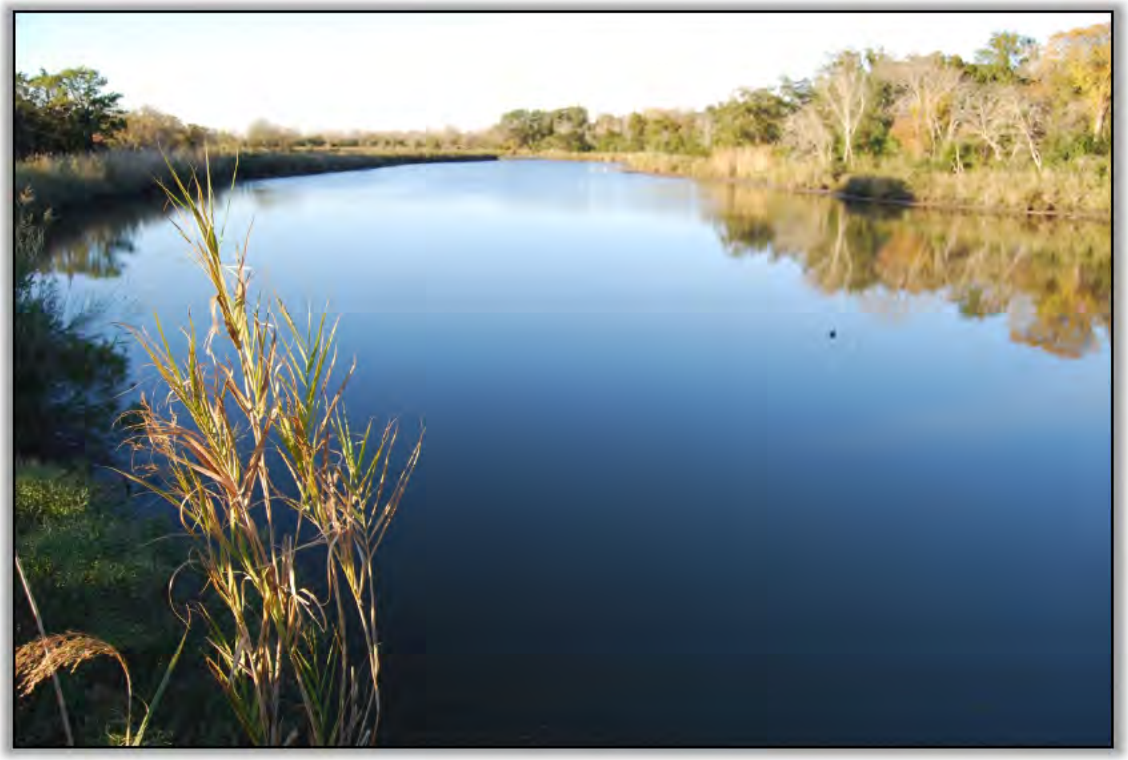
Technical Support Document for Three Total Maximum Daily Loads for Indicator Bacteria in Dickinson Bayou

Segments 1103, 1103D and 1103E

Assessment Units 1103_01, 1103D_01, and 1103E_01



Gum Bayou at FM 517

Prepared for
Total Maximum Daily Load Program
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Abbreviations and Acronyms

AU	Assessment Unit
BMP	Best Management Practice
cfs	Cubic Feet per Second
ECHO	Enforcement & Compliance History Online
E. coli	*Escherichia coli*
FDC	Flow Duration Curve
FG	Future Growth
HSPF	Hydrologic Simulation Program – FORTRAN
I&I	Inflow and infiltration
I-Plan	Implementation Plan
LA	Load Allocation
LDC	Load Duration Curve
LS	Lift Station
MGD	Million Gallons per Day
mL	Milliliter
MOS	Margin of Safety
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer System
MUID	Map Unit Identifier
NEIWPCC	New England Interstate Water Pollution Control Commission
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NWSO	National Weather Service Office
OSSF	Onsite Sewage Facility
SNC	Significant Non-compliance
SSO	Sanitary Sewer Overflow
SWMP	Stormwater Management Program
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TMDL	Total Maximum Daily Load
TNRIS	Texas Natural Resources Information System
TPDES	Texas Pollutant Discharge Elimination System
TPM	Tidal Prism Model
TSSWCB	Texas State Soil and Water Conservation Board
TWDB	Texas Water Development Board
USCB	United States Census Bureau
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WLA	Waste Load Allocation

WQMP	Water Quality Management Plan
WWTF	Wastewater Treatment Facility

SECTION 1
INTRODUCTION

1.1 Background

Section 303(d) of the federal Clean Water Act requires all states to identify waters that do not meet, or are not expected to meet, applicable water quality standards. States must develop a Total Maximum Daily Load (TMDL) for each pollutant that contributes to the impairment of a listed water body. The TCEQ is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. In addition to the TMDL an implementation plan (I-Plan) is developed, which is a description of the regulatory and voluntary management measures necessary to improve water quality and restore full use of the water body.

The TCEQ's TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies.

The Texas Commission on Environmental Quality (TCEQ) first identified the bacteria impairments within the Dickinson Bayou Tidal segment in 1996, and within the Gum Bayou and Cedar Creek segments in 2010 and then in each subsequent edition through the 2012 *Texas Water Quality Integrated Report for Clean Water Sections 305(b) and 303 (d)* (formerly called the *Texas Water Quality Inventory and 303(d) List*).

This document will consider bacteria impairments in 3 water bodies (segments), consisting of 3 total assessment units (AUs). The complete list of water bodies and their identifying AU number is shown below:

1) Dickinson Bayou Tidal 1103_01,
2) Gum Bayou (unclassified water body) 1103D_01, and
3) Cedar Creek (unclassified water body) 1103E_01

1.2 Water Quality Standards

To protect public health, aquatic life, and development of industries and economies throughout Texas, water quality standards were established by the TCEQ. The water quality standards describe the limits for indicators which are monitored in an effort to assess the quality of available water for specific users. The TCEQ is charged with monitoring and assessing water bodies based on these water quality standards, and publishes the *Texas Water Quality Integrated Report* list biennially.

The *Texas Surface Water Quality Standards* (TCEQ, 2010) are rules that:

- designate the uses, or purposes, for which the state's water bodies should be suitable;
- establish numerical and narrative goals for water quality throughout the state; and
- provide a basis on which TCEQ regulatory programs can establish reasonable methods to implement and attain the state's goals for water quality.

Standards are established to protect designated uses assigned to water bodies of which the primary uses assigned in the Texas Surface Water Quality Standards to water bodies are:

- aquatic life use
- contact recreation
- domestic water supply
- general use

Fecal indicator bacteria (FIB) are used to assess the risk of illness during contact recreation (e.g., swimming) from ingestion of water. Both *E. coli* (*Escherichia coli*) and Enterococcus spp. are present in the intestinal tracts of humans and other warm blooded animal. The presence of these bacteria in water indicates that associated pathogens from the wastes that may be reaching water bodies as a result of such sources as inadequately treated sewage, improperly managed animal waste from livestock, pets, aquatic birds, wildlife, and failing septic systems (TCEQ, 2006). *E. coli* is widely used as an indicator in freshwater, while Enterococci are more often used as an indicator in high saline inland waters and saltwater. *E. coli* are the relevant indicator for Cedar Creek (1103E_01); Enterococci are the relevant indictor for Gum Bayou (1103D_01) and Dickinson Bayou Tidal (1103_01).

On June 30, 2010 the TCEQ adopted revisions to the Texas Surface Water Quality Standards (TCEQ, 2010) and on June 29, 2011 the U.S. Environmental Protection Agency (EPA) approved the categorical levels of recreational use and their associated criteria.

For freshwater, recreational use consists of four categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for *E. coli* of 126 most probable number (MPN) per 100 mL and a single sample criterion of 399 MPN per 100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for *E. coli* of 630 per 100 mL;
- Secondary contact recreation 2 is similar to secondary contact 1, but activities occur less frequently. It has a geometric mean criterion for *E. coli* of 1,030 MPN per 100 mL; and

- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for *E. coli* of 2,060 MPN per 100 mL.

For saltwater, recreational use consists of three categories:

- Primary contact recreation is that with a significant risk of ingestion of water (such as swimming), and has a geometric mean criterion for Enterococci of 35 most probable number (MPN) per 100 mL and a single sample criterion of 104 MPN per 100 mL;
- Secondary contact recreation 1 covers activities with limited body contact and a less significant risk of ingestion of water (such as fishing), and has a geometric mean criterion for Enterococci of 175 per 100 mL;
- Noncontact recreation is that with no significant risk of ingestion of water, where contact recreation should not occur due to unsafe conditions. It has a geometric mean criterion for Enterococci of 350 per 100 mL.

In the Dickinson Bayou watershed, all three impaired assessment units - including Dickinson Bayou (1103_01), Gum Bayou (1103D_01), and Cedar Creek (1103E_01) – are approved for primary contact recreation. For Cedar Creek, considered a freshwater water body, the associated *E. coli* geometric mean criterion of 126 MPN per 100 mL and single sample of 399 MPN per 100 mL is applied; for both Gum Bayou and Dickinson Bayou Tidal, considered saltwater water bodies, the associated Enterococci geometric mean criterion of a 35 MPN per 100 mL and single sample of 104 MPN per 100 mL is applied.

1.3 Report Purpose and Organization

The TMDL project for the selected watersheds within Dickinson Bayou was initiated through a contract between the TCEQ and the Texas Institute for Applied Environmental Research (TIAER). This project is considered to be an addendum to the existing Dickinson Bayou Bacteria TMDL (TCEQ, 2012b) that was approved by EPA on June 6, 2012. The tasks of this project to be performed by TIAER were to (1) acquire existing (historical) data and information necessary to support assessment activities; (2) perform the appropriate activities necessary to allocate *E. coli* and Enterococci loadings; and (3) assist the TCEQ in preparing the TMDL.

Using historical bacteria and flow data, this portion of the project was to: (1) review the characteristics of the watershed and explore the potential sources of *E. coli* and Enterococci bacteria for the impaired AUs; (2) develop an appropriate tool for development of bacteria TMDLs for the impaired AUs; and (3) submit the draft and final technical support document for the impaired AUs. The purpose of this report is to provide technical documentation and supporting information for developing the bacteria TMDLs for the Dickinson Bayou watershed. This report contains:

- information on historical data,
- watershed properties and characteristics,

- summary of historical bacteria data that confirm the State of Texas 303(d) listings of impairment due to presence of indicator bacteria (*E. coli* and Enterococci),
- development of tools for assessing bacteria loadings, and
- development and presentation of TMDL allocation.

Whenever it was feasible, the data development and computations for developing the pollutant load allocations were performed in a manner to remain consistent with the previously completed indicator bacteria TMDLs for watersheds in the Dickinson Bayou watershed (TCEQ, 2012b).

SECTION 2
WATERSHED OVERVIEW AND DATA REVIEW

2.1 Description of Study Area

Dickinson Bayou, located along the Texas Gulf Coast within in the southeastern portion of the "Greater Houston" metropolitan area, is comprised of two segments – the upstream segment is designated as "Above Tidal (Segment 1104)" and the downstream segment is designated as simply "Tidal (Segment 1103)" (Figure 1). The above tidal portion of the bayou is a perennial freshwater stream, while the below tidal portion is influenced by seawater from lower Galveston Bay. For the purposes of this study, the entire watershed of Dickinson Bayou is considered in this overview section. However, the focus will be on the water bodies of the bacteria impairments – the most downstream AU of Dickinson Bayou Tidal (1103_01) and two tributaries to the tidal segment; Gum Bayou (1103D_01) and Cedar Creek (1103E_01).

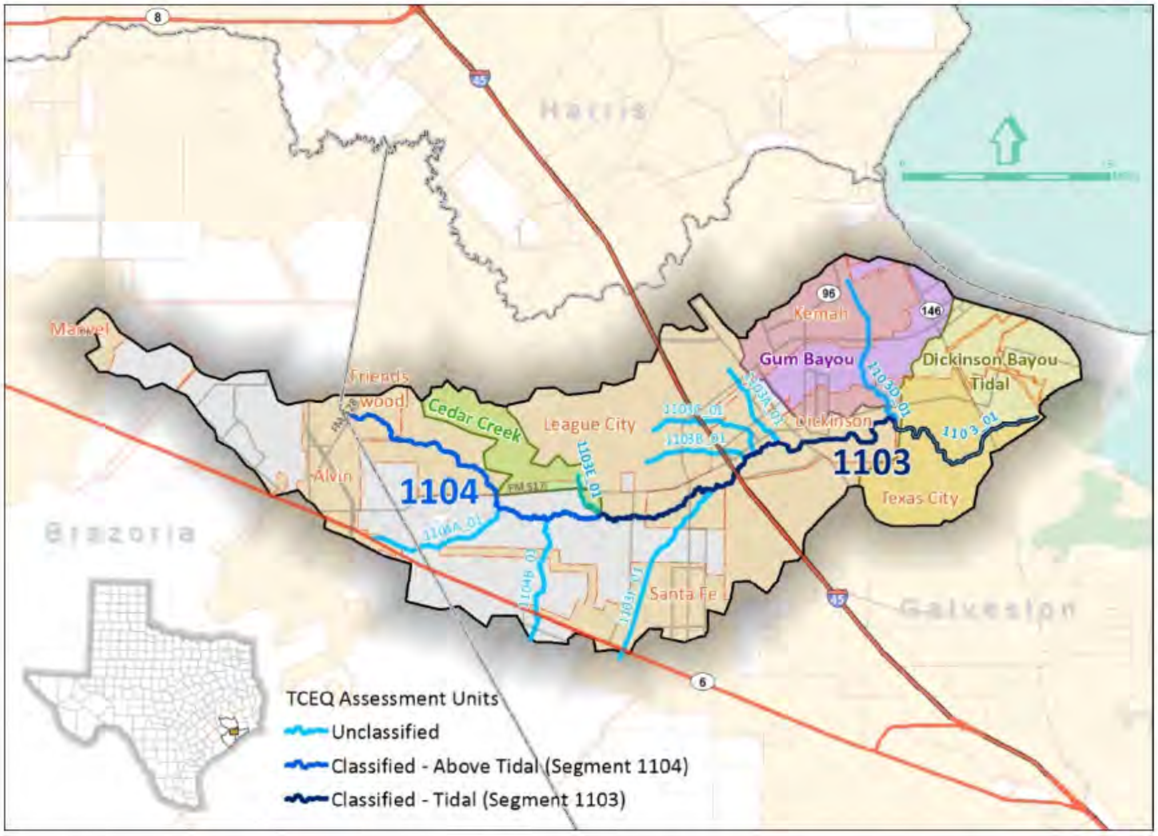

Figure 1. Overview map showing the entire Dickinson Bayou watershed, along with the impaired AU watersheds, including 1103_01, 1103D_01 and 1103E_01.

Sources: Assessment Units (TCEQ, 2011), Watershed Boundaries adapted from (TCEQ, 2012b)

Dickinson Bayou Above Tidal (Segment 1104) begins at the crossing of FM 528 in Galveston County, and flows 8.3 miles to the confluence with Cedar Creek (1103E_01), where Dickinson Bayou Tidal (Segment 1103) begins and flows 14.6 miles to the outlet into lower Galveston Bay.

At its mouth, Dickinson Bayou drains approximately 107 square miles in Galveston (86% of the watershed) and Brazoria (14% of the watershed) counties.

For the purposes of this report, we will focus on two tributary AUs, as well as the most downstream AU in Dickinson Bayou. Cedar Creek (1103E_01) is a freshwater stream that is 1.3 miles in length and drains an area of 4.2 square miles. Gum Bayou (1103D_01) is a tributary tidal stream that is 4.4 miles in length and drains an area of 13.7 square miles. The furthest downstream AU in Dickinson Bayou (1103_01) is 5.0 miles in length, and drains an immediate area of 15.8 square miles.

The 2012 Texas Integrated Report (TCEQ, 2012a) provides the following Segment and AU descriptions for the water bodies considered in this document:

- Segment 1103 Dickinson Bayou Tidal - From the Dickinson Bay confluence 2.1 km (1.3 miles) downstream of SH 146 in Galveston County to a point 4.0 km (2.5 miles) downstream of FM 517 in Galveston County
    - AU_ID: 1103_01 - From the Dickinson Bay confluence (downstream of State Hwy 146) upstream to the Gum Bayou confluence
- Segment 1103D (Same as AU 1103D_01) Gum Bayou (unclassified water body) - From the Dickinson Bayou Tidal confluence to State Hwy 96 in Galveston County
- Segment 1103E (Same as AU 1103E_01) Cedar Creek (unclassified water body) - From the Dickinson Bayou Tidal confluence to a point 0.63 km (0.39 mi) upstream FM 517 in Galveston County

2.2 Watershed Climate and Hydrology

The Dickinson Bayou watershed is located in the eastern portion of the state of Texas, where the climate is classified as “Subtropical Humid” (Larkin & Bomar, 1983). The region’s subtropical climate is caused by the “predominant onshore flow of tropical maritime air from the Gulf of Mexico,” while the increasing moisture content (from west to east) reflects variations in “intermittent seasonal intrusions of continental air” (Larkin & Bomar, 1983). For the period from 1981 to 2010, average annual precipitation over the entire Dickinson Bayou watershed was 56.1 inches (PRISM, 2012) (Figure 2).

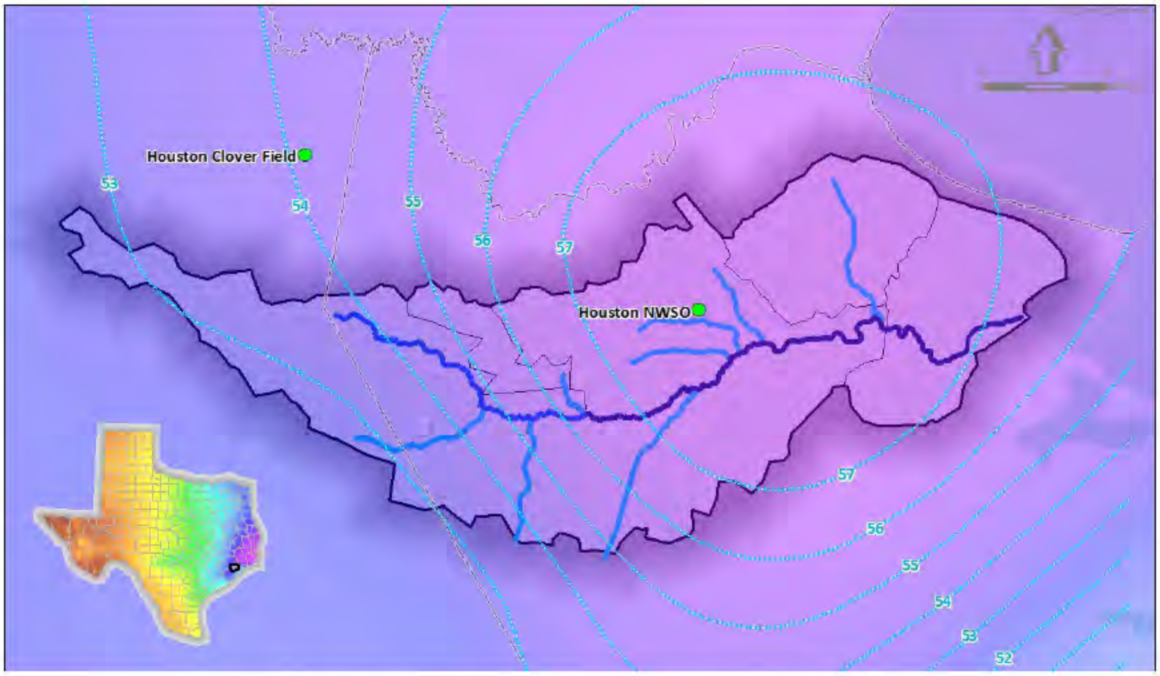

Figure 2: Annual average precipitation isohyets (in inches) in the Dickinson Bayou watershed (1981-2010). The two NCDC weather stations that were used to extend the time period of the HSPF simulation are shown.

Source: PRISM Climate Group at Oregon State University (2012)

In League City, the location of the Houston National Weather Service Office (NWSO), the average high temperatures generally reach their peak of 91°F in July and August, and highs above 100ºF are common in June, July and August. Fair skies generally accompany the highest temperatures of summer when nightly average lows drop to about 73ºF (NOAA, 2014). During winter, the average low temperature bottoms out at 43ºF in January (NOAA, 2014). The frost-free period in the region generally lasts for about 303 days, with the average last frost occurring February 12th and the average first frost occurring on December 12th (SRCC, 1994). At the Houston NWSO station, the wettest month is normally September (7.2 in), and the driest month is normally February (2.9 inches), although rainfall typically occurs year-round (NOAA, 2014) (Figure 3).

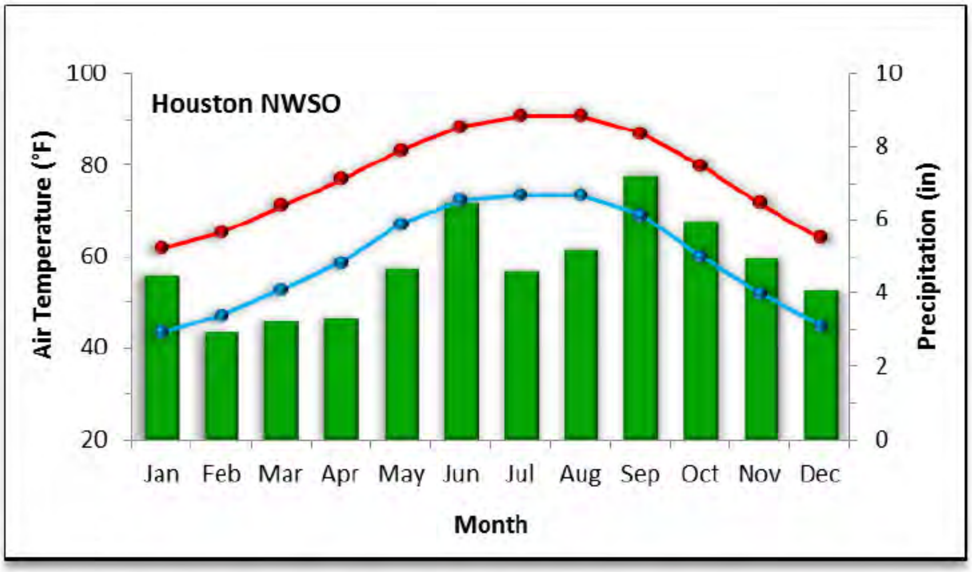

Figure 3: Average minimum and maximum air temperatures and total precipitation by month over 1981-2010 for the League City area.

Source: (NOAA, 2014)

2.3 Watershed Population and Population Projections

According to the 2010 Census, there were an estimated 72,095 people in the Dickinson Bayou watershed, indicating a population density of 676 people/ square mile. Of those, approximately 49,213 people (68%) are located within the cities of Alvin, Dickinson, Friendswood, Kemah, League City, Manvel, Santa Fe, and Texas City, indicating that the watershed population is mostly urban (Figure 4). Approximately 64% of the area of the watershed is included within these city boundaries.

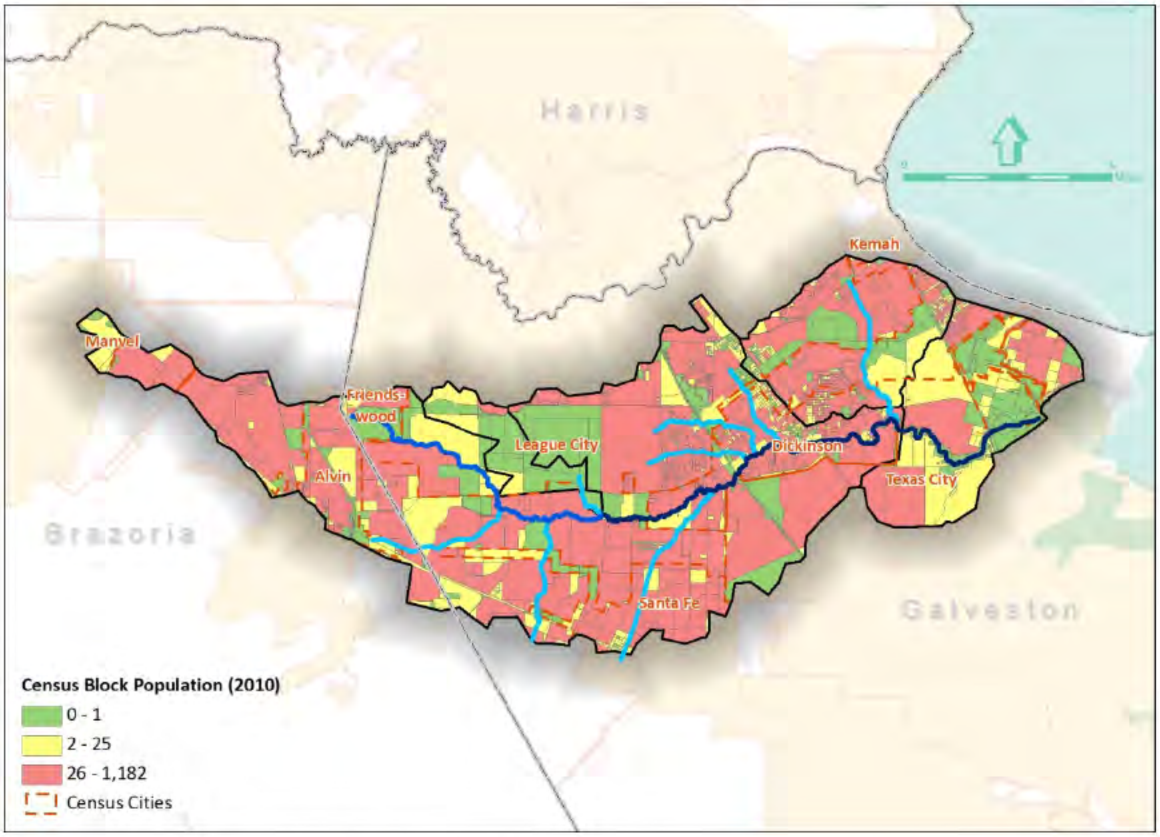

Figure 4: 2010 Total Population by Census Block.

Sources: Census Cities (TNRIS, 2012a), Census Blocks (TNRIS, 2012b), Population (USCB, 2010)

Population projections developed by the Office of the State Demographer and the Texas Water Development Board (TWDB, 2013) indicate that, between 2010 and 2050, the populations of Brazoria and Galveston counties are expected to increase substantially, by 65.9% and 46.87%, respectively. For the cities that are at least partially in Dickinson Bayou watershed (only the city of Dickinson is completely within the watershed), the expected growth rates vary substantially, from a low of 13% to a high of almost 540% (Table 1).

Table 1. 2010 Population and 2020-2050 Population Projections for cities in the Dickinson Bayou watershed.

Source: (TWDB, 2013)

City	2010 U.S. Census	2020 Population Projection	2030 Population Projection	2040 Population Projection	2050 Population Projection	Percent Increase (2010 - 2050)
Alvin	24,236	26,830	28,832	31,157	34,065	40.6%
Dickinson	18,680	19,103	20,048	21,121	22,176	18.7%
Friendswood	35,805	39,649	44,049	47,929	52,037	45.3%
Kemah	1,773	4,685	6,166	6,392	6,572	270.7%
League City	83,560	109,683	123,577	134,284	143,043	71.2%
Manvel	5,179	11,619	18,954	25,612	33,127	539.6%
Santa Fe	12,222	12,524	12,895	13,356	13,825	13.1%
Texas City	45,099	51,369	56,474	60,714	64,373	42.7%

2.4 Review of Dickinson Bayou Watershed Routine Monitoring Data

2.4.1 Data Acquisition

Ambient *E. coli* and Enterococci data were obtained from the TCEQ Surface Water Quality Monitoring Information System (SWQMIS) on 9 September 2013. The data represented all the historical routine ambient bacteria and other water quality data collected in the project area, and included bacteria data collected in the Dickinson Bayou watershed from September 1970 through April 2013, which was reduced for this project to more recently collected data beginning in 2003. General assessment criteria methodologies established by TCEQ were used in data evaluations.

2.4.2 Analysis of Bacteria Data

Recent environmental monitoring in AUs 1103_01, 1103D_01 and 1103E_01 has occurred at three TCEQ monitoring stations (Table 2 and Figure 5). Enterococci and *E. coli* data collected at these stations over the seven-year period of 1 December 2003 through 30 November 2010 were used in assessing attainment of the primary contact recreation use as reported in the 2012 Texas Integrated Report (TCEQ, 2012a). The 2012 assessment data indicate non-support of the primary contact recreation use because geometric mean concentrations exceed the geometric mean criteria of (1) 35 MPN/100 mL for Enterococci (Dickinson Bayou Tidal 1103_01 and Gum Bayou 1103D_01) and (2) 126 MPN/ 100 mL for *E. coli* (Cedar Creek 1103E_01).

Table 2. 2012 Integrated Report Summary for the Impaired AUs. (The geometric mean criterion for primary contact recreation use is 35 MPN/100 mL for Enterococci and 126 MPN/ 100 mL for *E. coli.*)

Source: (TCEQ, 2012a)

Water Body	Segment Number	Assessment Unit (AU)	Parameter	Station	No. of Samples	Data Date Range	Station Geometric Mean (MPN/100 mL)
Dickinson Bayou Tidal	1103	1103_01	Enterococcus	11455	29	12/2003 - 11/2010	72.99
Gum Bayou (unclassified)	1103D	1103D_01	Enterococcus	11436	30	12/2003 - 11/2010	85.13
Cedar Creek (unclassified)	1103E	1103E_01	*E. coli*	11434	31	12/2003 - 11/2010	173.54

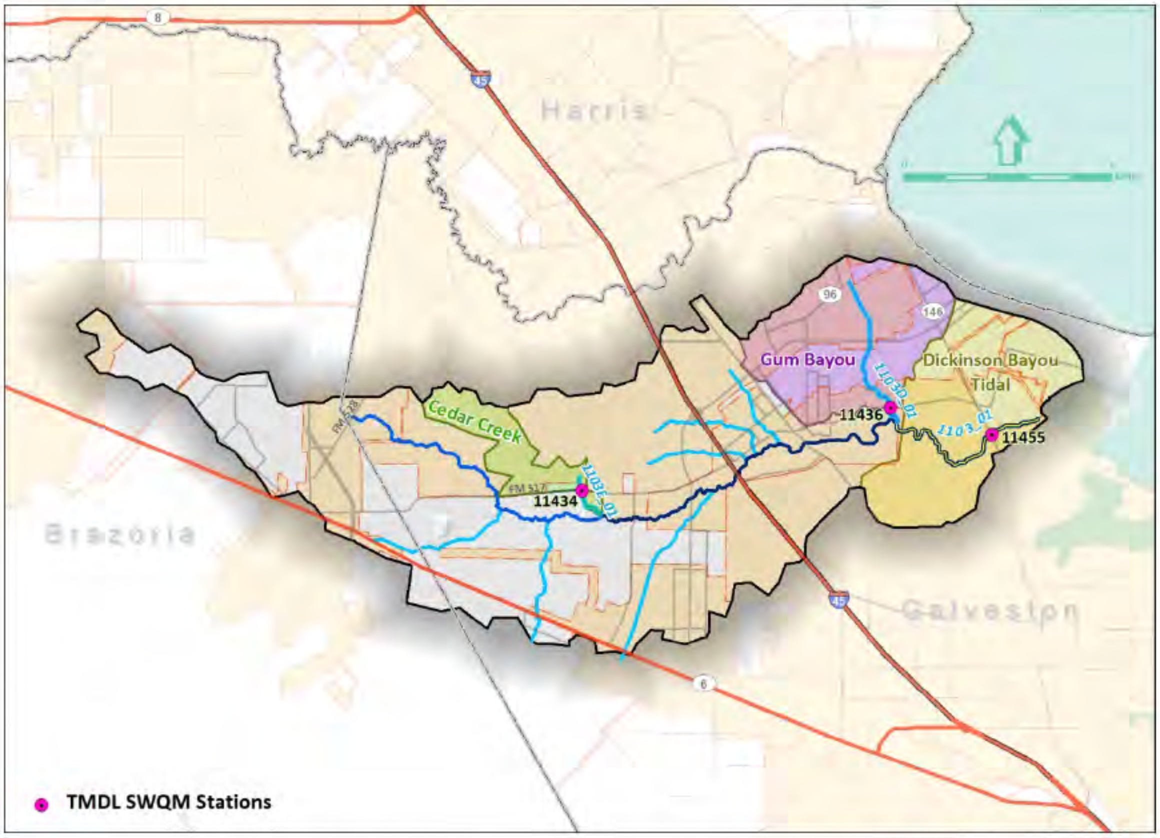

Figure 5. Dickinson Bayou watershed showing TCEQ surface water quality monitoring (SWQM) stations for the impaired AUs.

Source: SWQM stations (TCEQ, 2012d)

2.5 Land Use

The land use/land cover data for the watersheds of the Dickinson Bayou watershed was obtained from the 2011 National Land Cover Database (U.S. Geological Survey) and is displayed in Figure 6.

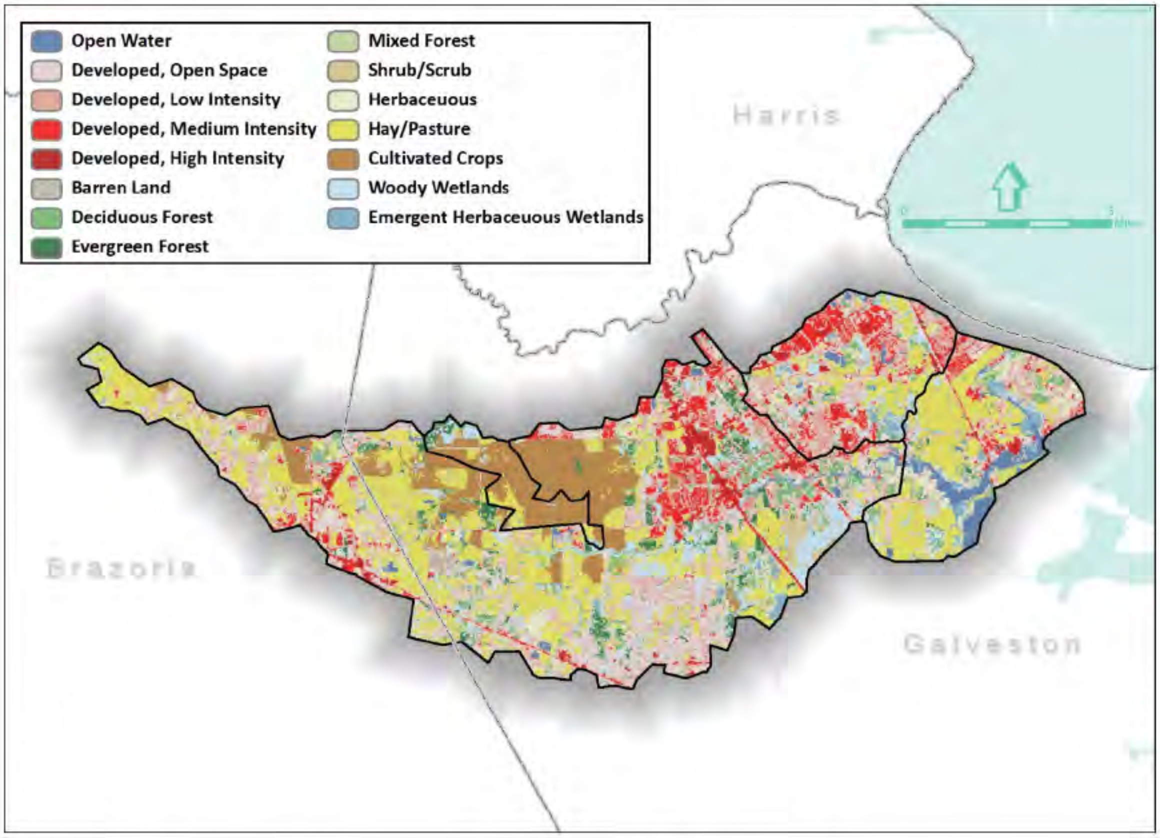

Figure 6. 2011 land use/ land cover within the Dickinson Bayou watershed.

Source: (USGS, 2014)

The land use/land cover is represented by the following categories and definitions (USGS, 2014):

- *Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.*
- *Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.*
- *Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.*
- *Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.*

- *Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.*
- *Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.*
- *Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.*
- *Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.*
- *Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.*
- *Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.*
- *Grassland/Herbaceous - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.*
- *Pasture/Hay – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.*
- *Cultivated Crops – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.*
- *Woody Wetlands - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.*
- *Emergent Herbaceous Wetlands - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.*

As displayed in Table 3, the dominant land use in the watershed area encompassing both the Tidal and Above Tidal segments of Dickinson Bayou (the entire Dickinson Bayou watershed) is Hay/ Pasture (22.6%) followed by Developed, Open Space (18.7%). The watershed is predominantly rural in land-use, though about 38% of the area is classified as Developed (open space, low intensity, medium intensity and high intensity). In the Dickinson Bayou Tidal watershed (1103_01), the predominant NLCD classification is Hay/Pasture (33%); in Gum Bayou watershed the predominant classification is Low Intensity Developed (23%); and in the Cedar Creek watershed (1103E_01), the predominant classification is Cultivated Crops (68%).

Table 3. Land/Use Land Cover within the Dickinson Bayou watershed.

Source: USGS (2011)

2011 NLCD	Dickinson Bayou Tidal Watershed (1103_01)		Gum Bayou Watershed (1103D_01)		Cedar Creek Watershed (1103E_01)		Entire Dickinson Bayou Watershed	
Classification	**mi^2**	**% of Total**	**mi^2**	**% of Total**	**mi^2**	**% of Total**	**mi^2**	**% of Total**
Open Water	1.6	10.2%	0.2	1.7%	0.0	0.0%	2.5	2.4%
Developed, Open Space	1.9	11.7%	3.0	21.7%	0.1	1.8%	20.0	18.7%
Developed, Low Intensity	1.4	8.8%	3.1	22.9%	0.0	0.3%	11.5	10.8%
Developed, Medium Intensity	0.6	3.9%	2.1	15.5%	0.0	0.0%	7.0	6.6%
Developed, High Intensity	0.1	0.7%	0.4	3.0%	0.0	0.0%	1.7	1.6%
Barren Land	0.3	1.6%	0.1	0.8%	0.0	0.0%	0.8	0.8%
Deciduous Forest	0.8	4.9%	0.7	5.2%	0.1	2.0%	5.5	5.1%
Evergreen Forest	0.1	0.5%	0.0	0.4%	0.1	3.5%	2.4	2.3%
Mixed Forest	0.0	0.1%	0.0	0.2%	0.0	0.5%	0.5	0.4%
Shrub/Scrub	0.9	5.6%	0.2	1.8%	0.2	3.9%	5.8	5.5%
Herbaceous	1.4	8.9%	0.5	3.6%	0.0	0.2%	5.5	5.2%
Hay/Pasture	5.2	33.1%	2.0	14.4%	0.5	12.5%	24.1	22.6%
Cultivated Crops	0.0	0.1%	0.0	0.0%	2.8	67.5%	10.7	10.0%
Woody Wetlands	0.6	3.6%	0.8	5.8%	0.3	7.5%	6.1	5.7%
Emergent Herbaceous Wetlands	1.0	6.3%	0.4	3.1%	0.0	0.3%	2.4	2.3%
Total	**15.8**	**mi^2**	**13.7**	**mi^2**	**4.2**	**mi^2**	**106.6**	**mi^2**

2.6 Soils

Soils in the watershed categorized by their map unit identifier (MUID) are shown in Figure 7, and summarized in Tables 4 and 5. These data were obtained through the Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) database (USGS, 1995), as well as from the Soil Survey for Galveston County (USDA SCS, 1988). All five of the soil groups within the Dickinson Bayou watershed are classified in Hydrologic Soil Group D, and therefore have the following characteristics: a high runoff potential when thoroughly wet, restricted water movement though the soil, and a high shrink-swell potential (NRCS, 2007). As described in the previously completed Dickinson Bayou bacteria TMDL Technical Support Document (CDM & UofH, 2012), the properties described in Table 4 were used in developing the HSPF watershed model.

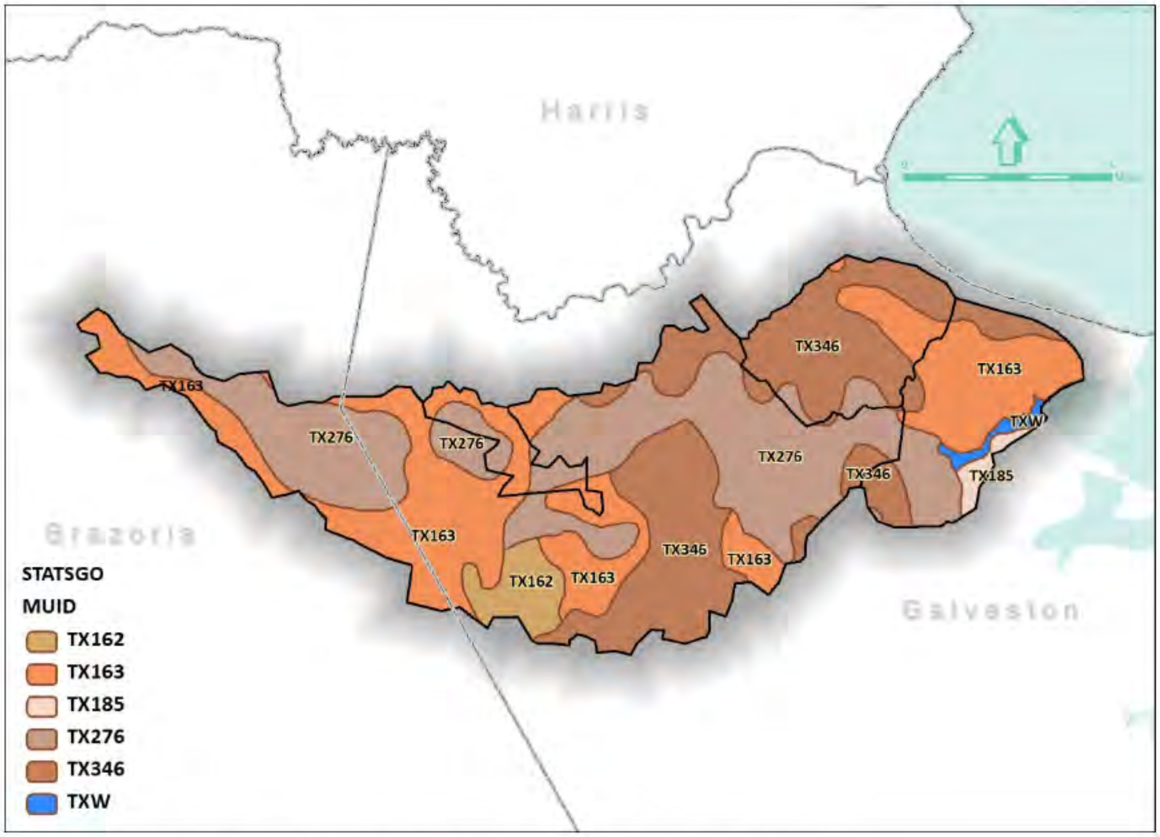

Figure 7. Dickinson Bayou watershed soil map, soils categorized by MUID

Source: USGS (1995)

2.7 Potential Sources of Fecal Indicator Bacteria

Potential sources of indicator bacteria pollution can be divided into two primary categories: *regulated* and *unregulated*. Pollution sources that are regulated have permits under the Texas Pollutant Discharge Elimination System (TPDES) and National Pollutant Discharge Elimination System (NPDES) programs. Examples of regulated sources are wastewater treatment facility (WWTF) discharges and stormwater discharges from industries, construction, and municipal separate storm sewer systems (MS4s) of cities.

Unregulated sources are typically nonpoint source in nature, meaning the pollution originates from multiple locations and is usually carried to surface waters by rainfall runoff. Nonpoint sources are not regulated by permit.

With the exception of WWTFs, which receive individual waste load allocations or WLAs (see report Section 4.5.2, Waste Load Allocation), the regulated and unregulated sources in this section are presented to give a general account of the potential sources of bacteria in the watershed.

Table 4. General characteristics of soils in the Dickinson Bayou watershed

Adapted from Table 2-4 in CDM & UofH (2012)

NRCS Soil Type (MUID)	Description	Surface Texture	Hydrological Soil Group	Total % as Sand	Total % as Silt	Total % as Clay	Weighted Average Water Capacity (cm/cm)
TX162	Leton-Lake Charles-Kemah-Edna-Bernard-Aris (s7307)	Fine Sandy Loam	D	58.64%	28.77%	12.60%	0.1375
TX163	Verland-Lake Charles-Edna-Bernard (s7308)	Fine Sandy Loam/Clay Loam	D	56.43%	29.82%	13.75%	0.181
TX185	Narta-Leton-Harris-Francitas (s7330)	Clay/Fine Sandy Loam	D	31.23%	28.27%	40.50%	0.13564
TX276	Lake Charles-Bernard (s7414)	Clay/Clay Loam	D	24.81%	28.32%	46.88%	0.17882
TX346	Mocarey-Leton (s7481)	Loam	D	38.87%	41.13%	20.00%	0.16145

Table 5. Distribution of soils in the Dickinson Bayou watershed

Source: USGS (1995). Adapted from Table 2-5 in 2012 TSD (CDM & UofH, 2012)

NRCS Soil Type (MUID)	Description	Area (Square Miles)	Percent of Watershed
TX162	Leton-Lake Charles-Kemah-Edna-Bernard-Aris (s7307)	3.6	3.4%
TX163	Verland-Lake Charles-Edna-Bernard (s7308)	34.2	32.4%
TX185	Narta-Leton-Harris-Francitas (s7330)	1.0	1.0%
TX276	Lake Charles-Bernard (s7414)	36.7	34.7%
TX346	Mocarey-Leton (s7481)	30.2	28.5%
TXW	Water	0.9	0.8%
Totals		**106.6**	**100.0%**

2.7.1 Permitted Sources

Permitted sources are regulated by permit under the TPDES and the NPDES programs. WWTF outfalls and stormwater discharges from industries represent the permitted sources in the Dickinson Bayou watershed.

2.7.1.1 Domestic and Industrial Wastewater Treatment Facilities

There are currently eleven facilities with TPDES/ NPDES permits that operate within the watershed (Figure 8 and Table 6). Three of the WWTFs are located in the Above Tidal portion of Dickinson Bayou (Segment 1104); the remaining eight WWTFs are located within Dickinson

Bayou Tidal (Segment 1103). Six facilities within the Dickinson Bayou watershed treat exclusively domestic wastewater; five additional facilities are associated with industrial stormwater and washwater. Three of the facilities discharge directly into Dickinson Bayou Above Tidal (1103), five into tributaries of Dickinson Bayou Tidal (including one into Gum Bayou), and three into tributaries of Dickinson Bayou Above Tidal (1104). For Cedar Creek (1103E), there are no WWTFs within the watershed; for Gum Bayou (1103D), there is one; and for the downstream Dickinson Bayou Tidal AU (1103_01), there are five WWTFs (See Figure 8).

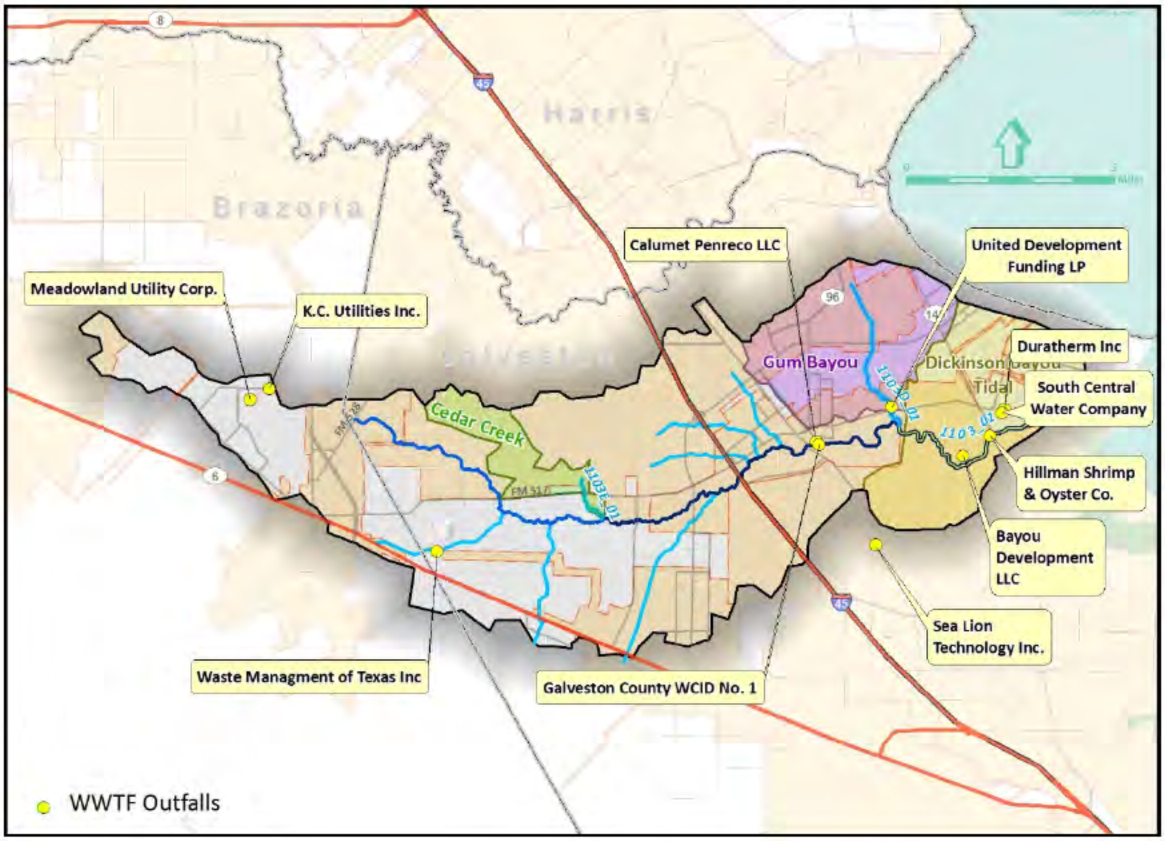

Figure 8. Dickinson Bayou watershed showing wastewater treatment facilities (WWTFs).

While Sea Lion Technology is outside of the watershed, it discharges into a canal which drains into Dickinson Bayou Tidal 1103_01.

Source: Permitted outfalls (TCEQ, 2012b)

Table 6. Permitted wastewater treatment facilities in the Dickinson Bayou watershed.

Source: Individual TPDES Permits

TPDES Permit No.	Facility	Held By	AU [a]	Receiving Waters	Discharge Type	Final Permitted Discharge [b] (MGD)	Recent Discharge [c] (MGD)
WQ0000377000	Dickinson Plant	Calumet Penreco LLC	1103_02	Dickinson Bayou Tidal (Outfall 001)	Discharge treated process wastewater, utility wastewater, and stormwater	0.075	0.081
WQ0003416000	Coastal Plains Recycling and Disposal Facility	Waste Management of Texas Inc.	1104_01	Bushway Draw; thence to Dickinson Bayou Above Tidal	Dewatering wells and stormwater	n/a	0.125
WQ0003479000	Sea Lion Technology	Sea Lion Technology Inc.	1103_01	unnamed ditch to Galveston County Drainage District No.2 (GCDD2) ditch 5B to GCDD2 ditch 5 to Dickinson Bayou Tidal	Non-process area stormwater runoff and utility wastewater	n/a (Outfalls 001, 101); 0.02 (Outfall 201)	0.103
WQ0003749000	Galveston Co Plant	Hillman Shrimp and Oyster Co	1103_01	Dickinson Bayou Tidal	Seafood washwater, domestic wastewater, and effluent	0.07	0.000
WQ0004086000	Duratherm	Duratherm Inc.	1103_01	drainage ditch to an unnamed tributary of Dickinson Bayou to Dickinson Bayou Tidal	Stormwater associated with industrial activity	n/a	0.528
WQ0010173001	Plant 1	Galveston County WCID 1	1103_02	Dickinson Bayou Tidal	Treated domestic wastewater	4.8	2.947
WQ0012935001	Pine Colony Utilities Facility	K C Utilities Inc.	1104_02	unnamed drainage ditch to Brazoria County Conservation and Reclamation Ditch #D-4 to Dickinson Bayou Above Tidal	Treated domestic wastewater	0.05	0.032
WQ0013632001	Meadowland Utility Corporation WWTP	Meadowland Utility Corporation	1104_02	Brazoria County Drainage Ditch, then to Dickinson Bayou Above Tidal	Treated domestic wastewater	0.0234	0.063[d]
WQ0014326001	Galveston Bay RV	Bayou Development LLC	1103_01	Pond 1 to an unnamed ditch to Pond 2 to an unnamed tidal drainage ditch to Dickinson Bayou Tidal	Treated domestic wastewater	0.02	0.002
WQ0014570001	Marlin Atlantis White WWTF	United Development Funding LP	1103D_01	Gum Bayou to Dickinson Bayou Tidal	Treated domestic wastewater	0.5 (post-expansion)	no data
WQ0014804001	Dolphin Cove WWTF	South Central Water Company	1103_01	unnamed tidal tributary to Dickinson Bayou Tidal	Treated domestic wastewater	0.95 (post-expansion)	no data

[a] From the 2012 TMDL (TCEQ, 2012b), except WQ0014804001

[b] Significant figures reflect MGDs presented in TPDES permits

[c] Average measured discharge from Jan. 2009 through Dec. 2013, as available

[d] Average measured discharge from Aug. 2012 through Oct. 2013. Multiple non-receipt violations issued over 5 year period.

2.7.1.2 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are unauthorized discharges that must be addressed by the responsible party, either the TPDES permittee or the owner of the collection system that is connected to a permitted system. SSOs in dry weather most often result from blockages in the sewer collection pipes caused by tree roots, grease and other debris. Inflow and infiltration (I&I) are typical causes of SSOs under conditions of high flow in the WWTF system. Blockages in the line may exacerbate the I&I problem. Other causes, such as a collapsed sewer line, may occur under any condition.

The TCEQ Region 12 Office maintains a database of SSO data reported by municipalities. These SSO data typically contain estimates of the total gallons spilled, responsible entity, and a general location of the spill. The reports of SSO events that occurred within the Dickinson Bayou watershed between October 2004 and January 2012 are shown in Table 7. Twenty-seven incidences were reported for one facility (Galveston County WCID 1). The data indicate that the SSOs occurred year-round, and that the durations lasted from 1 hour to 27 hours, and overflow volumes ranged from 40 gallons to 96,580 gallons. It is possible that SSOs are being under-reported in the Dickinson Bayou watershed as some data would have been anticipated for other facilities over the period covered in the dataset.

2.7.1.3 TPDES-Regulated Stormwater

When evaluating stormwater for a TMDL allocation, a distinction must be made between stormwater originating from an area under a TPDES or NPDES regulated discharge permit and stormwater originating from areas not under a TPDES or NPDES-regulated discharge permit. Stormwater discharges fall into two categories:

1) stormwater subject to regulation, which is any stormwater originating from TPDES-regulated Phase I or Phase II MS4, stormwater discharges associated with industrial activities, and stormwater discharges from regulated construction activities; and

2) stormwater runoff not subject to regulation.

Table 7. SSO incidences reported in the Dickinson Bayou watershed from Oct. 2004 – Jan. 2012.

Source: TCEQ Region 12

Segment	Permit	Location	Date	Time Known	Days	Hours	Minutes	Gallons	Cause	Collection System	Receiving Stream
1103	WQ0010173001	FM 517 & Timber	10/27/2004	YES		1		5,000	Lift Station (LS)Down	Main Line	Storm Drain
1103	WQ0010173001	2920 Colonial Dr	9/24/2006	YES		1	10	500	LS Power Outage	LS	Ground
1103	WQ0010173001	C Club Ln & Dickinson Bay	9/26/2006	NO				96,580	Failed Coupling	Force Main	Dickinson Bayou
1103	WQ0010173001	2111 FM 517	10/17/2006	YES		7	30	13,500	Heavy Rain	Manhole	Storm Drain
1103	WQ0010173001	Hwy 3 & Central	10/17/2006	YES		7	30	9,000	Heavy Rain	Manhole	Storm Drain
1103	WQ0010173001	Deats & Timber	10/26/2006	YES		2		8,400	Heavy Rain	Manhole	Storm Drain
1103	WQ0010173001	Ecret Lift Station (LS)	10/27/2006	YES		2		36,000	Broken Line	Lift Station	Dickinson Bayou
1103	WQ0010173001	2800 California Ave	12/6/2006	YES		2		2,400	LS Pump Failure	Manhole	Ditch
1103	WQ0010173001	2201 Oleander Dr	3/9/2007	YES		1		300	LS Down	Manhole	Ditch
1103	WQ0010173001	Hwy 3 & Central St	3/14/2007	YES		2		2,400	Power Outage/Rain	Manhole	Storm Sewer
1103	WQ0010173001	Yupon & Deats Rd	1/4/2007	YES		8		4,800	Rain	Manhole	Ditch
1103	WQ0010173001	4503 Mariners Mooring St	5/7/2007	YES		2		1,200	LS Failure	Manhole	Ditch
1103	WQ0010173001	4503 Mariners Mooring St	5/27/2007	YES		3		1,400	LS Failure Due To Lighting	Manhole	Ditch
1103	WQ0010173001	2111 FM 517	7/6/2007	YES	1	3		24,300	Heavy Rainfall	Manhole	Ditch
1103	WQ0010173001	4503 Mariners Mooring St	8/16/2007	YES		3		1,920	Lightning/ LS Failure	Manhole	Ditch
1103	WQ0010173001	4660 Country Club Dr	12/27/2007	YES		4		2,400	Power Failure	Manhole	Ditch
1103	WQ0010173001	Manhole 745 (Mariners Mooring)	1/16/2008	YES		2		2,400	LS Fuse Tripped	Manhole	Ditch
1103	WQ0010173001	Lininger LS	1/19/2008	YES		5		12,000	Crack In Force Main	LS/Force Main	Ditch
1103	WQ0010173001	201 West Bayou	2/10/2008	YES		10		12,000	LS Control Panel Error	Clean Out	Dickinson Bayou
1103	WQ0010173001	WWTF Main LS	9/13/2008	YES		8		UNK	Hurricane Ike	LS	

Seg-ment	Permit	Location	Date	Time Known	Days	Hours	Minutes	Gallons	Cause	Collection System	Receiving Stream
1103	WQ0010173001	Mariners Mooring Dr	9/16/2008	NO				5,000	Hurricane Ike		
1103	WQ0010173001	Country Club LS	9/15/2008	NO				50,000	Hurricane Ike	LS	Ground
1103	WQ0010173001	Oak Hallow LS	9/16/2008	NO				5,000	Hurricane Ike	LS	Ditch
1103	WQ0010173001	5020 Lininger	7/22/2009	YES		1	0	40	Pump Failure		
1103	WQ0010173001	WWTF	1/9/2012	YES		0	30	10,000	Rain/Pump Tripped	Manhole	
1103	WQ0010173001	Hughes Ln & West Bayou	1/10/2012	YES		14	0	8,400	Rain	Manhole	Dickinson Bayou
1103	WQ0010173001	WWTF	1/9/2012	YES		1	43	2,500	Rain	WWTF	Clear Creek

The TPDES/NPDES MS4 Phase I and II rules require municipalities and certain other entities in urban areas to obtain permits for their stormwater systems. Both the Phase I and II permits include any conveyance such as ditches, curbs, gutters, and storm sewers that do not connect to a wastewater collection system or treatment facility. Phase I permits are individual permits for large and medium sized communities with populations exceeding 100,000, whereas Phase II permits are for smaller communities within an EPA-defined urbanized area that are regulated by a general permit. The purpose of a MS4 permit is to reduce discharges of pollutants in stormwater to the "maximum extent practicable" by developing and implementing a Stormwater Management Program (SWMP). The SWMPs require specification of best management practices (BMPs) for six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge detection and elimination;
- Construction site runoff control;
- Post-construction runoff control; and
- Pollution prevention/good housekeeping.

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

No Phase I individual permits exist in the Dickinson Bayou watershed. For the TMDL watersheds containing entities with Phase II general permits, the areas included under these MS4 permits were used to estimate the areas under stormwater regulation for construction, industrial and MS4 permits (Figure 9).

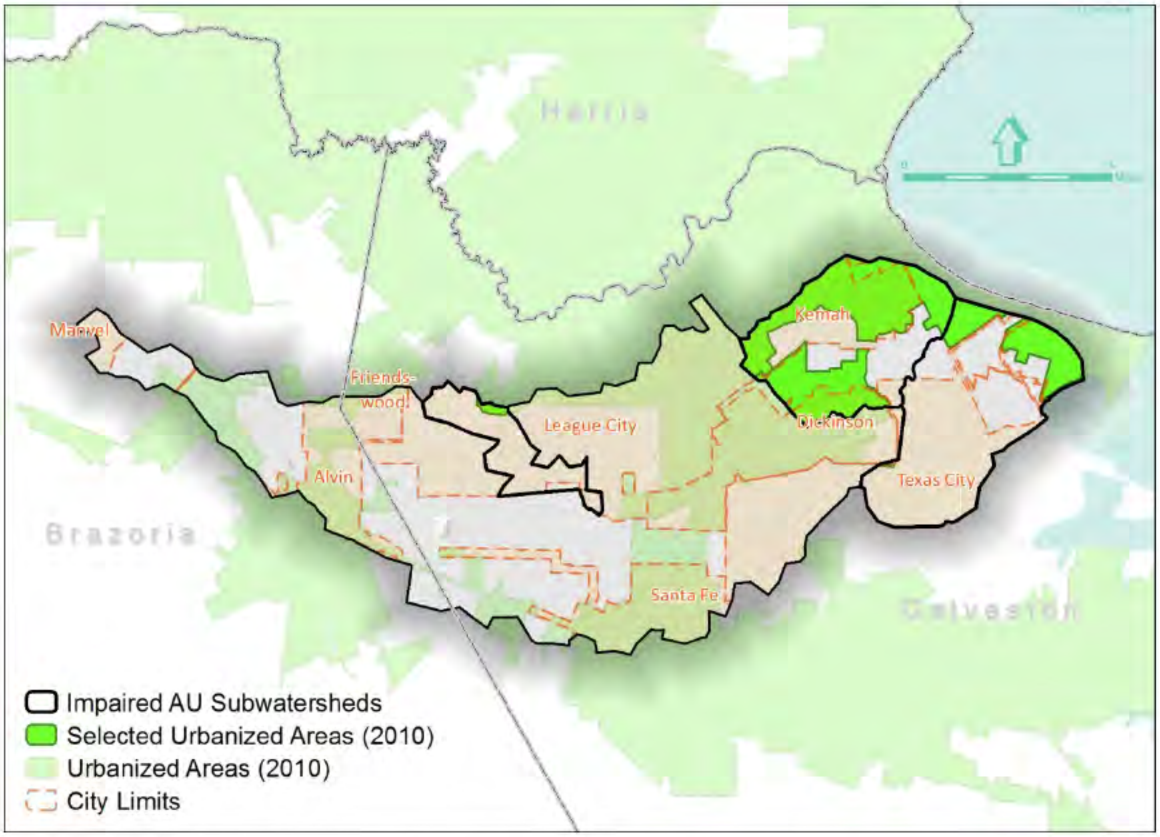

Figure 9. Dickinson Bayou watershed showing 2010 Urbanized areas (2010) with the impaired AU watersheds highlighted.

Source: (USCB, 2014)

The regulated area for the Phase II permits was based on the 2010 Urbanized Area from the U.S. Census Bureau. The entities regulated under MS4 permits for the TMDL watersheds are provided in Table 8. The AUs were identified using GIS analysis, which consisted of interpreting the permitted site descriptions using relevant GIS coverages (2010 Urbanized Areas, city boundaries, and drainage district boundaries). The associated AUs were those that either intersected the identified areas, or immediately drained the identified areas. The percentage of land area under jurisdiction of stormwater permits for each of the TMDL watersheds is presented in Table 9.

Table 8. TPDES MS4 Permits associated with Dickinson Bayou AUs .

Source: (USCB, 2014)

Permit Number	Entity	AUs
TXR040138	City of Alvin	1104_01, 1104A_02
TXR040271	City of Dickinson	1103_01, 1103_02, 1103_03, 1103A_01, 1103B_01, 1103C_01, 1103F_01
TXR040233	City of Friendswood	1104_02
TXR040193	City of Santa Fe	1103F_01, 1104B_01
TXR040364	Galveston County	1103_04, 1103B_01, 1103D_01, 1103F_01, 1104B_01
TXR040067	Galveston County Consolidated Drainage District	1104_02
TXR040203	Galveston County Drainage District 1	1103_01, 1103_02, 1103_03, 1103F_01, 1104_01, 1104A_01, 1104B_01
TXR040024	City of Texas City	1103_01, 1103_02, 1103_03, 1103_04

Table 9. Estimated area under stormwater permit regulations for impaired AU watersheds.

Source: (USCB, 2014)

Watershed	AU	AU Area within 2010 Urbanized Areas (mi^2)	AU Watershed Area (mi^2)	Percentage of drainage area under stormwater regulation (%)
Dickinson Bayou Tidal	1103_01	2.68	15.81	16.95%
Gum Bayou	1103D_01	9.12	13.67	66.72%
Cedar Creek	1103E_01	0.15	4.16	3.61%

2.7.1.4 Dry Weather Discharges/Illicit Discharges

Bacteria loads from regulated stormwater can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. The term "illicit discharge" is defined in TPDES General Permit No. TXR040000 for Phase II Municipal Separate Storm Sewer Systems as "Any discharge to a municipal separate storm sewer that is not entirely composed of stormwater, except discharges pursuant to this general permit or a separate authorization and discharges resulting from emergency firefighting activities." Illicit discharges can be categorized as either direct or indirect contributions. Examples of illicit discharges identified in the Illicit Discharge Detection and Elimination Manual: A Handbook for Municipalities (NEIWPCC, 2003) includes:

Examples of direct illicit discharges:

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

Examples of indirect illicit discharges:

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

2.7.1.5 Review of Compliance Information on Permitted Sources

A review of the EPA Enforcement & Compliance History Online (ECHO) database (USEPA, 2014) conducted 3 June 2014, revealed non-compliance issues regarding bacteria for at least one WWTF in the Dickinson Bayou watershed (See Table 10). The ECHO database review also revealed that compliance data for indicator bacteria was not available for four of the five WWTFs that have a bacteria monitoring requirement (See Table 10).

All five of the facilities with a bacteria monitoring requirement have a current compliance status of either "Unknown" (Hillman Shrimp and Oyster Co & Meadowland Utility Corporation) or "Noncompliance" (Galveston County WCID 1, K C Utilities Inc. and United Development Funding LP). For Galveston County WCID 1, none of the bacteria effluent violations were reported as Significant Non-compliance (SNC) effluent violations.

Table 10. Bacteria monitoring requirements and compliance status for WWTFs in the Dickinson Bayou Watershed.

Compliance status based on the period of record available through the EPA Enforcement & Compliance History Online (ECHO) database. The period of record for Galveston County WCID 1 (Plant 1) is May 2011 – March 2014. "% Monthly Exceedances" were calculated based on reported monthly records.

TPDES Permit No.	Facility	Held By	Bacteria Monitoring Requirement	Min. Self-Monitoring Requirement Frequency	Daily Average (Geometric Mean) Limitation	Single Grab (or Daily Max) Limitation	% Monthly Exceedances Daily Average	% Monthly Exceedances Single Grab
WQ0000377000	Dickinson Plant	Calumet Penreco LLC	none	-	-	-	-	-
WQ0003416000	Coastal Plains Recycling and Disposal Facility	Waste Management of Texas Inc.	none	-	-	-	-	-
WQ0003479000	Sea Lion Technology	Sea Lion Technology Inc.	none	-	-	-	-	-
WQ0003749000	Galveston Co Plant	Hillman Shrimp and Oyster Co	Enterococci	Two/ month	35[a]	89[a]	n/a[b]	n/a[b]
WQ0004086000	Duratherm	Duratherm Inc.	none	-	-	-	-	-
WQ0010173001	Plant 1	Galveston County WCID 1	Enterococci	One/ week	17.5	52	7%	21%
WQ0012935001	Pine Colony Utilities Facility	K C Utilities Inc.	*E. coli*	One/ quarter	63	200	n/a[b]	n/a[b]
WQ0013632001	Meadowland Utility Corporation WWTP	Meadowland Utility Corporation	*E. coli*	One/ quarter	126	394	n/a[b]	n/a[b]
WQ0014326001	Galveston Bay RV	Bayou Development LLC	none	-	-	-	-	-
WQ0014570001	Marlin Atlantis White WWTF	United Development Funding LP	Enterococci	One/ month	17.5	52	n/a[b]	n/a[b]
WQ0014804001	Dolphin Cove WWTP	South Central Water Company	none	-	-	-	-	-

[a] Beginning six months from the permit issuance date and lasting though the date of expiration

[b] Indicator bacteria compliance data was not available through ECHO for this facility.

2.7.2 Unregulated Sources

Unregulated sources of indicator bacteria are generally nonpoint and can emanate from wildlife, feral hogs, various agricultural activities, agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

2.7.2.1 Wildlife and Unmanaged Animal Contributions

Fecal indicator bacteria such as Enterococci and *E. coli* are common inhabitants of the intestines of all warm blooded animals, including wildlife such as mammals and birds. In developing bacteria TMDLs, it is important to identify by watershed the potential for bacteria contributions from wildlife. Wildlife are naturally attracted to riparian corridors of streams and rivers. With direct access to the stream channel, the direct deposition of wildlife waste can be a concentrated source of bacteria loading to a water body. Fecal bacteria from wildlife are also deposited onto land surfaces, where it may be washed into nearby streams by rainfall runoff.

2.7.2.2 Non-Permitted Agricultural Activities and Domesticated Animals

The number of livestock that are found within the impaired AU watersheds was estimated from county level data obtained from the 2012 Census of Agriculture (USDA, 2014). The county level data were refined to better reflect actual numbers within each impaired AU watershed. The refinement was performed by determining the total area of each county and each impaired AU that was designated as either "Herbaceous/ Grassland" or "Hay/ Pasture" in the 2011 National Land Cover Dataset (USGS, 2014). A ratio was then developed by dividing the selected land use area of the AU that resides within a county by the total area of the county. This ratio was then applied to the county level data.

Activities, such as livestock grazing close to water bodies and farmers' use of manure as fertilizer, can contribute indicator bacteria to nearby water bodies. The livestock numbers in Table 11 are provided to demonstrate that livestock are a potential source of bacteria in all three of the subject watersheds. These numbers, however, are not used to develop an allocation of allowable bacteria loading to livestock.

Table 11. Livestock population estimates for impaired AU watersheds within the Dickinson Bayou watershed, based on proportional area.

Source: (USDA, 2014). Estimated livestock numbers less than 10 reported as <10.

Sub-watershed	AU	Cattle and Calves	Goats	Hogs and Pigs	Horses and Ponies	Mules, Burros and Donkeys	Poultry	Sheep and Lambs
Dickinson Bayou Tidal	1103_01	1020	77	36	123	14	322	30
Gum Bayou	1103D_01	376	28	13	45	<10	119	11
Cedar Creek	1103E_01	80	<10	<10	10	<10	25	<10

2.7.2.3 On-site Sewage Facilities

Private residential on-site sewage facilities (OSSFs), commonly referred to as septic systems, consist of various designs based on physical conditions of the local soils. Typical designs consist of 1) one or more septic tanks and a drainage or distribution field (anaerobic system) and 2) aerobic systems that have an aerated holding tank and often an above ground sprinkler system for distributing the liquid. In simplest terms household waste flows into the septic tank or aerated tank, where solids settle out. The liquid portion of the water flows to the distribution system which may consist of buried perforated pipes or an above ground sprinkler system.

Several pathways of the liquid waste in OSSFs afford opportunities for bacteria to enter ground and surface waters, if the systems are not properly operating. Properly designed and operated, however, OSSFs would be expected to contribute virtually no fecal bacteria to surface waters. For example, it has been reported that less than 0.01% of fecal coliforms originating in household wastes move further than 6.5 feet down gradient of the drainfield of a septic system (Weikel et al., 1996). Reed, Stowe, and Yanke LLC (2001) provide information on estimated failure rates of OSSFs for different regions of Texas. Dickinson Bayou is located within the east-central Texas area has a reported failure rate of about 12 percent, which provide insights into expected failure rates for the area.

Estimates of the number of OSSFs in the Lake Houston watershed were deter-mined using H-GAC supplied data (H-GAC, 2014). For Brazoria and Galveston counties, the H-GAC data included registered OSSFs since 1985. Further, H-GAC supplied data included estimated OSSF locations that pre-dated registration requirements.

Table 12. OSSF estimate for impaired AU watersheds within the Dickinson Bayou watershed

Watershed	AU	OSSFs
Dickinson Bayou Tidal	1103_01	72
Gum Bayou	1103D_01	393
Cedar Creek	1103E_01	3

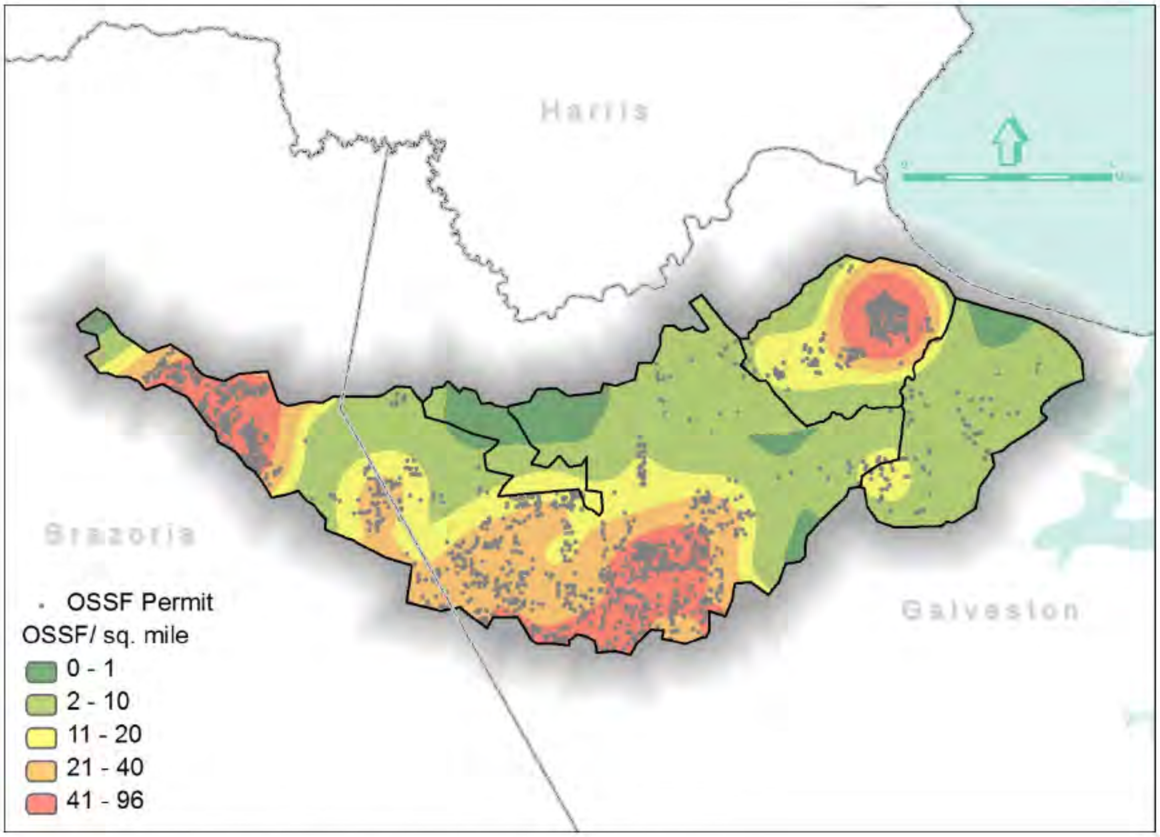

Figure 10. OSSF densities within the Dickinson Bayou watershed.

Source: (H-GAC, 2014)

2.7.2.4 Domestic Pets

Fecal matter from dogs and cats is transported to streams by runoff in both urban and rural areas and can be a potential source of bacteria loading. Table 13 summarizes the estimated number of dogs and cats for each segment of the TMDL watersheds. Pet population estimates were calculated as the estimated number of dogs (0.584) and cats (0.632) per household (AVMA, 2012). The actual contribution and significance of fecal coliform loads from pets reaching the water bodies of the impaired AU watersheds is unknown.

Table 13. Estimated Households and Pet Populations for the impaired AU watersheds within the Dickinson Bayou watershed.

Watershed	AU	Estimated Number of Households	Estimated Dog Population	Estimated Cat Population
Dickinson Bayou Tidal	1103_01	1,831	1,069	1,157
Gum Bayou	1103D_01	7,545	4,406	4,768
Cedar Creek	1103E_01	37	22	23

2.7.2.5 Bacteria Survival and Die-off

Bacteria are living organisms that survive and die. Certain enteric bacteria can survive and replicate in organic materials if appropriate conditions prevail (e.g., warm temperature). Fecal organisms can survive and replicate from improperly treated effluent during their transport in pipe networks, and they can survive and replicate in organic rich materials such as compost and sludge. While the die-off of indicator bacteria has been demonstrated in natural water systems due to the presence of sunlight and predators, the potential for their re-growth is less well understood. Both processes (replication and die-off) are in-stream processes and are not considered in the bacteria source loading estimates of each water body in the TMDL watersheds.

SECTION 3
DEVELOPMENT OF BACTERIA TOOLS

An essential component of a TMDL is to establish a linkage, or relationship, between pollutant sources and the water criteria. It is possible through this linkage to determine the capacity of the water body to assimilate bacteria loadings while still supporting its designated use. This section describes development of the tools used to provide this linkage and to provide the data for computing the pollutant load allocations of the project water bodies.

For consistency between the TMDLs of the Dickinson Bayou watershed for this project and the previously completed Dickinson Bayou watershed TMDLs, the development activities for the present TMDLs build upon the tools used and reported in the previously completed TMDLs. Details on the previous tool development are found in a technical support document by CDM and the University of Houston (CDM & UofH, 2012) and the TCEQ TMDL report (TCEQ, 2012b) These existing tools were provided to TIAER staff by the TCEQ Project Manager. Development activities under the present project were covered under a TCEQ approved QAPP (TIAER, 2014).

The tool selected for use in representing the watershed and freshwater flows of Dickinson Bayou and its tributaries was the Hydrologic Simulation Program – FORTRAN (HSPF). For the non-tidal portion of the watershed, load duration curve (LDC) analysis was the tool used to specify loadings for TMDL development with the necessary daily streamflow record developed from HSPF output. Hence, the TMDL computations for Cedar Creek (AU 1103E_01) were developed from LDC analysis with the HSPF output for that tributary used to provide the needed streamflow record.

For the tidally influenced receiving waters, a coupled watershed/receiving water modeling strategy was employed with HSPF providing the watershed modeling and a tidal prism model (TPM) for the tidally influenced receiving waters. This coupled modeling strategy was used in developing the data needed for the TMDL computations for Dickinson Bayou AU 1103_01 and Gum Bayou AU 1103D_01.

HSPF, LDCs, and TPM will be discussed separately. An overview of each tool is provided as well as relevant output from each tool for development of TMDL computations. The reader is referred to CDM & UofH (2012) and TCEQ (2012b) for additional information on the development of these tools.

3.1 HSPF

The overview of the HSPF model provided in the next several paragraphs is taken from CDM & UofH (2012) with only limited modification and adjustments. HSPF was developed in the 1970s and is now in its twelfth version (Bicknell, 2005). HSPF offers deterministic, continuous modeling of runoff and pollutant mobilization using a large array of lumped parameters such as land use, watershed boundaries, rainfall, stream geometry and capacity, bacteria loading, and bacteria die-off rates. HSPF is designed as a spatially and temporally variable model with results generated on time-steps specified by the user, generally an hourly or daily basis. An hourly basis of output generation was specified for this project with aggregation of data to daily through post-processing as required for LDC analysis. HSPF also contains a simple one-dimensional receiving water model to simulate streamflow routing and in-stream processes such as sediment resuspension and die-off of bacteria.

The HSPF model developed for the entire Dickinson Bayou watershed served two purposes: (1) supply in-stream flows for the non-tidal portion of Dickinson Bayou to support the development of LDCs to specify the total maximum daily load for Cedar Creek (AU 1103E_01); and (2) provide runoff loads to the TPM described in Section 3.3.

The original HSPF model development for Dickinson Bayou watershed required a significant amount of input data, including:

- Delineation of watersheds;
- Meteorological and watershed data;
- Hydrologic characteristics; and
- Bacteria loading for various sources within the watershed.

Only the aspects of the input data that required adjustments and modifications from the previous efforts will be discussed herein and the reader is referred to CDM & UofH (2012) and TCEQ (2012b) for the specifics on other aspects of the HSPF model input.

3.1.1 HSPF Subwatersheds

As a lumped parameter model, subwatersheds that define drainage areas with similar characteristics must be defined in HSPF. For the development of the bacteria TMDLs reported in TCEQ (2012b), subwatersheds were delineated as presented in Figure 11. As shown in the figure, there were a total of 12 subwatersheds in the HSPF model of the Dickinson Bayou watershed. Subbasin 12 and a portion of Subbasin 11 corresponded to Dickinson Bayou Above Tidal (Segment 1104). The remaining subwatersheds corresponded to Dickinson Bayou Tidal (Segment 1103).

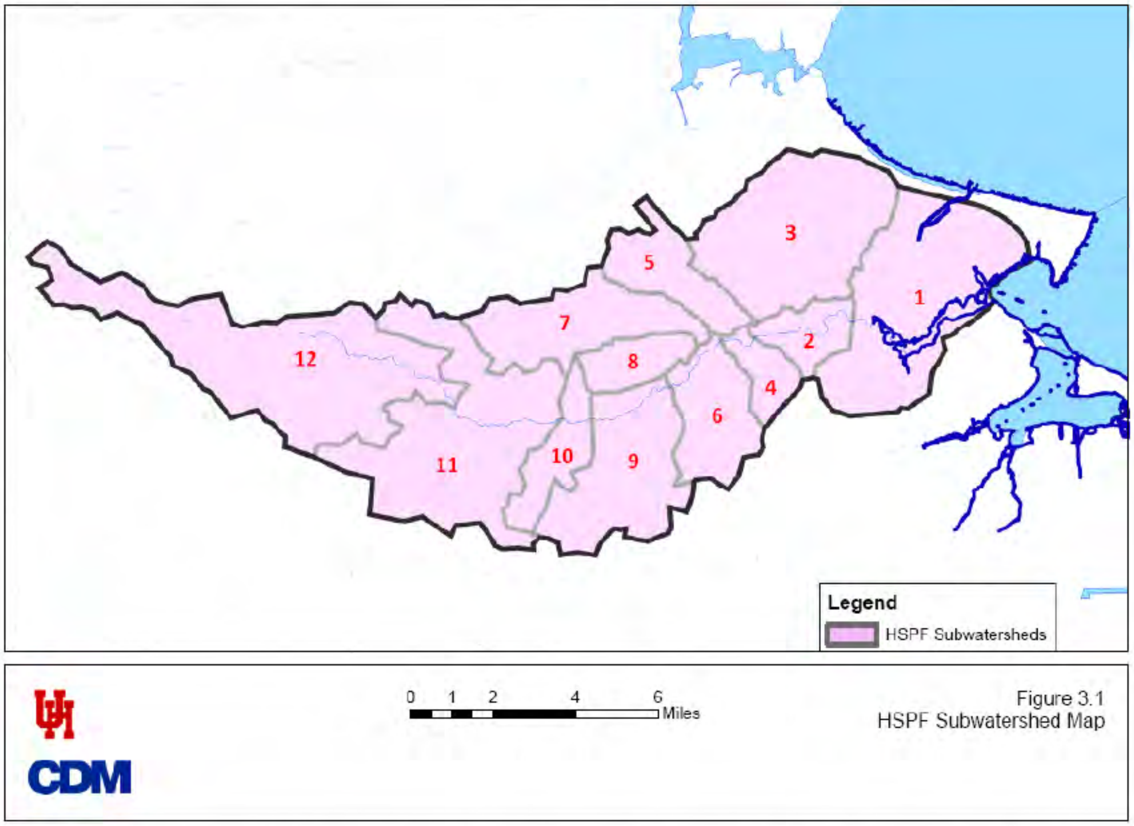

Figure 11. HSPF subwatershed delineation for previously completed bacteria TMDLs (TCEQ, 2012)

For the present project, two of the three water bodies were properly represented by the existing HSPF subwatershed delineation depicted in Figure 11. Gum Bayou (AU 1103_01) is represented by Subbasin 3 and Dickinson Bayou Tidal AU 1103_01 is represented by Subbasin 1. However, Cedar Creek (AU 1103E_01) was not delineated as a unique subwatershed in HSPF, but rather was subsumed in Subbasin 11 that contained areas for both Dickinson Bayou Above Tidal and Dickinson Bayou Tidal. For this project the HSPF delineation was modified to incorporate a unique subwatershed for Cedar Creek, which is depicted as Subbasin 13 in Figure 12. The drainage area of Subbasin 13 was limited to that portion of the overall Cedar Creek subwatershed above the FM 517 bridge crossing of the creek. The sole water quality monitoring station on Cedar Creek is Station 11434 located at the FM 517 bridge crossing, and it is at this sampling location that the TMDL was defined.

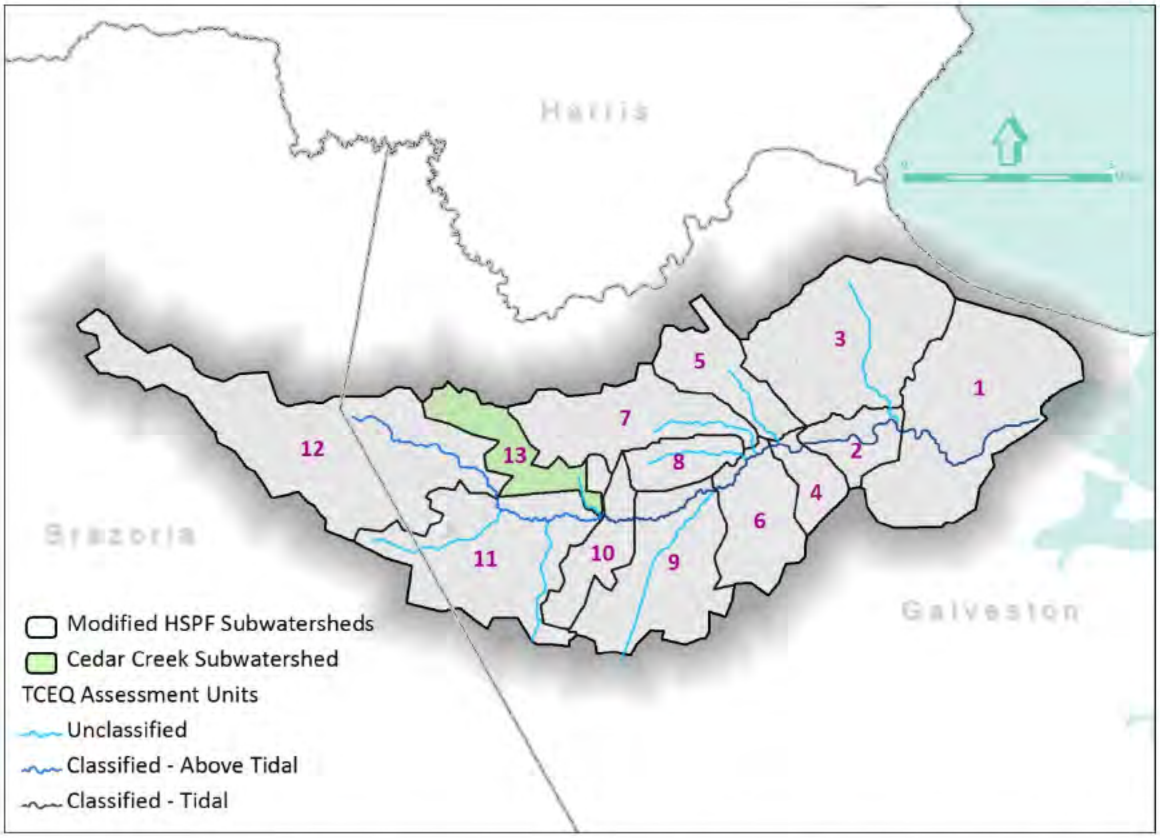

Figure 12. Modified HSPF subwatershed delineation to include Subbasin 13 representing Cedar Creek (AU 1103E_01).

3.1.2 Meteorological and Watershed Data

HSPF requires a large number of meteorological inputs, including precipitation, potential evapotranspiration, air temperature, dew point, solar radiation, cloud cover, and wind speed. Two meteorological stations were used for these data and include Houston NWSO and Houston Clover Field (see Figure 2). The simulation time period of the HSPF model for the previously completed TMDLs was June 1, 1999 through December 31, 2008. For the present project the ending date of the simulation was extended to December 31, 2012, which required extension of the meteorological data through the end of 2012 using the WDMUtil feature of HSPF.

The hourly predictions of streamflow at the outlet of Subbasin 13 were used in the LDC analysis process and will be discussed in more detail later in this section.

3.1.3 Hydrologic Characteristics and Addition of Cedar Creek Watershed

As discussed in more detail in CDM & UofH (2012), the hydrologic set-up and calibration for HSPF relies on data to specify stream characteristics, which were largely determined for the Dickinson Bayou HSPF model from information available from the USGS, including stream lengths, rating tables as well as stream and watershed slopes. In the absence of site specific rating tables for Cedar Creek in HSPF, the information for Gum Bayou (HSPF input FTable 3) was used, because of similarity of watershed size and shape.

For the intended use in TMDL computations employing LDCs, the hourly HSPF flow predictions for Cedar Creek at Station 11434 were averaged to a daily basis. Since only occasional instantaneous flow measurements were available for Cedar Creek, reasonableness of the predicted daily flows was determined indirectly by comparing the flow duration curves (FDCs) for the outlet of Subbasin 11 for the original HSPF subbasin configuration and the new configuration that includes Cedar Creek watershed as Subbasin 13 (Figure 13). The original HSPF model was calibrated for flow only at the outlet of Subbasin 11. Through this typical calibration process, the streamflow output for other subbasins was assumed to be adequately predicted because of consistency of model input data describing rainfall, soils and land uses for all subbasins. The very similar predicted flows at the outlet of Subbasin 11 for the new HSPF model and the original model (see Figure 13) as well as the care taken to assign proper rainfall, soils and land use characteristics when creating Subbasin 13 affords the same degree of confidence in the new HSPF flow output as for the original work effort. The time series of predicted daily streamflows for the outlet of Subbasin 13 is provided in Figure 14 for the period of June 1, 1999 through December 31, 2012.

From the new HSPF model of the Dickinson Bayou watershed, only the streamflow predictions at the outlet of Subbasin 13 were used. This streamflow record was used in the LDC analysis for Cedar Creek. The original HSPF streamflow predictions that became input to the TPM were not altered and remained identical to that used in the previously completed TMDLs.

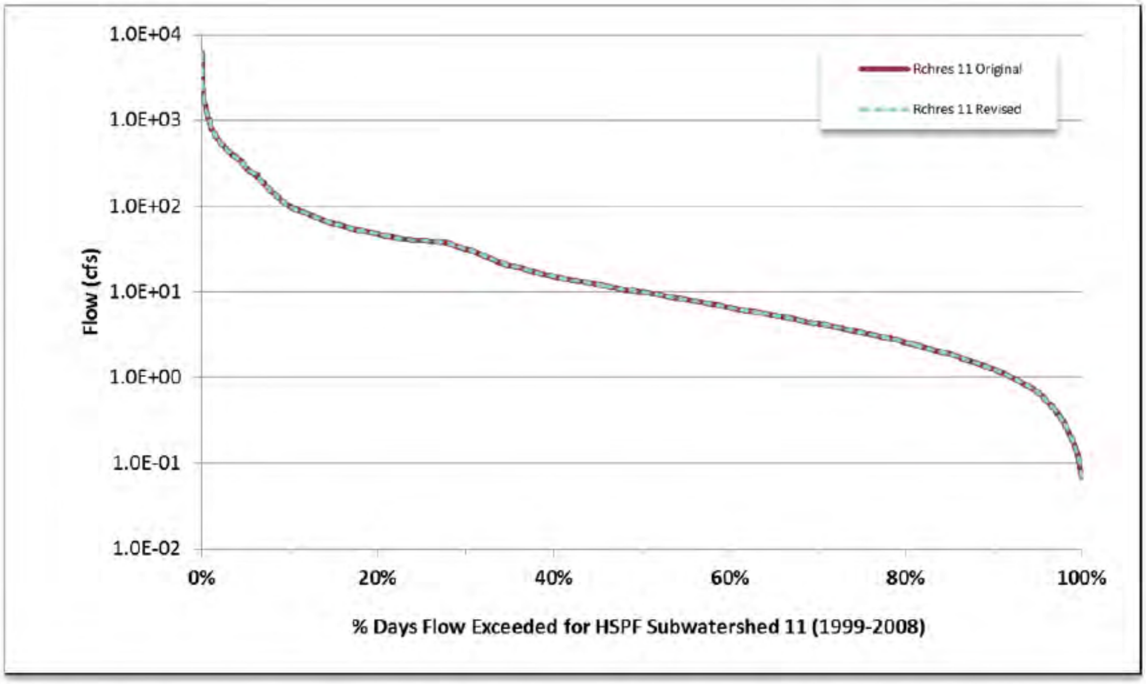

Figure 13. Comparison of flow duration curves for Subbasin 11 outlet from original HSPF model and the modified model to incorporate Cedar Creek watershed in Subbasin 13.

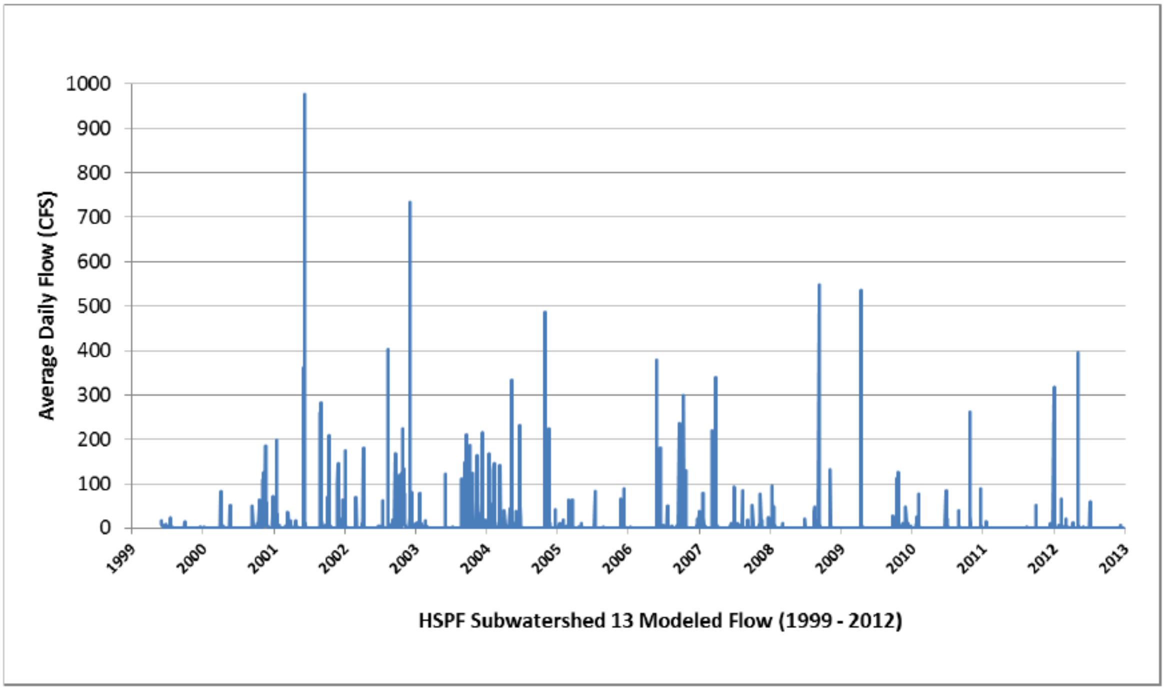

Figure 14. Time series of HSPF predicted daily flows for outlet of Subbasin 13, station 11434 on Cedar Creek.

3.2 Load Duration Curve Analyses

For the non-tidal Cedar Creek water body, LDC analysis was the tool used to specify loadings and for TMDL computations. The HSPF streamflow output for Subbasin 13 was used to develop the necessary data for the LDC analysis of Cedar Creek (AU 1103E_01).

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

To develop the FDCs and LDCs for Cedar Creek, the following series of sequential steps were performed:

Step 1: Determine the hydrologic periods of record to be used in developing the FDCs and LDCs and operate the revised HSPF model for those periods considering the output for the outlet of Subbasin 13.

Step 2: Develop FDCs for Cedar Creek (AU 1103E_01).

Step 3: Develop the allowable bacteria LDCs at the same stream locations based on the relevant criteria and the data from the streamflow duration curve.

Step 4: Add discrete flow regimes and superpose historical bacteria data on the allowable bacteria LDCs.

Additional information explaining the LDC method may be found in (Cleland, 2003) and (NDEP, 2003).

3.2.1 Step 1: Determine Hydrologic Period

Optimally, the period of record to develop a FDC should include as much data as possible in order to capture extremes of high and low streamflows and hydrologic variability from high to low precipitation years, but the flow during the period of record selected should also be representative of recent conditions experienced within the watershed and when the *E. coli* data were collected. Two periods of hydrologic record were selected for operation of HSPF and subsequent development of the FDC and LDC for Cedar Creek. The first period of June 1, 1999 through December 31, 2008 is the same period used in developing the LDCs and TMDL computations of the previously completed TMDLs. This first period was also selected for the TMDL computations to provide compatibility between the previously completed TMDLs that employed LDCs and the Cedar Creek TMDL of this project. The second period of June 1, 1999 through December 31, 2012 provides a more recent end date for the streamflow record used in developing the LDC for Cedar Creek, which allowed more recent measured *E. coli* data for Station 11434 to be plotted on the resulting LDC (see Step 4).

3.2.2 Step 2: Develop Flow Duration Curves

FDCs and LDCs are graphs indicating the percentage of time during which a certain value of flow or load is equaled or exceeded. To develop a FDC for Cedar Creek Station 11434 the following actions were undertaken:

- Take the time series of hourly streamflow predictions from HSPF predictions for the outlet of Subbasin 13 and determine the average daily flow from the 24 hourly values for each date in the time series. Perform this averaging of HSPF output for the two periods of June 1, 1999 through December 1, 2008 and June 1, 1999 through December 31, 2012.
- Order the daily streamflow data from highest to lowest values and assign a rank to each data point (1 for the highest flow, 2 for the second highest flow, and so on);
- Compute the percent of days each flow was exceeded by dividing each rank by the total number of data point plus 1; and
- Plot the corresponding flow data against exceedance percentages.

The FDCs for the two time periods for Cedar Creek (AU 1003E_01) at Station 11434 are shown on Figure 15. The FDC for the shorter period of June 1, 1999 through December 31, 2008 is indicated to have somewhat higher flows for each percent exceedance along the x-axis than those for the longer period of June 1, 1999 through December 31, 2012. The longer time period includes drought years punctuated by the very hot and dry year of 2011 and correspondingly HSPF flow predictions for this drought period contained more low flows than the shorter time period, which is reflected in the shapes of the two FDCs. Additional explanation of the differences in the FDCs is provided in Table 14, which depicts annual average rainfall for nearby Houston Intercontinental Airport for the period of 2000 – 2012 and shows that the years 2009 – 2012 each had annual rainfalls less than the 13-year mean.

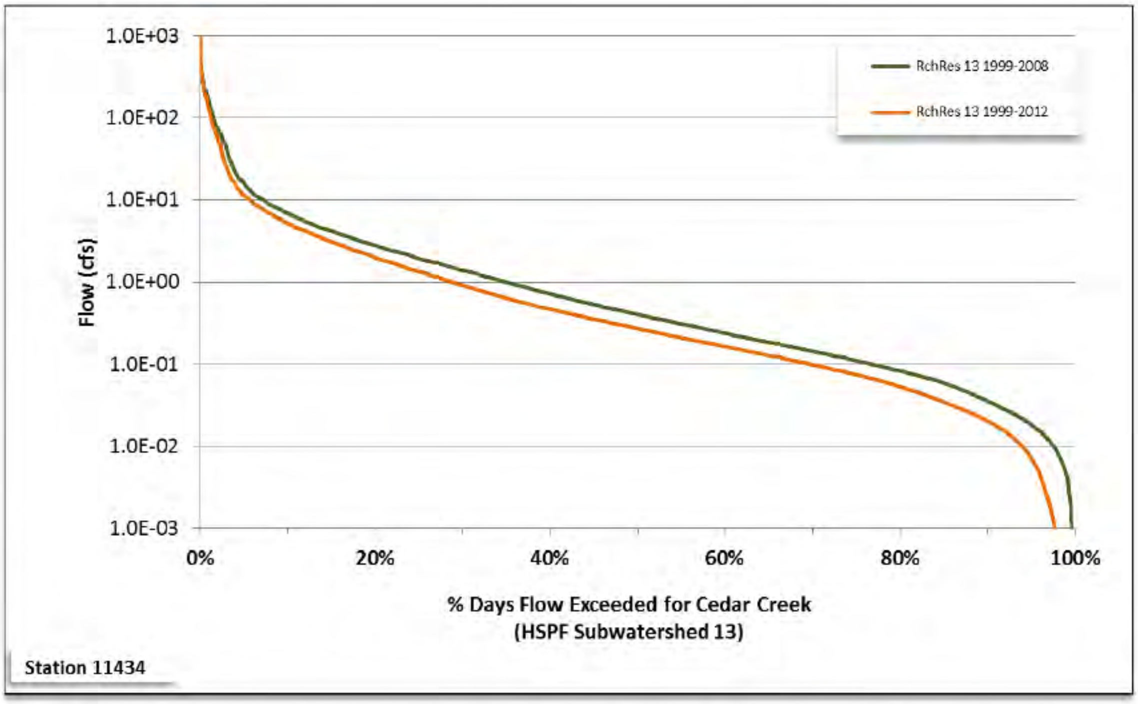

Figure 15. Flow duration curves at Station 11434 on Cedar Creek for the periods of June 1, 1999 through December 31, 2008 and June 1, 1999 through December 31, 2012.

Table 14. Annual rainfall totals and departures from the 13-year mean for the years 2000 – 2012 for Houston Intercontinental Airport.

Year	Annual Rainfall (inches)	Departure from Mean (%)
2000	47.61	-3.43
2001	71.18	20.14
2002	59.68	8.64
2003	45.76	-5.28
2004	65.06	14.02
2005	41.21	-9.83
2006	57.86	6.82
2007	65.52	14.48
2008	53.00	1.96
2009	47.01	-4.03
2010	42.72	-8.32
2011	24.57	-26.47
2012	42.32	-8.72

3.2.3 Step 3: Develop Load Duration Curves

Development of LDCs follows from the FDCs computationally using the same ordered daily streamflow data from HSPF Subbasin 13:

- Multiply the streamflow in cubic feet per second (cfs) by the appropriate water quality criterion for *E. coli* (geometric mean of 126 MPN/100 mL; single sample of 399 MPN/100 mL) and by a conversion factor (2.44658×10^7), which gives a loading in units of MPN/day; and
- Plot the exceedance percentages, which are identical to the value for the streamflow data points, against geometric mean criterion of *E. coli*.

The resulting curves represent the maximum allowable daily loadings for the geometric mean criterion and the single sample criterion. The geometric criterion curve is the more relevant of the two curves, since the endpoint for the TMDL was based on an *E. coli* concentration of 126 MPN/100 mL.

3.2.4 Step 4: Add Flow Regimes and Historical Bacteria Data to LDCs

The final actions to developing the complete LDCs involve these refinements to the basic LDCs:

- Three flow regimes were classified on each LDC based on the previously completed TMDL (TCEQ, 2012b).
    1) Highest flow regime defined as between the 0 and 20th percentiles,
    2) mid-range flow regime defined as between the 20th and 80th percentiles, and
    3) lowest flow regime defined as between 80th and 100th percentile.
- The critical condition for point sources is considered the lowest flow regime, as this is when the point sources would be expected to exert the most influence and experience the least dilution. For nonpoint and stormwater sources, the critical condition would be the highest flow regime as these conditions are most influenced by rainfall runoff.
- Using the data for Station 11434, the daily loads were computed for each sample by multiplying the measured *E. coli* concentrations on a particular day by the corresponding HSPF predicted streamflow on that day and the conversion factor (2.44658×10^7).
- Plot on the LDC the load for each measurement at the exceedance percentage for its corresponding date and streamflow.
- Determine the geometric mean concentration for the measured *E. coli* data within each of the three flow regimes and plot that geometric mean concentration at the median flow(i.e., at the 10th percentile for the high flow regime, the 50th percentile for the mid-range flow regime, and the 90th percentile for the low flow regime).

The plots of the LDC with the measured loads (*E. coli* concentration multiplied by daily streamflow) display the frequency and magnitude that measured loads exceed the maximum allowable loadings for the geometric mean and single sample criteria. Measured loads that are above a maximum allowable loading curve indicate an exceedance of the water quality criterion, while those below a curve show compliance.

The LDCs for Station 11434 on Cedar Creek with the three flow regimes shown and measured *E. coli* loads plotted are provided first for the shorter time period Figure 16 and then for the longer time period Figure 17. On Figure 16 measured data from March 2004 through October 2008 are plotted representing the same period as the previously completed TMDL, and on Figure 17 measured data from March 2004 through October 2012 are plotted providing more recently collected data to be added to the LDC.

Both figures indicate that *E. coli* loadings and concentrations are not greatly in exceedance of the geometric mean criterion and only infrequently exceed the single sample criterion. For the highest and mid-range flow regimes, the geometric mean of the measured data is slightly above the geometric mean criterion. For the lowest flow regime, Figure 16 (depicting the short period of time) indicates the highest exceedance of the geometric mean criterion, whereas Figure 17 (depicting the longer period of time) indicates that the geometric mean of the measured data is slightly below the criterion. The difference at the lowest flow regime between the measured data geometric means of the two figures is largely the result of a change in plotted position of two high loadings that were at about the 82nd percentile on Figure 16 (lowest flow regime) and at the 75th percentile on Figure 17 (mid-range flow regime).

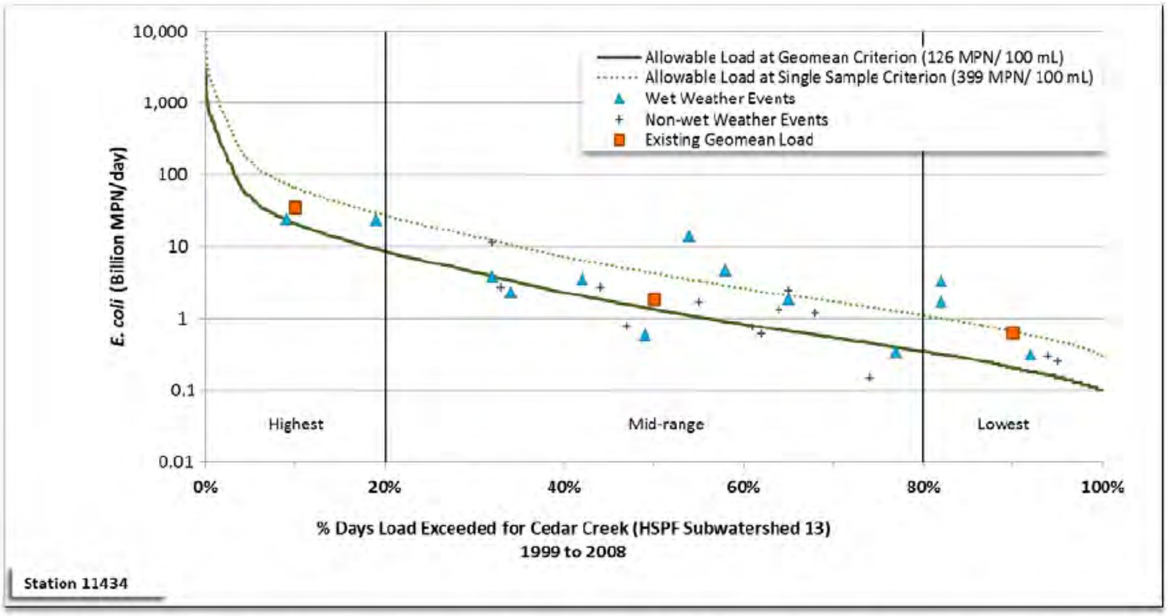

Figure 16. Load duration curves at Station 11434 on Cedar Creek for the period of June 1, 1999 through December 31, 2008.

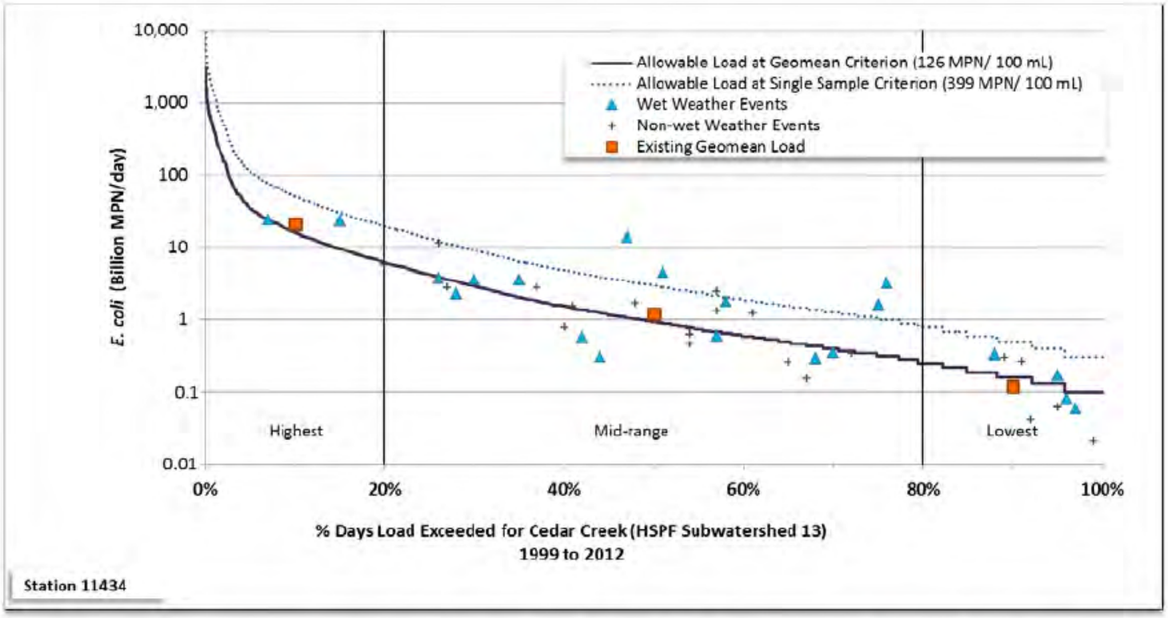

Figure 17. Load duration curves at Station 11434 on Cedar Creek for the period of June 1, 1999 through December 31, 2012.

3.3 Tidal Prism Model

As with the HSPF model, the overview of the TPM provided in the next several paragraphs is taken from CDM & UofH (2012) with only limited modification and adjustments. TPMs are one-dimensional steady-state receiving water models that utilize the concept of "tidal flushing" to simulate the physical transport of pollutants in a tidal basin over time. The theory of tidal flushing was originally developed by Ketchum (1988), and several TPMs have been developed and refined to apply the concept towards water quality modeling of a variety of constituents, including bacteria (Kuo & Neilson, 1988) (Shen, 2005) (Kuo et al., 2005) . TPMs in conjunction with a watershed model have also been successfully used for bacteria and nutrient TMDLs for coastal embayments in Virginia and North Carolina (Kuo & Neilson, 1988) (Shen, 2005) (Kuo et al., 2005) (Wang et al., 2005).

Data requirements are fairly low for TPMs compared to most other mechanistic receiving water models for tidally influenced systems, but generally TPMs are limited in application to smaller tidal basins and estuaries since one of the key assumptions is that the tide elevations transmit simultaneously throughout the modeled system. Other key input parameters besides tidal data include bathymetric data, such as water depth and surface area.

To simulate Enterococci and flows in the tidal portion of the Dickinson Bayou watershed, a time-variable TPM was developed in Microsoft Excel. The TPM was developed to simulate in-stream loading in the tidal portion of Dickinson Bayou by taking into account the volume of water that is carried upstream by the tidal fluctuations. A conceptual model of the TPM is shown in Figure 18. In general, the mass balance for a bayou segment can be defined as the difference between the storage within the bayou segment as well as any addition or removal of flow and load that results because of tidal exchange (from segments located upstream or downstream). The mass balance also accounts for inputs of bacteria and flow from watershed runoff, WWTFs and SSOs. Die-off and tidal exchange represent the two potential sinks of Enterococci in the tidal box model.

3.3.1 Tidal Prism Model Segmentation

The model segmentation in the tidal prism box model was determined based on three criteria. Starting with the first tidal segment in the bayou, model segments were identified based on the following criteria:

- The presence of a TCEQ monitoring station;
- The presence of an assessment unit boundary; or
- The presence of a reach boundary in HSPF.

Maintaining similar lengths of the segment was also a consideration but did not supersede the three criteria previously mentioned. The model segmentation is presented in Figure 19. As shown in the figure, there are a total of 18 model segments in the tidal prism box model, with 5 segments associated with tributaries.

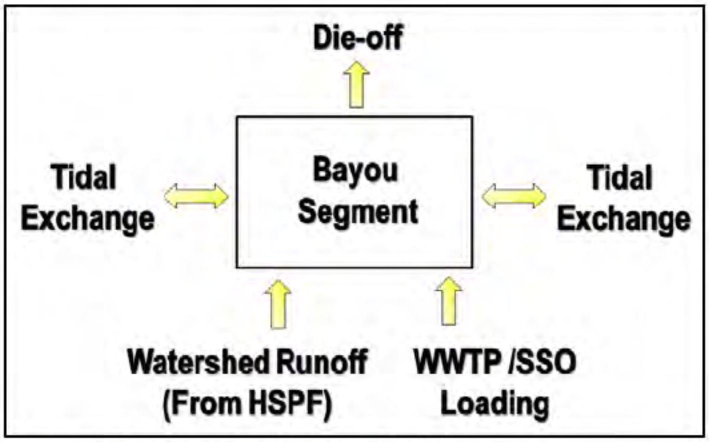

Figure 18. Conceptual Tidal Prism Model.

Source: CDM & UofH (2012)

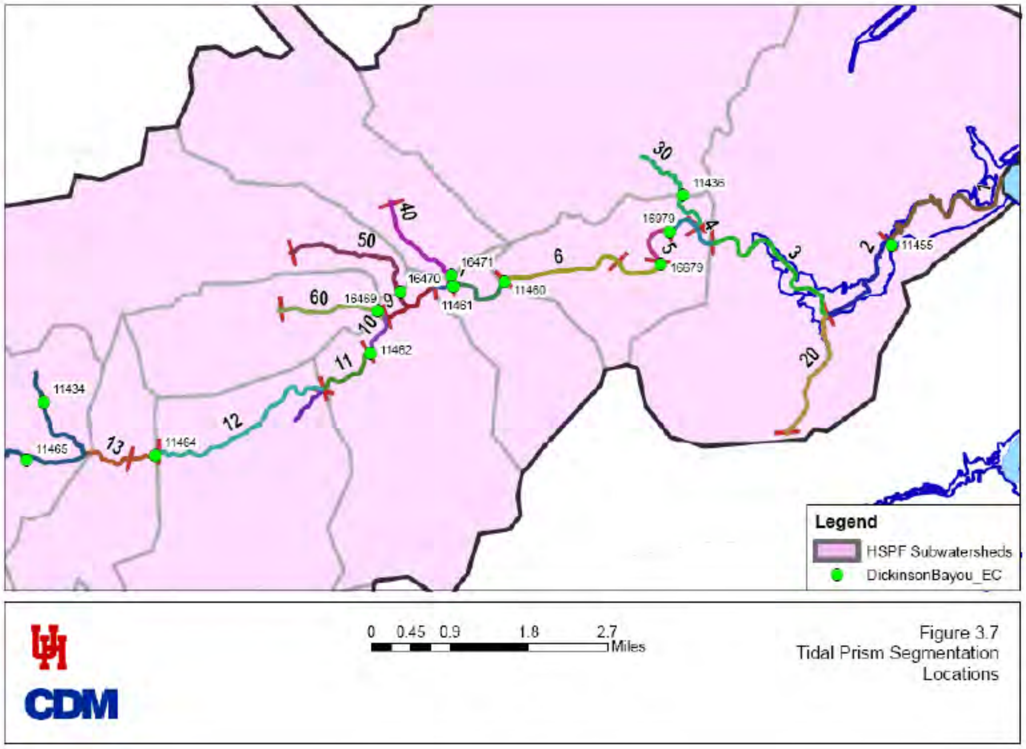

Figure 19. Tidal Prism Model segmentation.

Source: CDM & UofH (2012)

3.3.2 Simulation Period and Application of Tidal Prism Model

The information on the calibration of the TPM to Enterococci and salinity concentrations at monitoring stations within the tidal portion of Dickinson Bayou is provided in both CDM & UofH (2012) and TCEQ (2012b). The model was developed for an application period of June 1, 1999 through December 31, 2008, which was identical to the time period of the HSPF application to Dickinson Bayou watershed for the existing TMDLs.

The period of June 1, 1999 through November 5, 2001 was used for the calculations needed for developing the TMDLs for the previously completed TMDLs and this same period is used for the present project. The median flows predicted by the TPM for this same period of roughly 30-months were for each AU simulated as the basis of the TMDL.

It should be noted for the application needs of the TPM under the present project, the Enterococci portion of the model were not needed, since the TMDL calculations were based on the median flows predicted in the TPM obviating the need to consider the bacteria portion of the model. Additionally for the TPM application for this project, the model was used as developed and successfully calibrated previously with only minor adjustments needed to include the Dolphin Cove WWTF (WQ0014804001).

3.3.3 Tidal Prism Model Results for TMDL Computations

The TPM with the modification to include the Dolphin Cove WWTF discharge was operated for the period of June 1, 1999 through November 5, 2001. The Dolphin Cove WWTF discharge was included in the TMP at its full permit discharge limit of 0.95 MGD with an additional 20 percent increase to include future growth. (The future growth component of TMDL computations is discussed in Section 4.5.3.)

The TMDLS for Gum Bayou AU 1003D_01 and Dickinson Bayou AU 1003_01 were based on flows from the TPM multiplied by the geometric mean Enterococci criteria of 35 MPN/100 mL to give a load. The median of the load for Segment 30 was used to specify the TMDL for Gum Bayou, and the median of the load for Segment 2 was used to specify the TMDL for Dickinson Bayou AU 1003_01. The downstream outlet of segment 30 corresponds to the location of monitoring Station 16471 on Gum Bayou, and similarly the downstream outlet of Segment 2 corresponds to monitoring Station 11455, which is the most downstream station on AU 1003_01. The median loads used to define the TMDLs are

- 7.585 billion MPN/day for Gum Bayou, AU 1103D_01, and
- 922.405 billion MPN/day for Dickinson Bayou, AU 1103_01.

SECTION 4
TMDL ALLOCATION ANALYSIS

Presented in this report section is the development of the bacteria TMDL allocation for the three TMDL watersheds. The tools used for developing each TMDL allocation included HSPF, TPM and LDC analysis, which were previously described in Section 3 — Bacteria Tool Development. Endpoint identification, margin of safety, load reduction analysis, TMDL allocations, and other TMDL components are described herein.

For the purposes of this TMDL study, the TMDL watersheds are considered to be Dickinson Bayou Tidal (1103_01), Gum Bayou (1103D_01), and Cedar Creek (1103E_01) as shown in the overview map (Figure 1). The location of each TMDL is an active TCEQ station. For Dickinson Bayou Tidal the station is 11455, for Gum Bayou the station is 11436, and for Cedar Creek it is station 11434 (see Figure 5).

4.1. Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions. The water bodies within the two downstream TMDL watersheds (Gum Bayou and Dickinson Bayou Tidal) have a use of primary contact recreation, which is measured against a numeric criterion for the indicator bacteria Enterococci due to the fact that they are tidally influenced. The one upstream TMDL watershed (Cedar Creek) also has the use of primary contact recreation, which is measured against a numeric criterion for *E. coli*. Indicator bacteria are not generally pathogenic and are indicative of potential viral, bacterial, and protozoan contamination originating from the feces of warm-blooded animals. The Enterococci criterion to protect contact recreation in saltwater systems consists of a geometric mean concentration not to exceed 35 MPN/100 mL, and the *E. coli* criterion to protect contact recreation in freshwater systems consists of a geometric mean concentration not to exceed 126MPN/100 mL (TCEQ, 2010b).

The endpoint for the Dickinson Bayou and Gum Bayou TMDLs is to maintain concentrations of Enterococci below the geometric mean criterion of 35 MPN/100 mL. This endpoint is identical to the geometric mean criterion in the 2010 Surface Water Quality Standard (TCEQ, 2010) for primary contact recreation in saline water bodies.

The endpoint for the Cedar Creek TMDL is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100 mL. This endpoint is identical to the geometric mean criterion in the 2010 Surface Water Quality Standard (TCEQ, 2010) for primary contact recreation in fresh water bodies.

4.2 Seasonality

Seasonal variation (or seasonality) occurs when there is a cyclic pattern in streamflow and, more importantly, in water quality constituents. Federal regulations (40 CFR §130.7(c)(1)) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. For the

LDC analysis of Cedar Creek, the seasonal variation was accounted for by using six years of water quality data and over nine year of modeled flows to develop flow exceedance percentiles. For the mass balance analysis used for Dickinson Bayou and Gum Bayou, the seasonal variation was accounted for by using a continuous simulation model over a 2.5 year period that accounts for a range of seasonal and flow conditions.

Analysis of the seasonal differences in indicator bacteria concentrations were assessed by comparing *E. coli* and Enterococci concentrations obtained from routine monitoring collected in the warmer months (May - September) against those collected during the cooler months (November - March) for the indicator bacteria data available during the model period (2005-2008 for Cedar Creek, and 2003-2008 for both Gum Bayou and Dickinson Bayou Tidal). The months of April and October were considered transitional between the warm and cool seasons and were excluded from the seasonal analysis. Differences in indicator bacteria concentrations obtained in warmer versus cooler months were then evaluated by performing a Wilcoxon Rank Sum test on the original dataset. The nonparametric Wilcoxon Rank Sum test was selected because even with logarithmic transformation the bacteria data were non-normally distributed. This analysis of Enterococci data indicated that there was no significant difference ($\alpha=0.05$) in indicator bacteria between cool and warm weather seasons for all three of the impaired AUs (1103E_01, 1103D_01, 1103_01), signifying that seasonality was not detected.

4.3 Linkage Analysis

Establishing the relationship between instream water quality and the source of loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint. The relationship may be established through a variety of techniques.

Generally, if high bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing sources are likely to be point sources and direct fecal material deposition into the water body. During ambient flows, these inputs to the system will increase pollutant concentrations depending on the magnitude and concentration of the sources. As flows increase in magnitude, the impact of point sources and direct deposition is typically diluted, and would therefore be a smaller part of the overall concentrations.

Bacteria load contributions from permitted and non-permitted stormwater sources are greatest during runoff events. Rainfall runoff, depending upon the severity of the storm, has the capacity to carry indicator bacteria from the land surface into the receiving stream. Generally, this loading follows a pattern of lower concentrations in the water body just before the rain event, followed by a rapid increase in bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream. Over time, the concentrations decline because the sources of indicator bacteria are attenuated as runoff washes them from the land surface and the volume of runoff decreases following the rain event.

For Cedar Creek, LDC analysis was used to examine the relationship between instream water quality and the source of indicator bacteria loads. Inherent to the use of LDCs as the mechanism of linkage analysis is the assumption of a 1 to 1 relationship between instream loadings and loadings originating from point sources and the landscape as regulated and non-regulated sources. Further this 1 to 1 relationship was also inherently assumed when using LDCs to define the TMDL pollutant load allocation (Section 4.5). That is the allocation of pollutant loads was based on apportioning the loadings based on flows assigned to WWTFs, a fractional proportioning of the remaining flow based on the area of the watershed under stormwater regulation, and assigning the remaining portion to non-regulated stormwater.

For Dickinson Bayou and Gum Bayou, the combined tools of HSPF and TPM were used to establish the linkage between instream water quality and the source of indicator bacteria loads.

4.3.1 Load Duration Curve Analysis

For the freshwater water body of Cedar Creek (1103E_01), LDC analysis was used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, and is the basis of the TMDL allocations. The strength of the Cedar Creek TMDL is the use of the LDC analysis to determine the TMDL allocations. LDCs are a simple statistical method that provides a basic description of the water quality problem. This tool is easily developed and explained to stakeholders, and uses available water quality and flow data. The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The EPA supports the use of this approach to characterize pollutant sources. In addition many other states are using this method to develop TMDLs.

The weaknesses of this method include the limited information it provides regarding the magnitude or specific origin of the various sources. Only limited information is gathered regarding point and nonpoint sources in the watershed. The general difficulty in analyzing and characterizing *E. coli* in the environment is also a weakness of this method.

The LDC analysis allows for estimation of existing and TMDL loads by utilizing the cumulative frequency distribution of streamflow and measured pollutant concentration data (Cleland, 2003). In addition to estimating stream loads, this method allows for the determination of the hydrologic conditions under which impairments are typically occurring, can give indications of the broad origins of the bacteria (i.e., point source and stormwater) and provides a means to allocate allowable loadings.

The LDC analysis used the period of streamflow data from June 1999 through December 2008 to remain consistent with the time period used for the previously completed TMDLs. Also remaining consistent with the previously completed TMDLs, the mid-range flow regime (20th – 80th percentile) was selected as most representative and protective of the primary contact recreation use of Cedar Creek, since swimming is not expected to occur under either the high flows for safety reasons and low flows due to lack of sufficient depth of water. The Cedar Creek TMDL was derived using the median (50th percentile) within this flow regime.

4.3.2 Tidal Prism Model Analysis

For the tidal water bodies of Dickinson Bayou (1103_01) and Gum Bayou (1103D_01), TPM analysis were used to examine the relationship between instream water quality and the broad sources of indicator bacteria loads, and are the basis of the TMDL allocations. The required freshwater inputs to the TPM were provided through HSPF. A strength of these TMDLs is the use of mechanistic models and actual calibration and verification of modeled results against measured data resulting in reasonable representation of bacteria and flows in the tidal portion of Dickinson Bayou and its tributaries, as performed for the previously completed TMDLs for tidal water bodies. The development of this combined modeling system of HSPF and TPM was provided at an overview level in Section 3 of this report and in more detail in CDM & UofH (2012) and TCEQ (2012b).

The TMDLs for Dickinson Bayou (1103_01) and Gum Bayou (1103D_01) were derived using the median simulated flow from the approximately 30-month simulated period of June 1, 1999 through November 5, 2001. This approach remains consistent with that used with the tidal water bodies of the previously completed TMDLs.

4.4 Margin of Safety

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

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

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

The TMDLs covered by this report incorporate an explicit MOS by setting a target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. For primary contact recreation, this equates to a geometric mean target for Enterococci of 33.3 MPN/100 mL; for *E. coli* the geometric mean target is set at 119.7 MPN/100 mL. The net effect of the TMDL with MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced.

4.5 Pollutant Load Allocation

A TMDL represents the maximum amount of a pollutant that the water body can receive in a single day without exceeding water quality standards. The pollutant load allocations for the selected scenarios were calculated using the following equation:

TMDL = WLA + LA + FG + MOS (Eq. 1)

Where:

TMDL = total maximum daily load

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

LA = load allocation, the amount of pollutant allowed by non-regulated or non-permitted sources

FG = loadings associated with future growth from potential permitted facilities

MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For *E. coli* and Enterococci, TMDLs are expressed as MPN/day, and represent the maximum one-day load the water body can assimilate while still attaining the standards for surface water quality.

Typically, several possible allocation strategies will achieve the TMDL endpoint and water quality standards. Available control options depend on the number, location, and character of pollutant sources. For the Dickinson Bayou watershed, two methodologies were used to quantify the assimilative capacity of the bayou, define overall reduction goals, and specify TMDL allocations for point and nonpoint sources:

1) The LDC method for Cedar Creek AU 1103E_01.
2) The mass balance method using the TPM for Dickinson Bayou Tidal AU 1103_01 and Gum Bayou AU 1103D_01.

Bacteria sources in the Dickinson Bayou watershed are diverse and can occur in combination; as such, bacteria can be discharged at different flow rates during different time periods, resulting in varied critical conditions. The LDC approach calculates the maximum allowable load over the complete range of flow conditions for each assessment unit. Thus, this approach can account for both low flow conditions where point sources would be expected to dominate, high flow conditions where nonpoint and stormwater sources are the primary loading source, as well as the mid-range flows where point and nonpoint sources could exert influence.

In the TPM approach, the dynamic, continuous simulation model considers an approximately 2.5 year period between June 1, 1999 and November 11, 2001 to establish the TMDL. This multiple year period was chosen because it exhibited the most observed water quality to represent critical conditions likely to occur, such as wet and dry periods and a multiple-year period to account for meteorological and source variation.

Both the LCD approach for Cedar Bayou and TPM approach for Dickinson Bayou Tidal and Gum Bayou consider critical conditions for the TMDL. The allowable loadings for impaired AUs within the Dickinson Bayou watershed are provided in Table 15. At either the Median Load (Tidal AUs) or the 50% load duration exceedance (Above Tidal AU), the TMDL values are provided in Table 15.

Table 15. Summary of allowable loading calculations for impaired AUs within the Dickinson Bayou watershed

Watershed (Station)	AU	Indicator Bacteria	TMDL (Billion MPN/ day)
Dickinson Bayou Tidal (11455)	1103_01	Enterococci	922.405 [a]
Gum Bayou (11436)	1103D_01	Enterococci	7.585 [a]
Cedar Creek (11434)	1103E_01	*E. coli*	1.342 [b]

[a] Flow from TPM output, Section 3.3.3

[b] Flow from LDC, Figure 16

4.5.1 Margin of Safety

The margin of safety is only applied to the allowable loading for a watershed. Therefore the margin of safety is expressed mathematically as the following:

$$MOS = 0.05 * TMDL \qquad \text{(Eq. 2)}$$

Where:

MOS = margin of safety load

TMDL = total maximum allowable load

Since the MOS is based solely on the TMDL term, the calculation is straightforward (Table 16).

Table 16. MOS calculations for downstream stations within the TMDL watersheds.

Watershed	AU	Indicator Bacteria	TMDL [a] (Billion MPN/ day)	MOS [b] (Billion MPN/ day)
Dickinson Bayou Tidal	1103_01	Enterococci	922.405	46.120
Gum Bayou	1103D_01	Enterococci	7.585	0.379
Cedar Creek	1103E_01	*E. coli*	1.342	0.067

[a] TMDL from Table 15.

[b] MOS = 0.05 * TMDL (Equation 2)

4.5.2 Waste Load Allocation

The Waste Load Allocation (WLA) consists of two parts – the waste load that is allocated to TPDES-regulated wastewater treatment facilities (WLA_{WWTF}) and the waste load that is allocated to regulated stormwater dischargers (WLA_{SW}).

TPDES-permitted wastewater treatment facilities are allocated a daily waste load (WLA_{WWTF}) calculated using Equation 3. As shown in the equation, the WLA_{WWTF} for dischargers into the non-tidal portion of the watershed were calculated using one-half of the *E. coli* geometric mean criterion (i.e., 63 MPN/100 mL). For the tidal portion of the watershed one-half the Enterococci geometric mean criterion (1.e., 17.5 MPN/100 mL) was used to calculate the WLA_{WWTF} term. To remain consistent with the previously completed TMDL, the average reported flows in TCEQ (2012b) were used in the computations for WWTFs without permitted flow data (i.e., WQ0003146000 and WQ0003479000).

$$WLA_{WWTF} = 1/2 * Criterion * Flow * Conversion\ Factor \qquad (Eq.\ 3)$$

Where:

Criterion= 35 MPN/100 mL for Enterococci; 126 MPN/100 mL for *E. coli*

Flow = full permitted flow (MGD)

Conversion Factor (to MPN/day) = 1.54723 cfs/MGD *283.168 100 mL/ft^3 * 86,400 s/d

Table 17 presents the waste load allocations for each individual WWTF located within the Dickinson Bayou watershed. To remain consistent with the methodology of the previously completed TMDLs as reported in TCEQ (2012b), the WLA_{WWTF} for each AU includes the sum of the WWTF allocations for only those facilities in each AU.

Table 17. Waste load allocations for TPDES-permitted facilities

Watershed	AU	Indicator Bacteria	TPDES Permit No.	Facility	Permitted Flow	WLA_{WWTF} (Billion MPN/ day) [b]
Dickinson Bayou Tidal	1103_01	Enterococci	WQ0014804001	Dolphin Cove WWTF	0.9500 [a]	0.6293
Dickinson Bayou Tidal	1103_01	Enterococci	WQ0004086000	Duratherm	n/a [c]	0
Dickinson Bayou Tidal	1103_01	Enterococci	WQ0014326001	Galveston Bay RV	0.0200 [a]	0.0132
Dickinson Bayou Tidal	1103_01	Enterococci	WQ0003749000	Galveston Co Plant	0.0700 [a]	0.0464
Dickinson Bayou Tidal	1103_01	Enterococci	WQ0003479000	Sea Lion Technology	n/a [c]	0
Dickinson Bayou Tidal	1103_02	Enterococci	WQ0000377000	Dickinson Plant	0.0750 [a]	0.0497
Dickinson Bayou Tidal	1103_02	Enterococci	WQ0010173001	Plant 1	4.8000 [a]	3.1797
Gum Bayou	1103D_01	Enterococci	WQ0014570001	Marlin Atlantis White WWTF	0.5000 [a]	0.3312
Dickinson Bayou Above Tidal	1104_01	*E. coli*	WQ0003416000	Coastal Plains Recycling and Disposal Facility	0.8920 [d]	1.9770
Dickinson Bayou Above Tidal	1104_02	*E. coli*	WQ0013632001	Meadowland Utility Corporation WWTP	0.0234 [a]	0.0558
Dickinson Bayou Above Tidal	1104_02	*E. coli*	WQ0012935001	Pine Colony Utilities Facility	0.0500 [a]	0.1192

[a] Permitted Flow from Table 6

[b] WLA_{WWTF} = 1/2 *Criterion * Flow * Conversion Factor (Equation 3)

[c] Industrial process not associated with indicator bacteria

[d] From 2012 TMDL (TCEQ, 2012b) Table 18 recent self-reported flow; period of Nov. 99 – Feb. 07

Stormwater discharges from MS4, industrial, and construction areas are also considered permitted or regulated point sources. Therefore, the WLA calculations must also include an allocation for permitted stormwater discharges (WLA_{SW}). A simplified approach for estimating the WLA for these areas was used in the development of these TMDLs due to the limited amount of data available, the complexities associated with simulating rainfall runoff, and the variability of stormwater loading. The percentage of the land area included in each AU watershed that is under the jurisdiction of stormwater permits is used to estimate the amount of the overall runoff load that should be allocated as the permitted stormwater contribution in the WLA_{SW} component of the TMDL. The LA component of the TMDL corresponds to direct nonpoint runoff and is the difference between the total load from stormwater runoff and the portion allocated to WLA_{SW}.

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

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

Where:

WLA_{SW} = sum of all regulated stormwater loads

TMDL = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

FG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

FDA_{SWP} = fractional proportion of drainage area under jurisdiction of stormwater permits

In order to calculate the WLA_{SW} component of the TMDL, the fractional proportion of the drainage area under the jurisdiction of stormwater permits (FDA_{SWP}) must be determined in order to estimate the amount of overall runoff load that should be allocated to WLA_{SW}. The term FDA_{SWP} was calculated based on the area under regulated stormwater permits within each AU remaining consistent with the approach used in the previously completed TMDL (TCEQ, 2012b). As described in Section 2.7.1.3 , portions of the three impaired AUs are regulated under Phase II municipal separate storm sewer system (MS4) permits (also see Table 9).

In order to calculate WLA_{SW} (Equation 4), the Future Growth (FG) term must be known. The calculation for the FG term is presented in the next section, but the results will be included here for continuity. Table 18 provides the information needed to compute WLA_{SW}.

Table 18. Regulated stormwater calculations for impaired AU watersheds

Load units expressed as billion MPN/day

Watershed	AU	Indicator	TMDL [a]	WLA_{WWTF} [b]	FG [c]	MOS [d]	FDA_{SWP} [e]	WLA_{SW} [f]
Dickinson Bayou Tidal	1103_01	Enterococci	922.405	0.689	0.139	46.120	0.1695	148.390
Gum Bayou	1103D_01	Enterococci	7.585	0.331	0.992	0.379	0.6672	3.925
Cedar Creek	1103E_01	*E. coli*	1.342	0	0.048	0.067	0.0361	0.044

[a] TMDL from Table 15
[b] WLA_{WWTF} from Table 17
[c] FG from Table 19
[d] MOS from Table 16
[e] FDA_{SWP} from Table 9
[f] $WLA_{SW} = (TMDL - WLA_{WWTF} - FG - MOS) * FDA_{SWP}$ (Equation 4)

4.5.3 Future Growth

The Future Growth (FG) component of the TMDL equation addresses the requirement of TMDLs to account for future loadings that may occur as a result of population growth, changes in community infrastructure, and development. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard.

Currently, four facilities that treat domestic water are located within the impaired AU watersheds; three in the Dickinson Bayou Tidal watershed, one in the Gum Bayou watershed, and none in the Cedar Creek watershed. To account for the FG component of the impaired Tidal AUs (1103_01 and 1103D_01), the loading from only the WWTFs with outlets located within their respective AU watersheds are included in the FG computation. The FG equation contains an additional term from the WLA_{WWTF} computation (Equation 4) to account for projected population growth within the WWTF service areas between 2010 and 2050.

For all of the WWTFs, the 2050 permitted flow was computed using the methodology and population growth from TCEQ (2012b). For all but the newly-permitted Dolphin Cove WWTP (WQ0014804001), the calculated 2050 permitted flow matched the original TSD. For the newly-permitted Dolphin Cove WWTP (WQ0014804001), the percent increase in Future Growth was calculated based on the fact that the facility treats municipal waste, and is located in Galveston County (outside of any city limits).

$$FG = \frac{1}{2} * \text{Criterion} * [\%POP_{2010\text{-}2050} * WWTF_{FP}] * \text{Conversion Factor} \qquad \text{(Eq. 5)}$$

Where:

Criterion = 35 MPN/100 mL Enterococci or 126 MPN/100 mL for *E. coli*

$\%POP_{2010\text{-}2050}$ = estimated % increase in population between 2010 and 2050

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

Conversion Factor = 1.547 cfs/MGD *283.168 100 mL/ft^3 * 86,400 s/d

Because future growth from WWTFs could occur anywhere in the Dickinson Bayou watershed where conditions are amenable for new development, Cedar Creek was not considered exempted from that possibility. However, the absence of existing WWTFs in the Cedar Creek watershed precluded the standard approach provided in Equation 5 to perform the future growth computations. In lieu of any specific information on future growth in Cedar Creek a simplistic approach was used compute a loading for this term. For Cedar Creek watershed it was assumed that a new WWTF equal in size to the smallest domestic facility in Dickinson Bayou watershed (i.e., Via Bayou RV Park with full permitted flow of 0.02 MGD), and Equation 5 could then be applied using [%POP2010-2050*$WWTF_{FP}$] = 0.02 MGD.

The calculation results for the three impaired AUs are shown in Table 19.

Table 19. Future Growth Calculations for the impaired AU watersheds.

Watershed	AU	TPDES Permit No.	Facility	Held By	Full Permitted Flow (MGD)	Type/ Location of Outfall	% Increase (2000-2050)	2050 Permitted Flow (Future Growth) (MGD)	Enterococci FG (Billion MPN/ day)[e]	*E. coli* FG (Billion MPN/ day)[e]
Dickinson Bayou Tidal	1103_01	WQ0003749000	Galveston Co Plant	Hillman Shrimp and Oyster Co	0.07	Industrial/ Galveston County	27.0%	0.089[a]	0.013	-
Dickinson Bayou Tidal	1103_01	WQ0014326001	Galveston Bay RV	Bayou Development LLC	0.02	Municipal/ Dickinson	0.15%	0.02003[b]	0.000	-
Dickinson Bayou Tidal	1103_01	WQ0014804001	Dolphin Cove WWTP	South Central Water Company	0.95	Municipal/ Galveston County	20.0%	1.140[c]	0.126	-
Dickinson Bayou Tidal Total								1.249	0.139	-
Gum Bayou	1103D_01	WQ0014570001	Marlin Atlantis White WWTF	United Development Funding LP	0.5	Municipal/ Dickinson	299.6%	1.998[b]	0.992	-
Gum Bayou Total								1.998	0.992	-
Cedar Creek	1103E_01	-	-	-	-	-	-	0.020[d]	-	0.048
Cedar Creek Total								0.020	-	0.048

[a] Based on Table C-6 (p. 72) in the 2012 TMDL (TCEQ, 2012b).

[b] Based on Table C-4 (p. 72) in the 2012 TMDL (TCEQ, 2012b).

[c] New WWTF not presented in 2012 TMDL; calculated based on similar methodology using county population growth.

[d] Based on an assumed minimum new WWTF size of 0.02 MGD.

[e] FG = ½ * Criterion * [$\%POP_{2010\text{-}2050}$*$WWTF_{FP}$] * Conversion Factor (Equation 5)

4.5.4 Load Allocation

The load allocation (LA) is the loads from unregulated sources, and is calculated as:

$$LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS \qquad \text{(Eq. 6)}$$

Where:

LA = allowable loads from unregulated sources within the AU

$TMDL$ = total maximum daily load

WLA_{WWTF} = sum of all WWTF loads

WLA_{SW} = sum of all regulated stormwater loads

FG = sum of future growth loads from potential permitted facilities

MOS = margin of safety load

The calculation results are shown in Table 20.

Table 20. Load allocation calculations for the impaired AU watersheds.

Load units expressed as billion MPN/day

Watershed	AU	Indicator	TMDL [a]	WLA_{WWTF} [b]	WLA_{SW} [c]	FG [d]	MOS [e]	LA [f]
Dickinson Bayou Tidal	1103_01	Enterococci	922.405	0.689	148.390	0.139	46.120	727.067
Gum Bayou	1103D_01	Enterococci	7.585	0.331	3.925	0.992	0.379	1.958
Cedar Creek	1103E_01	*E. coli*	1.342	0	0.044	0.048	0.067	1.183

[a] TMDL from Table 15

[b] WLA_{WWTF} from Table 17

[c] WLA_{SW} from Table 18

[d] FG from Table 19

[e] MOS from Table 16

[f] $LA = TMDL - WLA_{WWTF} - WLA_{SW} - FG - MOS$ (Equation 6)

4.6 Summary of TMDL Calculations

Table 21 summarizes the TMDL calculations for the impaired AU watersheds. Each of the TMDLs was calculated based on either (1) the median flow value from the Tidal Prism Model, or (2) the median flow value in the in the 20-80 percentile range (50th percentile exceedance, mid-range flow regime) for flow exceedance from the LDC analysis. Allocations are based on the current geometric mean criterion of either (1) 35 MPN/100 mL for Enterococci or (2) 126 MPN/ 100 mL for *E. coli* for each component of the TMDL.

The final TMDL allocations (

Table 22) needed to comply with the requirements of 40 CFR 130.7 include the future growth component within the WLA_{WWTF}.

In the event that the criterion changes due to future revisions in the state's surface water quality standards, Appendix A provides guidance for recalculating the allocations in

Table 22. Figures A-1 through A-3 of Appendix A were developed to demonstrate how assimilative capacity, TMDL calculations, and pollutant load allocations change in relation to a number of proposed water quality criteria for Enterococci and *E. coli*. The equations and figures

provided in Appendix A allow calculation of new TMDLs and pollutant load allocations based on any potential new water quality criterion for Enterococci and *E. coli*.

Table 21. Load allocation calculations for impaired AU watersheds.

Load units expressed as billion MPN/day

AU	Stream Name	Indicator	TMDL [a]	MOS [b]	WLA_{WWTF} [c]	WLA_{SW} [d]	LA [e]	Future Growth [f]
1103_01	Dickinson Bayou Tidal	Enterococci	922.405	46.120	0.689	148.390	727.067	0.139
1103D_01	Gum Bayou	Enterococci	7.585	0.379	0.331	3.925	1.958	0.992
1103E_01	Cedar Creek	*E. coli*	1.342	0.067	0	0.044	1.183	0.048

[a] TMDL from Table 15

[b] MOS from Table 16

[c] WLA_{WWTF} from Table 17

[d] WLA_{SW} from Table 18

[e] LA from Table 20

[f] Future Growth from Table 19

Table 22. Final TMDL allocations for the impaired AU watersheds within Dickinson Bayou

Load units expressed as billion MPN/day

AU	TMDL	WLA_{WWTF} [a]	WLA_{SW}	LA	MOS
1103_01	922.405	0.828	148.390	727.067	46.120
1103D_01	7.585	1.323	3.925	1.958	0.379
1103E_01	1.342	0.048	0.044	1.183	0.067

[a] WLA_{WWTF} includes the FG component

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Appendix A.

Equations for Calculating TMDL Allocations for Changed Contact Recreation Standard

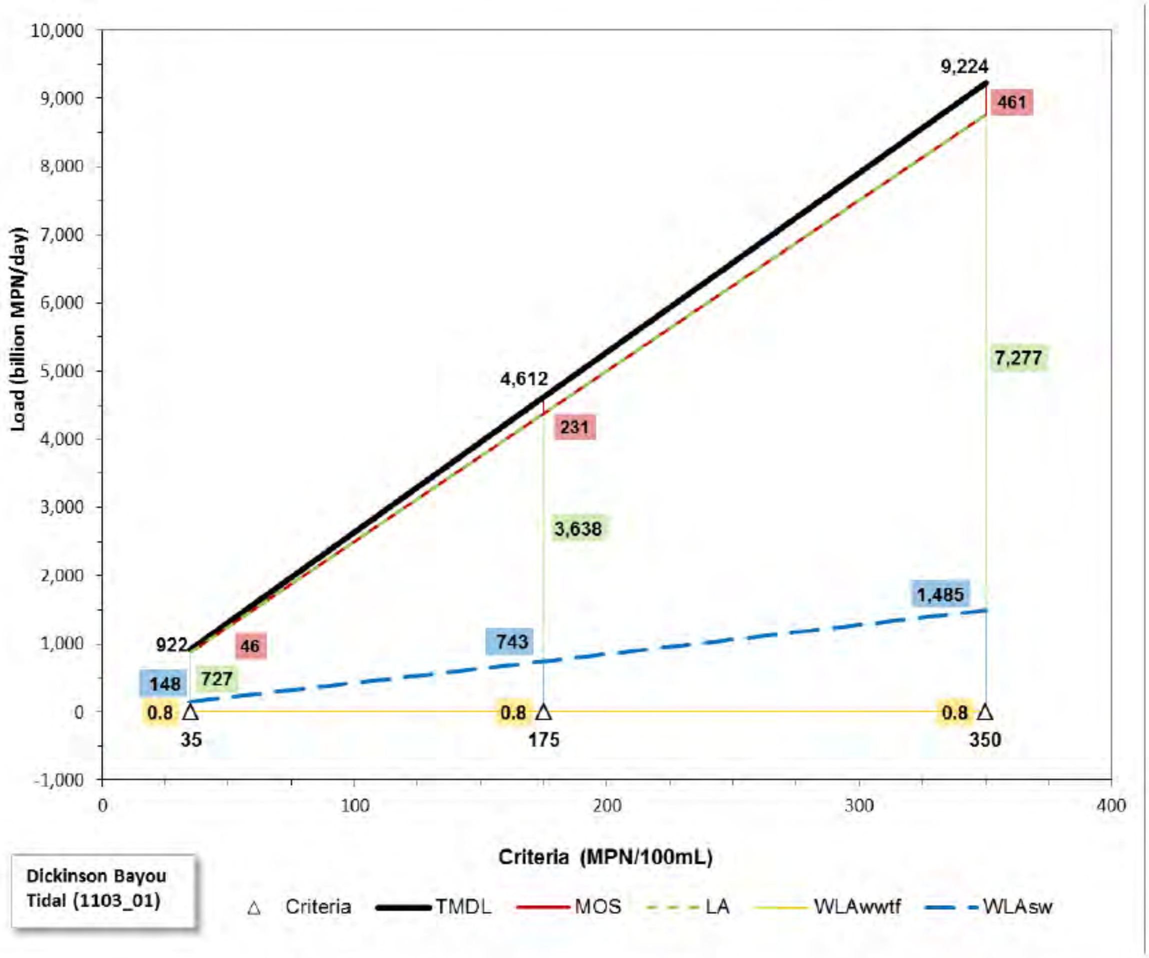

Figure A-1. Allocation loads for Dickinson Bayou Tidal (1103_01) as a function of water quality criteria.

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

TMDL =26.354429 * Std
MOS =1.317724 * Std
LA =20.792984 * Std - 0.687361
WLA_{WWTF} =0.8280
WLA_{SW} =4.243721 * Std - 0.140180

Where:

Std = Revised Contact Recreation Standard
MOS = Margin of Safety
LA = Total load allocation (non-permitted source contributions)
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
[Note: WWTF load held at Primary Contact (35 MPN/ 100 mL) criterion]
WLA_{SW} = Waste load allocation (permitted stormwater)

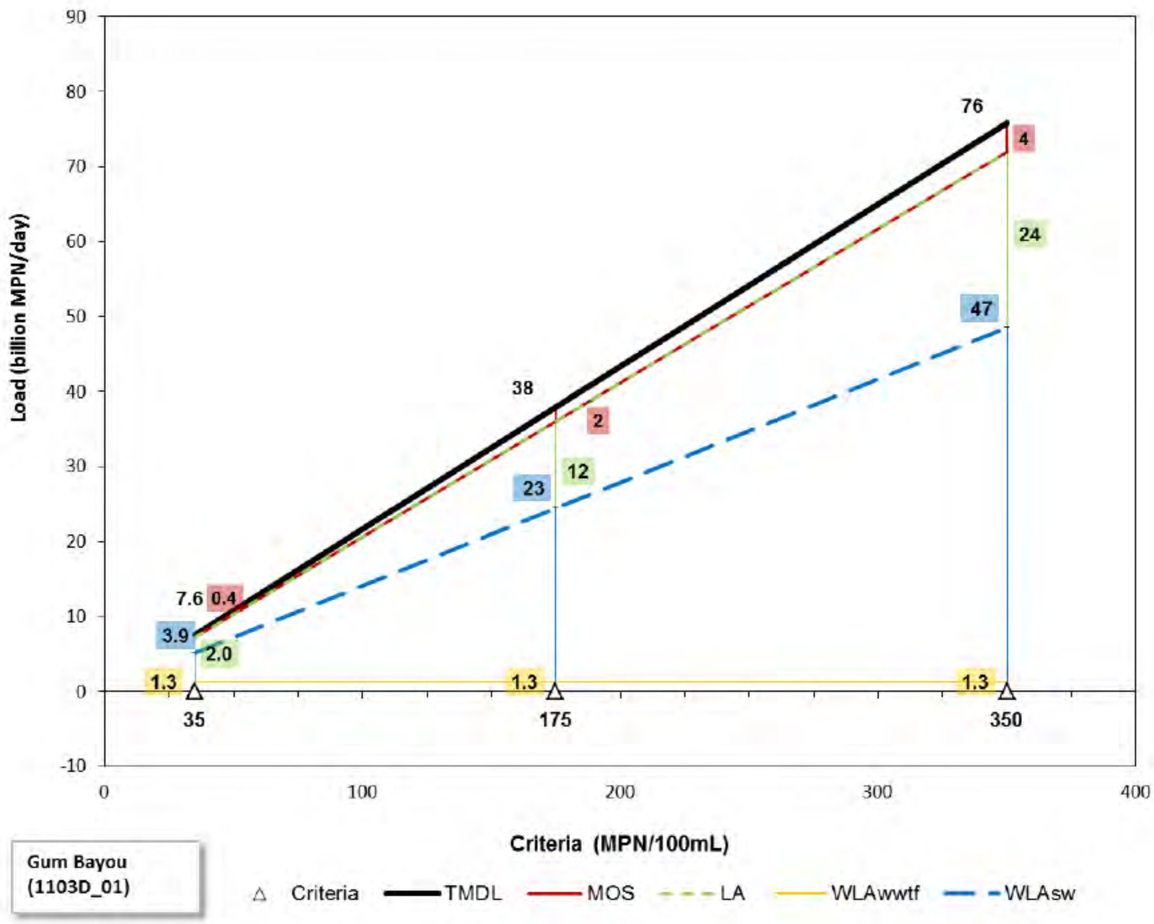

Figure A-2. Allocation loads for Gum Bayou (1103D_01) as a function of water quality criteria.

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

TMDL =0.216714 * Std

MOS =0.010838 * Std

LA =0.068514 * Std - 0.440000

WLA_{WWTF} =1.3230

WLA_{SW} =0.137362 * Std - 0.882541

Where:

Std = Revised Contact Recreation Standard

MOS = Margin of Safety

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

WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
[Note: WWTF load held at Primary Contact (35 MPN/ 100 mL) criteria]

WLA_{SW} = Waste load allocation (permitted stormwater)

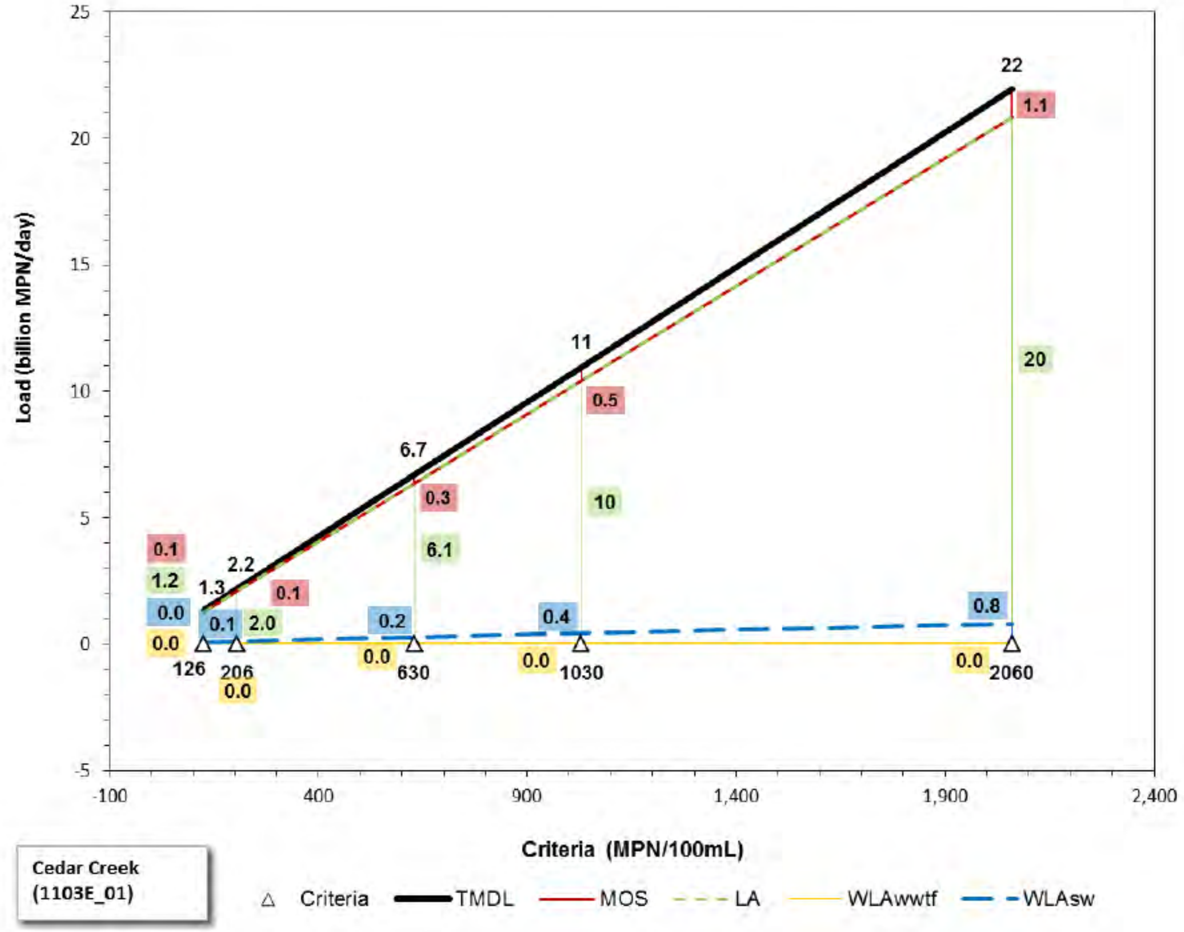

Figure A-3. Allocation loads for Cedar Creek (1103E_01) as a function of water quality criteria.

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

TMDL =0.0106476 * Std
MOS =0.0005325 * Std
LA =0.0097500 * Std - 0.0457933
WLA_{WWTF} =0.0480
WLA_{SW} =0.0003651 * Std - 0.0020729

Where:

Std = Revised Contact Recreation Standard
MOS = Margin of Safety
LA = Total load allocation (non-permitted source contributions)
WLA_{WWTF} = Waste load allocation (permitted WWTF load + future growth)
[Note: WWTF load held at Primary Contact (126 MPN/ 100 mL) criteria]
WLA_{SW} = Waste load allocation (permitted stormwater)