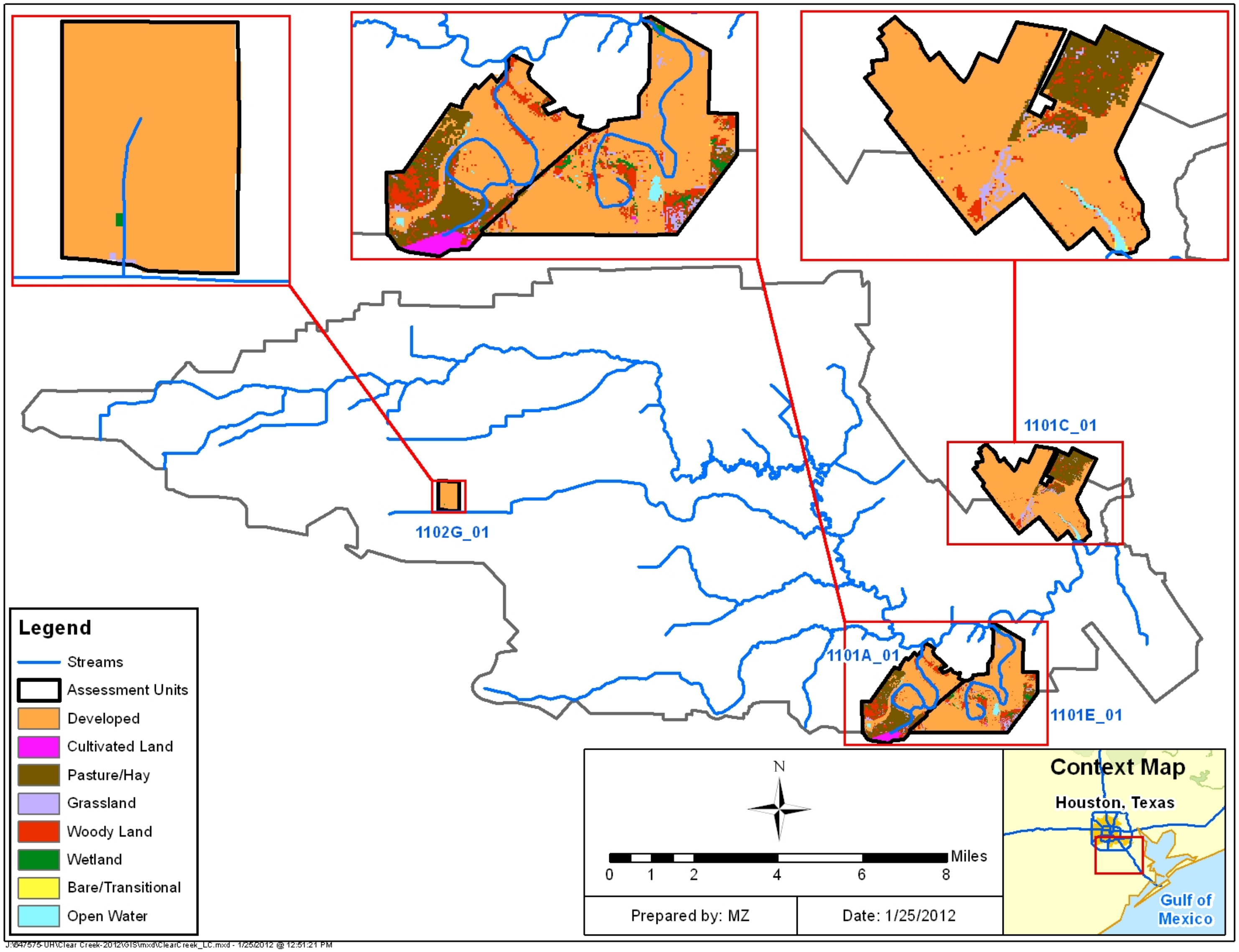

Figure 1-3 Land Use Map

1.2.3 Precipitation

There are 13 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 1-5 summarizes total annual rainfall for the three gauges for a 10-year period. The region has high levels of humidity and receives annual precipitation ranging between 21 and 78 inches per year (Table 1-5). Based on data for the period 1999 to 2009, the watershed average is around 54.6 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 1-6. These average values were used to support the development of flow duration curves (Section 4).

Table 1-5 Annual Totals at Rainfall Gages in Clear Creek Watershed

Gage number *	Year											Average
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	
Gage 105	N/A	46.9	78.1	68.7	53	55.6	36.3	62.2	69.7	53.6	52.7	57.7
Gage 110	30.9	52	77	81.3	59.4	58.7	39.0	57.6	68.9	43.9	56.9	56.9
Gage 115	N/A	48.6	56.4	70.6	N/A	62.7	26.1	60.7	66.2	44.3	57.5	54.8
Gage 120	35.7	35.1	74.7	77.9	52.5	64.2	37.0	63.5	63.5	48.5	68.1	56.4
Gage 125	N/A	36.3	72.6	78	53	64	35.7	62.4	64.3	52.6	56.8	57.6
Gage 130	N/A	45.3	80.4	75	55.3	67.1	36.1	64.2	64.9	35.4	56.7	58.0
Gage 135	N/A	N/A	N/A	79.9	42.6	59.9	41.5	65.9	61.3	44.4	49.4	55.6
Gage 140	34.9	46.2	69.3	68	47	59	34.3	64.4	70.5	35.0	31.5	50.9
Gage 150	35.6	49.9	77.4	62.1	37	59.4	33.1	68.4	77.7	39.8	50.5	53.7
Gage 160	32.8	45.7	64.5	74.9	48.7	59.4	33.8	64.9	70.6	N/A	52.0	54.7
Gage 170	31.4	38.5	60.9	61.6	54.3	57.7	36.0	58.9	59.1	67.6	50.6	52.4
Gage 180	47.1	23.6	80.5	69.5	48.9	57.3	33.8	55.6	66.3	N/A	50.6	53.3
Gage 190	48.2	42	65.9	58.8	46.7	55.1	33.5	48.5	62.4	32.5	37.6	48.3
Average rainfall across watershed (inches)												**54.6**

Table 1-6 Average Annual Precipitation in Clear Creek Subwatersheds, 1988-2007 (in inches)

Segment Name	Segment ID	Average Annual (Inches)
Magnolia Creek	1101A_01	55.26
Cow Bayou	1101C_01	54.10
Unnamed Tributary of Clear Creek Tidal	1101E_01	55.20
Unnamed Tributary of Mary's Creek	1102G_01	50.25

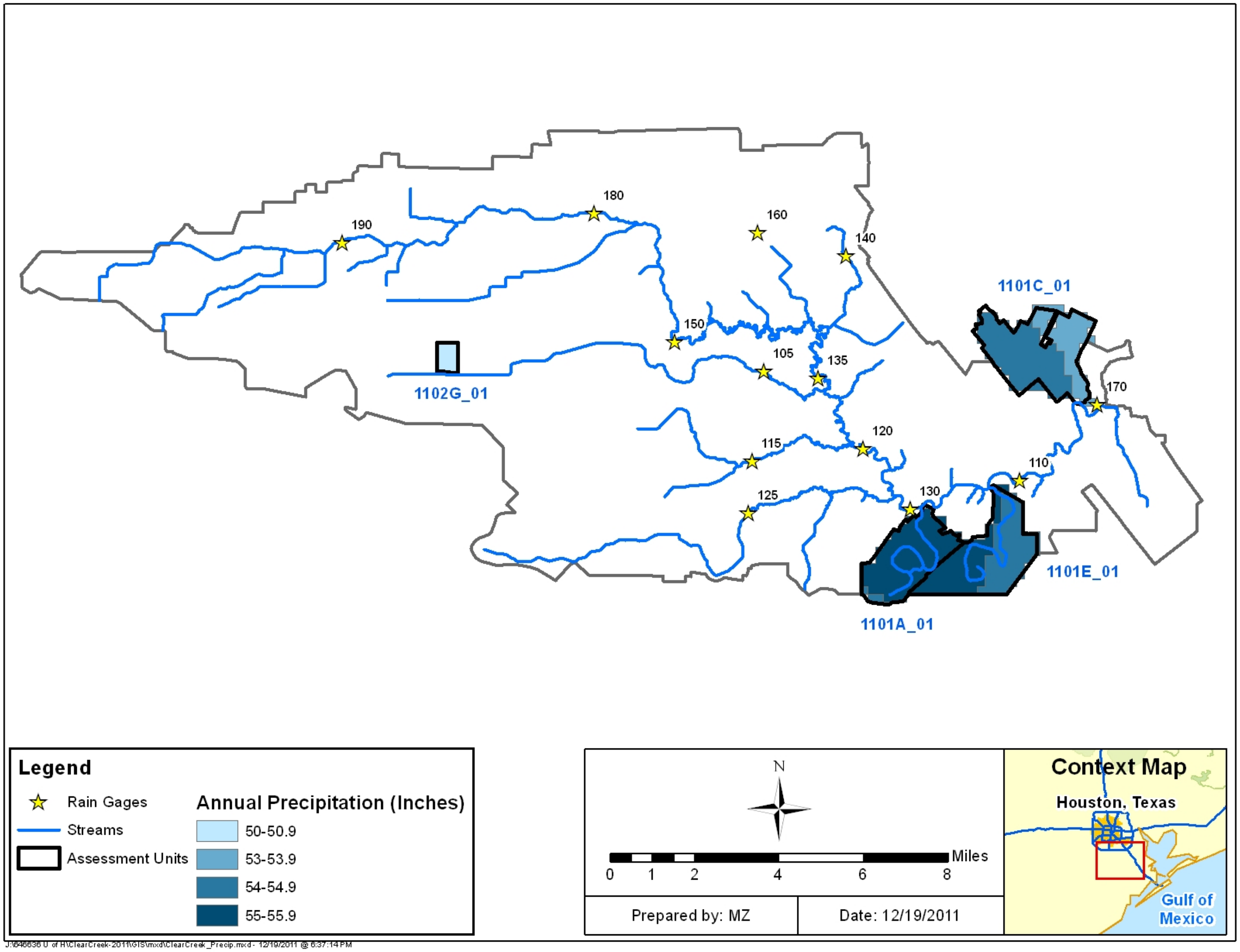

Figure 1-4 Precipitation Map

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 Clear Creek Watershed. Historical indicator bacteria data for the period 2002 to 2011 were obtained from the TCEQ SWQMIS database, which includes results from the sampling events conducted under this project in 2006. Forty-nine percent of the data correspond to Enterococci (78 samples), 42 percent correspond to *E. coli* concentrations (66 samples), while 9 percent correspond to fecal coliform concentrations (15 samples).

Table 1-7 summarizes the historical ambient water quality data for indicator bacteria (2002-2011) for select TCEQ Water Quality Monitoring (WQM) stations in the Clear Creek Watershed. Figure 1-5 shows the locations of the WQM locations with indicator bacteria data. The complete ambient water quality data set for bacteria used to prepare Table 1-7 is provided in Appendix A. Table 1-7 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 data set is provided in Subsections 2.3 and 2.4.

Table 1-7 Historical Water Quality Data for TCEQ Stations from 2002 to 2011

Segment	Station ID	Indicator Bacteria	Geometric Mean Concentration (MPN/100ml)	Number of Samples	Number of Samples Exceeding Single Sample Criterion	% of Samples Exceeding
1101A_01	16611	EC	548	31	17	55%
		ENT	2721	26	26	100%
1101C_01	17928	EC	424	20	10	50%
		ENT	99	26	13	50%
1101E_01	18818	ENT	4658	26	26	100%
1102G_01	18636	FC	359	15	7	47%
		EC	326	15	5	33%

EC: E. coli, FC: Fecal Coliform; ENT: Enterococci
Geometric Mean Criteria: 126 MPN/100 ml for EC, 35 MPN/100 ml for ENT, 200 MPN/100 ml for FC.
Single Sample Criteria: 399 MPN/100 ml for EC, 104 MPN/100 ml for ENT, 400 MPN/100 ml for FC.
Highlighted stations are tidally influenced. A tidal prism model approach, rather than load duration curve analysis, is applied to WQM stations that are tidally influenced.

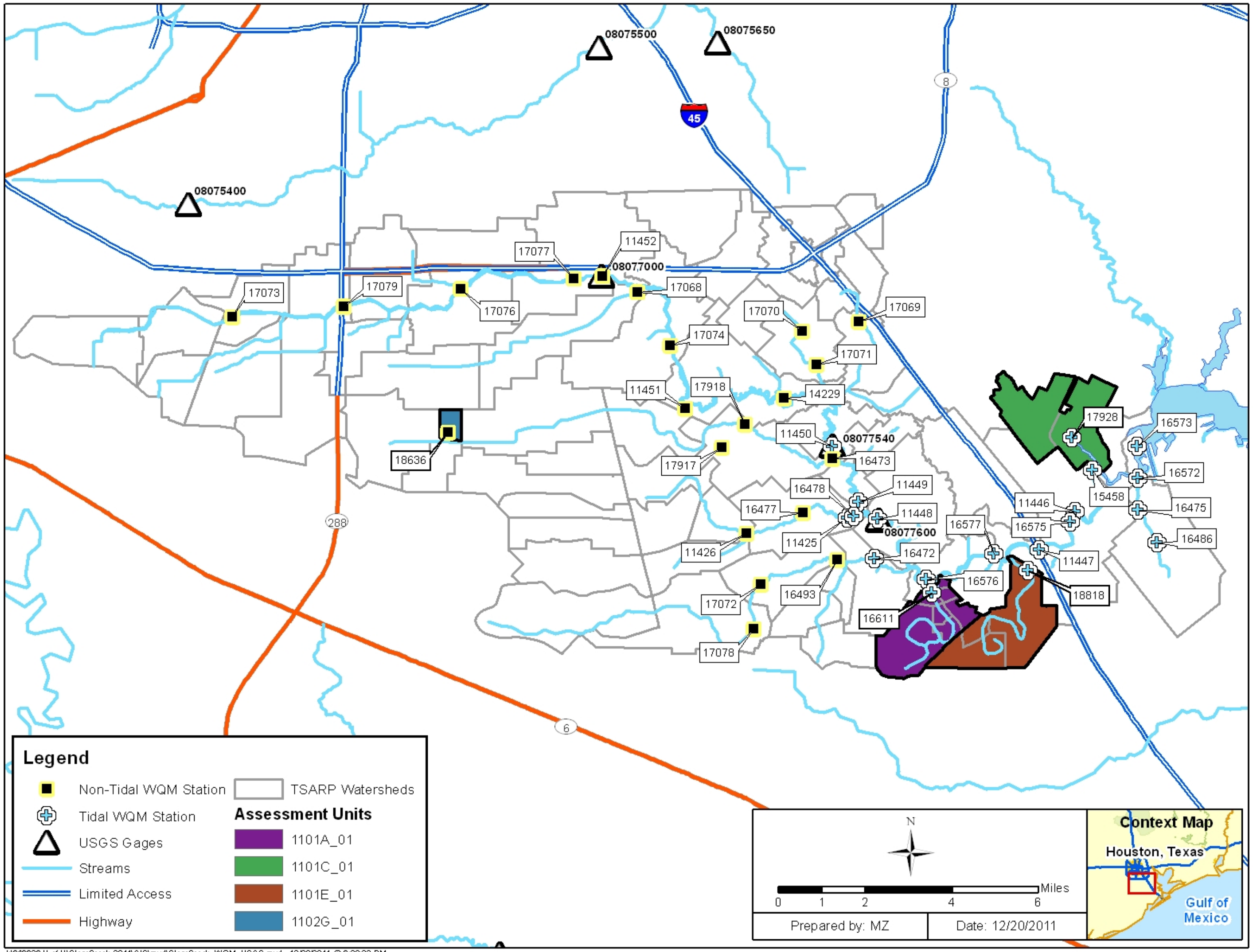

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Figure 1-5 WQM Station Locations

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) has operated flow gages at three locations along Clear Creek to measure flow and elevations. The period of record and type of data collected at these gages are listed from upstream to downstream in Table 1-8. The locations of these gage stations are shown on Figure 1-5. The limited historical flow data available from these stations are summarized as flow exceedance percentiles in Appendix B.

Table 1-8 USGS Gages in the Clear Creek Watershed

USGS Gage Number	Name	Period of Record	Data Type
08077000	Clear Ck nr Pearland, TX	8/1/1944 - 9/4/1994	Discharge (cfs)
08077540	Clear Ck at Friendswood, TX	10/18/1994- 4/26/1997	Peak Stream flow (cfs)
08077600	Clear Ck nr Friendswood, TX	8/27/1997 - present	Elevation (ft)[a]

[a] *tidal gage*

The most downstream USGS station on Clear Creek, 08077600, is currently the only active gage in the watershed; however, because it is on a tidally influenced reach, it records water surface elevation but not stream flow. This lack of current, long-term flow data for Clear Creek above Tidal and its tributaries does presents complications when attempting to conduct estimates of pollutant fate and transport. However, flow projections can be estimated for the freshwater streams in the Clear Creek Watershed using long-term flow records from USGS gage stations in surrounding watersheds. Consequently, it was necessary to expand the data compilation and analysis of flow data to USGS gage stations from watersheds nearby in the Houston metropolitan area. As such, other USGS gages just north of the Clear Creek Watershed in Harris County were analyzed in search of flow data for a continuous period of record from 2000 through 2010. Using the most recent 10-year period of record was considered the most ideal data set since it would reflect current hydrologic conditions, meteorological characteristics, and a 10-year period was considered sufficient to account for seasonal variability. Furthermore, the time period of 2000 through 2010 was chosen as the 10-year period since instream bacteria samples and discharge monitoring reports (DMR) for wastewater treatment facilities were available for the same time period as well.

Nearby watersheds with similar precipitation patterns, drainage areas, and NRCS curve numbers are expected to produce similar area-normalized natural stream flows, though wastewater discharges will tend to alter low stream flows. The curve number (CN) reflects the efficiency of surface runoff from the land surface based on land use and soil properties. Because of its proximity and general similar characteristics, USGS station 080875400 in Sims Bayou was selected for predicting streamflows in the Clear Creek Watershed. Table 1-9 summarizes the drainage area, curve number, annual precipitation, and mean flow calculated for USGS gage station 080875400 in Sims Bayou. The location of this station is also displayed in Figure 1-5. The historical flow data available from this station is summarized as a flow exceedance percentile in Appendix B.

Table 1-9 USGS Gage 080875400 in Sims Bayou

Gage Number	Name	Drainage Area (sq. miles)	CN	Annual Average Precipitation (in.)	Mean Flow (cfs)	Number of Continuous Data Points
08075400	Sims Bayou at Hiram Clarke St, Houston, TX	20.7	83.2	50.3	45.1	3605

Instantaneous flow was measured at 2 locations in the tidal segments of Clear Creek during intensive surveys, instream sampling and storm sampling conducted during summer 2006. Historical flow data measured at the same time as bacteria samples were being collected were also compiled from the TCEQ SWQMIS database to assist with characterizing stream flows. Table 1-10 lists the stations where instantaneous flow measurements were collected. The complete set of instantaneous flow data is provided in Appendix B.

Table 1-10 Historical Number of Flow Measurements in the Study Area

Segment	Station	Number of Flow Measurements	
		2006 Intensive Survey and In-Stream Sampling	Additional measurements from 1996 – 2011 in SWQMIS database
1101A_01	16611	22	13
1101E_01	18818	24	

1.2.6 Tide Data

Tide data were compiled to support the assessment and modeling of bacteria loading in the tidal segments of Clear Creek. There are two water level elevation gages in the tidal portion of Clear Creek. The Texas Coastal Ocean Observation Network (TCOON) operates station 502 at Clear Lake and the USGS operates USGS gage 08077600 at Clear Creek near Friendswood. One hour gage data for the period of 1/01/2000 – 09/13/2008 were downloaded from TCOON for station 502 at Clear Lake (http://lighthouse.tamucc.edu/overview/502) to support modeling of the tidal segments. Because the tidal prism model extends up to 12/31/2010 and the period of record for TCOON station ends on 09/13/2008, tide data for station 502 at Clear Lake, was augmented with data for TCOON station 507 at Eagle Point for the period 09/14/2008 – 12/31/2010 (an adjustment of 0.09 m was applied to the Eagle Point data to account for the difference in tide height at the two locations).

1.3 Clear Creek 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 1-11) and the following criteria were used to divide the data sets into warmer (24 – 32°C) and cooler months (12 – 18°C). Based on these temperature ranges, November, December, January, and February were cooler months, and May, June, July, August, and September were warmer months.

Table 1-11 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 6 or more samples. Geometric means were also calculated for the warmer and cooler months. Table 1-12 shows seasonal variation for two stations for *E.Coli* and Enterococci.

For *E. coli*, only one station (16611) had more than 6 samples to conduct the analysis for both cooler and warmer months. For that station, the geometric mean of the samples for colder months was 615 counts/dL (8 samples), while the geometric mean for the warmer months was 537 counts/dL (11 samples).

For Enterococci, only one station (17298) had more than 6 samples to conduct the analysis for both cooler and warmer months. For that station, the geometric mean of the samples for colder months was 243 counts/dL (6 samples), while the geometric mean for the warmer months was 77 counts/dL (11 samples).

Table 1-12 Seasonal Differences for *E. coli* and Enterococci Concentrations

Segment	Station ID	Indicator	Warm Months		Cold Months		*p*-value
			n	Geomean	n	Geomean	
1101A_01	16611	EC	11	537	8	615	0.75
1101C_01	17298	ENT	11	77	6	243	0.08

n = number of samples
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 counts/dL.

CHAPTER 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 the 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 an indicator of the potential presence of fecal contamination (USEPA 1986). The USEPA-recommended criteria for recreational waters in 1976 included a geometric mean criterion: no more than 200 counts/dL 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 counts/dL (USEPA 1986). Shortly thereafter, these recommended criteria were adopted by the State of Texas in its SWQSs. 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. The USEPA recommended new criteria for swimming areas, using *E. coli* and Enterococci as new fecal indicator organisms, and incorporating the idea of varying criteria with the level of swimming use.

In Texas, three indicator bacteria are analyzed in water samples collected to determine support of the contact recreation use: fecal coliform and *E. coli* in freshwater and fecal coliform and Enterococci in marine waters. *E. coli* and Enterococci bacteria are measured to determine the relative risk of contact recreation, depending on whether the water body is fresh or marine. The presence of these bacteria indicates that associated pathogens from the fecal waste of warm-blooded species (human or animal) may be reaching 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 bacteria in water indicate there may be an increased risk of becoming ill from recreational activities.

Texas water quality standards (WQS) 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 has 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 four waterbodies within the Clear Creek Watershed that are on the federal Clean Water Act §303(d) list because they do not support contact recreation use. Table 2-1 summarizes the designated uses and the applicable bacteria indicators 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' Clean Water Act §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 Clear Creek Watershed

Segment ID	Segment Name	Parameter	Designated Use*				Year Impaired	Stream Length (miles)
			CR	AL	GU	FC		
1101A_01	Magnolia Creek	*E. coli* **	NS	S			2010	4.8
1101C_01	Cow Bayou	ENT	NS	S			2010	2
1101E_01	Unnamed tributary of Clear Creek Tidal	ENT	NS	S			2010	1.9
1102G_01	Unnamed tributary of Mary's Creek	*E. coli*	NS	S			2010	0.75

* *CR: Contact recreation; AL: Aquatic Life; GU: General Use; F: Fish Consumption; NS: Nonsupport, ENT: Enterococci, NS = Non Support; S = Support*

***Magnolia Creek is tidally influenced, but has relatively low salinity levels. Hence, the selection of E. coli as bacteria indicator.*

The excerpts below from Chapter 307, Texas SWQS (TCEQ 2010) stipulate how water quality data were assessed to determine support of 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 Clear Creek Watershed will also adhere to §307.5 of the SWQS which defines the antidegradation policy and procedures that apply to authorized wastewater discharges, TMDLs, waste load 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 2010).

§307.7. Site-specific Uses and Criteria.

(a) Uses and numerical criteria are established on a site-specific basis in Appendices A,B,D,E,F and G of §307.10 of this title (relating to Appendices A - G). 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 human activities. 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 four categories – primary contact recreation, secondary contact recreation 1, secondary contact recreation 2, and noncontact recreation waters. Classified segments are designated for primary contact recreation unless sufficient site-specific information demonstrates that elevated concentrations of indicator bacteria frequently occur due to sources of pollution which cannot be reasonably controlled by existing regulations, wildlife sources of bacteria are unavoidably high and there is limited aquatic recreational potential, or primary or secondary 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 primary or secondary 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 bacteria per 100 milliliters (ml) of water (in terms of colony forming units, most probable number, or other applicable reporting measures). Even where the concentration of indicator bacteria is less than the criteria for primary or secondary 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 TCEQ Guidance for Assessing and Reporting Surface Water Quality Data in Texas, as amended.

(A) Freshwater

(i) Primary contact recreation. The geometric mean criterion for E. coli is 126 per 100 mL. In addition, the single samples criterion for E. coli is 399 per 100 mL.

(ii) Secondary contact recreation 1. The geometric mean criterion for E. coli is 630 per 100 mL.

(iii) Secondary contact recreation 2. The geometric mean criterion for E. coli is 1,030 per 100 mL.

(iv) Noncontact recreation. The geometric mean criterion for E. coli is 2,060 per 100 mL.

(v) For high saline inland water bodies where Enterococci is the recreational indicator for instream bacteria sampling at all times for the classified water body and for the unclassified water bodies that are within the watershed of that classified segment, unless it is demonstrated that an unclassified water body is not high saline. E. coli is the applicable

recreational indicator for instream bacteria sampling at all times for unclassified water bodies where conductivity values indicate that the water bodies are not high saline. For high saline water bodies with primary contact recreation, the geometric mean criterion for Enterococci is 33 per 100 ml and the single sample criterion is 78 per 100 ml. For high saline inland waters with secondary contact recreation 1, the geometric mean criterion for Enterococci is 165 per 100 ml. For high saline inland waters with secondary contact recreation 2, the geometric mean criterion for Enterococci is 270 per 100 ml. For high saline inland water bodies with noncontact recreation, the geometric mean criterion for Enterococci is 540 per 100 ml.

(B) Saltwater

(i) Primary contact recreation. The geometric mean criterion for Enterococci is 35 per 100 mL. In addition, the single sample criterion for Enterococci is 104 per 100 mL.

(ii) Secondary contact recreation 1. A secondary contact recreation 1 use for tidal streams and rivers can be established on a site-specific basis in §307.10 of this title if justified by a use-attainability analysis and the water body is not a coastal recreation water as defined in the Beaches Environmental Assessment and Coastal Health Act of 2000 (BEACH Act). The geometric mean criterion for Enterococci is 175 per 100 mL.

(iii) Noncontact recreation. A noncontact recreation use for tidal streams and rivers can be established on a site-specific basis in §307.10 of this title if justified by a use-attainability analysis and the water body is not a coastal recreation water as defined in the BEACH Act. The geometric mean criterion for Enterococci is 350 per 100 mL.

(C) Fecal coliform bacteria. Fecal coliform bacteria can be used as an alternative instream indicator of recreational suitability in high saline inland water bodies where Enterococci is the designated recreational indicator in Appendix A of §307.10 of this title for two years after the adoption of this title to allow time to collect sufficient data for Enterococci. Fecal coliform criteria for high saline inland water bodies are as follows:

(i) Primary contact recreation. The geometric mean criterion for fecal coliform is 200 per 100 mL. In addition, single sample criterion for fecal coliform is 400 per 100 mL.

(ii) Secondary contact recreation 1 and 2. The geometric mean criterion for fecal coliform is 1,000 per 100 mL.

(ii) Noncontact recreation. The geometric mean criterion for fecal coliform is 2,000 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 USEPA 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.

As stipulated in 2010 *Guidance for Assessing and Reporting Surface Water Quality in Texas* (TCEQ 2010), 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.

2010 Guidance for Assessing and Reporting Surface Water Quality in Texas (TCEQ 2010)*:*

- *All assessment methods based on the average will require 10 samples for listing and delisting, although in rare instances the assessor will make the use attainment decision with fewer samples and indicate this by reporting a data set qualifier of JQ (based on judgment of the assessor)..*
- *The 2010 assessment period of record for the last seven years is December 1, 2001 through November 30, 2008. Samples from these seven years are evaluated when available, if necessary; the most recent samples collected in the preceding three years (December 1, 1998 through November 30, 2000) 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 2010 Texas Water Quality Inventory and §303(d) List (TCEQ 2010). Between 1996 and 2010 as the TCEQ WQSs and water quality assessment method were modified and additional water quality data were collected throughout the Clear Creek Watershed, areas of impairment were added to the §303(d) List. 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 waterbodies requiring the TMDLs were first listed in 2010. The locations of these WQM stations are displayed in Figure 2-1 and on this map each station is designated as a tidal or non-tidal station.

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, and Enterococci for marine waters;
- 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, the historical data set used to support the TMDLs in this report have been narrowed, wherever possible, to utilize only *E. coli* and Enterococci data from 2002 through 2011. In situations where there were an insufficient number of samples for *E. coli* or Enterococci to conduct adequate data analyses, fecal coliform data were utilized.

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

Segment	Water Body	Description	Monitoring Station IDs	Year
1101A_01	Magnolia Creek	From the Clear Creek Tidal confluence upstream 7.7 km (4.8 mi)	16611	2010
1101C_01	Cow Bayou	From the Clear Creek Tidal confluence to SH3	17928	2010
1101E_01	Unnamed tributary of Clear Creek Tidal	From the Clear Creek Tidal confluence to a point 3.0 km (1.9 mi) upstream	18818	2010
1102G_01	Unnamed tributary of Mary's Creek	From the Mary's Creek confluence 1.3 km (0.84 mi) west of FM 1128 to a point 1.2 km (0.75 mi) upstream to the confluence of an unnamed tributary	18636	2010

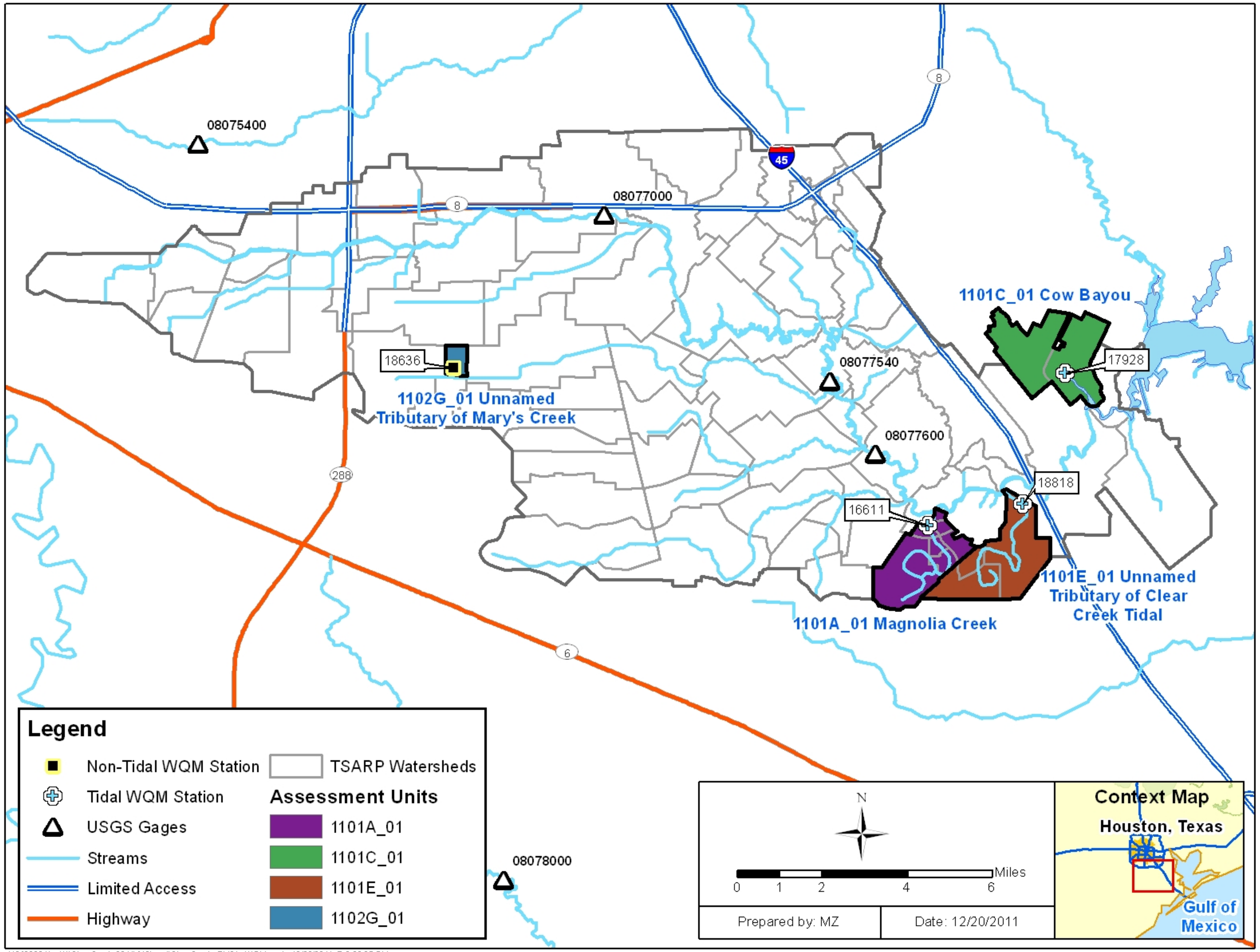


Figure 2-1 TCEQ WQM Stations in the Clear Creek Watershed

Table 2-3 summarizes the ambient water quality data for the TCEQ WQM stations on each impaired waterbody. From these data results, 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 Stations from 2002 to 2011

Segment	Station ID	Indicator Bacteria	Geometric Mean Concentration (MPN/100ml)	Number of Samples	Number of Samples Exceeding Single Sample Criterion	% of Samples Exceeding
1101A_01	16611	EC	548	31	17	55%
		ENT	2721	26	26	100%
1101C_01	17928	EC	424	20	10	50%
		ENT	99	26	13	50%
1101E_01	18818	ENT	4658	26	26	100%
1102G_01	18636	FC	359	15	7	47%
		EC	326	15	5	33%

EC: E. coli, FC: Fecal Coliform; ENT: Enterococci
Geometric Mean Criteria: 126 MPN/100 ml for EC, 35 MPN/100 ml for ENT, 200 MPN/100 ml for FC.
Single Sample Criteria: 399 MPN/100 ml for EC, 104 MPN/100 ml for ENT, 400 MPN/100 ml for FC.
Highlight indicates the indicator bacteria selected as water quality target.

Magnolia Creek (Segment 1101A_01): The single sample criteria for *E. coli* and Enterococci were exceeded in 55 percent and 100 percent of the samples, respectively at the only WQM station location within this subwatershed. The geometric mean criteria for both *E. coli* and Enterococci were also exceeded.

Cow Bayou (Segment 1101C_01): The single sample criteria for *E. coli* and Enterococci were exceeded in 50 percent of the samples at the only WQM station location within this subwatershed. The geometric mean criteria for both *E. coli* and Enterococci were also exceeded.

Unnamed Tributary of Clear Creek Tidal (Segment 1101E_01): The single sample criteria for Enterococci was exceeded in 100 percent of the samples at the only WQM station location within this subwatershed. The geometric mean criteria for Enterococci was also exceeded.

Unnamed Tributary of Mary's Creek (Segment 1102G_01): The single sample criterion for *E. coli* was exceeded in 33 percent of the samples collected at the only WQM station location within this subwatershed. The geometric mean criterion for *E. coli* was also exceeded.

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 2010) 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 2010 Texas SWQSs as described in Subsection 2.2 above. *E. coli* is the preferred indicator bacteria for assessing contact recreation use in freshwater, and Enterococci is the preferred indicator bacteria is saltwater.

Several studies have been performed by the USEPA that show a stronger link between the concentrations of *E. coli* and Enterococci 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 399 per dL for single samples of *E. coli* and a geometric mean limit of 126 per dL for waterbodies that have been designated for contact recreation use. Within tidal streams and saltwater bodies, however, the USEPA determined that Enterococci concentrations were the strongest predictor of illness. The TCEQ adopted a limit of 104 per dL for Enterococci in any single sample, and a limit of 35 per dL for the geomean of all samples at any location for Enterococci concentrations within a tidal stream designated for contact recreation uses (TCEQ 2010).

The water quality target for the TMDLs for freshwater segments is to maintain concentrations below the geometric mean criterion of 126 counts per dL for *E. coli*. The water quality target for the TMDLs for tidal (saltwater) segments is to achieve concentrations of Enterococci below the geometric mean criterion of 35 counts per dL. The tidal segments are Magnolia Creek, Cow Bayou, and Unnamed Tributary of Clear Creek Tidal. 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 the attainment of the contact recreation use. TMDLs will be based on a percent reduction goal required to meet the geometric mean criterion.

The water quality target for each waterbody will incorporate an explicit 5 percent margin of safety (MOS). For example, if *E. coli* is utilized to establish the TMDL, then the water quality target would be 379 counts/dL, 5 percent lower than the single sample water quality criterion (399 counts/dL) and the geometric mean water quality target would be 120 counts/dL, 5 percent lower than the criterion value (126 counts/dL). For Enterococci, the single sample water quality target would be 99 counts/dL and the geometric mean water quality target would be 33 counts/dL, both 5 percent lower than the criterion values.

For non-tidal segments, each water quality target will be used to determine the allowable bacteria load that is derived by using the actual or estimated flow record multiplied by the instream criteria minus a 5 percent MOS. For tidal segments, a mass-balance model will be used to determine the maximum amount of loading discharged to the water bodies that result in meeting the geometric mean criteria throughout the length of the segment.

CHAPTER 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* and Enterococcus 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 municipal separate storm sewer systems (MS4). 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 (municipal separate 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.

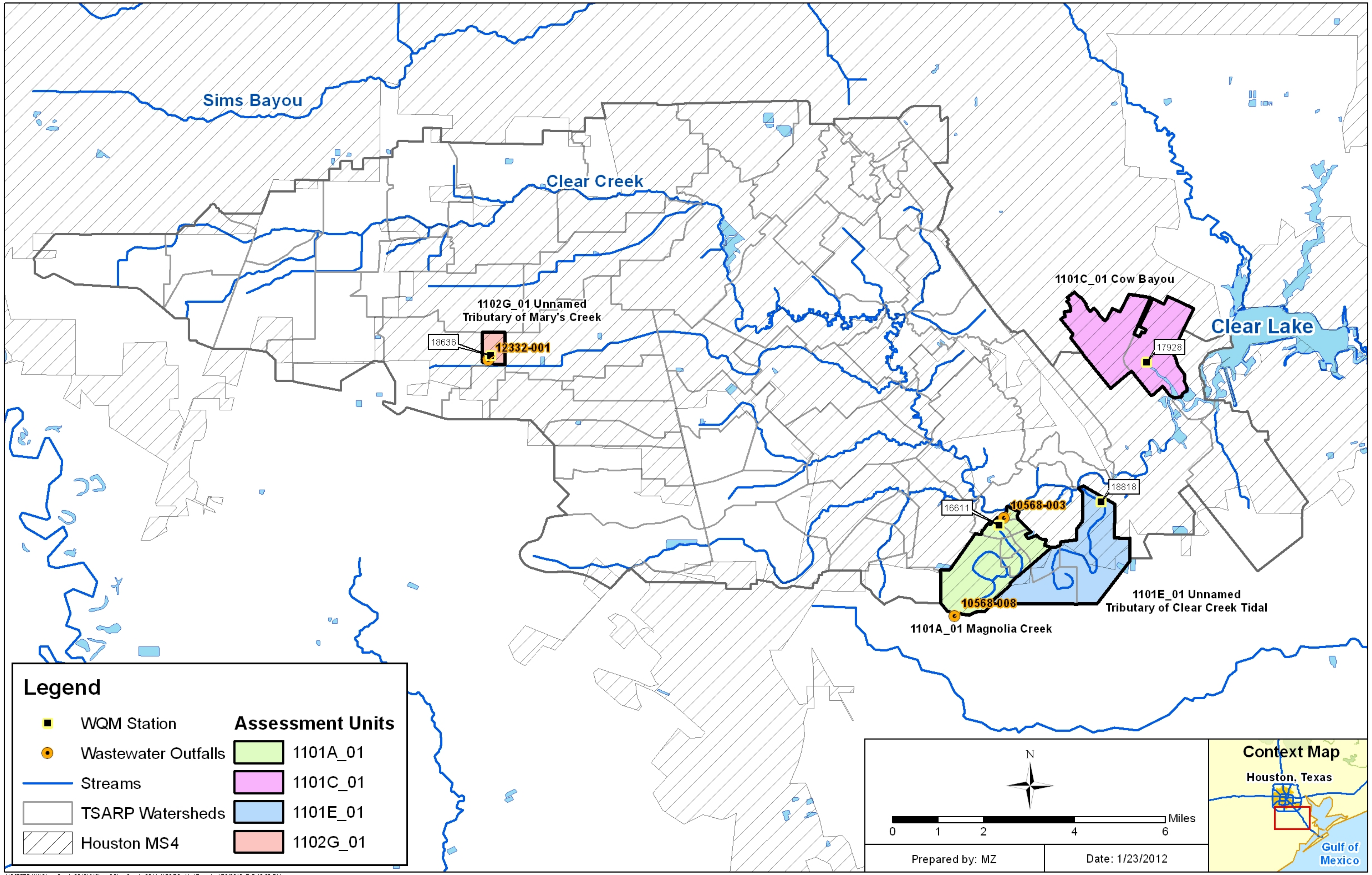
Two watersheds in the Study Area, including Magnolia Creek (1101A_01) and Unnamed Tributary of Mary's Creek (1102G_01) have NPDES/TPDES-permitted sources. A significant portion of the Study Area is regulated under the TPDES storm water discharge permit jointly held by

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 two TPDES-permitted facilities that continuously discharge wastewater to surface waters addressed in these TMDLs as shown in Figure 3-1. In addition, a third WWTF (City of League City, Southwest Water Reclamation WWTP) has been permitted and is being built. Table 3-1 lists the TPDES-permitted facilities for which wasteload allocations will be developed under this TMDL study. There are no WWTFs located in Cow Bayou (1101C_01) or Unnamed Tributary of Clear Creek Tidal (1101E_01) watersheds.

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* and Enterococci bacteria, permit limits are based on levels of fecal coliform, another measure of fecal bacteria of which *E. coli* is often the major constituent. Table 3-2 summarizes self-reporting data available for the two existing facilities in the Study Area. DMRs were used to determine the number of fecal coliform analyses that were performed for the two TPDES WWTFs (See Appendix D for self-reported data). The 90th percentile of the monthly average load and the maximum monthly average loads are provided to estimate fecal coliform loads from these two TPDES WWTPs. Table 3-3 lists the number of reported monthly exceedances of the geometric mean concentration of 200 counts/dL, and the number of reported daily exceedances of the single sample standard of 400 counts/dL. As shown in Table 3-3, neither permitted facility exceeded fecal coliform permit limits during the monitoring time frame.



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 Clear Creek Watershed

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

Segment	Receiving Water	TPDES Number	NPDES NUMBER	Facility Name	Facility Type	DTYPE	County	Permitted Flow (MGD)	Average Monthly Flow (MGD)
1101A_01	Magnolia Creek	10568-003	TX0071447	City of League City	Sewerage Systems	D	Galveston	0.66	0.44
1101A_01	Magnolia Creek	10568-008	TX0133043	City of League City; Southwest Water Reclamation WWTP	Sewerage Systems	W	Galveston	12	N/A
1102G_01	Unnamed Tributary of Mary's Creek	12332-001	TX0086118	Brazoria County Mud No. 3	Sewerage Systems	W	Brazoria	2.4	0.86

Source: TCEQ Wastewater Outfall Shapefile, June 2011
MGD - Millions of Gallons per Day; TYPE: D = Domestic < 1 MGD; W=Domestic >= 1 MGD; N/A: Not available, facility is under construction

Table 3-2 DMR Data for Permitted Wastewater Discharges (June 1998-September 2001)

TPDES Number	NPDES Number	Facility Name	Segment	Stream Name	Dates Monitored		# of Records	Monthly Average Flow (MGD)	Permitted Flow (MGD)	FC Daily Load (cfu)	
					Start	End				90 Percentile Monthly Average	Maximum Monthly Average
10568-003	TX0071447	City of League City	1101A_01	Magnolia Creek	03/30/99	09/30/01	4	0.44	0.66	8.99E+09	9.99E+09
12332-001	TX0086118	Brazoria County Mud No.3	1102G_01	Unnamed Tributary of Mary's Creek	06/30/98	03/31/00	8	0.86	2.4	3.27E+10	3.63E+10

Source: EPA, PCS monitoring data search August 2011; Notes: FC = Fecal Coliform, NA = Not Applicable, MGD = Millions of Gallons per Day, counts = Colony Forming Unit

Table 3-3 Fecal Coliform Exceedance Data for Permitted Wastewater Discharges (June 1998-September 2001)

Facility Name	TPDES Number	NPDES Number	Number of Records	# of MCMX Exceedances	# of MCAV Exceedances	% of MCMX Exceedances	% of MCAV Exceedances
City of League City	10568-003	TX0071447	4	0	0	0%	0%
Brazoria County Mud No. 3	12332-001	TX0086118	8	0	0	0%	0%

Source: EPA, PCS monitoring data search August 2011; Notes: 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 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. The TCEQ maintains a database of SSO data collected from wastewater operators in the Clear Creek Watershed. TCEQ Region 12-Houston provided two database queries for SSO data – one is collected by the City of Houston and the other is compiled from the remainder of the wastewater dischargers in the Clear Creek Watershed (Rice 2005). These data are included in Table 3-4. As can be seen from Table 3-4, there were three sanitary sewer overflows reported in the Unnamed Tributary of Clear Creek Tidal (1101E_01) in February 2004. The SSOs were caused by a collapsed line. The locations and magnitudes of the reported SSOs are displayed in Figure 3-2. The WWTF service area boundaries are also shown in Figure 3-2.

Table 3-4 Sanitary Sewer Overflow (SSO) Summary

Facility Name	NPDES Permit No.	Facility ID	Date	Amount (Gallons)	Location
City of League City	TX0085618	10568-005	2/11/2004	500	2316 Colonial Ct. N
City of League City	TX0085618	10568-005	2/11/2004	600	2130 Savannah Ct N
City of League City	TX0085618	10568-005	2/11/2004	N/A	1009 Newport

N/A: Not Available

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 CWA. Small MS4 storm water programs must address the following minimum control measures:

- Public Education and Outreach;
- Public Participation/Involvement;
- Illicit Discharge Detection and Elimination;

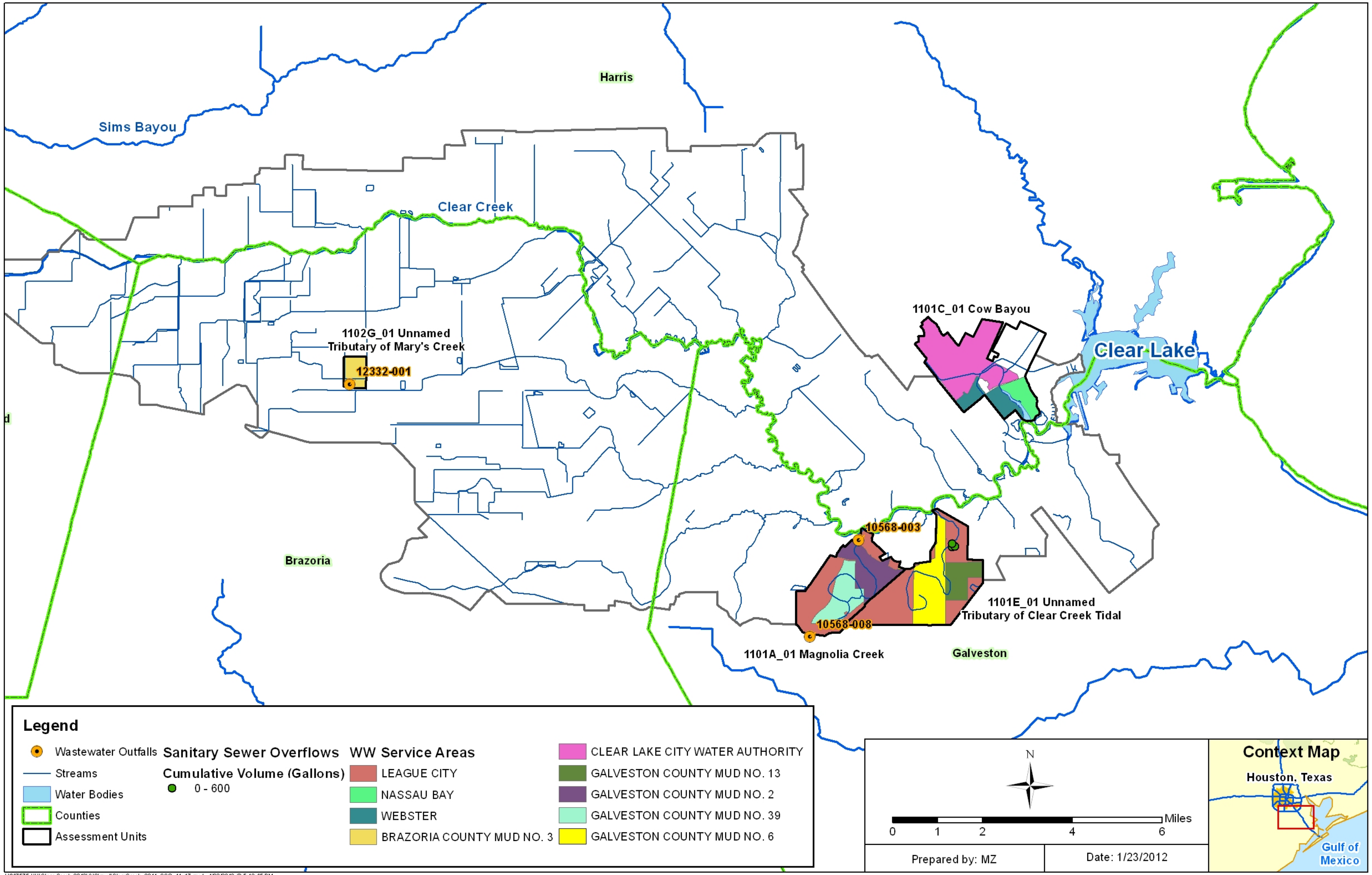


Figure 3-2 Sanitary Sewer Overflow Locations

- 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 co-permittees. These agencies do not have any monitoring points located on water bodies that drain into the Clear Creek Watershed (Martin 2005). Therefore, there are no monitoring data available to characterize bacteria concentrations or loads from regulated storm water discharged to receiving waters in the Clear Creek Watershed. Table 3-5 lists the percentage of area within each watershed covered under the Houston MS4 permit.

Table 3-5 Percentage of Permitted Storm Water in each Watershed

Segment	Receiving Stream	TPDES Number	Total Area (acres)	Area under MS4 Permit (Acres)	Percent of Watershed under MS4 Jurisdiction
1101A_01	Magnolia Creek	WQ0004685000	1,894	1,894	100%
1101C_01	Cow Bayou	WQ0004685000	2,613	2,613	100%
1101E_01	Unnamed Tributary of Clear Creek Tidal	WQ0004685000	2,340	990	42%
1102G_01	Unnamed Tributary of Mary's Creek	WQ0004685000	220	220	100%

Storm water runoff sampling was conducted in May and July 2006 to estimate the potential magnitude of loading from storm water in the Study Area. Samples were collected at the mouths of the tributaries in response to significant rainfall in the project area. Significant rainfall events were defined as those that produced discharge of storm water runoff into the study segments. Sampling was initiated as soon as possible on the rising limb of the hydrograph. Samples were collected during two storm events at nine locations, only one of which is located in the Study Area (Station 16611 on Magnolia Creek).

Detailed data from storm water sampling are presented in Table 3-6. These data were used to estimate storm water loads discharged from Magnolia Creek (Segment 1101A_01) and Unnamed Tributary of Clear Creek Tidal (1101E_01). Table 3-6 summarizes the geometric mean of the bacteria loads at Stations 16611 and 18818.

Table 3-6 Bacteria Loading from Storm Water

WQM Station ID	Tributaries	1st Storm Sampling	2nd Storm Sampling
		Geomean of Enterococci Load (MPN/day)	Geomean of Enterococci Load (MPN/day)
16611	Magnolia Creek	2.27E+12	3.44E+13
18818	Unnamed Tributary of Clear Creek Tidal	3.67E+11	5.69E+10

Notes:
1. Orange indicates Maximum Load, and Light Green indicates Minimal Load.
2. The sequence of sites are from upstream to downstream

3.1.4 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 /dL 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 Enterococci 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 coliform and Enterococci 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. Agricultural activities of greatest concern are typically those associated with livestock operations (Drapcho and Hubbs 2002). The following are examples of livestock activities that can contribute to bacteria sources:

Processed livestock manure is often applied to fields as fertilizer, and can contribute to fecal bacteria loading to waterbodies if washed into streams by runoff.

Livestock grazing in pastures deposit manure containing fecal bacteria onto land surfaces. These bacteria may be washed into waterbodies by runoff.

Livestock often have direct access to waterbodies and can provide a concentrated source of fecal bacteria loading directly into streams.

Table 3-7 provides estimated numbers of selected livestock by watershed based on the 2002 USDA county agricultural census data (USDA 2002). The county-level estimated livestock populations were distributed among watersheds based on GIS calculations of pasture land per watershed, based on the Texas 2005 C-CAP Land Cover Data (NOAA 2007). If watersheds were located in multiple counties, then the agricultural numbers were calculated separately by county and then summed for the entire watershed. Because the watersheds are generally much smaller than the counties, and livestock are not evenly distributed across counties or constant with time, these are rough estimates only. Cattle are the most abundant species of livestock in the Study Area, and often have direct access to the waterbodies or their tributaries.

The Texas AgriLife Extension Service was contacted in January 2007 to get feedback from local experts on whether the livestock numbers from the 2002 USDA Census of Agriculture reflect current livestock numbers in the Clear Creek watershed. County Extension Agents in Galveston, Harris and Brazoria Counties stated that overall the numbers of livestock animals have decreased since 2002 as grazing land continues to be developed. All stated that no manure application is occurring in the Study Area. It was also indicated that broilers (chickens) may have increased because of the increase in youth livestock programs such as Future Farmers of America and 4-H (Cranfill 2008). Livestock numbers and their contributions to bacteria loadings, in the Clear Creek watershed are expected to decrease over time as more land is converted from grazing to developed, urban uses.

Table 3-7 Livestock and Manure Estimates by Watershed

Segment	Stream Name	Cattle & Calves-all	Dairy Cows	Horses & Ponies	Sheep & Lambs	Hogs & Pigs	Ducks & Geese	Chickens & Turkeys
1101A_01	Magnolia Creek	668	1	109	10	19	17	155
1101C_01	Cow Bayou	609	7	111	13	12	11	95*
1101E_01	Unnamed Tributary of Clear Creek Tidal	832	1	135	12	23	21	193
1102G_01	Unnamed Tributary of Mary's Creek	78	0	5	1	5	1	1*

*Chicken Data for these watersheds is incomplete due to County Agricultural Census Data withheld to avoid disclosing data for individual farms.

According to a livestock study conducted by the American Society of Agricultural Engineers (ASAE), the daily fecal coliform production rates by livestock species were estimated as follows (ASAE 1999):

- Beef cattle release approximately 1.04E+11 per animal per day;
- Dairy cattle release approximately 1.01E+11 per animal per day
- Swine release approximately 1.08E+10 per animal per day
- Chickens release approximately 1.36E+08 per animal per day
- Sheep release approximately 1.20E+10 per animal per day
- Horses release approximately 4.20E+08 per animal per day;
- Turkey release approximately 9.30E+07 per animal per day
- Ducks release approximately 2.43E+09 per animal per day
- Geese release approximately 4.90E+10 per animal per day

Using the estimated livestock populations and the fecal coliform production rates from ASAE, an estimate of fecal coliform production from each group of livestock was calculated in Table 3-8 for each watershed of the Study Area. It should be noted that only a fraction of these fecal coliform loading estimates are expected to reach the receiving water, either washed into streams by runoff or by direct deposition from wading animals. Cattle appear to represent the most likely livestock source of fecal bacteria.

Table 3-8 Fecal Coliform Production Estimates for Selected Livestock (x10^9 /day)

Segment	Stream Name	Cattle & Calves-all	Dairy Cows	Horses & Ponies	Sheep & Lambs	Hogs & Pigs	Ducks & Geese	Chickens & Turkeys	Total
1101A_01	Magnolia Creek	69,454	109	46	118	202	255	21	70,204
1101C_01	Cow Bayou	63,339	676	46	152	124	192	13	64,543
1101E_01	Unnamed Tributary of Clear Creek Tidal	86,571	136	57	147	251	318	26	87,506
1102G_01	Unnamed Tributary of Mary's Creek	8,068	1	2	11	56	10	0	8,149

3.2.3 Failing On-site Sewage Facilities

On-site sewage facilities (OSSFs) 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 3-9 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 -2010. Permits are obtained to install or replace systems. However, some permits are obtained when an older failing system needs repair (H-GAC 2005). It is assumed that there are more OSSFs in each city or county listed in Table 3-9 which were installed prior to 1992. Because the Clear Creek Watershed covers only portions of three of the counties listed in Table 3-9, specific steps were taken to estimate the proportion of OSSFs that exist within the four sub-watersheds of the Clear Creek Watershed.

Table 3-9 Numbers of Permits Issued by Authorized County or City Agent

Year	Brazoria	Fort Bend	Galveston	Harris
1990 Census Totals	25,772	9,721	12,733	44,120
1992	177	113	134	243
1993	499	252	319	651
1994	398	343	361	881
1995	660	347	321	1,035
1996	811	304	344	1,327
1997	570	343	360	1,393
1998	713	504	446	1,301
1999	712	594	456	1,606
2000	701	544	401	1,422
2001	655	444	432	1,388
2002	755	495	461	1,397
2003	788	538	506	1,424
2004	724	501	568	1,174
2005	720	550	511	1,080
2006	668	555	425	1,039
2007	687	458	394	989
2008	472	448	305	788
2009	422	366	460	721
2010	436	328	375	645
Total	**36,010**	**17,748**	**20,312**	**64,624**

Note: Data obtained from TCEQ On-Site Activity Reporting System
NA: Not 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 3-10 shows the estimated number of OSSFs calculated using this GIS method.

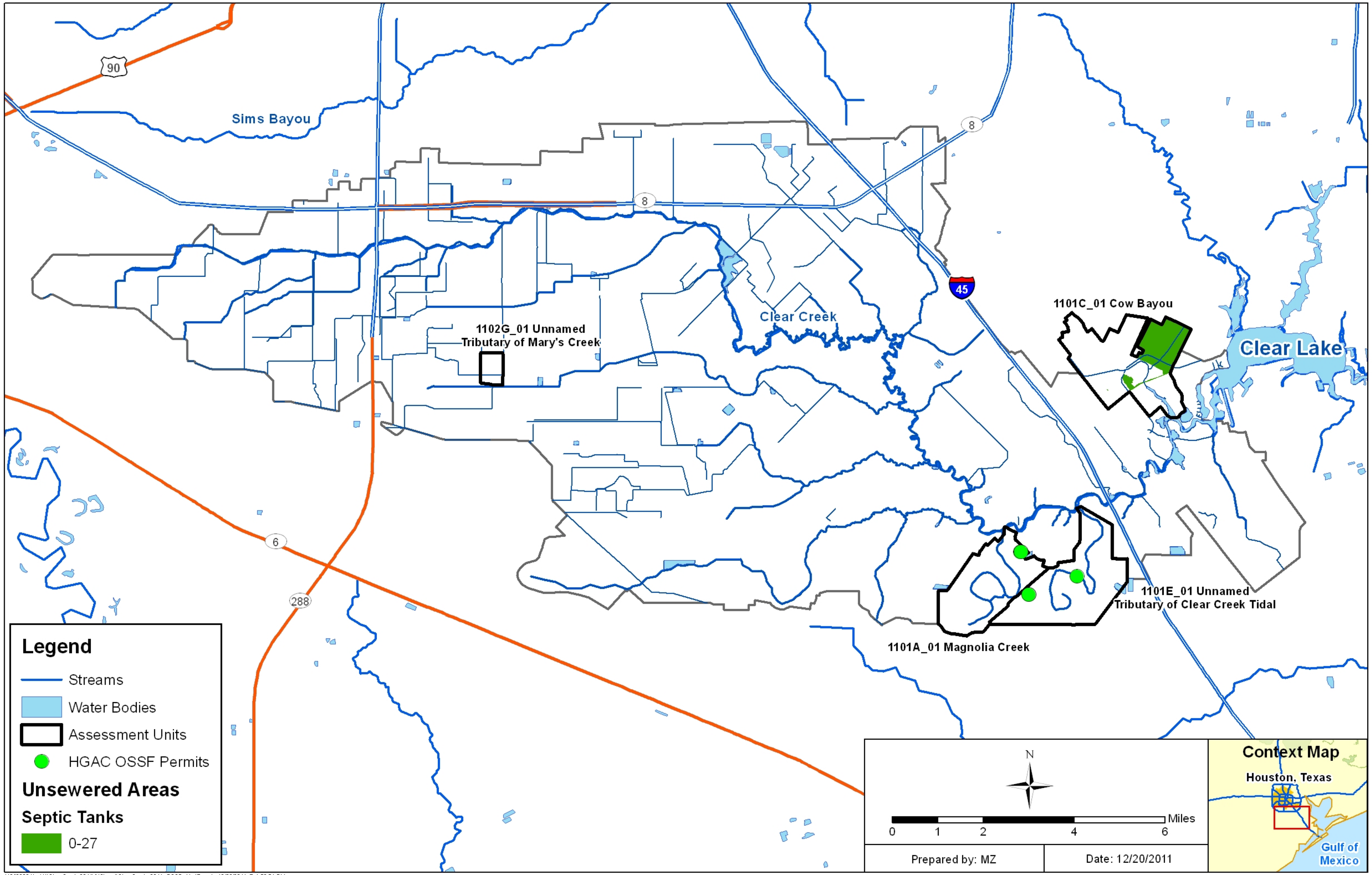


Figure 3-3 Unsewered Areas and Subdivisions with OSSF

H-GCA provided additional OSSF data for select portions of the Study Area. There is one existing structure in the Unnamed Tributary of Clear Creek Tidal watershed area and two existing structures in the Unnamed Tributary of Mary's Creek watershed, with low failure occurrences, as shown in Table 3-10. Figure 3-3 points out the watersheds that have been identified as having OSSFs.

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):

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

The average of number of people per household was calculated to be 2.78 for counties in the Study Area (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 dL 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 failing septic systems within the watersheds was summarized below in Table 3-10. Based on this data, it was determined that the estimated fecal coliform loading from OSSFs in the Study Area were found to be negligible.

Table 3-10 Estimated Number of OSSFs per Watershed and Fecal Coliform Load

Segment	Stream Name	OSSF Estimate using 1990 Census method	OSSF data from HGAC	# of Failing OSSFs	Estimated Loads from OSSFs (x 10^9 counts/day)
1101A_01	Magnolia Creek	0	2	0.24	2
1101C_01	Cow Bayou	27	0	3.24	24
1101E_01	Unnamed Tributary of Clear Creek Tidal	0	3	0.36	3
1102G_01	Unnamed Tributary of Mary's Creek	0	0	0	0

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 2007). Using the U.S. Census data at the block level (U.S. Census Bureau 2010), dog and cat populations can be estimated for each watershed. Table 3-11 summarizes the estimated number of dogs and cats for the watersheds of the Study Area.

Table 3-11 Estimated Numbers of Pets

Segment	Stream Name	Dogs	Cats
1101A_01	Magnolia Creek	5,530	6,239
1101C_01	Cow Bayou	1,400	1579
1101E_01	Unnamed Tributary of Clear Creek Tidal	1,598	1,802
1102G_01	Unnamed Tributary of Mary's Creek	521	588

Table 3-12 provides an estimate of the fecal coliform load from pets. These estimates are based on estimated fecal coliform production rates of $5.4x10^8$ per day for cats and $3.3x10^9$ 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 3-12 Estimated Fecal Coliform Daily Production by Pets (x 10^9)

Segment	Stream Name	Dogs	Cats	Total (cfu/day)
1101A_01	Magnolia Creek	18,248	3,369	21,617
1101C_01	Cow Bayou	4,620	853	5,473
1101E_01	Unnamed Tributary of Clear Creek Tidal	5,272	973	6,245
1102G_01	Unnamed Tributary of Mary's Creek	1,719	317	2,036

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.

CHAPTER 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* or Enterococci bacteria, TMDLs are expressed as numbers per day, where possible, or as a percent reduction goal, and represent the maximum one day load the stream can assimilate while still attaining the standard for contact recreation. For the Clear Creek Watershed, to quantify allowable pollutant loads, percent reduction goals to achieve standard for contact recreation, and specific TMDL allocations for point and nonpoint sources, two different methods are used: 1) the load duration curve method for the non-tidal stream (1102G_01 Unnamed Tributary of Mary's Creek) and 2) a mass balance method using a tidal prism for the three tidal streams (1101A_01 Magnolia Creek, 1101C_01, Cow Bayou, and 1101E_01 Unnamed Tributary of Clear Creek Tidal). These two different technical approaches are 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 E.

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. As previously mentioned in Section 1.2.2, there are no long-term flow data from within the Study Area. Therefore, flows needed to be estimated for Unnamed Tributary of Mary's Creek. USGS gage station 08075400 (Sims Bayou at Hiram Clarke Street, Houston, Texas), which is located outside the watershed, was chosen to conduct flow projections. The period of record for flow data used from this station was 2000 through 2010.

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 abscissa 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 in this application is described as follows:

Table 4-1 Hydrologic Classification Scheme

Flow Exceedance Percentile	Hydrologic Condition Class
0-20	Highest flows
20-80	Mid-range flows
80-100	Lowest flows

Figure 4-1 presents the FDC developed for the downstream WQM station used for calculating the TMDL of the 303(d) listed freshwater stream using the flow projection method outlined above and further described in Appendix E.

Figure 4-1 represents the FDC for Unnamed Tributary of Mary's Creek, segment 1102G_01 at WQM station 18636. WWTF discharges occur in Unnamed Tributary of Mary's Creek, average monthly WWTF flows obtained from DMRs were added to the projected naturalized flows. The flow exceedance percentiles for this segment is presented I tabular form in Appendix F.

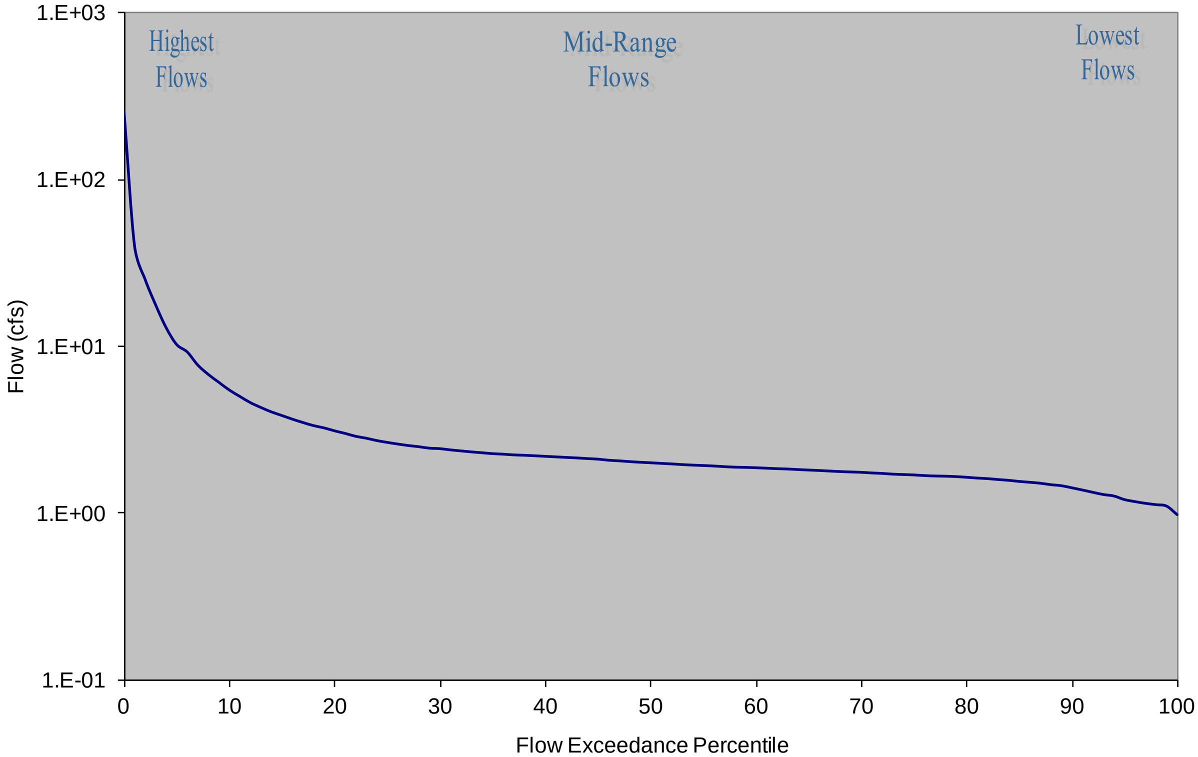


Figure 4-1 Flow Duration Curve for Unnamed Tributary of Mary's Creek (1102G_01)

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, data necessary for this calculation were extracted from each point source's discharge monitoring reports from 2000 through 2010. 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 the WQM station 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 ordinate is expressed in terms of a bacteria load in counts/day. The curve represents the instantaneous water quality criterion for *E. coli* (399 counts/dL), 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;

display 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 = 399 counts/dL (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 (counts/dL) by the instantaneous flow (cubic feet per second [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 4-2 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.

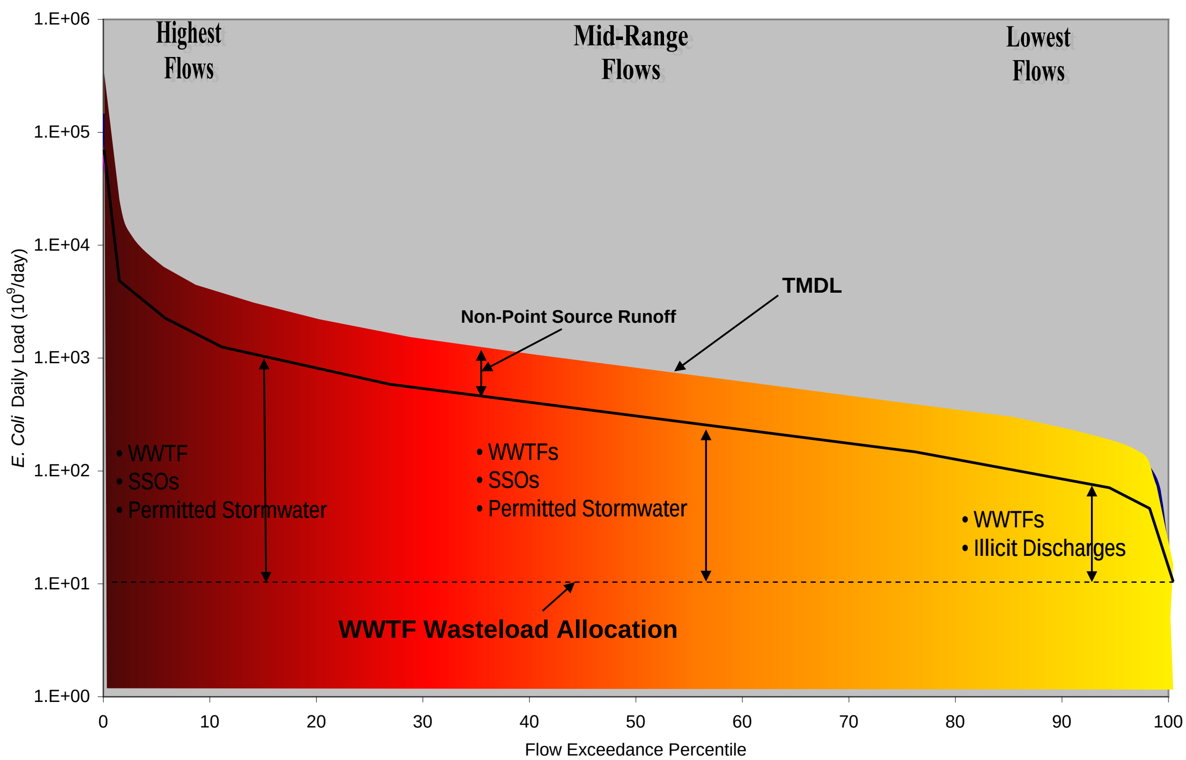


Figure 4-2 LDC Schematic Diagram – Interpreting Sources and Loads

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. This data was matched to the date which 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. An 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 standard 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 * flow * unit conversion factor (#/day)*

Where: criterion = 126/dL (E. coli) or 35/dL (Enterococci); flow (mgd) = permitted flow;

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

WLA for NPDES/TPDES MS4s. 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 (MS4) 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 220 acres, 100 percent of the Unnamed Tributary of Mary's Creek (Segment 1102G_01) watershed. Therefore, 100 percent of the LA calculated at any flow condition will be designated as the WLA the City of Houston/Harris County permitted storm water discharge. The WLA for MS4s can be expressed as a value for each flow exceedance frequency.

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.

$$LA = TMDL - MOS - \Sigma WLA_{WWTF} - \Sigma WLA_{MS4}$$

Where:

LA = allowable load from non-permitted sources
TMDL= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
ΣWLA_{MS4} = sum of all MS4 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 applicable indicator bacteria (fecal coliform or *E. coli*), 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 (10^{th}, $50^{th,}$ and 90^{th} flow exceedance percentile) of each of the three flow regimes multiplied by the geometric mean concentration of the historical bacteria data. For example, for the 0-20th percentile flow range, the flow corresponding to the 10th percentile was used. The geometric mean of the indicator bacteria samples within the 0-20^{th} flow percentile range was then multiplied by the 10^{th} flow 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 formula of:

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

4.5 Development of Bacteria TMDLs for Tidal Streams Using a Mass Balance Approach

4.5.1 Modeling Approach

A time-variable tidal prism modeling approach with a moderate level of spatial resolution was used to simulate the bacterial indicator loads and establish TMDLs for the tidal segments of the Study Area. The tidal prism is the volume of water gained in a tidal stream between low and high tide levels. An existing, calibrated model for the Clear Creek watershed, developed in 2007 (Parsons, 2008) was modified to include two of the three tidal segments included in the Study Area (Magnolia Creek was included in the 2007 model). In addition, the model was extended to include data up to 12/31/2010. Load calculations were developed for a series of reaches within Clear Creek Tidal as well as the portions of the major tributaries discharging to Clear Creek Tidal that periodically are influenced by tidal fluctuations. The model incorporates the three primary mechanisms through which Enterococci loadings and water enter the impaired systems: i) rain-induced freshwater inputs via tributaries or direct runoff, ii) direct point source discharges, and iii) tidally influenced loadings, which are introduced during the diurnal tidal fluctuations that occur in the system. The model assumes that Enterococci are removed with the net estuarine flow from the system and via net decay. A generalized schematic of the source and sink terms for the tidally influenced impaired waterbodies is presented in Figure 4-3.

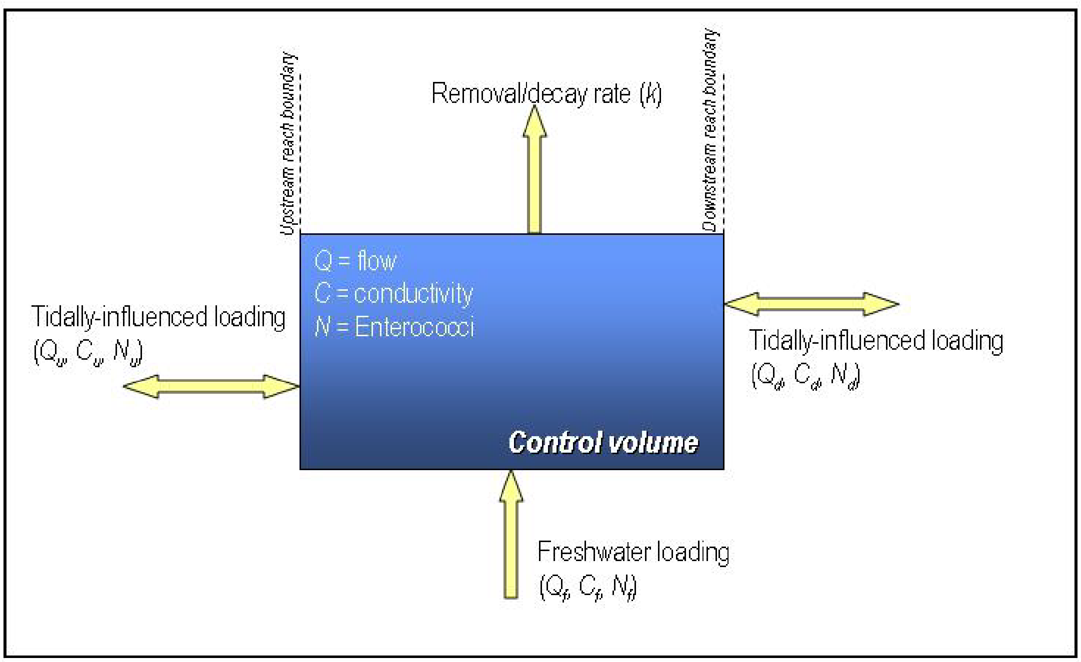


Figure 4-3 Conceptual Model for Sources and Sinks of Enterococci

The mass balance of water for a given reach at a given time step can be written as follows:

$$\frac{dV}{dt} = Q_u + Q_f - Q_d \quad (1)$$

Where: Q_u = volume of water crossing the upstream boundary of the reach [m^3/hr]

Q_d = volume of mixed water crossing the downstream boundary of the reach [m^3/hr]

Q_f = volume of freshwater inflow (runoff, tributaries, and WWTFs) discharging along the reach [m^3/hr],

dV/dt = change in volume of the reach with time [m^3/hr]

The following paragraphs summarize the steps that were followed to complete the tidal prism model.

Step 1: Define Reaches. Clear Creek Tidal, Segment 1101, was divided into eleven reaches (Figure 4-4). A small downstream reach of Clear Creek above Tidal (Reaches A and B) is also incorporated into the tidal prism model because it is tidally influenced. The tidal prism model includes reaches for the tidal portions of tributaries discharging to Clear Creek Tidal including Robinson Bayou, Cowart Creek, Chigger Creek, Magnolia Creek, Unnamed Tributary of Clear Creek Tidal, and Cow Bayou.

Data from TSARP models were used to calculate cross-sectional areas for the boundaries of each main stem reach. Cross-sectional areas for small tributaries were estimated using LiDAR (Light Detection and Ranging) 2-foot contour elevation data collected in 2001 provided by TSARP. Cross-section data for the three streams included in the Study Area are provided in electronic format in Appendix G. The cross-sections for Clear Creek and the other tributaries included in the 2007 model were provided in Parsons, 2008.

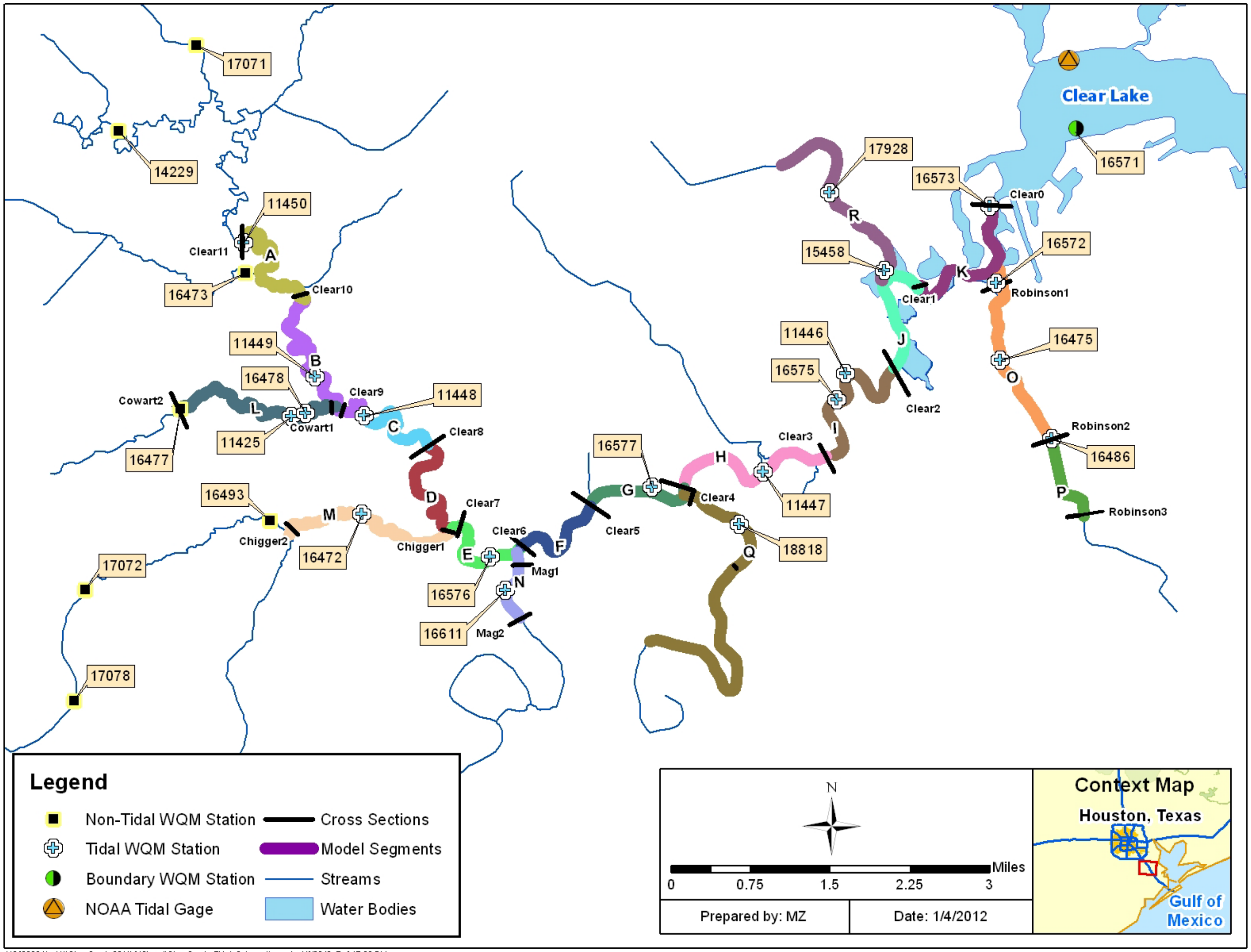


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Figure 4-4 Schematic of the Modified Tidal Prism Model

Step 2: Establishing Tributary Inflows and Loads

The model requires time series for inflow and bacterial indicator loads from the freshwater tributaries (the model headwaters) discharging to the tidal portions. The methods for estimating these headwater boundary flows and Enterococci loads are summarized in this step.

Inflows from Non-Tidal Tributaries to Tidal Model Reaches

Estimated daily inflows from non-tidal (freshwater) tributary streams to the tidal model reaches were derived from the drainage area ratio method described in Appendix E. These daily inflows were then disaggregated to hourly time series for the modeled period (2000 through 2010), and provided in Appendix H in electronic format.

Enterococci Loads from Upstream Freshwater Segments

Indicator bacteria concentrations measured at the most downstream WQM stations on non-tidal tributaries, including Mary's Creek (16473), Chigger Creek (16493), Cowart Creek (16477), and Clear Creek above Tidal (14299) were used to estimate Enterococci loads to the tidal prism model. For most of the WQM stations on these tributaries, only *E. coli* or fecal coliform data were available. Therefore, Enterococci concentrations were estimated from *E. coli* or fecal coliform data using Enterococci/*E. coli* (ENT/EC) or Enterococci/fecal coliform (ENT/FC) conversion ratios, based on data collected by the City of Houston and H-GAC for their Alternate Indicator Study (Running 2007). The median ENT/EC and ENT/FC ratios were 0.34 and 0.27, respectively. For dates with no historical water quality data available, the geometric mean of the observed values of each respective station was used. For Magnolia Creek, Robinson Bayou, and Unnamed Tributary of Clear Creek Tidal, the load time series were developed using the geometric means of the data collected during the 2006 Intensive Surveys (stations 16611, 16486, and 18818, respectively) for low flows (defined as flows lower than the 60^{th} percentile), while the geometric means of the storm water data collected for the same locations were used for high flows. For Cow Bayou and Tributaries A through D, the overall geometric means of the intensive surveys and the storm water sampling were used for low and high flows, respectively. Tributary load input datasets for Enterococci are included in electronic format in Appendix H and summarized in Table 4-2.

Table 4-2 Summary of Tributary Inflows and Loads to the Tidal Prism Model

Interface	Average Flow (m^3/day)	Average Flow (cfs)	Average Enterococci Load (counts/day)
Clear Creek above Tidal (Reach A-K)	7.71E+04	3.15E+01	6.45E+10
Cowart Creek (Reach L)	2.89E+04	1.18E+01	2.24E+10
Chigger Creek (Reach M)	1.04E+04	4.26E+00	1.12E+10
Magnolia Creek (Reach N)	1.08E+04	4.42E+00	2.43E+12
Robinson Bayou (Reach P)	4.06E+02	1.66E-01	2.92E+10
Unnamed Tributary (Reach Q)	7.19E+03	2.94E+00	1.05E+12
Cow Bayou (Reach R)	1.65E+04	6.75E+00	2.53E+12
Mary's Creek (Reach A)	9.96E+04	4.07E+01	1.47E+11
Tributary A (Reach A)	3.07E+03	1.25E+00	4.70E+11
Tributary B (Reach G)	1.65E+02	6.74E-02	2.41E+10
Tributary C (Reach H)	4.49E+03	1.84E+00	6.87E+11
Tributary D (Reach H)	4.63E+03	1.89E+00	7.08E+11

Step 3: Estimating Direct (non-tributary) Point and Nonpoint Source InFlows and Loading to the System.

The key variables required for estimating loading into the model reaches are direct runoff to the tidal streams modeled, WWTF discharges to the various reaches, and indicator bacteria concentrations in runoff and WWTF effluents. The methods for estimating these tidal prism inputs are summarized below.

Permitted Sources: Continuous Point Source Dischargers (WWTFs)

Six TPDES-permitted WWTFs that continuously discharge wastewater are located in the Clear Creek Tidal Watershed. To be consistent with estimating bacterial indicator loads under the LDC method, average monthly flows from DMRs were again used to estimate fecal coliform loads from discrete point sources as inputs to the tidal prism model. Loads were calculated using maximum monthly geometric mean data for fecal coliform when available from TCEQ, then converted to estimates to Enterococci loads before using the 0.27 ENT/FC ratio). *E. coli* data collected from a select group of WWTFs by Harris County in November 2007 were also used if no other data were available to characterize the bacteria concentrations in wastewater effluent. A summary of these data are shown in Table 4-3.

Table 4-3 Summary of Existing WWTF Loads in Model

Model Reach	TPDES Permit Number	Flow (average self reported) m^3/day	Flow (average self reported) MGD	Enterococci Concentration (counts/dL)	Enterococci Load (counts/day)
D	11571-001	20,222	5.343	28[a]	5.66E+09
I	10520-001	5,169	1.366	0.5[b]	2.58E+07
J	10526-001 (outfall 1)	2,303	0.608	1[b]	2.30E+07
J	10568-005	23,356	6.170	13[a]	3.04E+09
K	10526-001 (outfall 2)	2,618	0.692	1[b]	2.62E+07
N	10568-003	1,450	0.383	4[a]	5.80E+07

[a] *Maximum value of monthly self-reported fecal coliform geomeans times 0.27 (ENT/FC ratio)*
[b] *Maximum E. coli data from Harris County, 2007 times 0.34 (ENT/EC ratio)*

Permitted and Non-permitted Storm Water Runoff

Storm water runoff loads discharging directly to the model reaches were input to the model for the days on which a rain event occurred (as indicated by the closest HCOEM gage to each segment). Drainage areas were estimated using TSARP subwatersheds displayed in Figure 4-5. Daily Enterococci runoff loads were calculated using land cover information from the C-CAP Texas 2005 Land Cover Data, and the amounts of rainfall recorded for the simulation period.

The amount of runoff for each drainage area was calculated using the NRCS runoff curve number method (NRCS 1986). The NRCS runoff equation is:

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

where Q = runoff (in);

P = rainfall (in);

S = potential maximum retention after runoff begins (in); and

I_a = initial abstraction (in).

Initial abstraction refers to all the losses before runoff begins and includes water intercepted by vegetation, infiltration, evaporation, and water retained in surface depressions. This parameter is highly variable but is correlated to land cover and soil type (NRCS 1986). The NRCS (1986) estimates I_a to be equal to:

$$I_a = 0.2S \tag{3}$$

thus,

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{4}$$

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

$$S = \frac{1000}{CN} - 10 \tag{5}$$

CN values range from 0 to 100 and are based on land cover and soil group. For this runoff calculation, all subwatersheds were assumed to be in soil group D (silt and clay) that generally has low infiltration rates. Land coverage data developed by C-CAP were aggregated from 22 categories into the six land cover categories listed in Table 4-4. The classification system and their corresponding runoff curve numbers are included in Table 4-4.

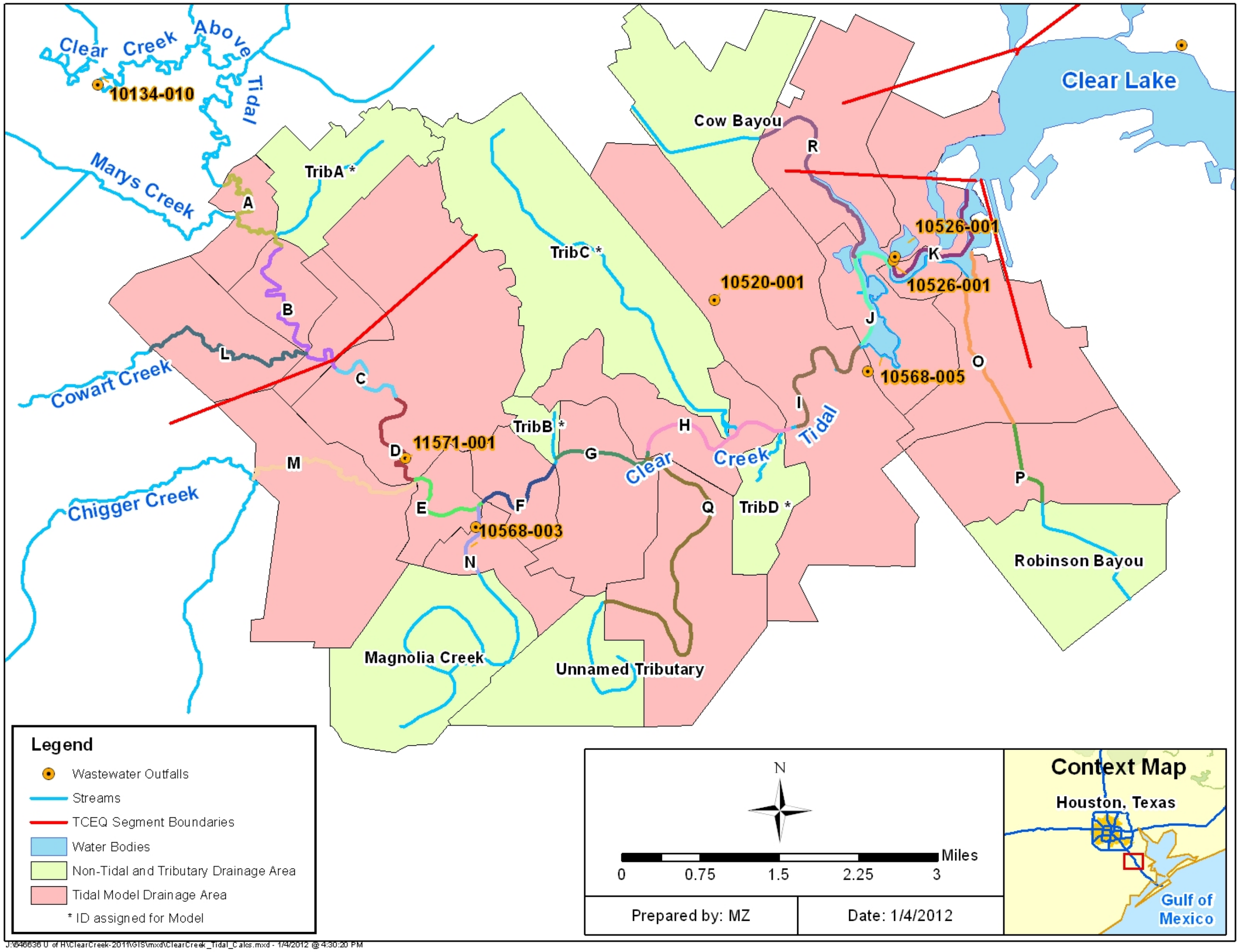


Figure 4-5 Drainage Areas for the Tidal Prism Model Reaches

Event mean concentrations (EMC) for Enterococci were estimated based on fecal coliform EMCs obtained from the Storm Water Management Joint Task Force in 2002. The ENT/FC ratio (0.27) was applied to obtain Enterococci EMCs for different land cover categories. The Enterococci concentrations used for the tidal prism model are included in Table 4-4.

Table 4-4 Runoff Curve Numbers for the Clear Creek Watershed

Land Cover Description	CN	Enterococci EMCs (cfu/dL)
Developed	92[a]	18,000
Cultivated Land	84[b]	700
Grassland/Herbaceous	80[b]	700
Pasture/Hay	80[b]	700
Woodland	77[c]	400
Open Water	0	0
Wetlands	0	0
Transitional/Bare	89[d]	12,000

[a] Obtained from C-CAP Medium-Intensity Developed
[b] Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Cultivated agricultural land, small grain, contoured. (Good)
[c] Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Pasture, grassland, or range- continuous forage for grazing. (Good)
[c] Obtained from C-CAP Mixed Forest
[d] Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Open space (lawns, parks, golf courses, cemeteries, etc.) Poor condition (grass cover < 50%)

Average storm water runoff loads from the contributing subwatershed of each reach are summarized in Table 4-5. The total average daily loads from runoff into Magnolia Creek, Unnamed Tributary of Clear Creek Tidal and Cow Bayou were estimated to be 4.52×10^{11}/day, 1.29×10^{12}/day, and 8.98×10^{11}/day, respectively. Total runoff load to Clear Creek Tidal (including the tidal portions of the major tributaries not included in this TMDL report) was estimated to be 9.60×10^{12} /day, the total for Robinson Bayou was estimated to be 7.85×10^{11} /day. Runoff flow and Enterococci load calculations are provided in electronic format in Appendix I.

Table 4-5 Storm Water Runoff Loads to the Tidal Prism Model

Reach	Average Flow (m^3/day)	Average Flow (cfs)	Average Enterococci Load (counts/day)
A	1.73E+03	7.08E-01	2.40E+11
B	4.48E+03	1.83E+00	7.16E+11
C	7.72E+03	3.16E+00	1.12E+12
D	7.13E+03	2.91E+00	1.03E+12
E	1.57E+03	6.43E-01	1.56E+11
F	1.57E+03	6.40E-01	1.22E+11
G	5.61E+03	2.29E+00	8.14E+11
H	3.73E+03	1.52E+00	3.18E+11
I	1.82E+04	7.43E+00	2.35E+12

Reach	Average Flow (m^3/day)	Average Flow (cfs)	Average Enterococci Load (counts/day)
J	5.86E+03	2.39E+00	9.48E+11
K	4.25E+02	1.74E-01	5.32E+10
L	5.21E+03	2.13E+00	8.19E+11
M	8.69E+03	3.55E+00	9.19E+11
N	2.82E+03	1.15E+00	4.52E+11
O	2.31E+02	9.43E-02	2.50E+10
P	5.16E+03	2.11E+00	7.60E+11
Q	7.94E+03	3.24E+00	1.29E+12
R	6.58E+03	2.69E+00	8.98E+11

Note: Variable daily loads were input into the model. The loads presented here are the averages over the simulation period (01/01/2000 to 12/31/2010).

Step 4: Estimate Tidal Flows. Tidal flows for each reach were computed as the tidal exchange over the course of one hour, and were estimated as the difference in volume between two consecutive time steps (Equation 1). To calculate volumes, one hour gage data for the period of 01/01/2000 – 09/18/2008 were downloaded from the Texas Coastal Ocean Observation Network Station 502 at Clear Lake (http://lighthouse.tamucc.edu/overview/502). Data for Station 507 at eagle Point were used for the remainder of the simulation period (09/19/2008 – 12/31/2010). After adjusting cross-sectional areas to reflect tidal elevation, the hourly volumes for each reach were calculated as the average of the cross-sectional areas at the downstream and upstream reach boundaries times the length of the reach.

Step 5: Verify Flow Balance Using Conductivity. An important step to estimating freshwater loading is to construct a conductivity balance of the system to ensure that the model is correctly estimating freshwater inflows and tidal exchange. Electrical conductivity measures the salt content (salinity) of water, and the major salts are considered a conservative (non-reactive) tracer. To accomplish this, conductivity data from TCEQ stations and from the NOAA gage were used as a conservative tracer to determine the flow balance of each reach. The conductivity balance calculation for each reach is represented as:

$$C_t V_t = C_{t-1} V_{t-1} + \sum C_{in} V_{in} - \sum C_{out} V_{out} + C_f V_f \qquad (6)$$

Where: V_t = volume of reach at time step t [m^3]

V_{t-1} = volume of reach at time step t-1 [m^3]

V_f = freshwater volume [m^3]

V_{in}, V_{out} = tidally influenced volumes for time step t [m^3]

C_t = conductivity in the reach [µS/cm]

C_f = conductivity in the freshwater inputs [µS/cm]

C_{in}, C_{out} = conductivity of the tidally influenced flows [µS/cm]

The average conductivity values for the existing water quality monitoring stations were used to define the initial conductivity levels in the model reaches. Because a long-term conductivity record was not available at the downstream boundary (*i.e*., Clear Lake), long-term conductivity records for the NOAA gage at Eagle Point (Station 8771013) were multiplied by the ratio of average salinities for the Clear Lake and Eagle Point NOAA gages to estimate salinities at the downstream boundary. Conductivity in freshwater (runoff, tributaries and effluent) was assumed equal to 1,000 µS/cm. Tidally influenced volumes were calculated using Equation 1 and freshwater volumes as described earlier. Using the above information Equation 6 was solved for the conductivity in the reach (C_t). The computed conductivity levels were then compared to existing measurements within the impaired waterbody to corroborate that the flows are accurately represented throughout the system. Figure 4-6 presents a comparison of observed and modeled average conductivity concentrations along Clear Creek Tidal.

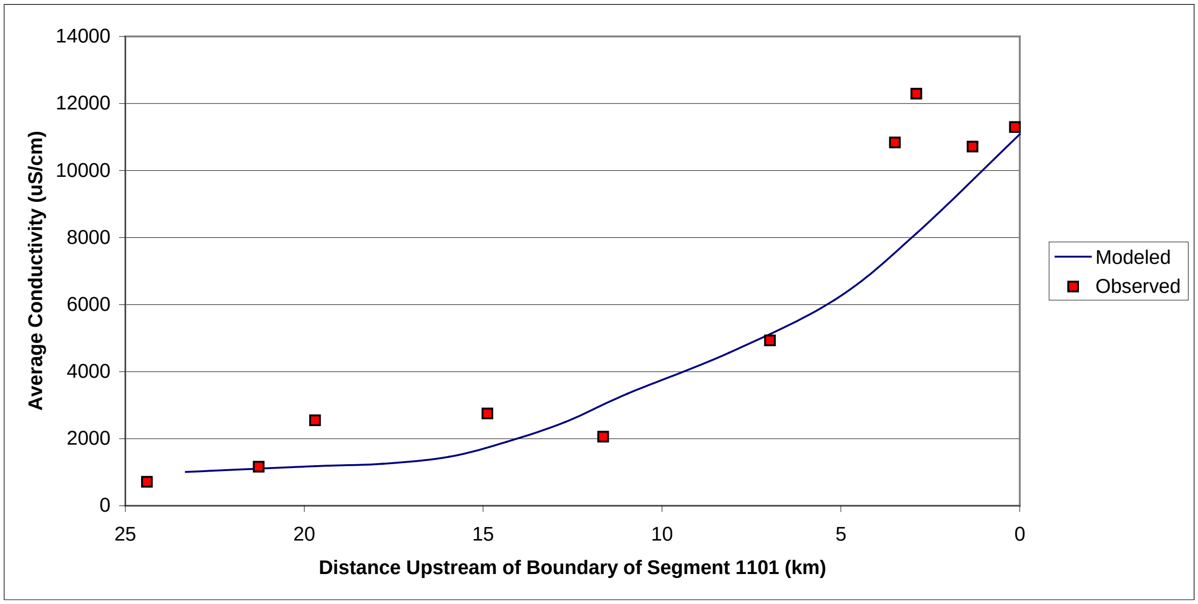


Figure 4-6 Longitudinal Profile of Average Conductivity

Step 6: Perform Mass Balance on Enterococci Levels. Upon validation of the flow balance, a mass-balance on Enterococci for each reach can be computed as follows:

$$N_t V_t = N_{t-1} V_{t-1} + \sum N_{in} V_{in} - \sum N_{out} V_{out} + N_f V_f - k N_{t-1} V_{t-1} \quad (7)$$

Where: N_t = Enterococci level in the reach [counts/dL]

N_f = Enterococci level in the freshwater flow [counts/dL]

N_{in}, N_{out} = Enterococci level in tidally influenced flow [counts/dL]

k = Enterococci first-order decay rate [hr^{-1}]

The average Enterococci concentrations measured at each of the water quality monitoring stations along Clear Creek Tidal and tributaries were used to define the initial conditions in each model reach. The geometric mean of Enterococci concentrations measured in Clear Lake station 16571 (12 counts/dL) was used to set the downstream boundary concentration of Enterococci. Enterococci levels in runoff, tributaries and WWTFs were estimated as described in Steps 2 and 3.

The model was calibrated by varying the decay rate by reach and adjusting this decay rate within the bounds of reported rates until the model accurately reproduced the temporal and spatial distribution of observed Enterococci within the system. Sinton, *et al*. (1994) and Davies-Colley, *et al*. (1998) reported decay rates between 0.12 and 40 day^{-1}, Anderson, *et al*. (2005) reported rates between 0.73 and 2.1 day^{-1}, and Kay, *et al*. (2005) measured decay rates between 2.2 and 8.5 day^{-1}. Final decay rates applied to the model ranged from 0.12 to 2.3 day^{-1}, which are within the ranges reported in the literature. The decay rates were not varied temporally because insufficient data were available to estimate the seasonal variation in decay rates. The calibrated spreadsheet model is included in Appendix J in electronic format.

Figure 4-7 presents a comparison of measured and modeled Enterococci concentrations along the main stem of Clear Creek. As can be seen, the model reasonably predicts the spatial distribution of Enterococci along the creek. For the tidal prism model, indicator bacteria data (including fecal coliform and *E. coli*), from 2000 through 2006 for a given station were used to compare to modeled values. Fecal coliform and *E. coli* data were converted to Enterococci concentrations using calculated ENT/FC and ENT/EC ratios (0.27 and 0.34, respectively) as previously described.

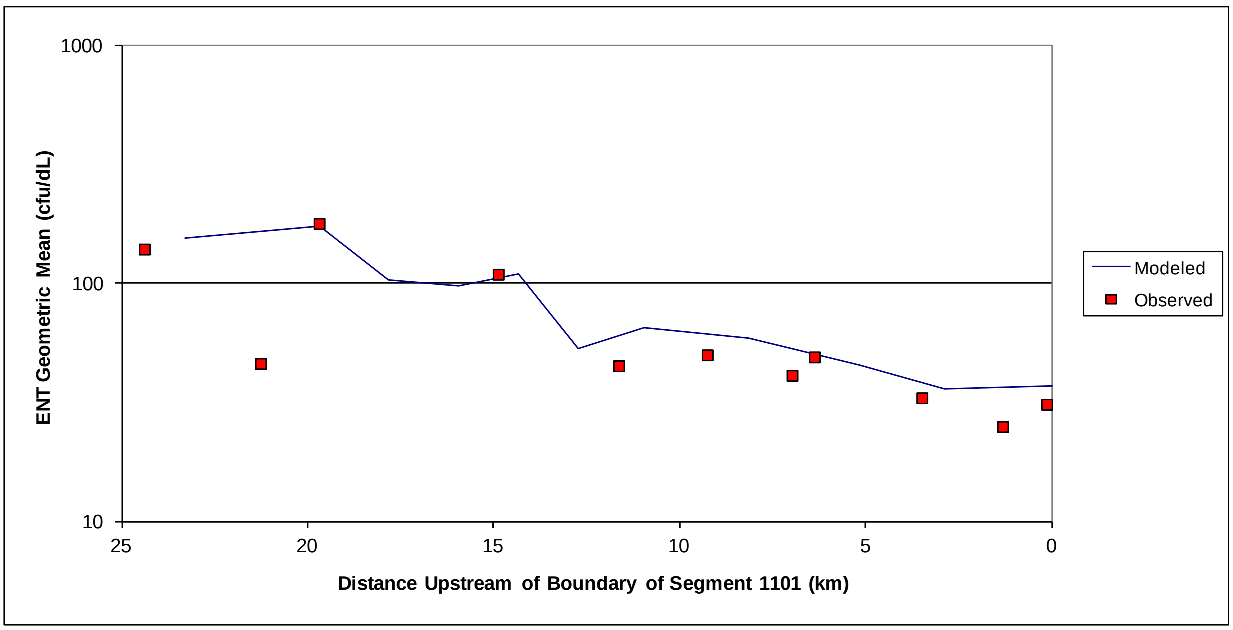
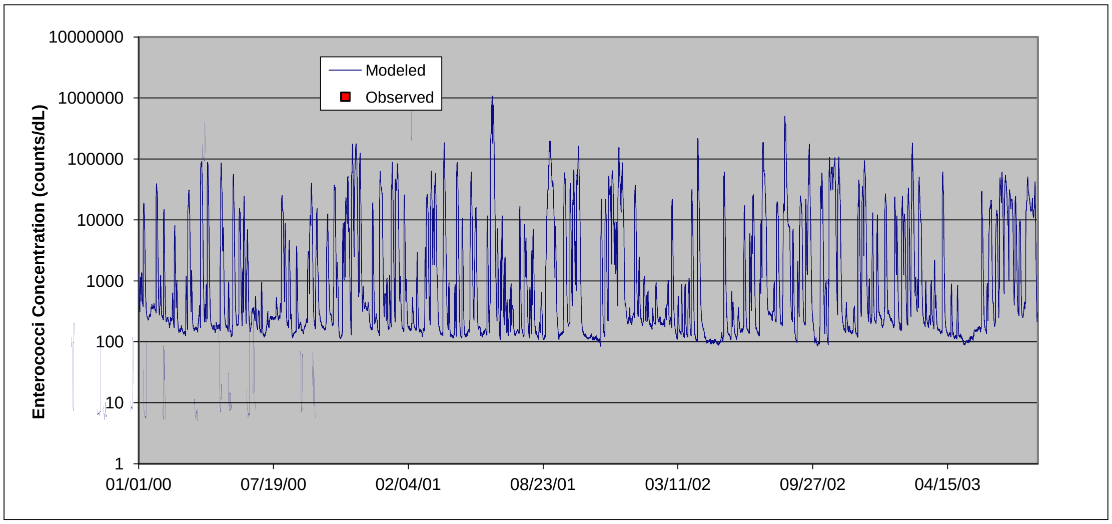
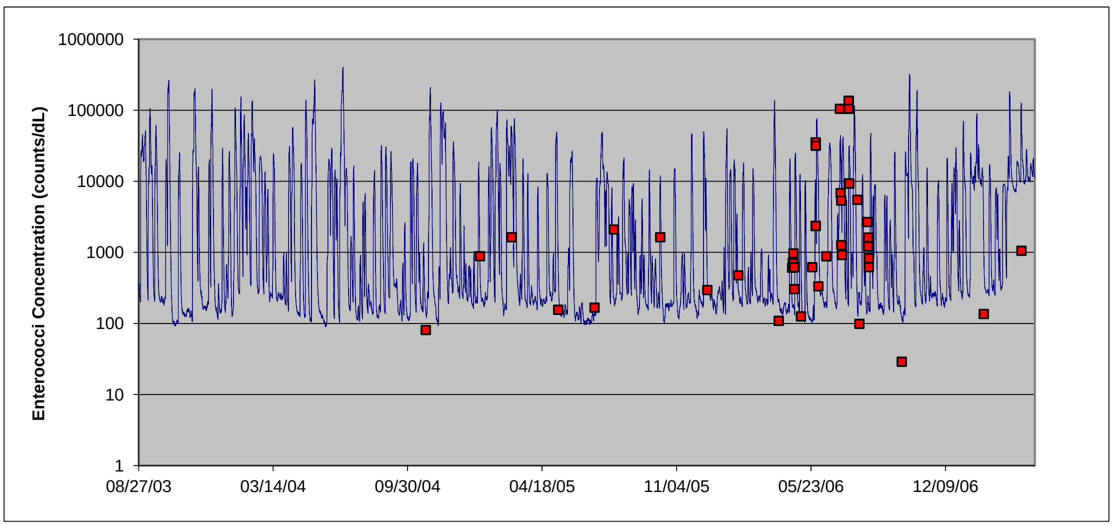


Figure 4-7 Longitudinal Profile of Enterococci Concentrations

Figures 4-8 through 4-10 show time series of Enterococci concentrations for the water quality monitoring stations in the three streams included in this TMDL report. As indicated by the figures, the model reasonably represents the temporal distribution of Enterococci concentrations for the various WQS.





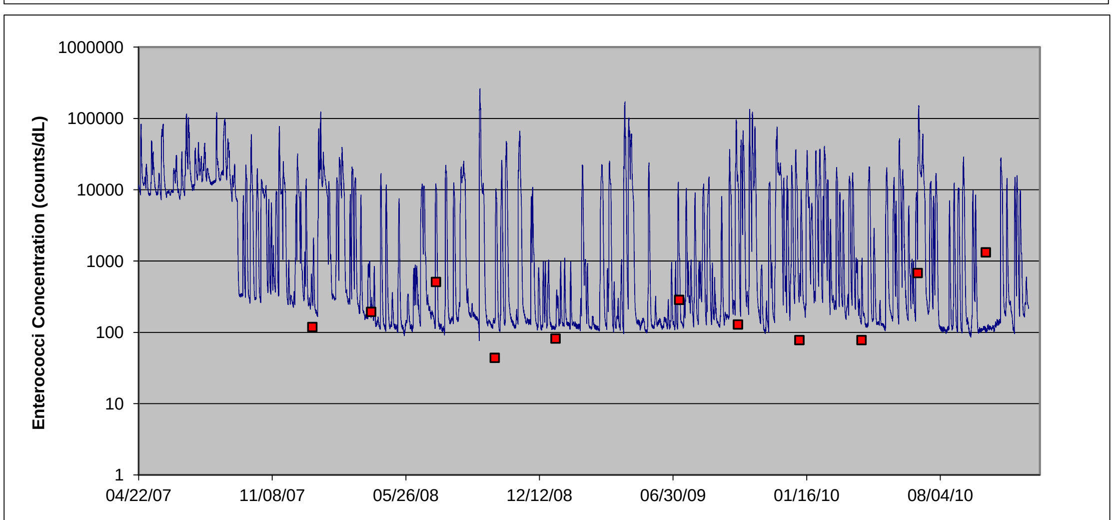


Figure 4-8 Enterococci Levels at Station 16611 (Reach N), Magnolia Creek (1101A_01)

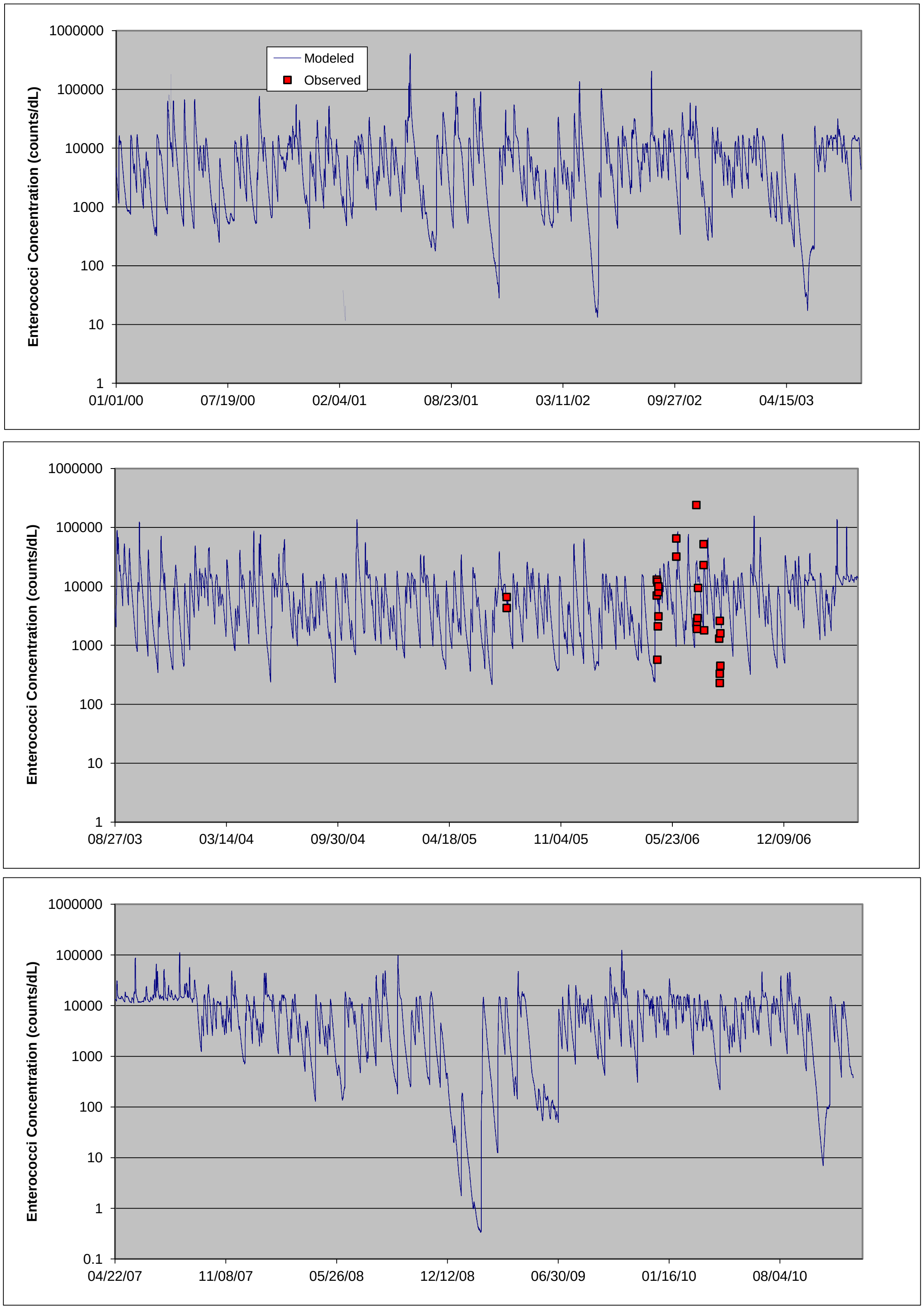


Figure 4-9 Enterococci Levels at Station 18818 (Reach Q), Unnamed Tributary of Clear Creek Tidal (1101E_01)

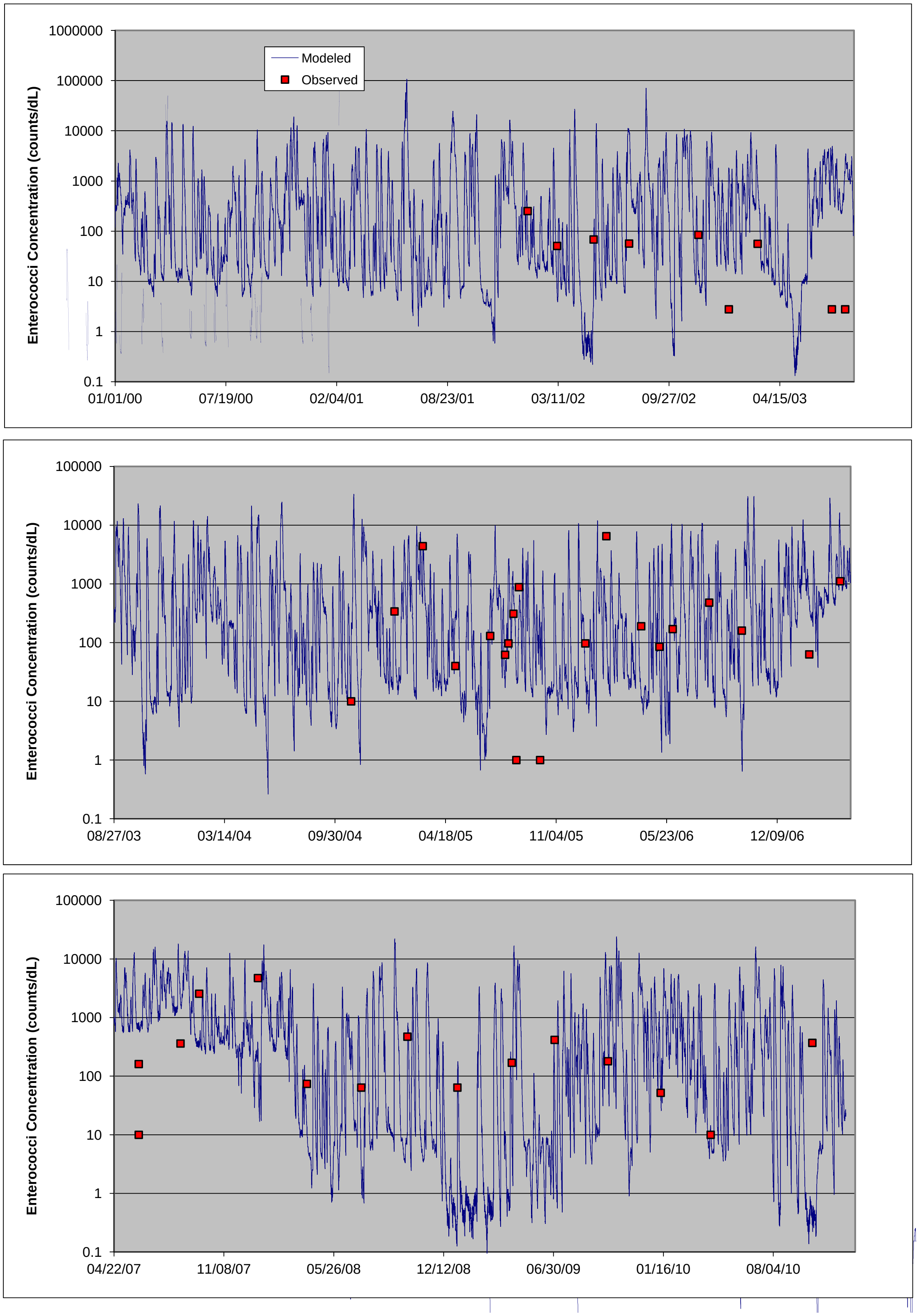


Figure 4-10 Enterococci Levels at Station 19728 (Reach R), Cow Bayou (1101C_01)

4.5.2 Critical Conditions and TMDL Calculation for the Tidal Segments

To calculate the WLA and LA components of the TMDLs for the tidal streams, steps similar to those used for the LDC method are applied. 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.

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 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 WWTPs 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 * permitted flow * unit conversion factor (#/day)*

Where: criterion = 35/dL (Enterococci)

flow (mgd) = permitted flow

*unit conversion factor = 37,854,120-dL/day*mgd*

Storm water runoff can contribute both permitted and non-permitted sources of bacteria which must also be accounted for in the TMDL allocations. To be consistent with the LDC method, any storm water runoff originating from the area of a watershed under the jurisdiction of an MS4 permit is considered a point source contribution and is therefore included as part of the WLA calculation. As such the WLA will be split into WWTP WLA and MS4 WLA. Again to be consistent with the LDC method, the estimated loading from storm water runoff within each drainage area is separated into storm water loading from MS4 areas and storm water loading from non-permitted areas. This is done by using the percentage of each drainage area covered by the MS4 permit. An explicit MOS of 5 percent of the criterion is also included in the TMDL calculation. The storm water loading from non-permitted areas is considered the LA. Therefore, another way of expressing the LA from non-permitted storm water runoff is calculated as the TMDL minus the margin of safety minus the WLA (sum of WWTP and MS4).

Percent reduction goals were calculated by changing the loads in the tidal prism model until all the reaches have concentrations lower than or equal to the 35 counts/dL criterion for Enterococci. It is noted that the loads coming from upstream freshwater segments, addressed with LDCs, were assumed to be in compliance with the 126 counts/dL criterion for *E. coli* or 42 counts/dL for Enterococci if the 0.34 ratio is used.

The fact that most the WQM stations on the Study Area exceed the geometric mean standard for Enterococci indicates that evaluating mean source inputs (*i.e*., under mean conditions) via a mass balance approach will be sufficient to ascribe load allocations. The daily load estimates for the simulation period were reduced by a constant such that the geometric mean standard was met (*i.e*., 33/dL). The percent reduction was computed as follows:

$$\%R = \left(1 - \frac{1}{C_R}\right) \cdot 100 \qquad (8)$$

where C_R is the constant by which the daily Enterococci loadings are reduced and %R is the associated percent reduction in the Enterococci levels.

CHAPTER 5
TMDL CALCULATIONS

5.1 Results of TMDL Calculations

The calculations and results of the TMDLs for the 303(d) listed water bodies in the Study Area are provided in Section 5. The bacteria load allocations derived from the two different technical approaches used for freshwater and tidal water bodies are discussed together in each subsection of Section 5 below.

5.2 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, tidal flux, and the magnitude of water quality criteria exceedance. TMDLs are derived for specific indicator bacteria in 303(d) listed water bodies at specific WQM stations based on LDCs for Unnamed Tributary of Mary's Creek (1102G_01) and a mass balance calculation using a tidal prism for tidal streams.

To calculate the bacteria load at the criterion for the freshwater segment, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (*24,465,755 dL/ft3 * seconds/day*) and the *E. coli* criterion. This calculation produces the maximum bacteria load in the stream without exceeding the instantaneous standard over the range of flow conditions. *E. coli* loads are 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.

For the tidal streams, the maximum allowable load at the criterion is calculated as the sum of the input loads that result in attainment of the water quality criteria for the reaches in the tidal prism model.

To estimate existing loading in the Unnamed Tributary of Mary's Creek (1102G_01), bacteria observations from 2000 to 2010 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 F. 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.

Percent reduction goals for Unnamed Tributary of Mary's Creek (1102G_01) 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 the sampling location is determined by selecting the percent reduction goal calculated for the geometric mean criterion. The TMDL percent reduction goal for Unnamed Tributary of Mary's Creek (1102G_01) is based on the geometric mean criterion.

The pollutant load allocations and percent reduction goals for each flow regime are summarized in Section 5.8. The highest percent reduction goals for the segment was found to occur in the flow regime with the highest flows (0–20th percentile). The percent reduction goals for the highest flows was 75 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, was 63 percent.

Figure 5-1 represents the LDC for Unnamed Tributary of Mary's Creek (1102G_01) is based on *E. coli* bacteria measurements at sampling location 18363 (Tributary Of Mary's Creek Thalerfield). The LDC indicates that *E. coli* levels exceed the instantaneous and geometric mean water quality criteria under highest flows and lowest flow conditions. Wet weather influenced *E. coli* observations are found under high and mid-ranged flow conditions.

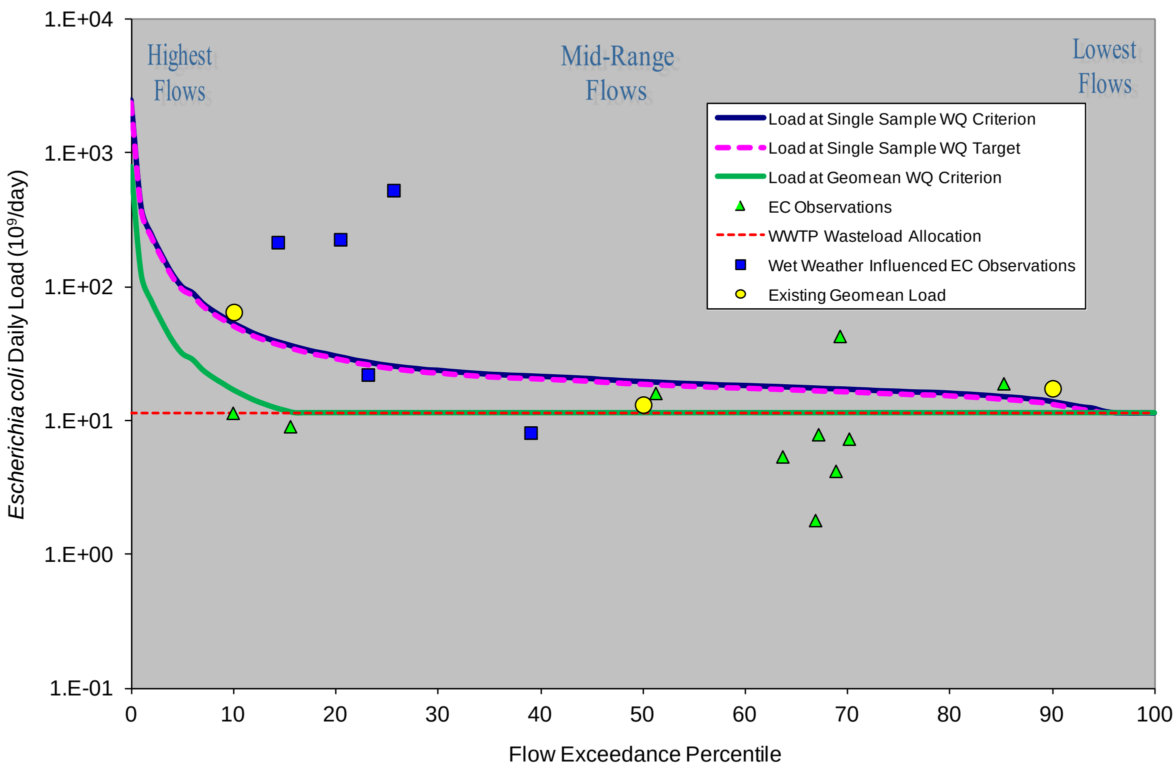


Figure 5-1 Load Duration Curve for Unnamed Tributary of Mary's Creek (1102G_01)

Existing Enterococci loads to the TMDL tidal segments are summarized in Table 5-1. The estimated existing loads are calculated as the sum of runoff, tributary, and WWTF loads to model reaches N (Magnolia Creek), Q (Unnamed Tributary of Clear Creek Tidal), and R (Cow Bayou).

Table 5-1 Estimated Existing Enterococci Loads to TMDL Tidal Segments

Segment	Receiving Stream	Enterococci Load (counts/day)
1101A_01	Magnolia Creek (Reach N and Magnolia Creek above Tidal)	2.88E+12
1101E_01	Unnamed Tributary of Clear Creek Tidal (Reach Q and Non-tidal portion of Unnamed Tributary to Clear Creek Tidal)	2.34E+12
1101C_01	Cow Bayou (Reach R and Cow Bayou above Tidal)	3.43E+12

The percent reduction goals that are required to meet the geometric mean standard for contact recreation in the TMDL tidal segments are illustrated in Figure 5-2. The required load reductions were calculated at the end of the reach containing the sampling location. Required load reductions are summarized in Table 5-2.

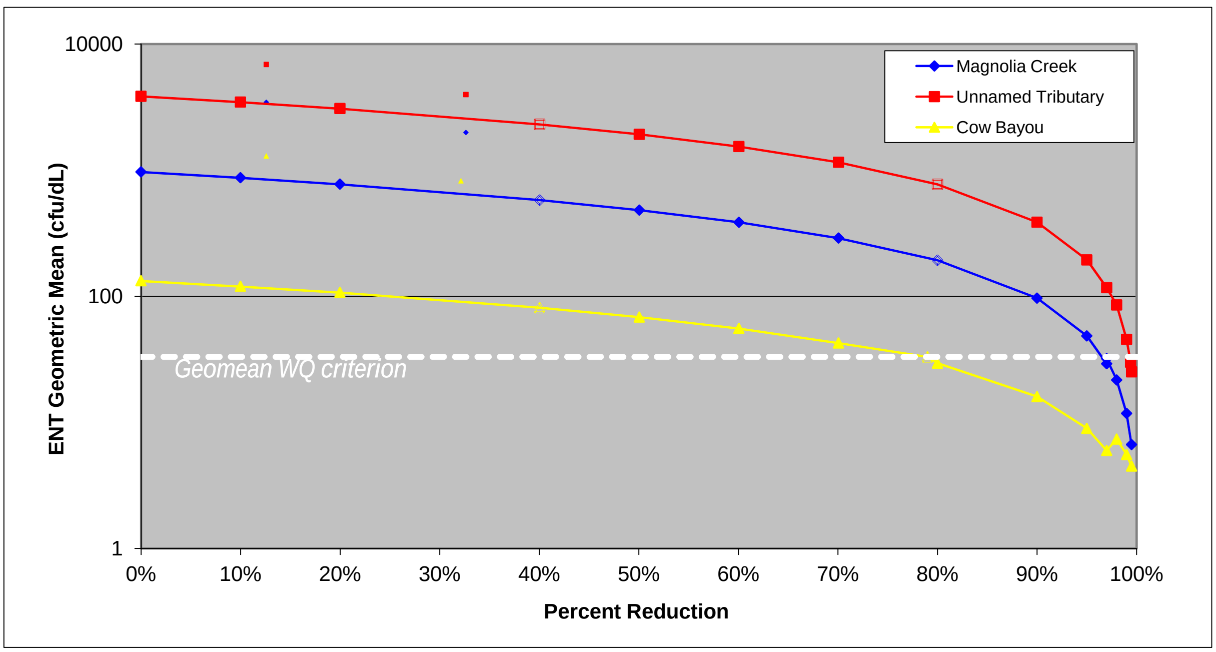


Figure 5-2 Contact Recreation Standards Attainment for Tidal Segments

Table 5-2 TMDL Percent Reductions Required to Meet Contact Recreation Standard for Tidal Segments

Segment	Sampling Location	Stream Name	Percent Reduction Required
1101A_01	16611	Magnolia Creek (Reach N and Magnolia Creek above Tidal)	96.7%
1101E_01	18818	Unnamed Tributary of Clear Creek Tidal (Reach Q and Non-tidal portion of Unnamed Tributary to Clear Creek Tidal)	99.3%
1101C_01	17928	Cow Bayou (Reach R and Cow Bayou above Tidal)	79.0%

5.3 Wasteload Allocation

TPDES-permitted facilities are allocated a daily wasteload calculated as their permitted discharge flow rate multiplied by the instream geometric mean water quality criterion. In other words, the facilities are required to meet instream criteria at their points of discharge. Table 5-3 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 * flow * unit conversion factor (#/day)*

Where:

criterion = 35 and 126 counts/dL for Enterococci and E. coli, respectively

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 both the LDC and tidal prism 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 5-3 Wasteload Allocations for TPDES-Permitted Facilities

	Magnolia Creek (1101A_01)	Magnolia Creek (1101A_01)	Unnamed Tributary of Mary's Creek (1102G_01)
TPDES Number	10568-003	10568-008	12332-001
NPDES NUMBER	TX0071447	TX0133043	TX0086118
Facility Name	City of League City	City of League City, Southwest Water Reclamation WWTP	Brazoria County Mud No. 3
Final Permitted Flow (MGD)	0.66	12.0	2.4
***E.Coli* (counts/day)**	3.15E+09	5.72E+10	1.14E+10
Enterococci (counts/day)	8.74E+08	1.59E+10	N/A

N/A = not applicable

For the freshwater stream, the flow dependent calculations for the MS4 portion of the WLA are derived using LDC and the MS4 percentages provided in Table 3-5. Likewise for the tidal segments, any runoff occurring within the boundaries of an MS4 permit are considered a point source contribution and are included in the WLA calculation. The allowable load from all storm water runoff ($LA_{Stormwater}$) is first calculated as the maximum allowable load (TMDL) minus the margin of safety minus the load allocated to WWTFs (WLA_{WWTF}). The resulting load ($LA_{Stormwater}$) is split into WLA_{MS4} component (permitted storm water) and LA component (non-permitted storm water) using the percentages of the drainage areas within the tidal prism model covered by MS4 permits provided in Table 3-5.

5.4 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 MS4 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

$\sum WLA_{STORM\ WATER}$ = sum of all Storm water loads
MOS = margin of safety

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 estimating flows to develop flow exceedance percentiles.

Analysis of the available data for *E. coli* and Enterococci from two stations showed higher geometric mean concentrations for the cooler months than the warmer months.

5.6 Allowance 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. 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 high 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 2050 using population projections completed by the Texas Water Development Board. A summary of the methodology used to predict waste water flow capacity based on population growth is included in Appendix K. For the freshwater segment, the projected WWTF permitted flows were added to the flows from runoff to build the $TMDL_{future}$ for various flows. For the tidally influenced segments, loads calculated using the projected flows and a 35 counts/dL concentration were input in the tidal prism model along with all the other existing loads. The loads were then reduced by different percentages until the contact recreation criterion was met in all the reaches. The reduced loads were then added to calculate the assimilative capacity or $TMDL_{future}$. In both cases, the LA_{WWTF} for future population growth is the difference between the $TMDL_{future}$ and the TMDL calculated using current conditions.

5.7 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.

The TMDL for the freshwater segment incorporates an explicit MOS by setting a more stringent target for indicator bacteria loads that is 5 percent lower than the single sample criterion. The explicit margin of safety was used because of the limited amount of data. For contact recreation, this equates to a single sample target of 379 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 TMDL for the freshwater stream in this report incorporate an explicit MOS in the LDC by using 95 percent of the single sample criterion. For the tidal segments, the MOS was also explicit. But in this case, the MOS was based on allowable loading, not concentration. After the tidal prism model calculated the total assimilative capacity for Enterococci (the TMDL), 5 percent of the allowable load was computed as the MOS.

5.8 TMDL Calculations

The bacteria TMDLs for the 303(d)-listed WQM stations covered in this report were derived using LDCs and the tidal prism model. 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:

$$\textbf{\textit{TMDL}} = \Sigma\ \textbf{\textit{WLA}} + \Sigma\ \textbf{\textit{LA}} + \textbf{\textit{MOS}} + \textbf{\textit{Future Growth}}$$

Table 5-4 summarizes the pollutant load allocations and percent reduction goals at current flows, for each flow regime, for the freshwater segment. Table 5-5 summarizes the estimated maximum allowable load of *E. coli* for the freshwater assessment unit included in this project.

For the tidal stream segments, Table 5-6 summarizes the estimated maximum allowable loads of Enterococci that will ensure the contact recreation standard is met. These are calculated from the tidal prism model based on average percent reductions from total existing loading (WWTFs, runoff and tributaries) to the water body (Table 5-1). Table 5-6 includes WLA, LA, and MOS calculations.

The final TMDL allocations required to comply with the requirements of 40 CFR 130.7 are summarized in Table 5-7. In this table, the future capacity for WWTF has been added to the WLA_{WWTF}.

Table 5-4 *E. coli* TMDL Calculations for Unnamed Tributary for Mary's Creek (1102G_01)

Station 18636			
Flow Regime %	**0%-20%**	**20%-80%**	**80%-100%**
Median Flow, Q (cfs)	5.5	2.02	1.43
Existing Load (10^9 org/day)	6.50E+01	1.32E+01	1.75E+01
TMDL (Q*C) (10^9 org/day)	1.70E+01	6.22E+00	4.40E+00
MOS (Q*C*0.05) (10^9 org/day)	8.48E-01	3.11E-01	2.20E-01
Allowable Load at Water Quality Target, Load Allocation, TMDL-MOS (10^9 org/day)	1.61E+01	5.91E+00	4.18E+00
Load Reduction (10^9 org/day)	4.89E+01	7.29E+00	1.33E+01
Load Reduction (%)	**75.2%**	55.3%	76.1%
Overall Load Reduction* (%)	**63%**		
TMDL (Q_{future}*WQS) (10^9 org/day)	4.88E+01		

Table 5-5 E. coli TMDL Summary Calculations for Unnamed Tributary of Mary's Creek (1102G_01)

TMDL[a] (MPN/day)	WLA_{WWTF}[b] (MPN/day)	$WLA_{STORM\ WATER}$[c] (MPN/day)	LA[d] (MPN/day)	MOS[e] (MPN/day)	Future Growth[f] (MPN/day)
4.88E+10	1.14E+10	9.27E+09	0	2.44E+09	2.57E+10

[a] *Maximum allowable load for the flow range requiring the highest percent reduction (Table 5-4)*
[b] *Sum of loads from the WWTF discharging upstream of the TMDL station. Individual loads are calculated as permitted flow * 126 (E. coli) MPN/100mL*conversion factor (Table 5-3)*
[c] *$WLA_{STORM\ WATER}$ = (TMDL – MOS –WLA_{WWTF})*(percent of drainage area covered by storm water permits)*
[d] *LA = TMDL – MOS –WLA $_{WWTF}$ –WLA $_{STORM\ WATER}$-Future growth*
[e] *MOS = TMDL x 0.05*
[f] *Projected increase in WWTF permitted flows*126*conversion factor*

Table 5-6 TMDL Calculations for Tidal Segments

Segment	Stream Name	Indicator	TMDL[a] (counts/day)	WLA_{WWTF}[c] (counts/day)	WLA_{MS4}[d] (counts/day)	LA[f] (counts/day)	MOS[g] (counts/day)	$TMDL_{Future}$[b] (counts/day)	$WLA_{WWTF-Future}$[e] (counts/day)
1101A_01	Magnolia Creek (Reach N and Magnolia Creek above Tidal)	ENT	9.50E+10	1.68E+10	7.35E+10	0	4.75E+09	9.94E+10	4.41E+09
		EC[h]	*2.79E+11*	*4.93E+10*	*2.16E+11*	*0*	*1.40E+10*	*2.92E+11*	*1.30E+10*
1101E_01	Unnamed Tributary of Clear Creek Tidal (Reach Q and Non-tidal portion of Unnamed Tributary to Clear Creek Tidal)	ENT	1.64E+10	NA*	6.54E+09	9.04E+09	8.20E+08	1.64E+10	NA*
1101C_01	Cow Bayou (Reach R and Cow Bayou above Tidal)	ENT	7.20E+11	NA*	6.84E+11	0	3.60E+10	7.20E+11	NA*

[a] *Sum of WWTF, storm water runoff, and tributary loads discharging directly to the WQ segment that result in attainment of the geometric mean criterion*
[b] *Sum of WWTF with projected permitted flows for 2050, storm water runoff, and tributary loads discharging directly to the WQ segment that result in attainment of the geometric mean criterion*
[c] *Sum of loads from the WWTF discharging to the segment. Individual loads are calculated as permitted flow*35 counts/dL*conversion factor (Table 5-3)*
[d] $WLA_{MS4} = (TMDL - MOS - WLA_{WWTF})$ *percent of drainage area covered by MS4 permits*
[e] *Difference between* $TMDL_{Future}$ *and the TMDL*
[f] $LA = TMDL - MOS - WLA_{WWTF} - WLA_{MS4}$
[g] $MOS = 0.05*TMDL$
[h] *Because the listing for segment 1101A_01 is based on E.coli, the ENT allocations calculated using the tidal prism model were converted to EC using the 0.34 ENT/EC ratio.*
* *NA – Allocation not applicable at this time. New WWTF must comply with* WLA_{WWTF}

Table 5-7 Final TMDL Allocations

Assessment Unit	Indicator	TMDL[a] (counts/day)	WLA_{WWTF}[c] (counts/day)	WLA_{MS4}[d] (counts/day)	LA[f] (counts/day)	MOS[g] (counts/day)
1102G_01	EC	4.88E+10	3.71E+10	9.27E+09	0	2.44E+09
1101A_01	EC	2.92E+11	6.23E+10	2.16E+11	0	1.40E+10
1101E_01	ENT	1.64E+10	NA*	6.54E+09	9.04E+09	8.20E+08
1101C_01	ENT	7.20E+11	NA*	6.84E+11	0	3.60E+10

** NA – Allocation not applicable at this time. New WWTF must comply with WLAWWTF*

TMDL values and allocations in Table 5-7 are derived from calculations using the existing water quality criteria for *E. coli* and Enterococci. However, designated uses and water quality criteria for these water bodies are subject to change through the TCEQ standards revision process. Figures 5-3 through 5-6 were developed to demonstrate how assimilative capacity, TMDL calculations and pollutant load allocations change in relation to a number of hypothetical water quality criteria. The equations provided along with Figures 5-3 through 5-6 allow calculating new TMDLs and pollutant load allocations based on any potential new water quality criteria for *E. coli* and Enterococci.

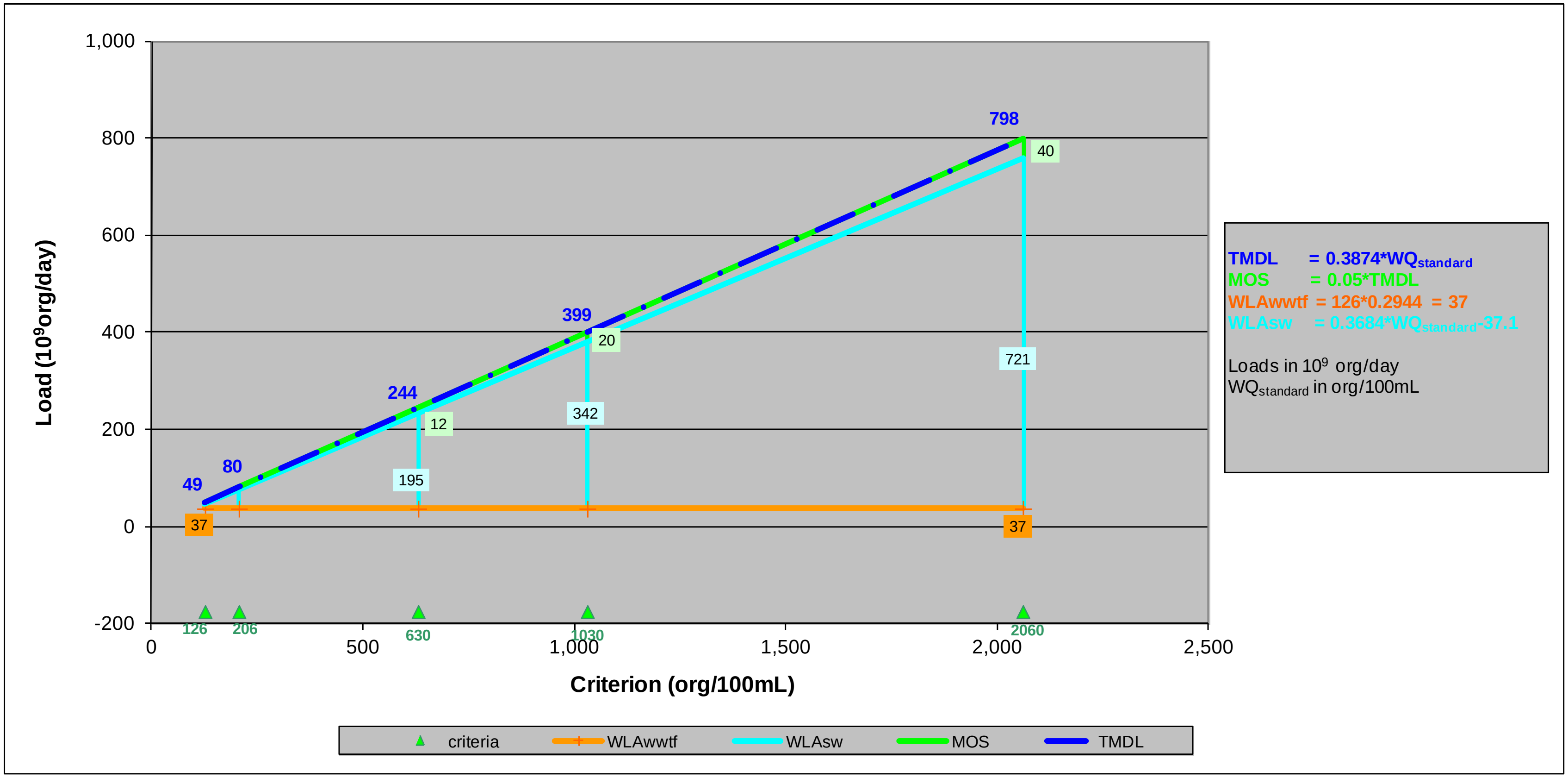


Figure 5-3 Allocation Loads for AU 1102G_01 as a Function of *E. coli* WQ Criteria

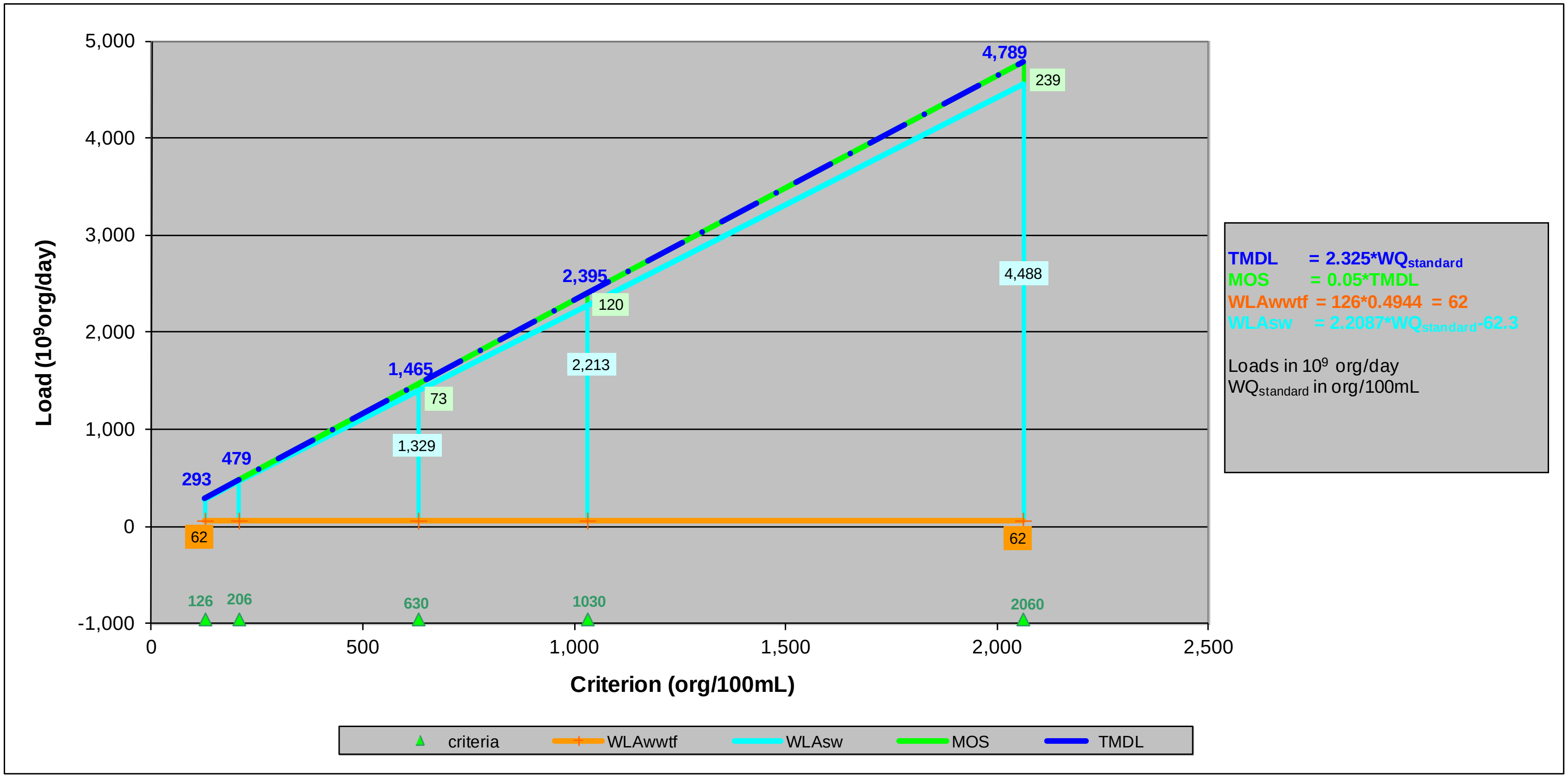


Figure 5-4 Allocation Loads for AU 1101A_01 as a Function of *E. coli* WQ Criteria

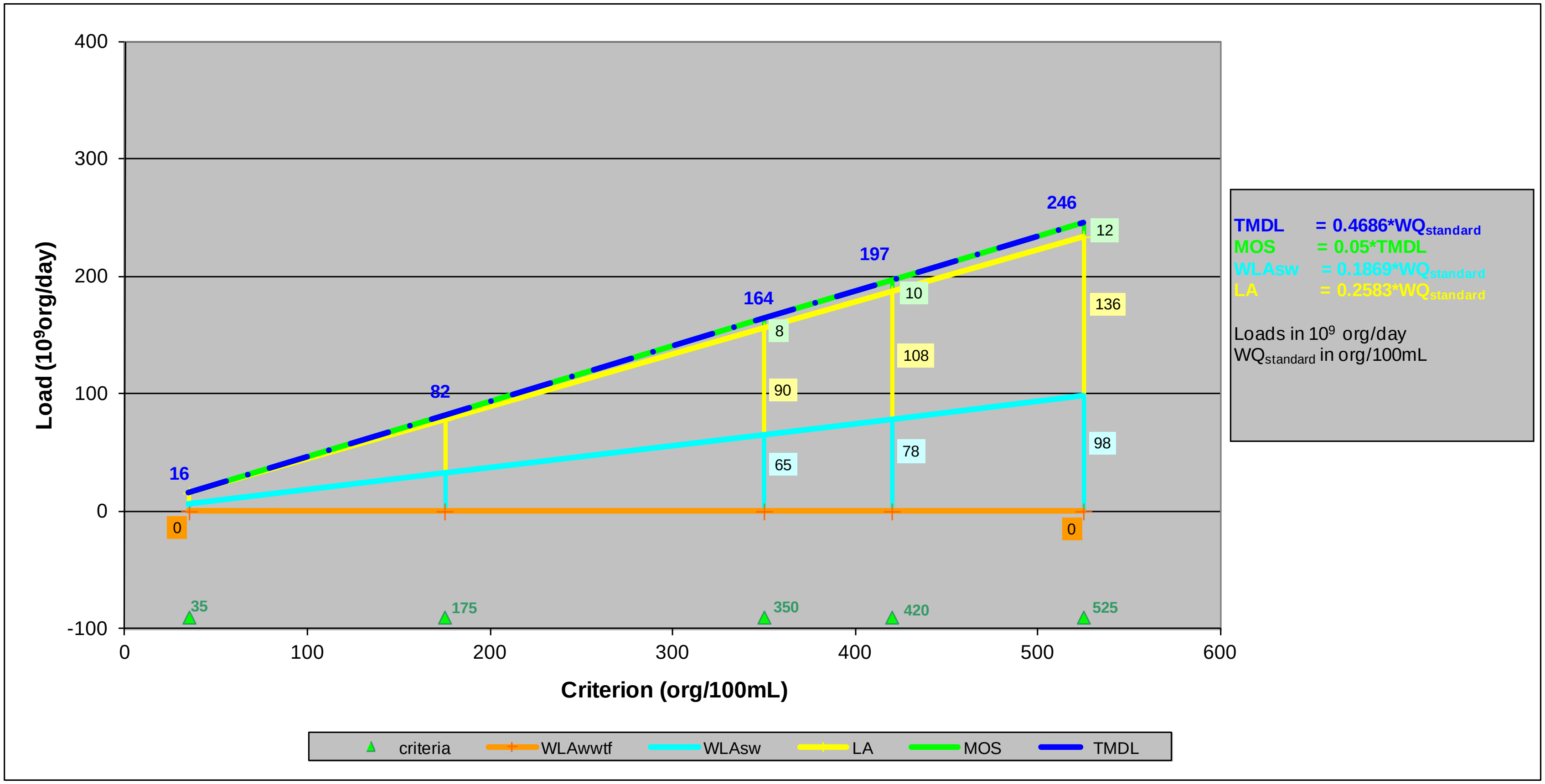


Figure 5-5 Allocation Loads for AU 1101E_01 as a Function of Enterococcci WQ Criteria

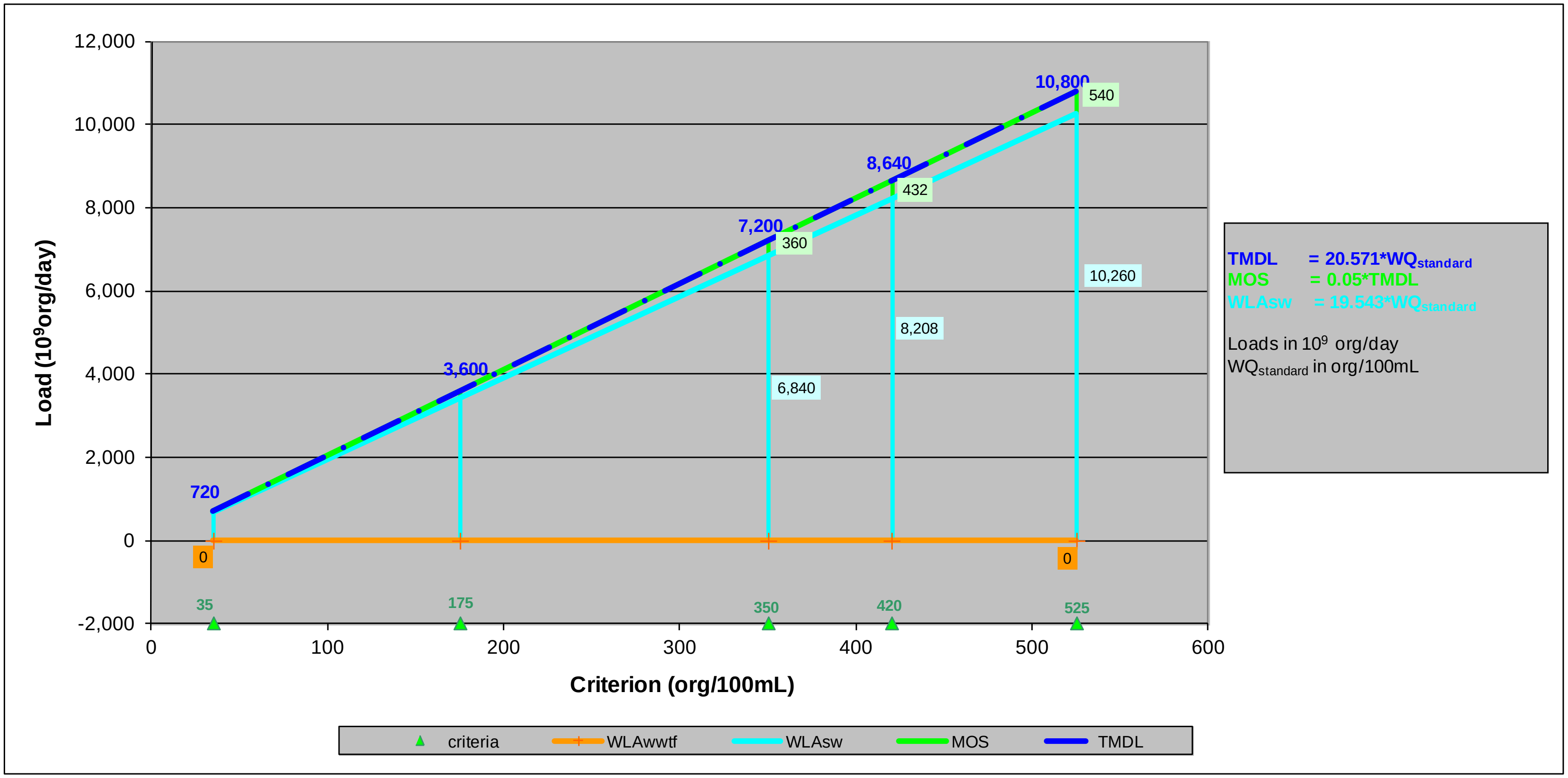


Figure 5-6 Allocation Loads for AU 1101C_01 as a Function of Enterococcci WQ Criteria

CHAPTER 6
PUBLIC PARTICIPATION

To provide focused stakeholder involvement in the Clear Creek Bacteria TMDL and the implementation phase, a 24 member steering committee was formed. In accordance with House Bill 2912, the group has balanced representation within the watershed and commitment was formalized. TCEQ approved the formation of a Clear Creek stakeholder group and approved the membership. The group has ground rules and H-GAC maintains a membership roster and has a web page dedicated to the Clear Creek Bacteria TMDL project: (http://www.h-gac.com/HGAC/Programs/Water+Resources/Total+Maximum+Daily+Loads+TMDL+/default.htm).

The responsibility of each stakeholder on the committee is to communicate project information to others being represented and provide personal/organization perspective on all issues; knowledge of the watershed; comments and suggestions during the project; and solicit input from others. Regular meetings have been held and TCEQ solicits stakeholder comment at each project milestone; and assist stakeholders with communications. H-GAC has assisted TCEQ with the public participation and with a facilitator (M.J. Naquin). As contractors to TCEQ, the University of Houston and Parsons provide technical support and presentations at stakeholder meetings.

CHAPTER 7
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APPENDIX A
AMBIENT WATER QUALITY BACTERIA DATA – 2002 TO 2011

APPENDIX B
USGS FLOW DATA AND CLEAR CREEK INSTANTANEOUS FLOW DATA

APPENDIX C
TIDE DATA*

**** See attached CD***

APPENDIX D
DISCHARGE MONITORING REPORTS – 1998 TO 2001

APPENDIX E
GENERAL METHODS FOR ESTIMATING FLOW AT TMDL WQM STATIONS

Appendix E
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:

If simultaneous daily flow data matching the water quality sample date are available, these flow measurements will be used to prepare flow exceedance percentiles.

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.

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.

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 E-1.

The average curve number is then calculated from all the grid cells within the delineated watershed.

The average rainfall is calculated for each watershed from gridded average annual precipitation datasets for the period 1971-2000 (Spatial Climate Analysis Service, Oregon State University, http://www.ocs.oregonstate.edu/prism/, created 20 Feb 2004).

Table E-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

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:

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

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.

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.

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.

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APPENDIX F
FLOW EXCEEDANCE PERCENTILES FOR TMDL WQM STATIONS

APPENDICES G – J*

***** See attached CD***

Appendix G Cross Sections for TMDL Tidal Reaches
Appendix H Freshwater Daily Flows and Enterococci Loads for Tidal Prism Boundaries
Appendix I Direct Runoff Flows and Enterococci Loads
Appendix J Enterococci Mass Balance Model

APPENDIX K
METHOD FOR ESTIMATING FUTURE WWTF PERMITTED FLOWS

Appendix K - Methodology to Project Permitted Flows for WWTFs Discharging to the Clear Creek Watershed

This methodology is intended to estimate future permitted WWTF flows on a watershed basis. The growth in wastewater flow is assumed to be the result of increases in population. A projected flow is initially determined for each WWTF and the flows are subsequently summed by watershed to allow a calculation of additional assimilative capacity and additional capacity for future waste load allocations that may be associated with expanding or new WWTFs. The steps followed for the flow projection are summarized below.

1. Projection of flows from municipal/residential mobile home discharges

- Find population estimates from TWDB for municipalities and county facilities (Table K-1).
- For residential mobile home parks, determine the city where they are located
- Find all the municipal/home park outfalls for a given city and find the total permitted flow (Table K-2).
- Find gallons/capita/day (GPCD) by city by dividing the total permitted flow per city by the population in 2010 (Table K-3).
- Determine the fraction of flow that a given outfall corresponds to respect to the total permitted flow for the city it falls in (Table K-4).
- Calculate projected flow for 2050 by multiplying the GPCD for the city by the fraction of flow for the given facility by the population for 2050 for the city where the facility is located (Table K-4).

2. Projection of flows from industrial discharges

- Determine the percent increase in water demand from manufacturing facilities between 2010 and 2050 by county (from the TWDB projections).
- Multiply the current permitted flow for the facility by the expected percent increase in manufacturing industry water demand for the county in which the facility is located. This is the projected flow for 2050 (Table K-4).
- The Gulf Coast Waste Disposal Authority facility (Blackhawk Regional WWTF) treats a combination of the municipal sewage from the city of Friendswood and effluent from manufacturing industries. Thus, the projected flow in 2050 was calculated as the sum of the projected flow from the city (calculated as outlined in the municipal/residential mobile homes category) and the projected increase in flow using the percent increase in water demand for the manufacturing industry in Harris County (Table K-4).

3. Calculation of flows by watershed

- Add up the flows discharging to a given water body (Table K-5).
- Use the projected flow to recalculate LDCs or to re-run the tidal prism model for future conditions.

Table K-1 TWDB Population Projections

Water User Group	County Name	P2000	P2010	P2020	P2030	P2040	P2050
Alvin	Brazoria	21,413	23,231	25,123	26,935	28,605	30,375
Brazoria County MUD #3	Brazoria	4,110	7,517	11,063	14,458	17,587	20,904
Pearland	Brazoria	35,696	63,685	80,689	96,167	110,461	125,585
League City	Galveston	45,306	53,403	60,392	64,532	66,207	67,454
Friendswood	Galveston	21,237	24,553	27,415	29,110	29,796	30,307
Harris County WCID #89	Harris	2,430	2,475	2,519	2,562	2,605	2,648
Houston	Harris	1,919,813	2,199,988	2,472,783	2,741,099	3,006,695	3,270,641
Nassau Bay	Harris	4,170	4,170	4,170	4,170	4,170	4,170
Webster	Harris	9,083	13,076	16,964	20,788	24,573	28,334

Table K-2 Total Permitted Flows by City

Permit	Permittee	Segment	Use Population Projection For	Permitted Flow (MGD)
12332-001	Brazoria County MUD 3	1102G_01	Brazoria County MUD 3	2.4
10005-001	City of Alvin	2432	City of Alvin	5
14440-001	R. West Development Co Inc	1104	City of Alvin	0.24
12935-001	K C Utilities	1104	City of Alvin	0.05
12822-001	Walker Water Works Inc	1102	City of Alvin	0.035
14039-001	Walker Water Works Inc	2432	City of Alvin	0.056
10134-002	City of Pearland	1102	City of Pearland	4.5
10134-007	City of Pearland	1102	City of Pearland	6
10134-008	City of Pearland	1102	City of Pearland	2
10134-010	City of Pearland	1102	City of Pearland	2.5
10134-007	City of Pearland	1102	City of Pearland	2.5
12849-001	CMH Parks Inc	1102	City of Pearland	0.075
13865-001	TIKI Leasing Co Ltd	1102	City of Pearland	0.049
12680-001	H & R Realty Investments	1102	City of Pearland	0.012
13864-001	Fresno Manufacturing LLC	1102	N/A Used Manufacturing % Increase For Fort Bend County	0.0084
10568-005	City of League City	1101	City of League City	7.5
10568-003	City of League City	1101A_01	City of League City	0.66
10568-008	City of League City Southwest Reclamation WWTP	1101A_01	City of League City	12.0
10495-002	City of Houston	1007	City of Houston	25

Permit	Permittee	Segment	Use Population Projection For	Permitted Flow (MGD)
10495-003	City of Houston	1007	City of Houston	28
10495-009	City of Houston	1007	City of Houston	7
10495-010	City of Houston	1007	City of Houston	2
10495-016	City of Houston	1006	City of Houston	7
10495-030	City of Houston	1014	City of Houston	26.4
10495-037	City of Houston	1007	City of Houston	60
10495-050	City of Houston	1007	City of Houston	3.75
10495-053	City of Houston	1007	City of Houston	4
10495-065	City of Houston	1007	City of Houston	3
10495-075	City of Houston	1102	City of Houston	6.14
10495-076	City of Houston	1017	City of Houston	21
10495-077	City of Houston	1006	City of Houston	7.25
10495-078	City of Houston	1016	City of Houston	8
10495-079	City of Houston	1102	City of Houston	5.33
10495-090	City of Houston	1007	City of Houston	200
10495-095	City of Houston	1007	City of Houston	7.2
10495-099	City of Houston	1017	City of Houston	4
10495-100	City of Houston	1016	City of Houston	3.7
10495-101	City of Houston	1016	City of Houston	4
10495-109	City of Houston	1014	City of Houston	12
10495-111	City of Houston	1007	City of Houston	13.3
10495-112	City of Houston	902	City of Houston	0.82
10495-115	City of Houston	1016	City of Houston	3
10495-116	City of Houston	1007	City of Houston	18
10495-119	City of Houston	1007	City of Houston	23
10495-122	City of Houston	1016	City of Houston	5
10495-126	City of Houston	1016	City of Houston	2
10495-133	City of Houston	1016	City of Houston	3
10495-135	City of Houston	1014	City of Houston	3.5
10495-136	City of Houston	1113	City of Houston	5
10495-139	City of Houston	1017	City of Houston	0.995
10495-146	City of Houston	1002	City of Houston	6.6
10495-148	City of Houston	1016	City of Houston	0.49
10495-149	City of Houston	1002	City of Houston	0.95
10495-150	City of Houston	1016	City of Houston	0.7
10495-151	City of Houston	1006	City of Houston	0.75
10526-001	City of Nassau Bay	1101	City of Nassau Bay	1.33

Permit	Permittee	Segment	Use Population Projection For	Permitted Flow (MGD)
10520-001	City of Webster	1101	City of Webster	3.3
11571-001	Gulf Coast WDA & City of Friendswood	1101	City of Friendswood and% Increase Manufacturing for Harris County	9.25
12939-001	Harris County WCID #89	1102	Harris County WCID #84	0.95

Table K-3 GPCD by City

Municipality/County MUD	Total Permitted Flow (MGD)[a]	Population 2010[b]	GPCD Year 2010[c]
Brazoria County MUD 3	2.4	7,517	319
City of Alvin	5.381	23,231	232
City of Friendswood	9.25	24,553	377
City of Houston	532.026	2,199,988	242
City of League City	20.16	53,403	378
City of Nassau Bay	1.33	4,170	319
City of Pearland	13.636	63,685	214
City of Webster	3.3	13,076	252
Harris County WCID #84	0.95	2,475	384

[a] *Sum of permitted flows in Table K-2 for each city*
[b] *From Table K-1*
[c] *Total permitted flow*10^6/Population 2010*

Table K-4 Flow Projections

Permit #	Facility	Permitted Flow (MGD)	Receiving Segment	Use Pop Projection from	GPCD[a]	Pop 2050[b]	% Flow In City[c]	Flow 2050[d] (MGD)	Adj Flow 2050[e] (MGD)
12332-001	Brazoria County Mud No. 3	2.4	1102G_01	Brazoria County MUD 3	319	24,368	100%	7.78	7.78
10568-003	City of League City	0.66	1101A_01	City of League City	378	67,454	3.3%	0.834	0.834
10568-008	City of League City Southwest Reclamation WWTP	12.0	1101A_01	City of League City	378	67,454	59.5%	15.157	15.157

[a] *From Table K-3*
[b] *From Table K-1*
[c] *Permitted flow for facility/total permitted flow for the city in which the facility is located*
[d] *GPCD*Population 2050*%flow in city*
[e] *Flow 2050+Permitted Flow*% increase of manufacturing industry water demand by county (Harris 23% and Fort Bend 14%)*

Table K-5 Projected Flows by Watershed

Watershed	Segment	Projected Permitted Flow (MGD)
Unnamed Tributary of Mary's Creek	1102G_01	7.78
Magnolia Creek	1101A_01	15.991
Cow Bayou	1101C_01	NA
Unnamed Tributary of Clear Creek Tidal	1101E_01	NA

NA = Allocation not applicable at this time. There are no WWTFs discharging to the Assessment Unit.