Total Maximum Daily Loads for Fecal Bacteria in the Dickinson Bayou
TECHNICAL SUPPORT DOCUMENT
Revision 2

Contract No. 582-10-90494
Work Order No. 582-10-90494-7

Prepared by
University of Houston
CDM

Principal Investigator
Hanadi Rifai

PREPARED IN COOPERATION WITH THE
TEXAS COMMISSION ON ENVIRONMENTAL QUALITY AND
U.S. ENVIRONMENTAL PROTECTION AGENCY

The preparation of this report was financed through grants from the U.S. Environmental Protection Agency through the Texas Commission on Environmental Quality

TCEQ Contact:
Roger Miranda
TMDL Program
P.O.Box 13087, MC – 203
Austin, Texas 78711-3087
rmiranda@tceq.state.tx.us

March 30, 2012

Contents

Appendices

Appendix A - Summary of Self-Reported Flows in Dickinson Bayou
Appendix B - Future Growth Analysis

Tables

Figures

CHAPTER 1:
INTRODUCTION

In 1996, Dickinson Bayou was included in the State of Texas' Clean Water Act §303(d) list of impaired water bodies because fecal indicator bacteria levels were observed to exceed the criteria established by the state of Texas to assure the safety of contact recreation. This impairment was expanded in 2002 to include four major tributaries of Dickinson Bayou (i.e., Bensons Bayou, Bordens Gully, Giesler Bayou and Gum Bayou). These water bodies remain on the EPA-approved list of impaired water bodies for the state of Texas (i.e., 2008 Texas 303[d] List) with the exception of Gum Bayou which was removed from the State of Texas 303(d) list in 2006. The most current draft of the State of Texas' 303(d) list (2010) has placed Gum Bayou back on the list for non-attainment of the contact recreational use.

The state of Texas requires water quality in the Dickinson Bayou and its tributaries to be suitable for swimming and wading and employs the TMDL process to restore designated uses to these and other impaired water bodies of the state. Several years of quarterly monitoring has yielded enough information to verify the indicator bacteria impairments in these water bodies.

This TMDL Technical Support Document presents a summary of the TMDL project to date. **Chapter 1** provides an introduction to the report. In **Chapter 2**, the physical characteristics of the Dickinson Bayou watershed are described as is historical bacteria data for the watershed. A discussion of the watershed water quality targets for contact recreation is presented in **Chapter 3**. **Chapter 4** contains a discussion of the bacteria sources that exist in the Dickinson Bayou watershed. The water quality models developed for this project, HSPF and the tidal prism box model, are described in detail within **Chapter** 5. **Chapter 6** provides a summary of the TMDL calculations undertaken for this study and **Chapter 7** provides a summary of stakeholder participation for the project.

CHAPTER 2:
PROBLEM DEFINITION: PHYSICAL SETTING AND BACTERIA DATA

This chapter provides a detailed characterization of the Dickinson Bayou watershed, including descriptions of major water bodies and the designated segments and assessment units associated with each water body of interest. The chapter also provides geographic, demographic, hydrologic and climatologic information associated with the Dickinson Bayou watershed. The last portion of the chapter provides an analysis of historical water quality monitoring data collected at various TCEQ water quality monitoring stations located in assessment units of interest in the watershed and provides background information regarding the *E. coli* and enterococci, which are fecal bacteria that originate in the intestines of warm-blooded species (human and animal). While these bacteria do not directly cause illness in humans, the United States Environmental Protection Agency (US EPA) has determined their presence in a water body indicates a heightened risk of other harmful microbes also being in the water body (US EPA, 1986). A summary of indicator bacteria and their relevant standards for the State of Texas are presented in **Chapter 3**.

2.1 Watershed Description

Dickinson Bayou, shown in **Figure 2-1**, is a coastal stream comprised of tidal and non-tidal waters that subsequently drain to Dickinson Bay, and, thence to Galveston Bay. The bayou is divided into two designated segments by the Texas Commission on Environmental Quality (TCEQ), the Above-Tidal Segment, 1104, and the Tidal Segment, 1103. The water quality segments and Assessment Units (AUs) covered by this document were included in the 2008 303(d) list under category 5a indicating that they are a priority for developing a TMDL.

According to TCEQ water quality segment definitions, Segment 1104 is approximately 14.8 miles long while Segment 1103 is 6.9 miles long. These two segments are subdivided into several smaller areas called Assessment Units, with six Assessment Units being included in Segment 1103 and two Assessment Units being included in Segment 1104. Three main tributaries of interest drain into Dickinson Bayou:

- Bensons Bayou, approximately 2.5 miles long and comprises Assessment Unit 1103A_01;
- Bordens Bayou (or Gully), approximately 2.4 miles long and comprises assessment unit 1103B_01;
- Giesler Bayou, approximately 1.9 miles long and comprises assessment unit 1103C_01.

Gum Bayou is also a tributary of Dickinson Bayou that has been shown in the past to exceed the criteria for safe contact recreation. However, Gum Bayou was dropped from Texas' 303(d) List in 2006, after bacteria data collected in the Bayou between 1999-2006 showed that the contact recreation use was being supported in Gum Bayou. Although a tributary of interest to the Dickinson Bayou Bacteria TMDL, Gum Bayou is not included in the pollutant load allocation calculations of this TMDL, because it is not officially considered an impaired water body. Gum Bayou is, however, included in the draft 2010 Texas 303(d) List and it will be included in the updates to the TMDL conducted through revisions of the State of Texas' Water Quality Management Plan.

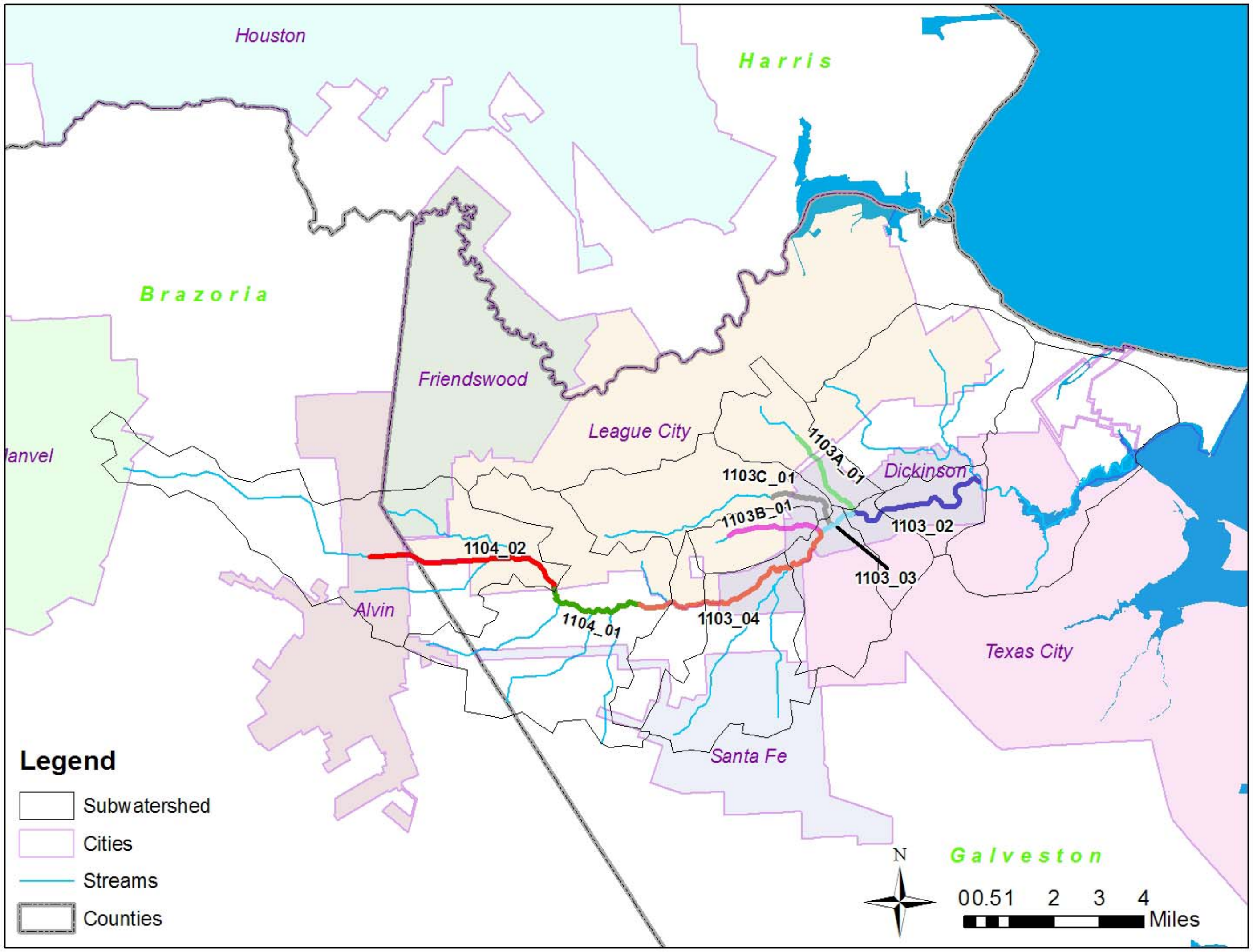


Figure 2-1 **Overview of Dickinson Bayou Watershed**

The Dickinson Bayou watershed includes several different political boundaries and spans approximately 100 square miles. About a third of the upper segment lies in Brazoria County and comprises approximately 1% of the total county area, while the remaining area of the watershed is in Galveston County, where it encompasses approximately 11% of the total county area. County population and population density from the 2000 and 2010 U. S. Census are shown in **Table 2-1**. Populations and population densities, as projected by the Office of the State Demographer[1], are also shown for comparison purposes. It can be noted that although the counties have comparable populations, the population density of Galveston County is more than three times greater than that of Brazoria County and the populations of both counties are anticipated to continue increasing based on projections from the Texas State Demographer.

Table 2-1 County Population and Density

County Name	2000 U. S. Census	2000 Population Density (per square mile)	Texas State Demographic Projections 2008	2008 Population Density (per square mile)	2010 U.S. Census	2010 Population Density (per square mile)
Brazoria	241,767	174	296,691	214	313,166	226
Galveston	250,158	627	286,987	719	291,309	732

There are also several cities that have their jurisdictions at least partially within the watershed. These cities include Manvel, League City, Alvin, Friendswood, Dickinson, Texas City and Santa Fe. These cities are projected to grow by an average of 28% between 2000 and 2050, according to the Texas Water Development Board (TWDB, 2006), as shown in **Table 2-2**.

---

[1] Source: 2010 State Water Plan (TWDB, 2010).

Table 2-2 Dickinson Bayou Watershed Population Increases by City, 2000 to 2050

City	2000 U. S. Census Population	2010 Population Estimate	2050 Population Estimate	Growth Rate (2000-2050)
Alvin 21,413		23,231	30,375	42%
Dickinson 17,093		19,955	24,921	16%
League City	45,444	32,353	67,613	49%
Manvel 3,046		53,546	3,046	0%
Friendswood 29,037		3,046	38,107	31%
Texas City	41,521	10,141	42,534	2%
Santa Fe	9,548	41,891	11,170	17%

2.2 Summary of Existing Geographic and Climatologic Data

The following subsections contain a summary of relevant data concerning land use, soil type, and precipitation throughout the watershed as well as flow estimates and tidal patterns.

2.2.1 Land Use

Although extensively urbanized in certain areas, the Dickinson Bayou watershed has a large amount of undeveloped land. It is, as previously stated, undergoing rapid development like many coastal areas in Texas. In 2002 and 2008, the Houston-Galveston Area Council (H-GAC) performed land use/land cover studies across the watershed area (2002, 2008). These data were used to characterize current land use in the project area as shown in **Table 2-3** and **Figure 2-2**.

Table 2-3 Summary of Land Use in Watershed

Land Description	Land Use #	2008		2002	
		Area (Square meters)	% of Watershed	Area (Square meters)	% of Watershed
High Intensity Developed	1 11,8	34,969	4.54%	17,146,162	6.58%
Low Intensity Developed	2 58,7	57,752	22.54%	22,102,118	8.48%
Open Space Developed	3	32,011,765	12.28%	Category Not Used in 2002	Category Not Used in 2002
Cultivated Land	4	67,542,739	25.91%	16,557,521	6.35%
Grassland/Shrub 5		42,543,323	16.32%	120,113,565	46.08%
Forest 6		6,517,053	2.50%	67,655,898	25.95%
Woody wetland	7	20,776,366	7.97%	1,862,587	0.71%
Herbaceous Wetland	8	8,550,374	3.28%	5,657,231	2.17%
Bare/Transitional Land	9	5,865,348	2.25%	1,909,996	0.73%
Open Water	10	6,282,439	2.41%	7,677,050	2.94%
Total		260,682,128	100.00%	260,682,128	100.00%

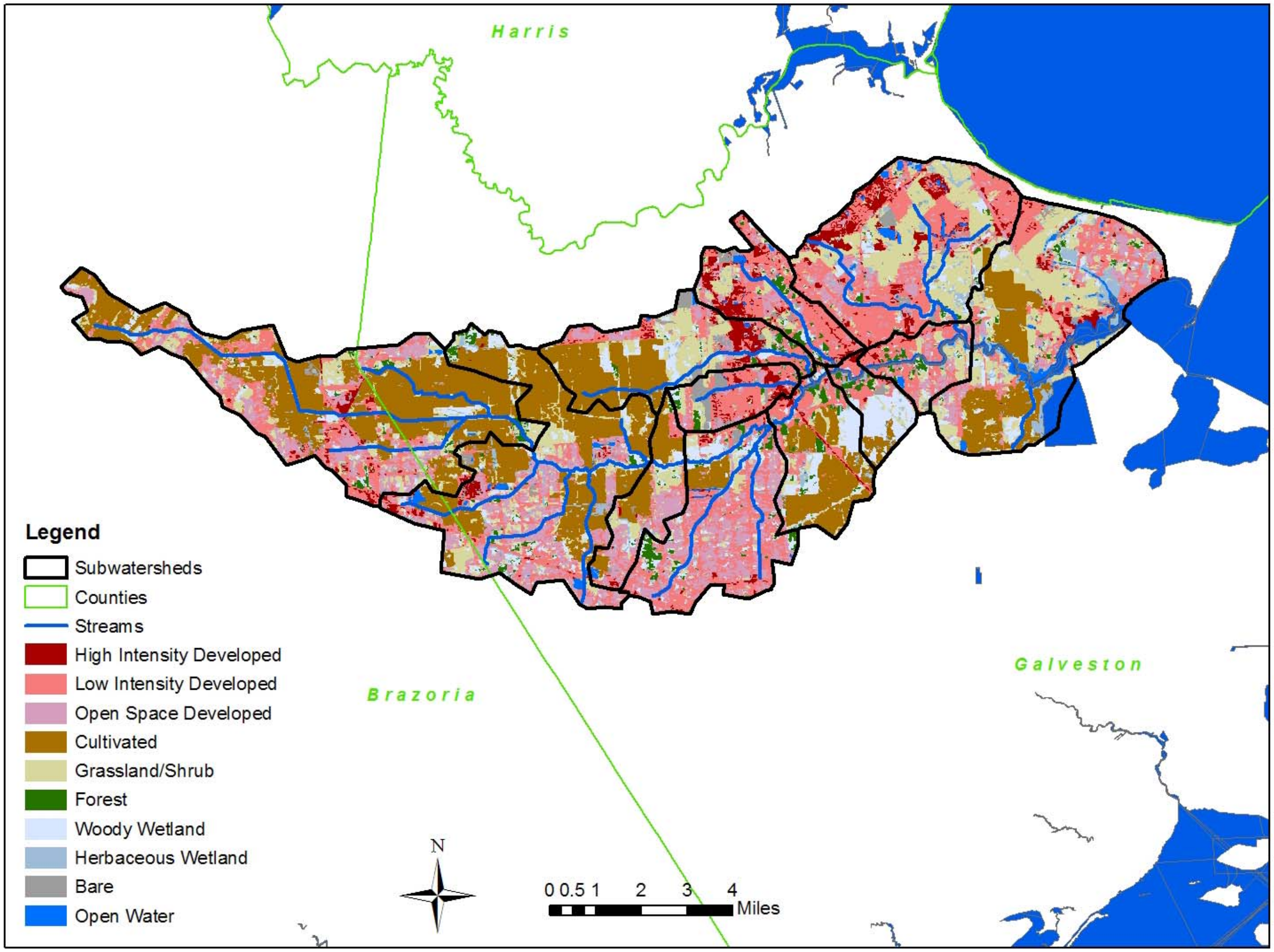


Figure 2-2 Land Use Map, Dickinson Bayou (2008 H-GAC Land Use)

The major portion of the Dickinson Bayou watershed that is currently developed land, encompasses approximately 40% of the total watershed area, with low intensity developed land being the most prevalent developed land use in the watershed. Cultivated land accounts for approximately 25% of the watershed area, while grassland or shrub comprises 16%. Woody wetland accounts for 8%, and forest, herbaceous wetland, bare/transitional land, and open water combined total less than 11% of the total watershed area. Between 2002 and 2008 the amount of developed land has more than doubled due to increased urbanization and rises in the population within the watershed. A significant increase in cultivated land is also seen as it has risen to nearly 26% of the watershed from only 6% in 2002. The most prevalent land uses in 2002, grassland/shrub and forest, have seen sharp declines during this six year period. Only one-third of the grassland/shrub area remains and 10% of the forest land. Between 2002 and 2008 the land use categories used by the HGAC were slightly altered and the category "Open Space Developed" was added as a tenth category. This new categorization could cause a change in land classification, resulting in a shift of some categories between the two data sets.

Although more recent land use data were available, the 2002 data from H-GAC were used to develop the HSPF model (discussed in more detail in Chapter 5). This is because the calibration period for the modeling effort was selected as June 1, 1999 through November 5, 2001 based on source, bathymetry and boundary condition data availability during that time period.

2.2.2 Soils

Soils data, obtained from the Natural Resource Conservation Service (NRCS) State Soil Geographic (STATSGO) Database (2006) as well as the Soil Survey for Galveston County (Crenwelge *et al.*, 1988), are summarized in **Tables 2-4** and **2-5**. The geographic distribution of soils in the watershed is presented in **Figure 2-3**. As shown in **Table 2-4**, the watershed is entirely composed of soils that fall within Hydrologic Soil Group D. These types of soil have high runoff potential, with very slow infiltration when thoroughly wetted. They consist chiefly of clay soils with high swelling potential and have a very slow rate of water transmission.

Table 2-4 General Characteristics of Soils in Dickinson Bayou Watershed

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

NRCS = Natural Resource Conservation Service

Table 2-5 Distribution of Soils in Dickinson Bayou Watershed

NRCS Soil Name	Soil Name	Total (Square Meters)	Percent of Watershed
TX162	Edna-Aris-Kemah	9,199,559	3.53%
TX163	Edna-Bernard-Verland	77,572,660	29.76%
TX185	Francitas-Narta-Harris	2,407,401	0.92%
TX276	Lake Charles-Bernard-Edna	95,217,252	36.53%
TX346	Mocarey-Leton-Algoa	74,151,615	28.45%
TXW	Water	2,070,861	0.79%
Totals		260,619,348	100.00%

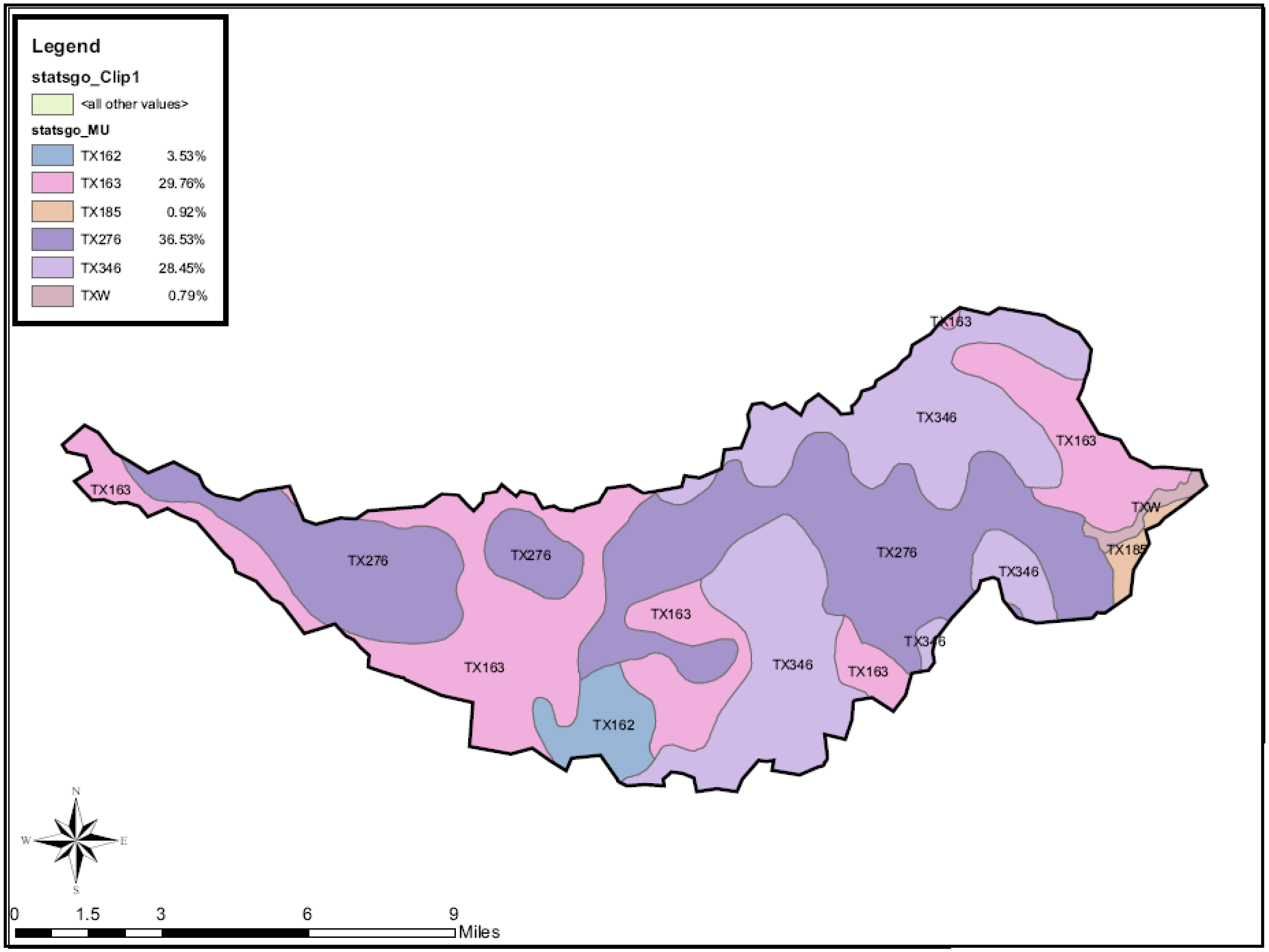


Figure 2-3 Soil Area Map, Dickinson Bayou

The soils in the watershed include three primary soil groups, the Edna-Bernard-Verland group, Lake Charles-Bernard-Edna group, and Mocarey-Leton-Algoa group. All three are fine sandy to clay loams. The Edna-Bernard-Verland group is composed of approximately 56% sand, 30% silt and 14% clay as shown in **Table 2-5**. The Lake Charles-Bernard-Edna is somewhat similar, with 25% sand, 28% silt, and 47% clay. Finally, the Mocarey-Leton-Algoa group is 39% sand, 41% silt and 20% clay. The soils data described above were used to define infiltration parameters and general sediment parameters in the (HSPF) watershed model developed for Dickinson Bayou Bacteria TMDLs. This model is discussed in more detail in Chapter 5.

2.2.3 Precipitation

Precipitation data for the Dickinson Bayou watershed are somewhat limited, as there are few gages in Galveston and Brazoria County. One rainfall gage, Station 4333 associated with the National Weather Services, is located at the National Weather Service Office in League City. This is the only gage located inside the watershed. Other rainfall gages surrounding the watershed include those from the Harris County Office of Emergency Management (HCOEM) and several National Weather Service rainfall gages (Clover Field in Pearland and Scholes Field in Galveston).

Rainfall gages in close proximity to the watershed were plotted on a map as shown in **Figure 2-4**. The cumulative yearly rainfall data recorded for these four gages is listed in **Table 2-6** for the years 2003 to 2008. Because data availability was limited at some gages, the period from 2003 to 2008 was selected for the analysis because it provided the most complete data set for the analysis. Assuming these stations are representative of rainfall in the Dickinson watershed, the average yearly rainfall can be approximated as 52.11 inches based on the 2003 to 2008 data. The precipitation patterns in Dickinson Bayou are typical of a coastal watershed, with more frequent rainfall in the spring and summer months and less in the fall and winter.

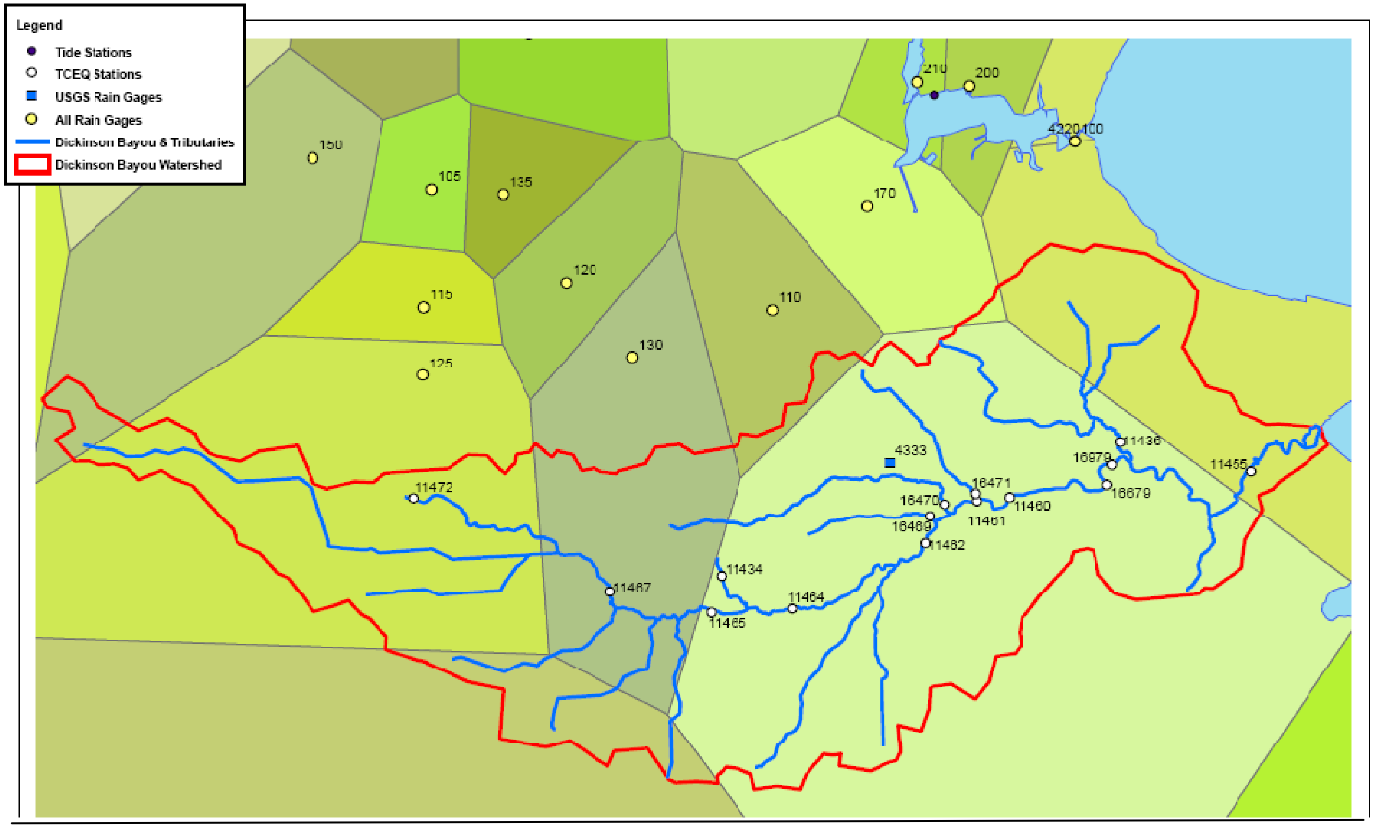


Figure 2-4 Rainfall Gage Location Map, Dickinson Bayou

Table 2-6 Summary of Annual Average Rainfall

Gage Number	Year						Average
	2003	2004	2005	2006	2007	2008	
NWS 4333	63.17	71.6	42.49	62.85	59.97	54.73	59.14
HCOEM 100	38.01	49.02	32.64	43.07	46.38	41.97	41.85
HCOEM 125	47.83	64.02	35.67	62.44	64.29	52.60	54.48
HCOEM 130	50.12	67.12	36.10	64.17	64.885	35.39	52.96
Average Rainfall (inches)							52.11

2.2.4 Flow and Tidal Conditions

Dickinson Bayou and its tributaries are not currently monitored by the United States Geological Survey (USGS) for flow or stage. However, the TCEQ operates fifteen monitoring stations for water quality and flow measurements, as shown in **Figure 2-4**. Seven of these TCEQ monitoring stations have instantaneous flow measurements recorded by the TCEQ. To address the deficiency in flow measurements, flow data from a neighboring watershed, Chocolate Bayou, were used to develop a synthetic flow time series used to calibrate the HSPF model. A more detailed description of the flow modeling conducted as part of this TMDL is provided in Chapter 5.

In addition to TCEQ monitoring within the bayou, the National Oceanic and Atmospheric Administration (NOAA) operates one active tide gage in the vicinity of the watershed. This site, station 8771013, is located at Eagle Point in Galveston Bay and shown in **Figure 2-5**. The Eagle Point Station has been in operation since April 16, 1993. An inactive gage is also located in the Dickinson Bayou watershed (station 8771096); it was only active between January 1, 1994 and February 16, 1996. No current data are available from that gage.

A plot of tide water surface elevations is presented for Eagle Point in **Figure 2-6**. Data from March 2006 are presented in **Figure 2-6 (A)** to present typical tidal water surface elevation patterns while a four-year period, starting with the first collected measurements in 2004 through 2008 is presented in **Figure 2-6 (B)**. The daily variation in tide elevation that can be seen in **Figure 2-6 (A)** is affected by daily patterns of high and low tides. The monthly and seasonal patterns apparent in **Figure 2-6 (B)** show the influence of rainfall, the location of the Moon with respect to the Earth, and solar gravitational effects. Water surface elevation data were used to develop the tidal prism model. The development of this model is described in more detail in Chapter 5

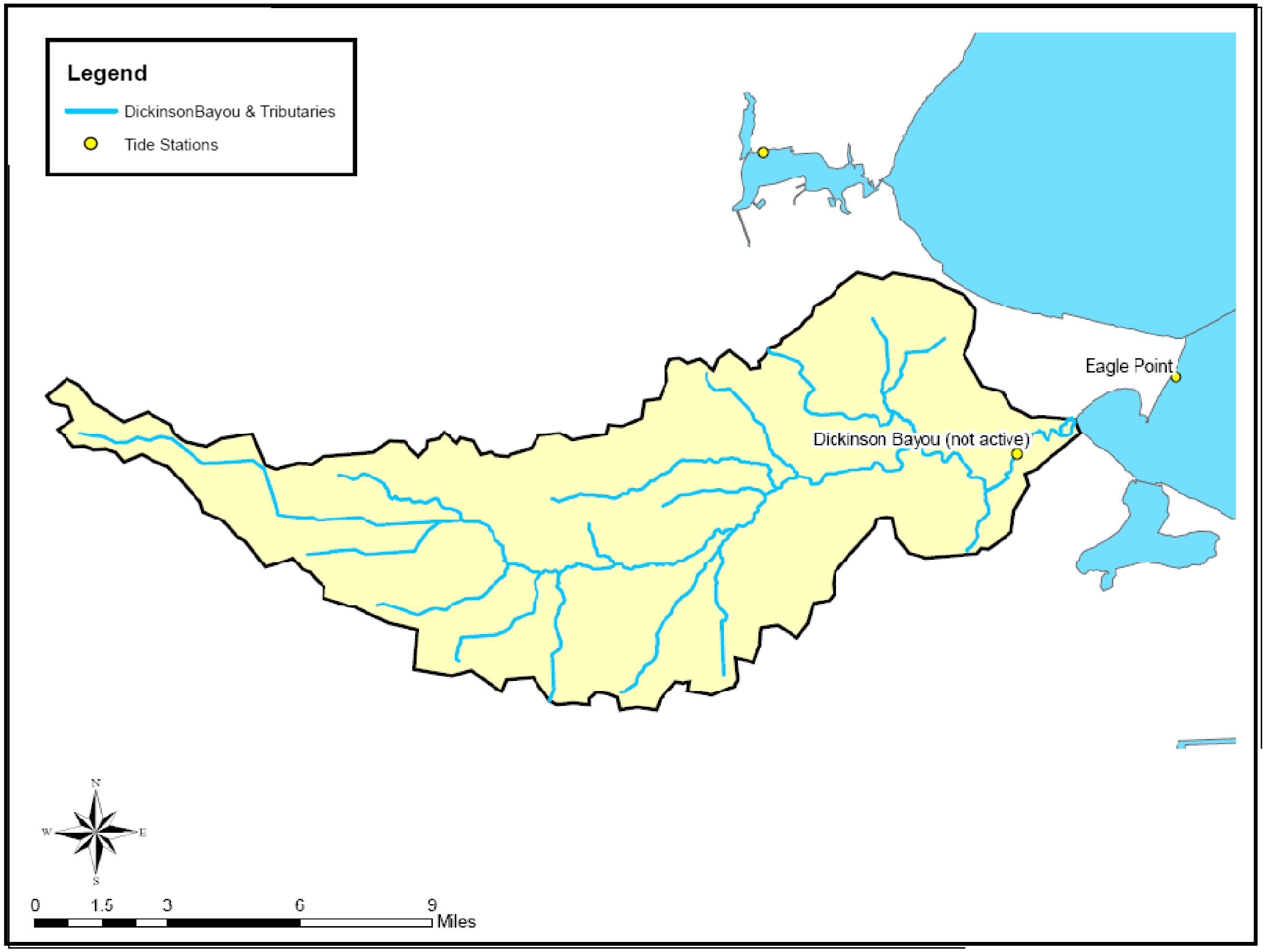


Figure 2-5 Tide Gauge Location Map, Dickinson Bayou

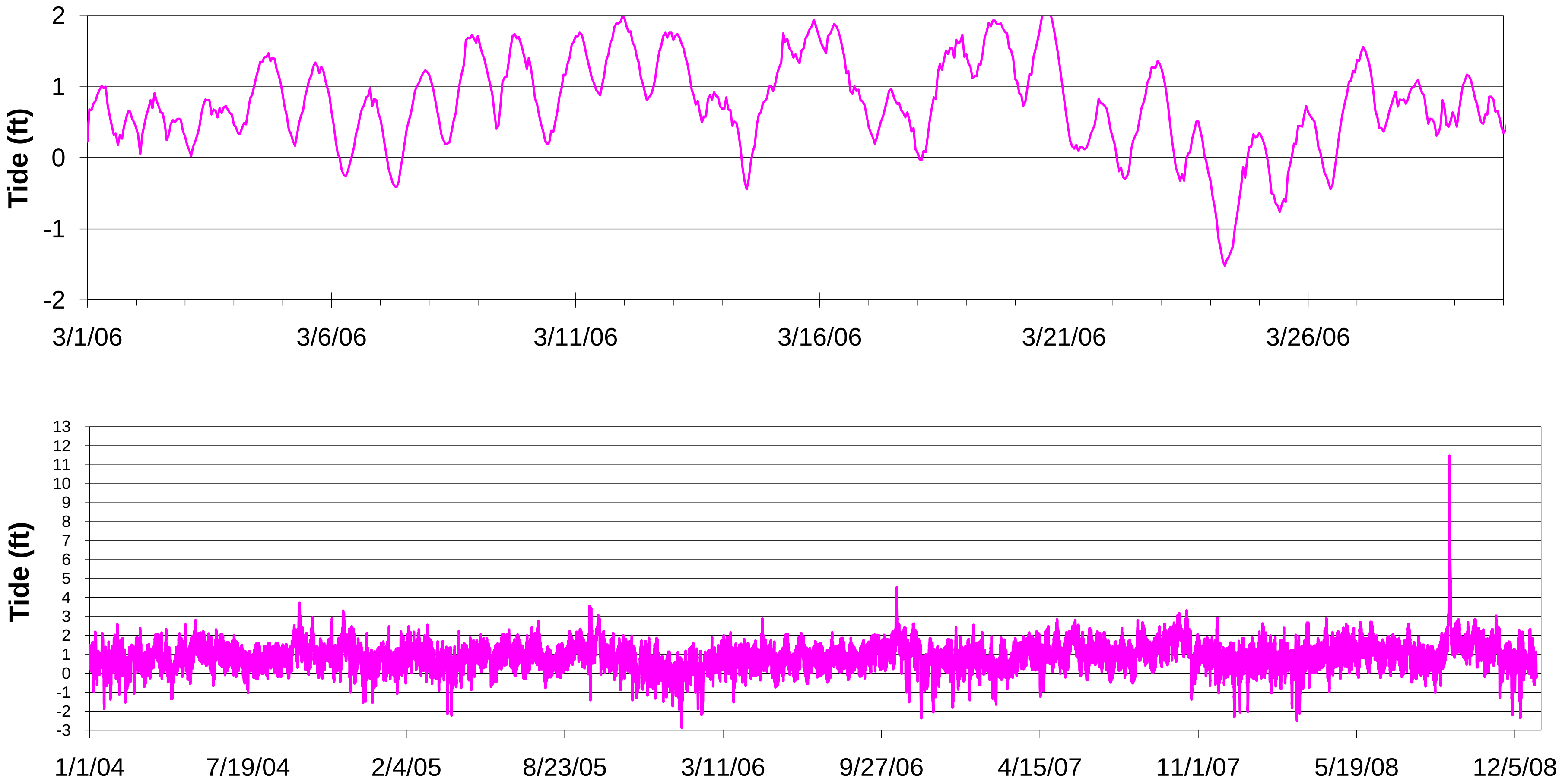


Figure 2-6 **Tide Elevations for Eagle Point for (A) March 2006 and (B) Period From 2004 through 2008**

2.3 Bacteria and other Water Quality Parameters

The following subsections contain a summary of available data, the water quality characteristics of Dickinson Bayou as well as an analysis of seasonal and spatial variability. As will be demonstrated in this section, the bacteria levels in Dickinson Bayou currently do not meet water quality standards for contact recreation. The applicable water quality standards are described in more detail in **Chapter 3**.

2.3.1 Monitoring Data- Historical Data Analysis

The historical data used for analysis came from two primary sources: (1) TCEQ through the Surface Water Quality Monitoring Information System (SWQMIS); (2) data available from the Galveston County Health District (GCHD). Because of quality control issues, the GCHD data could not be validated and are not included in the discussion for this section. The locations of the Water Quality Monitoring Stations are shown in **Figure 2-7 and** a description of each is included in Table 2-7. It is important to note that the data used to develop the analyses in the following sections were completed in 2010 and reflect the most current data at that time. Therefore, one station (station 11466) did not have monitoring data at the time the analyses were completed but data to support the TMDL development have since been collected at the site.

Other data sources were also used to evaluate bacteria data as described previously for rainfall, soils data, and land use. The data used in this analysis were summarized in project Final Historical Data Review and Analysis Report (University of Houston and CDM, 2007). The following section provide summary of the results from this report.

Table 2-7 Monitoring Stations for Dickinson Bayou

Station	Description	Latitude	Longitude
11455	Dickinson Bayou Tidal at SH146	29.4606 -	94.9724
11460	Dickinson Bayou at SH3	29.45701 -	95.0473
11461	Dickinson Bayou Tidal at Benson Bayou Confluence	29.45651 -	95.0575
16679	Dickinson Bayou Tidal at Mariners Mooring	29.45822 -	95.018
16979	Dickinson Bayou Near Gum Bayou	29.46183 -	95.0201
11434	Cedar Creek at FM517	29.43867 -	95.136
11464	Dickinson Bayou Tidal Near Arcadia	29.42961 -	95.1147
16471	Bensons Bayou on Wagon Rd	29.4575 -	95.0578
16469	Bordens Gully at FM517	29.45188 -	95.0723
16470	Geisler Bayou at FM517 Bridge	29.455 -	95.0677
11436	Gum Bayou at FM517	29.46949 -	95.0132
11467	Dickinson Bayou at FM517	29.43593 -	95.1701
11466	Dickinson Bayou at Happy Hollow	29.43593 -	95.1701
11472	Dickinson Bayou at FM528	29.46278 -	95.2281
11465	Dickinson Bayou at Jack Beaver	29.42958 -	95.1437

Samples for bacteria have been collected and analyzed in the Dickinson Bayou watershed since the early 1970's. A summary of the locations and dates when the bacteria data were collected and analyzed is shown in **Table 2-8**. As the table shows, an extensive bacteria data set is available for analysis on the main stem of the bayou as well as the tributaries. Most of the bacteria sampling on Dickinson Bayou was performed after 1999. There are no fecal coliform data after 2001 due to the change in the bacteria standard from fecal coliform to *Escherichia coli* (*E. coli*) in 2000 by the TCEQ. Most recent sampling efforts have focused on Enterococci sampling in Segment 1103, where the parameter is the regulatory standard for tidal waters.

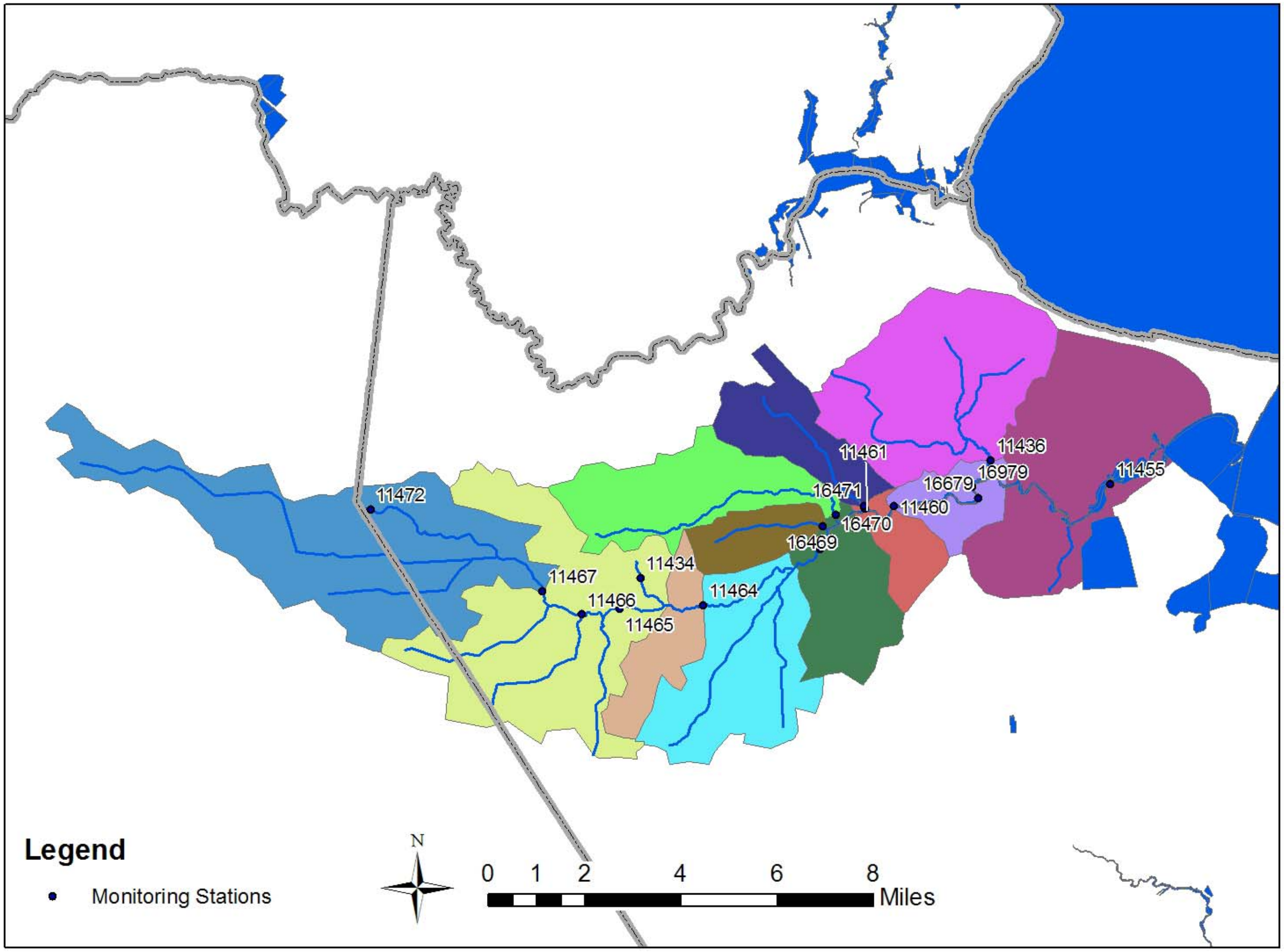


Figure 2-7 Water Quality Monitoring (WQM) Station Locations

Table 2-8 Summary of Bacteria Sampling on Dickinson Bayou

Assess-ment Unit	Station	Bayou	Enterococci[2, 4]		*E. coli* [3,4]		Fecal Coliform[3, 4]	
			n	Range of Dates	n	Range of Dates	n	Range of Dates
1103_01[1]	11455	Dickinson Bayou Tidal	42	9-Mar-99 - 22-Aug-06	43	9-Mar-99 - 13-Dec-02	90	21-Oct-70 - 21-Nov-01
1103_02	11460	Dickinson Bayou Tidal	121	9-Mar-99 - 20-Mar-07	110	9-Mar-99 - 5-Feb-03	216	19-Apr-72 - 21-Nov-01
1103_02	11461	Dickinson Bayou Tidal	44	10-Jul-00 - 17-May-01	44	10-Jul-00 - 17-May-01	44	10-Jul-00 - 17-May-01
1103_02	11462	Dickinson Bayou Tidal	82	9-Mar-99 - 21-Aug-06	88	9-Mar-99 - 10-Apr-03	85	19-Jan-99 - 21-Nov-01
1103_02	16679	Dickinson Bayou Tidal	26	9-Mar-99 - 18-Aug-03	43	9-Mar-99 - 5-Feb-03	39	19-Jan-99 - 21-Nov-01
1103_02	16979	Dickinson Bayou Tidal	43	10-Jul-00 - 17-May-01	42	10-Jul-00 - 17-May-01	42	10-Jul-00 - 17-May-01
1103_04 1	1434	Cedar Creek	1	3-Nov-04 - 3-Nov-04	26	10-Dec-01 - 21-Aug-06	n/a	
1103_04	11464	Dickinson Bayou Tidal	85	9-Mar-99 - 20-Mar-07	92	9-Mar-99 - 14-Dec-04	91	23-Aug-73 - 21-Nov-01
1103A_01 16	471	Bensons Bayou	40	9-Mar-99 - 22-Aug-06	45 9-M	ar-99 - 10-Apr-03	49	19-Jan-99 - 21-Nov-01
1103B_01 1	6469	Bordens Gully	38	9-Mar-99 - 22-Aug-06	48	9-Mar-99 - 12-Jun-03	40	19-Jan-99 - 21-Nov-01
1103C_01 1	6470	Geisler Bayou	38	9-Mar-99 - 22-Aug-06	46	9-Mar-99 - 10-Apr-03	40	19-Jan-99 - 21-Nov-01
1103D_01[1] 1	1436	Gum Bayou	41	9-Mar-99 - 22-Aug-06	44	9-Mar-99 - 13-Dec-02	41	19-Jan-99 - 21-Nov-01
1104_01 1	1467	Dickinson Bayou Above Tidal	26 9	-Mar-99 - 3-Nov-04	73	9-Mar-99 - 20-Mar-07	143	20-May-74 - 21-Nov-01
1104_01 1	1472	Dickinson Bayou Above Tidal	n/a		2	12-Jun-03 - 18-Aug-03	n/a	
1104_02 1	1466	Dickinson Bayou Above Tidal	10 9	-Jul-08 - 13-Nov-08	10	9-Jul-08 - 13-Nov-08	10	9-Jul-08 - 13-Nov-08
1104_02 1	1465	Dickinson Bayou Above Tidal	22 10	-Jul-00 - 17-May-01	19	10-Jul-00 - 17-May-01	19	10-Jul-00 - 17-May-01

Abbreviations: n = number, n/a = not applicable, Notes: [1] not applicable; AU not impaired, [2] Enterococci samples collected in fresh water segments are not used by TCEQ to assess bacterial water quality; data are included for illustrative purposes only, [3] E. coli samples collected in saline water segments are not used by TCEQ to assess bacterial water quality; data are included for illustrative purposes only; [4] TMDL prepared in February 2010 and data presented herein are the most current information available at that time with the exception of 11466 which reflects more recent water quality data

The Dickinson Bayou watershed has been sampled extensively by several different agencies, including the University of Houston Clear Lake Environmental Institute Of Houston (EIH), and the TCEQ Regional Office. In addition, numerous methods have been used by these agencies to characterize bacteria indicator concentrations in the watershed.

Analyses were undertaken to determine whether or not the datasets collected by different agencies using different methods could be grouped as a single set of data for analysis. Only *E. coli* and enterococci were included in this qualification analysis since they will form the basis of the TMDL allocations. Fecal coliform data are useful for historical purposes, but are not the current standard for contact recreation.

An extensive data set of *E. coli* samples has been collected in Dickinson Bayou. Of the 16 TCEQ stations presented in **Table 2-9**, a total of 10 stations have been sampled since 1999. Only two stations in the watershed, 11467 and 11434, have had continued monitoring after 2004. Geometric mean concentrations range from 7 MPN/dL, at station 11472 where only two samples have been collected, to 711 MPN/dL at station 16469.

Minimum measured concentrations of *E. coli* are typically below the detection limit, with the maximum concentrations reaching up to greater than 24,192/dL at station 11467. Exceedances of the single sample standard were observed 69% of the time at station 16469.

Table 2-9 Summary of *E. coli* Data[2]

Station ID	Assessment Unit	No. of Samples	% > 394 MPN/dL	Range of Dates	Minimum (MPN/dL)	Maximum (MPN/dL)	Geometric Mean[2] (MPN/dL)
11455	1103_01[1]	43	12%	9-Mar-99 - 13-Dec-02	<10	5,000	45
11460	1103_02	110	27%	9-Mar-99 - 5-Feb-03	<5	16,000	188
11461	1103_02	44	34%	10-Jul-00 - 17-May-01	<20	16,000	252
11462	1103_02	88	27%	9-Mar-99 - 10-Apr-03	<5	16,000	200
16679	1103_02	43	23%	9-Mar-99 - 5-Feb-03	<5	16,000	122
16979	1103_02	42	33%	10-Jul-00 - 17-May-01	<20	16,000	144
11434	1103_04	26	19%	10-Dec-01 - 21-Aug-06	<5	1,300	123
11464	1103_04	92	22%	9-Mar-99 - 14-Dec-04	<5	16,000	189
16471	1103A_01	45	51%	9-Mar-99 - 10-Apr-03	<5	24,000	440
16469	1103B_01	48	69%	9-Mar-99 - 12-Jun-03	<5	24,000	711
16470	1103C_01	46	57%	9-Mar-99 - 10-Apr-03	<10	24,000	542
11436	1103D_01[1]	44	34%	9-Mar-99 - 13-Dec-02	<5	24,000	252
11467	1104_01	73	34%	9-Mar-99 - 20-Mar-07	<5	24,192	272
11472	1104_01	2	0%	12-Jun-03 - 18-Aug-03	<5	10	7
11466	1104_02	10	70%	9-Jul-08 - 13-Nov-08	250	120,000	4,563
11465	1104_02	19	26%	10-Jul-00 - 17-May-01	40	9,000	271

Abbreviations: MPN – most probable number, Notes: [1] not applicable; AU not impaired, [2] TMDL prepared in February 2010 and data presented herein are the most current information available at that time with the exception of 11466 which reflects more recent water quality data

A summary of enterococci data for Dickinson Bayou are presented in **Table 2-10**. A total of 14 stations have been sampled for enterococci in the watershed. The majority of the stations were sampled in 2006. Minimum enterococci concentrations have been measured as below 1 MPN/dL while maximum concentrations have been reported up to 25,200 MPN/dL at station 11462. The geometric means in the watershed range from 11 MPN/dL at station 11455, which was sampled 42 times, to 321 MPN/dL at station 11465. Single sample standard exceedances have been found as high as 92% at station 11467.

Table 2-10 Summary of Enterococci Data[2]

Station ID	Assessment Unit	No. of Samples	% > 89 MPN/dL	Range of Dates			Minimum (MPN/dL)	Maximum (MPN/dL)	Geometric Mean[2] (MPN/dL)
11455	1103_01[1]	42	10%	9-Mar-99	-	22-Aug-06	<1	12,900	11
11460	1103_02	121	28%	9-Mar-99	-	20-Mar-07	<1	18,300	40
11461	1103_02	44	52%	10-Jul-00	-	17-May-01	<1	18,600	110
11462	1103_02	82	29%	9-Mar-99	-	21-Aug-06	<1	25,200	60
16679	1103_02	26	15%	9-Mar-99	-	18-Aug-03	<2	8,000	12
16979	1103_02	43	30%	10-Jul-00	-	17-May-01	<2	6,720	31
11434	1103_04	1	0%	3-Nov-04	-	3-Nov-04	<1	1	n/a
11464	1103_04	85	61%	9-Mar-99	-	20-Mar-07	6	12,100	130
16471	1103A_01	40	30%	9-Mar-99	-	22-Aug-06	<1	10,400	53
16469	1103B_01	38	74%	9-Mar-99	-	22-Aug-06	<10	12,800	240
16470	1103C_01	38	42%	9-Mar-99	-	22-Aug-06	6	10,100	86
11436	1103D_01[1]	41	17%	9-Mar-99	-	22-Aug-06	<2	11,000	33
11467	1104_01	26	92%	9-Mar-99	-	3-Nov-04	<1	8,200	310
11466	1104_02	10	100%	9-Jul-08	-	3-Nov-08	94	92,000	6,634
11465	1104_02	22	86%	10-Jul-00	-	17-May-01	<2	9,500	321

Abbreviations: MPN – most probable number, n/a – not available because inadequate data to calculate, Notes: [1] not applicable; AU not impaired, [2] TMDL prepared in February 2010 and data presented herein are the most current information available at that time with the exception of 11466 which reflects more recent water quality data

Time-series plots of enterococci concentrations and regression analysis at all stations, listed in **Table 2-11** for the period from 2001 when data were first collected through 2007, showed that there is not general trend across the dataset, as six stations exhibit an increasing trend and seven exhibit a decreasing trend. A statistically significant increase in enterococci concentrations was observed at station 11467. Thus, there does not appear to be any consistent, long-term trends with time within the watershed.

Almost all stations sampled for *E. coli* have also been sampled for enterococci, and most were also previously sampled for fecal coliform. A comparison of standard exceedances among different indicator organisms for the single sample standard and geometric mean standard are presented in **Figure 2-8** and **2-9**, respectively.

Table 2-11 Summary of Regression Parameters for Bacterial Indicators[3]

Parameter	Station ID	R^2	Slope	Increase/Decrease	p-value	Significant
E. coli	11434[2]	0.23	0.0014	Increase	0.013	Yes
	11436[2]	0.147	-0.00186	Decrease	0.01	Yes
	11455 0	.009	0.0004	Increase	0.552	No
	11460 0	.005	-0.00048	Decrease	0.448	No
	11461 0	.015	0.0024	Increase	0.426	No
	11462 0	.005	0.00044	Increase	0.517	No
	11464 0	.012	-0.00045	Decrease	0.291	No
	11465 0	.024	0.0024	Increase	0.529	No
	11466[3]	N/A N/A		N/A	N/A	N/A
	11467 0	.235	0.016	Increase	0.093	No
	11472 1		0.0103	Increase	N/A	N/A
	16469[2]	0.224	-0.00094	Decrease	0.00068	Yes
	16470 0	.031	-0.00062	Decrease	0.242	No
	16471 0	.055	-0.0011	Decrease	0.121	No
	16679 0	.069	0.00143	Increase	0.09	No
	16979 0	.006	0.00185	Increase	0.632	No
Enterococci	11434[1] N/A		N/A	N/A	N/A	N/A
	11436 0	.012	0.0002	Increase	0.435	No
	11455 0	.08	0.0006	Increase	0.069	No
	11460 0	.015	-0.0004	Decrease	0.18	No
	11461 0	.005	0.00156	Increase	0.638	No
	11462 0	.003	-0.0002	Decrease	0.65	No
	11464 0	.017	-0.0003	Decrease	0.235	No
	11465 0	.01	0.0019	Increase	0.648	No
	11466[3]	N/A N/A		N/A	N/A	N/A
	11467[2]	0.378	0.0233	Increase	0.033	Yes
	16469 0	.038	-0.00028	Decrease	0.242	No
	16470 0	.005	0.0001	Increase	0.668	No
	16471 0	.026	-0.0001	Decrease	0.756	No
	16679 0	.002	-0.0002	Decrease	0.858	No
	16979 0	.002	-0.0011	Decrease	0.794	No

Note: [2] Only one data point, [2] Yellow highlighted rows were found to have a statistically significant trend over time. [3]Only data prior to 2008 were analyzed; for this tabe; data for station 11466 were not available prior to 2008.

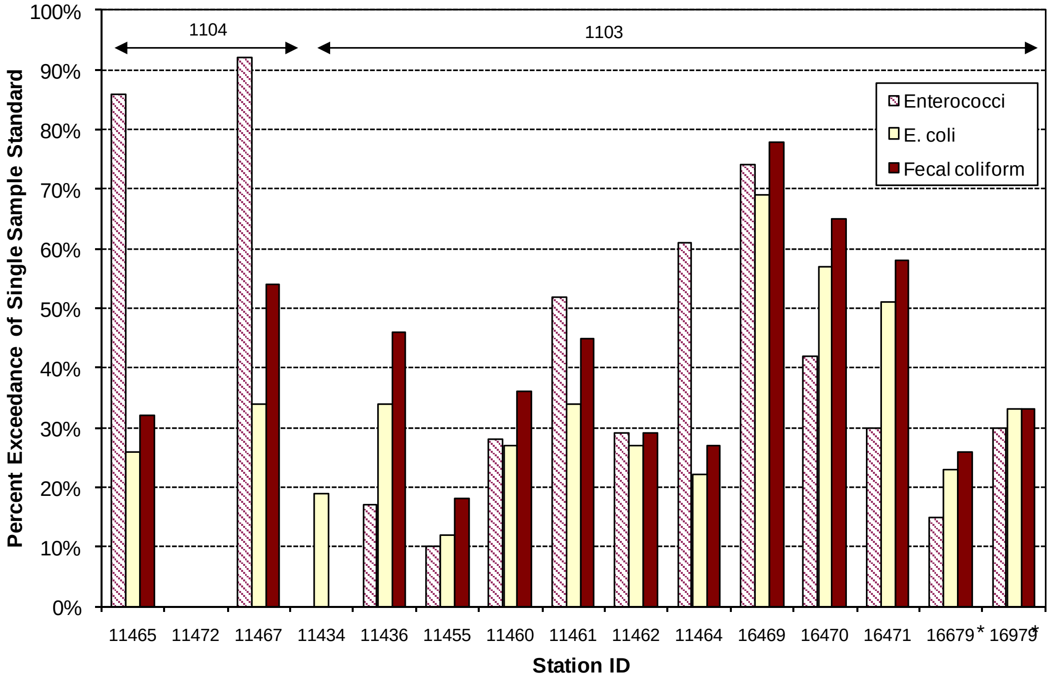


Figure 2-8 Comparison of Exceedances of the Single Sample Standard for the Two Bacterial Indicators

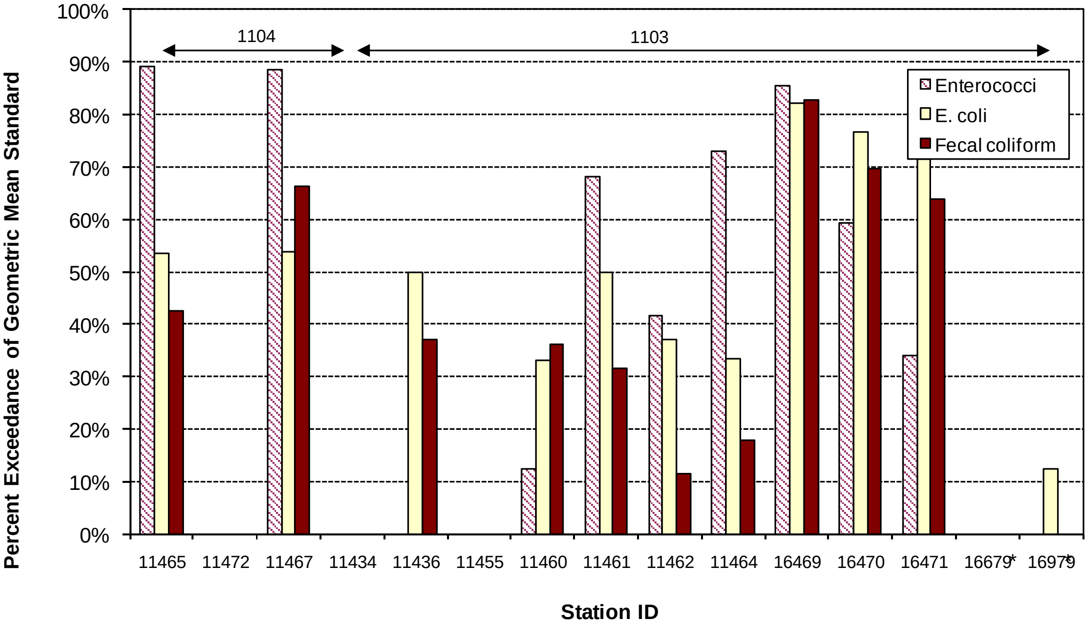


Figure 2-9 Comparison of Exceedances of the Geometric Mean Standard for the Two Bacterial Indicators

2.3.2 Trend Analysis

Several correlations between bacteria concentrations and environmental factors were analyzed in the Historical Data Report (University of Houston and CDM, 2007). Three main variables are discussed here: location, precipitation, and salinity.

Both *E. coli* and enterococci concentrations were evaluated for spatial trends across the Dickinson Bayou watershed. The spatial variation in *E. coli* geometric mean concentrations calculated using the entire period of record at each station was plotted as shown in **Figure 2-10,** only stations with data prior to 2008 were used, therefore station 11466 was excluded from the analysis. In addition, a map of *E. coli* geometric means was prepared as shown in **Figure 2-11,** again excluding station 11466. The upper most sampling point in the watershed had very low concentrations of *E. coli*, although the station was not sampled as frequently as other sites in the watershed. Concentrations then increase around river mile 15 and *E. coli* concentrations increase towards the middle of the watershed. *E. coli* concentrations then decline closer to the mouth of the watershed.

The trend observed in *E. coli* concentrations may reflect the physical constraints of Dickinson Bayou. The non-tidal upper watershed has very little flow, and thus is often dry. Thus, the concentrations there are somewhat varied. The mid-watershed is tidal and thus the bayou holds more water. It appears that the *E. coli* concentrations stay fairly stable in this region, except for a very slight increase in concentrations noted at Station 11461. Finally, the lower part of the watershed (i.e., near the terminus), has decreasing concentrations because of the increasing salinity toward Dickinson and Galveston Bays.

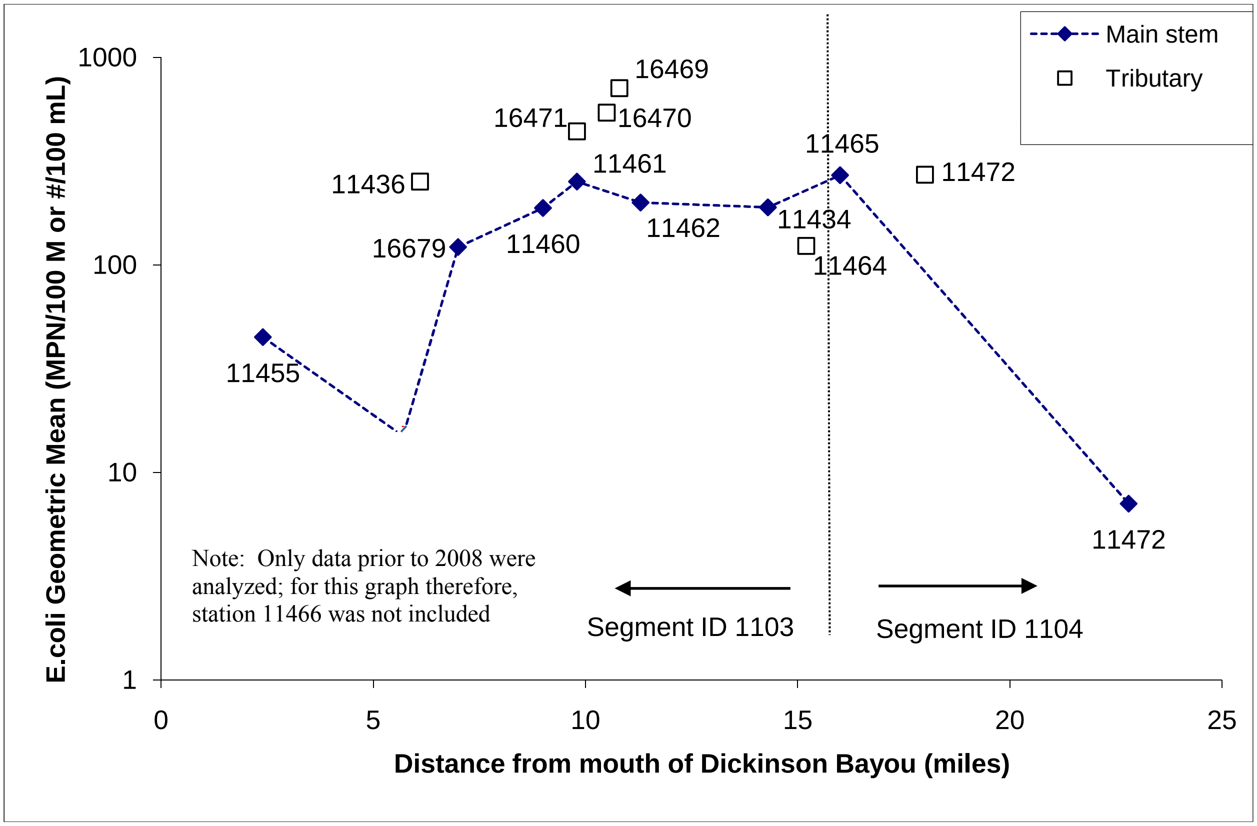
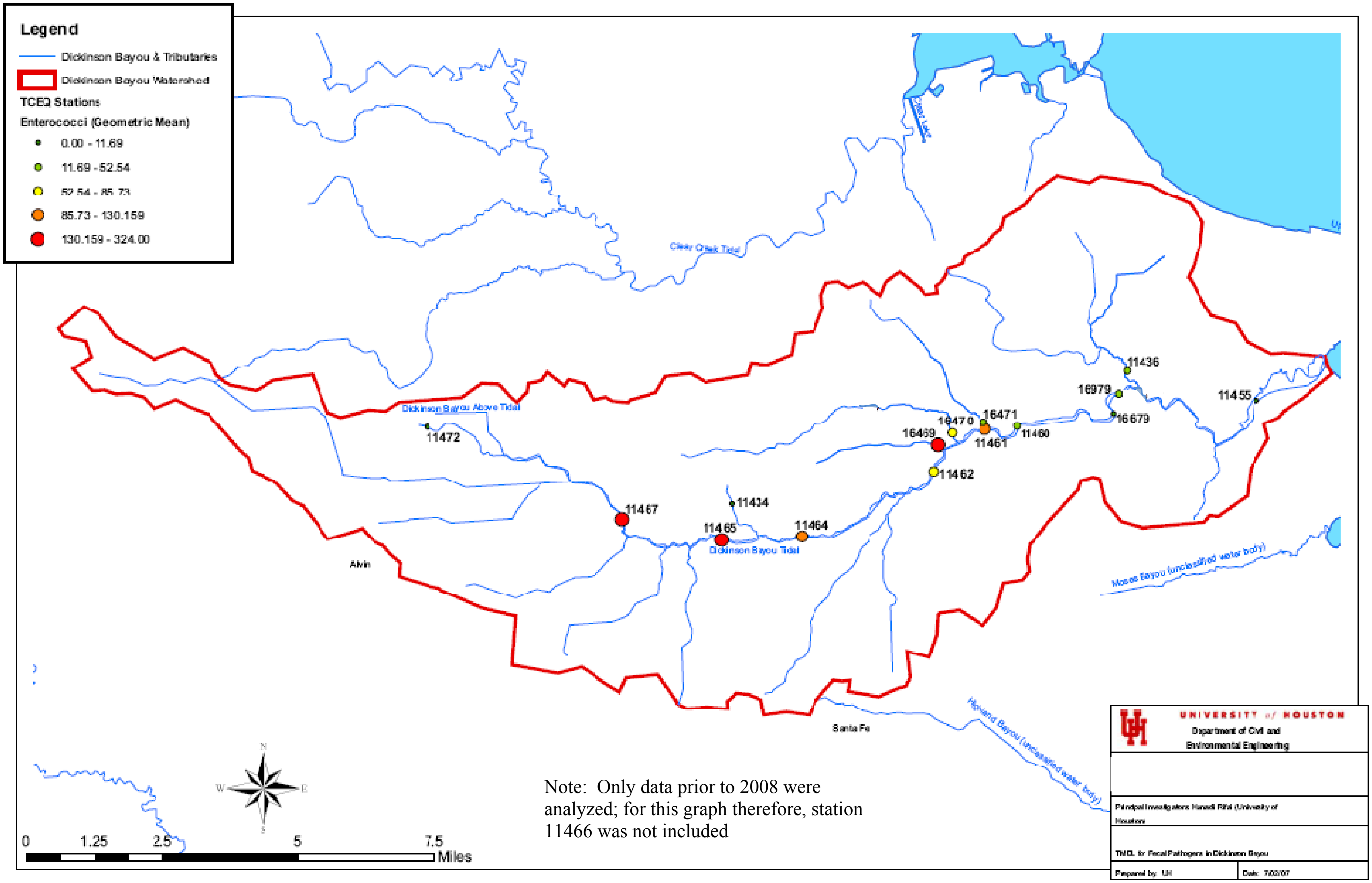


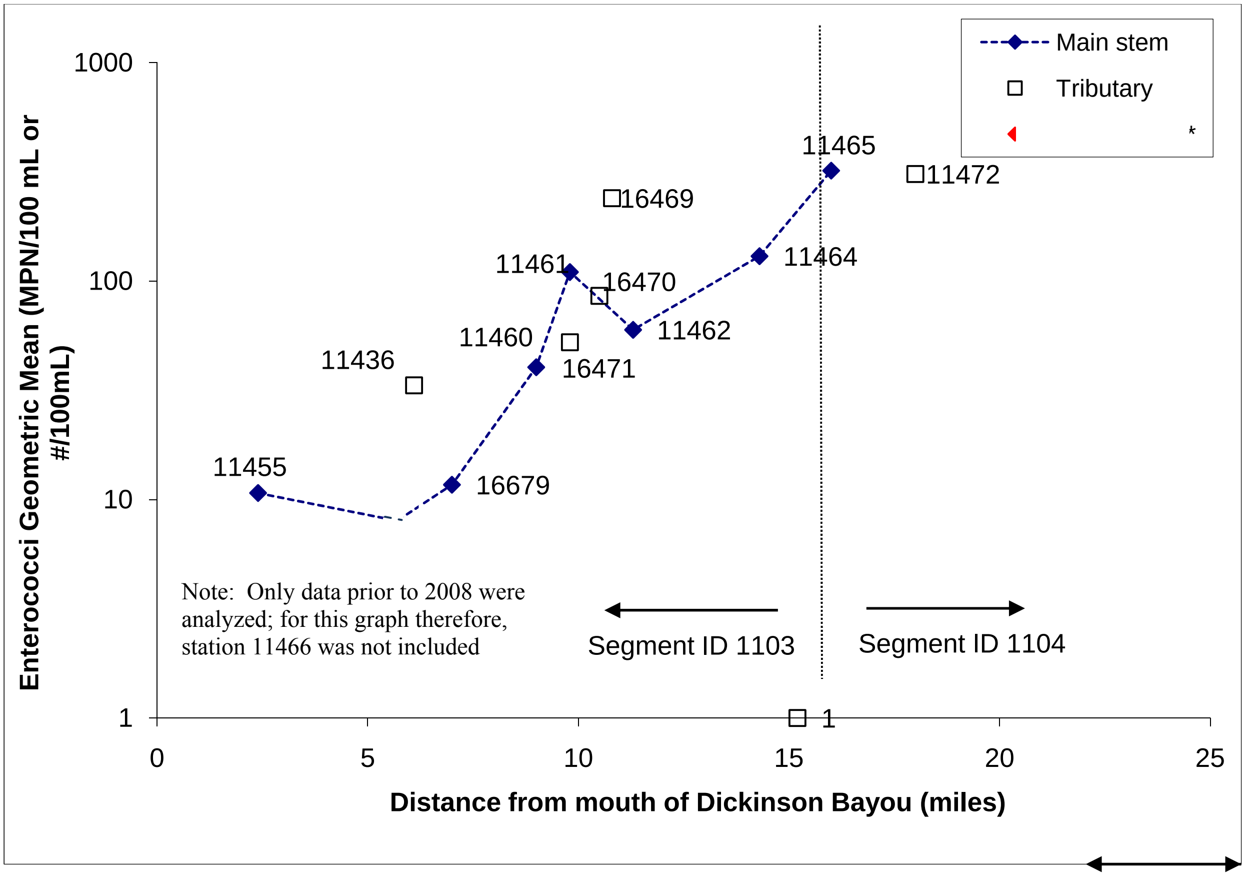
Figure 2-10 *E. coli* vs River Mile



Note: Only data prior to 2008 were analyzed; for this graph therefore, station 11466 was not included

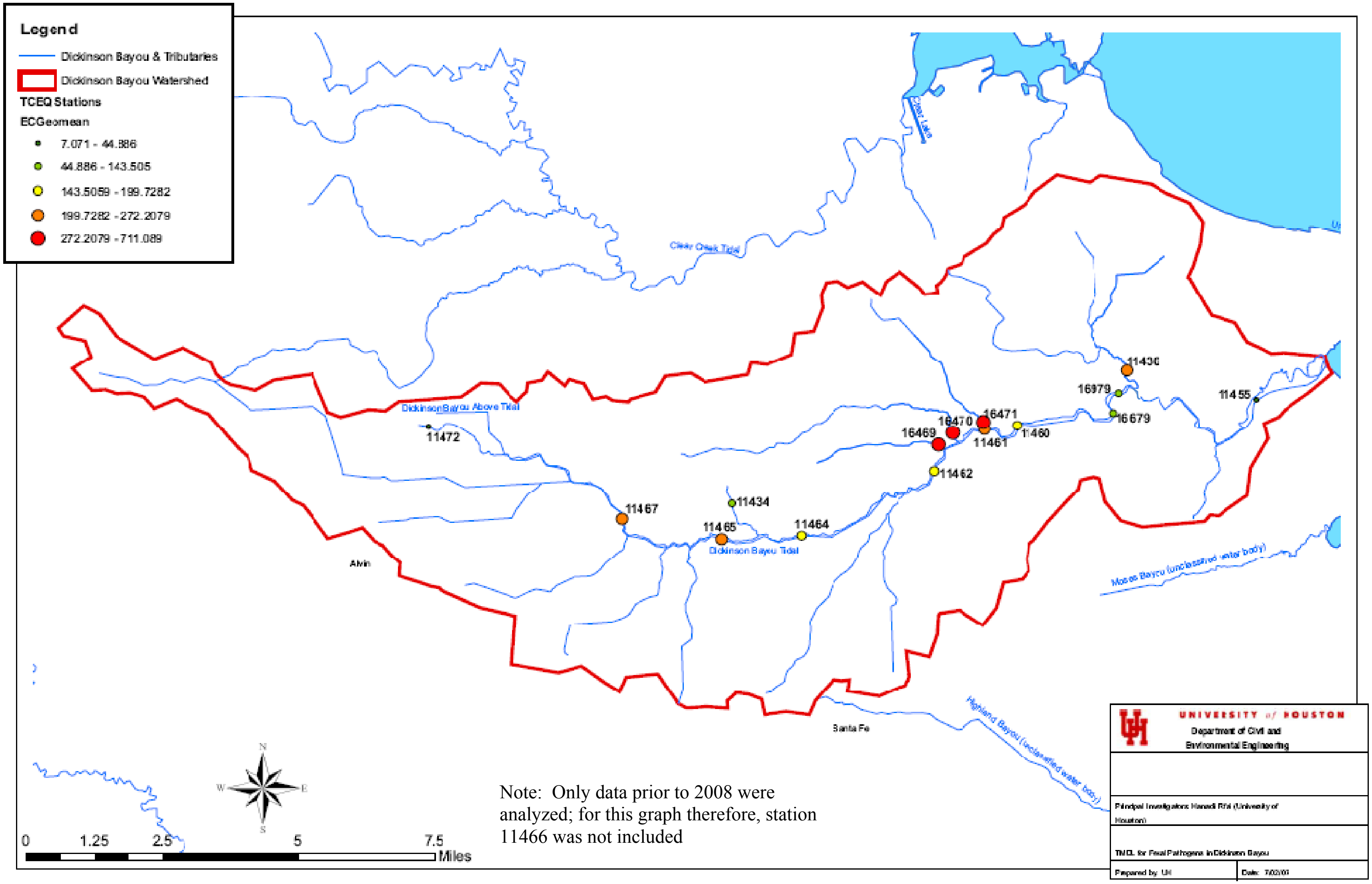
Figure 2-11 *E. coli* Station Map, Dickinson Bayou

A spatial plot of enterococci geometric mean concentrations is presented in **Figure 2-12,** station 11466 was excluded from the study due to the lack of data. A map of Enterococci geometric means is also presented in **Figure 2-13,** excluding station 11466. The figures show that the concentrations exhibit a similar trend to the *E. coli* geometric mean concentrations. The enterococci concentrations start out very high in the upper watershed and decline as the bayou flows through the watershed toward the bay. Station 11461 around river mile 10 exhibits an increase in enterococci concentrations, similar to that observed in *E. coli*.



Note: Only data prior to 2008 were analyzed; for this graph therefore, station 11466 was not included

Figure 2-12 Enterococci vs River Mile



Note: Only data prior to 2008 were analyzed; for this graph therefore, station 11466 was not included

Figure 2-13 Enterococci Station Map, Dickinson Bayou

Bacteria concentrations in Dickinson Bayou were evaluated to examine if a relationship with rainfall could be discerned. The rainfall data were obtained from the four rainfall gages described in **Section 2.2.3** and were assigned to individual monitoring stations based upon Thiessen polygons shown in **Figure 2-4**. Thiessen polygons are used to establish areas of influence around a set of and define an area that is closest to a point, relative to other points. Two different analyses of bacteria concentration and rainfall were undertaken. The first involved looking at the effect of extended dry weather on bacteria concentrations, while the other examined the impact of rainfall amounts on bacteria concentrations.

The bacteria concentrations at each station in Dickinson Bayou were categorized by the number of dry days that had occurred prior to their collection as shown in **Figure 2-14(A)** for *E. coli* and **Figure 2-14(B)** for enterococci.

As shown in **Figure 2-14(A)**, as the number of dry days increased in the watershed, the *E. coli* geometric means at the majority of the stations in the watershed did not exhibit a strong trend. Some stations, such as 11455, 16471, and 16679, did decrease. For these stations, concentrations that were above the geometric mean standard of 126 MPN/dL the day after rainfall generally fell below the standard after several days of dry weather. This indicates that rainfall may play a role in elevated *E. coli* concentrations at these locations. Some stations, such as stations 11436, 11434, 11461 and 11464, however, do not show a decline. These sites may reflect the influence of other active sources in maintaining elevated concentrations of *E. coli*.

Enterococci data exhibit trends similar to those observed in the *E. coli* data as shown in **Figure 2-14(B).** For the majority of the stations, there does not appear to be a strong relationship with dry weather. These sites may reflect the influence of other active, steady-state sources in maintaining elevated concentrations of *E. coli* Stations 11460, 11461, 16471, 16679,

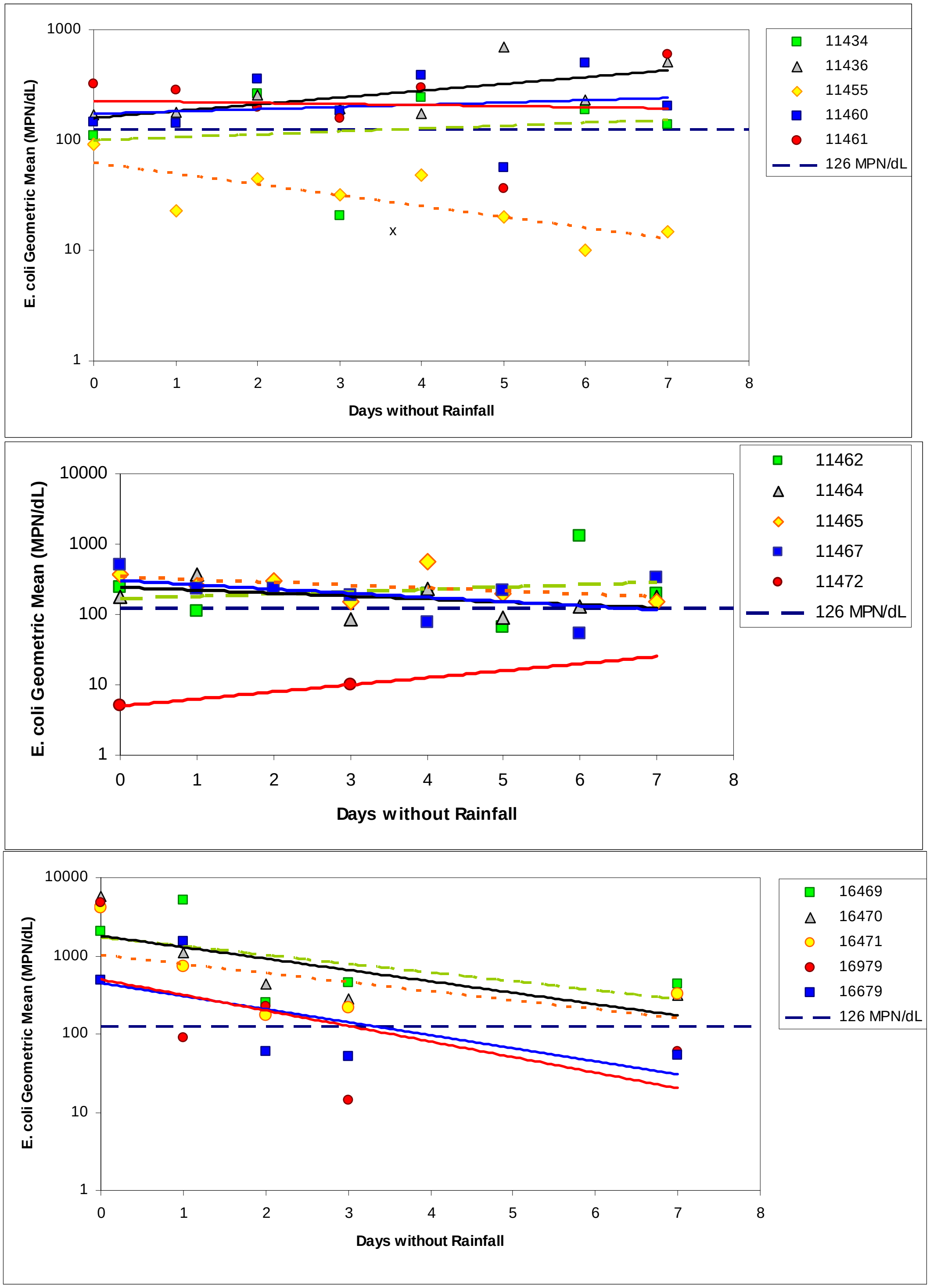


Figure 2-14(A) Dry Day Evaluation vs *E. coli*

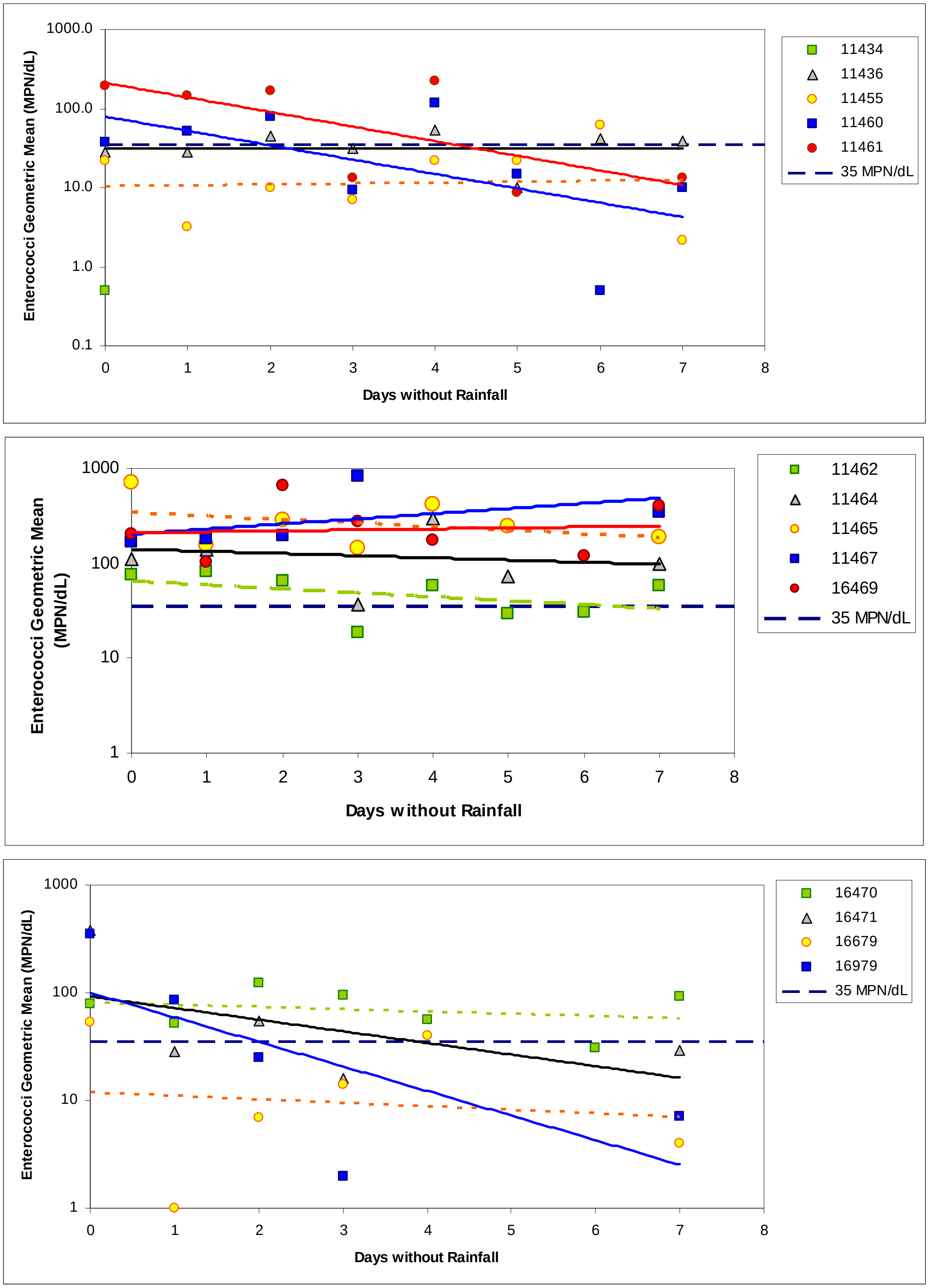


Figure 2-14(B) Dry Day Evaluation vs Enterococci

In addition to an evaluation of dry days and their effect on bacteria levels, an analysis of rainfall amount was also undertaken. The evaluation looked at the impacts of rainfall in the three previous days on bacteria levels. The results of these analyses are presented in **Figure 2-15(A)** for *E. coli* and **Figure 2-15(B)** for enterococci. The period of record used in these analyses is between 2000 when E. coli data were first collected through 2007.

The results for *E. coli* show that rainfall has varying effects on bacteria levels. Stations such as 11455, 11467, 11469, 16470, 16471, 16679, and 16979 exhibit increases in *E. coli* geometric mean concentrations as the amount of rainfall in the three prior days increases. This trend is typically expected, as numerous studies have indicated that runoff exhibits high concentrations of bacteria. Other stations, such as 11460, 11436, and 11462, exhibit a decline in geometric mean concentrations as the amount of rainfall increases. The cause for these decreases in geometric means is not as clear. The declining trend might be a result of dilution in the stream, especially at station 11436. That station is located on Gum Bayou which consistently has very high levels of bacteria during dry weather.

The results of rainfall on enterococci geometric mean concentrations are shown in **Figure 2-15(B)**. Results for enterococci are similar to those for *E. coli* in that both declining and increasing trends are observed across the watershed. Increasing concentrations with rainfall were observed at station 11455, 16470, 16471 and 16979. All four of these stations exhibited increasing trends in *E. coli* geometric mean concentrations as well. Decreasing or stable trends were observed at the remaining stations. As most stations exhibited decreasing or stable trends rather than the expected increasing trend, more investigation is required into the relationship between rainfall and bacteria.

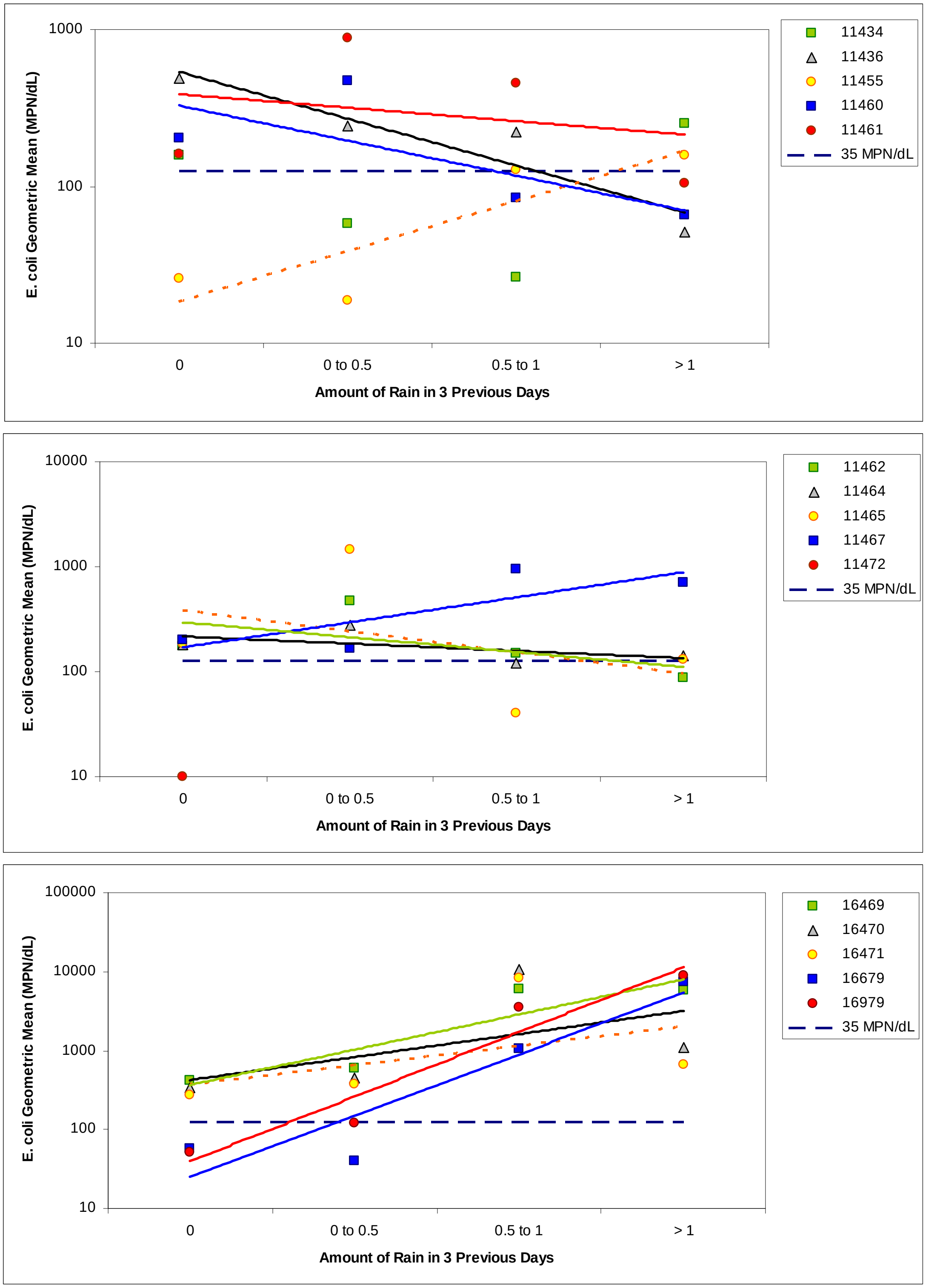


Figure 2-15(A) Wet Day Evaluation vs *E. coli*

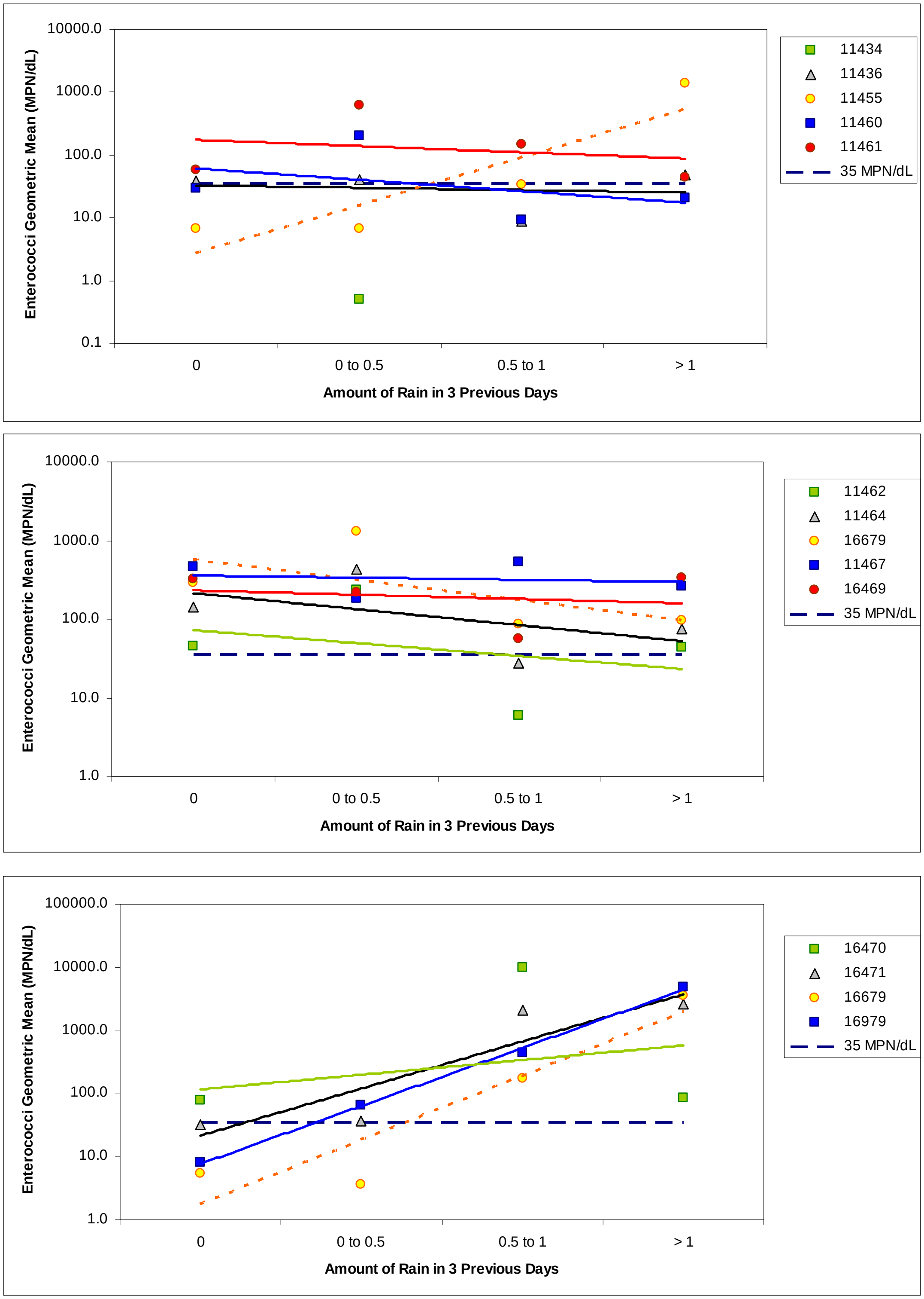


Figure 2-15(B) Wet Day Evaluation vs Enterococci

As part of the data evaluation, the relationship between bacteria concentrations and other parameters were evaluated. These parameters include dissolved oxygen, temperature, total suspended solids (TSS) and salinity. Salinity is known to have an adverse effect on bacteria survival and thus its relationship with indicator bacteria was evaluated in Dickinson Bayou. **Table 2-12** presents a summary of depth-averaged salinity concentrations. Salinity in the watershed ranges on average from 1 ppt to almost 12 ppt.

The relationship between salinity and bacteria concentrations is shown in **Figure 2-16** for *E. coli* and **Figure 2-17** for enterococci. As shown in both figures, salinity has a strong negative impact on both *E. coli* and enterococci. Thus, salinity appears to play a role in mitigating indicator bacteria levels in the watershed.

Table 2-12 Summary of Salinity Data

Station ID	Min. Of Enddate	Max. Of Enddate	Total No. of samples	Min. salinity (PPT)	Max. Salinity (PPT)	Average Salinity (PPT)	Geometric Mean (PPT)
11434	10-Dec-01	21-Aug-06	21	1	1	1.0	1.0
11436	19-Mar-92	22-Aug-06	73	0.2	16.9	6.3	3.8
11455	06-Oct-87	22-Aug-06	116	0.3	25.4	11.9	9.2
11457	19-Mar-92	08-Jul-97	13	0.3	5.6	2.0	1.3
11460	06-Oct-87	20-Mar-07	332	0.1	21.4	6.5	3.6
11461	10-Jul-00	17-May-01	44	1	21.2	7.9	4.6
11462	19-Jan-99	21-Aug-06	110	1	19.9	6.1	3.4
11464	19-Jan-99	20-Mar-07	111	0.1	11.7	2.0	1.4
11465	10-Jul-00	17-May-01	22	1	1	1.0	1.0
11467	07-Jul-88	21-Aug-06	61	0.2	8	1.3	1.1
11472	12-Jun-03	18-Aug-03	2	1	1	1.0	1.0
16469	19-Jan-99	22-Aug-06	54	1	15	3.7	2.3
16470	19-Jan-99	22-Aug-06	55	1	16	4.5	2.8
16471	19-Jan-99	22-Aug-06	56	1	15.5	4.9	3.0
16679	19-Jan-99	18-Aug-03	42	1	17.5	6.2	3.9
16979	10-Jul-00	17-May-01	44	1	23.2	9.7	6.6

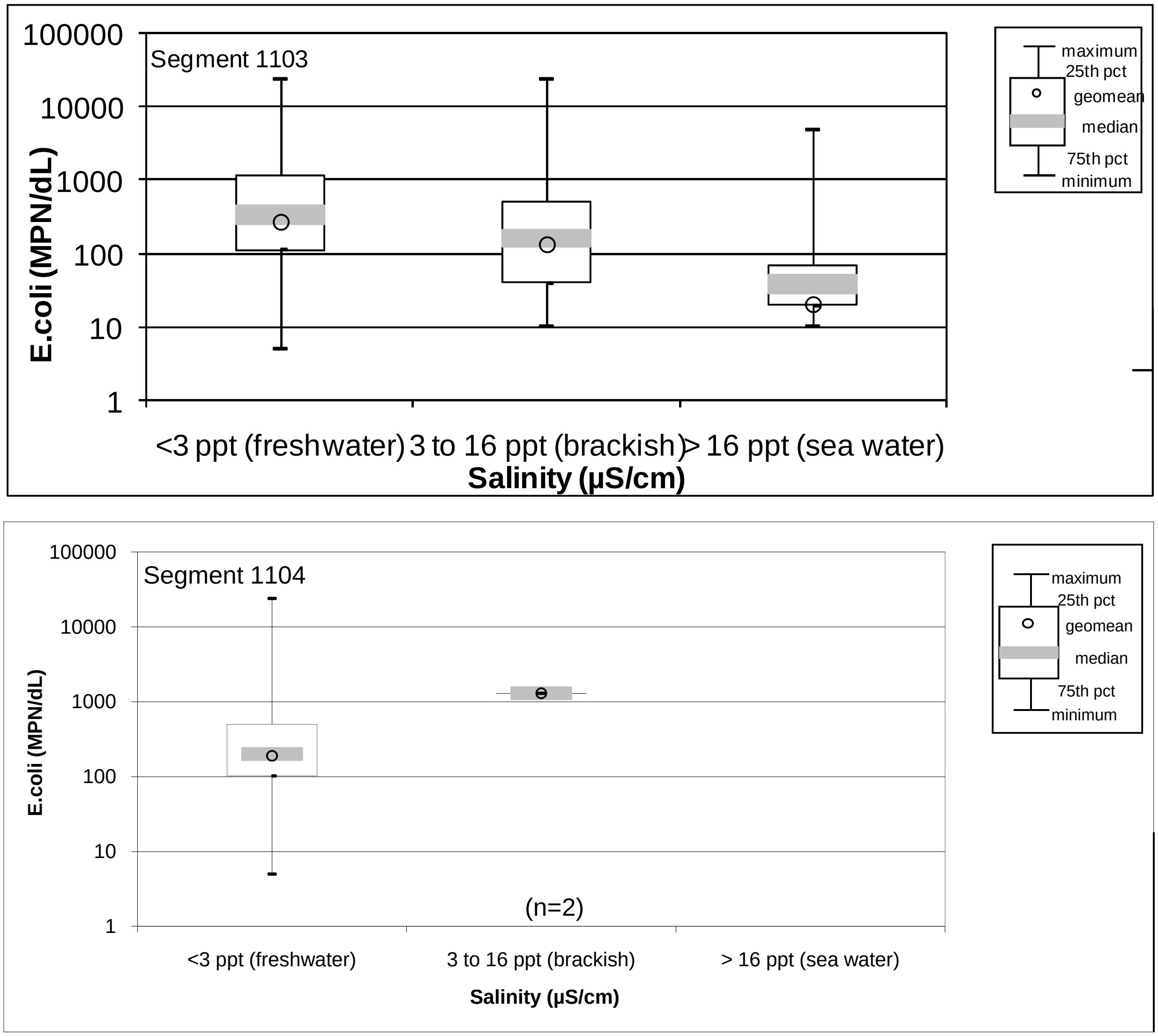
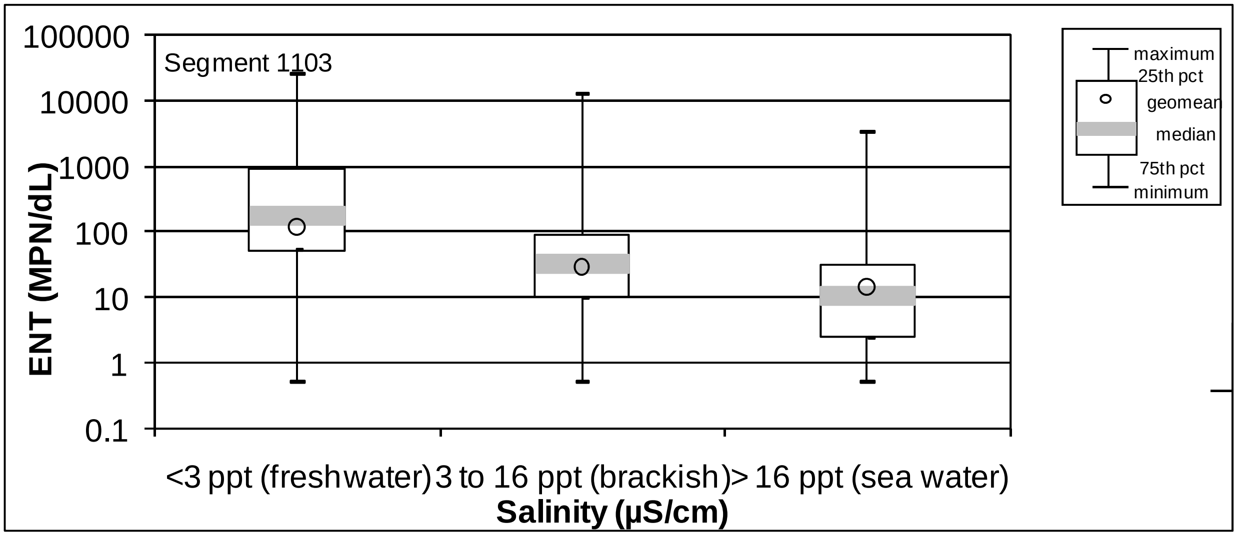


Figure 2-16 Effect of Surface Salinity on *E. coli* Concentrations



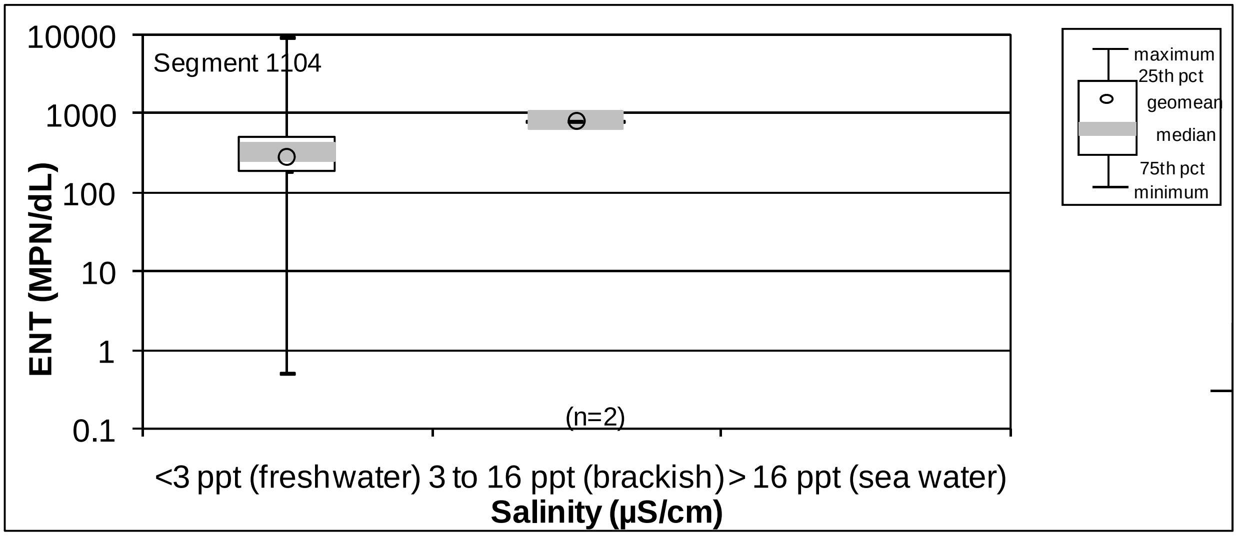


Figure 2-17 Effect of Surface Salinity on Enterococci Concentrations

2.3.3 Seasonality

An analysis of seasonal trends for both *E. coli* and Enterococci is presented in **Figure 2-18** and **Figure 2-19**. In general, there does not appear to be a strong trend in bacteria concentrations from month to month. Some station do, however, appear to follow similar trends toward the later part of the year (October through December) for both *E. coli* and enterococci. Summer months exhibit some very low concentrations, possibly due to the high temperature that southeast Texas experiences during summer months. However, no clear trend could be discerned over the year and thus seasonality was not observed.

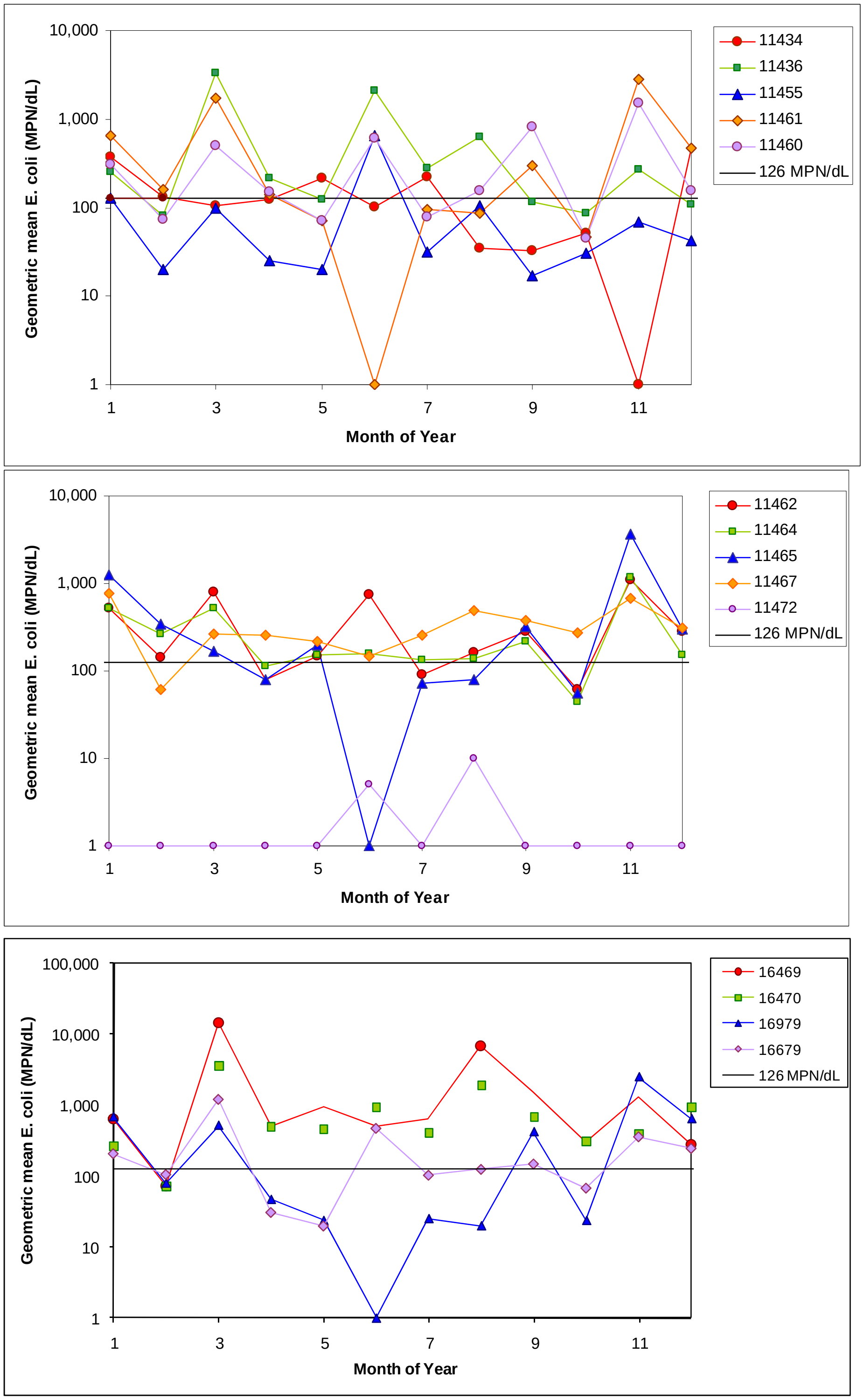


Figure 2-18 Monthly Geometric Means for *E. coli* at Individual Stations

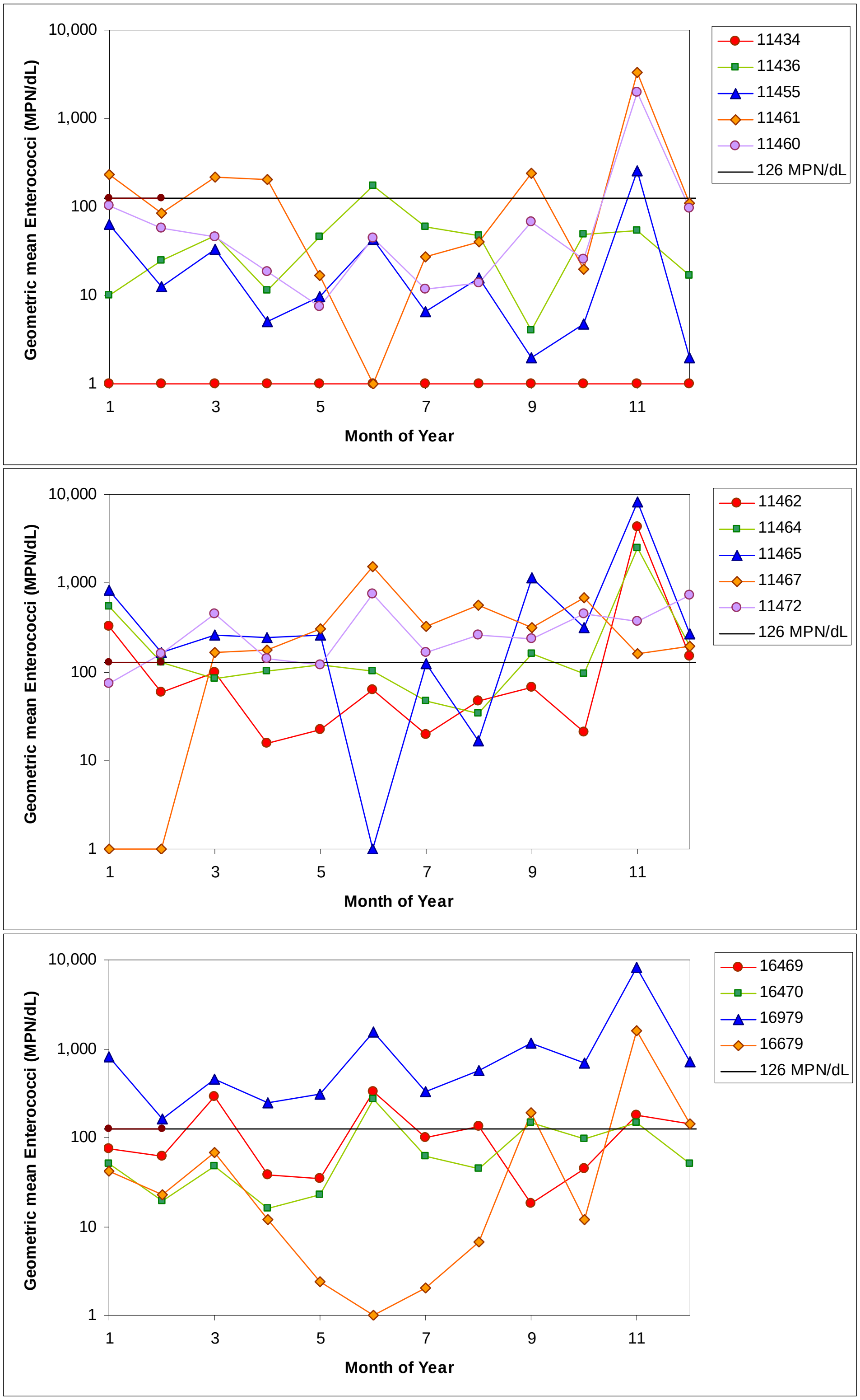


Figure 2-19 Monthly Geometric Means for Enterococci at Individual Stations

2.4 Summary of TMDL Monitoring

Water quality monitoring data were collected to assist in characterizing sources of bacteria and provide key data for the model. This section summarize the data and details the findings of those studies.

2.4.1 Bayou Wildlife Park Wet Weather Sampling

The goal of this task was to update existing water quality data for the monitoring location and evaluate the impact of runoff over the course of a storm event. The data collected during two wet weather events are presented in **Table 2-13**, with locations that were monitored presented in **Figure 2-20** as station 11466 and 11467. In **Table 2-13**, the suffix that follows the hyphen after the station ID designates the event (1 through 5) in which the sample was taken. As the table demonstrates, the geometric mean of the first flush samples downstream of the park are much higher than those upstream of the park, especially for *E. coli* results. It should be noted that the significance of the differences between the means cannot be determined because of inadequate data to conduct statistical testing.

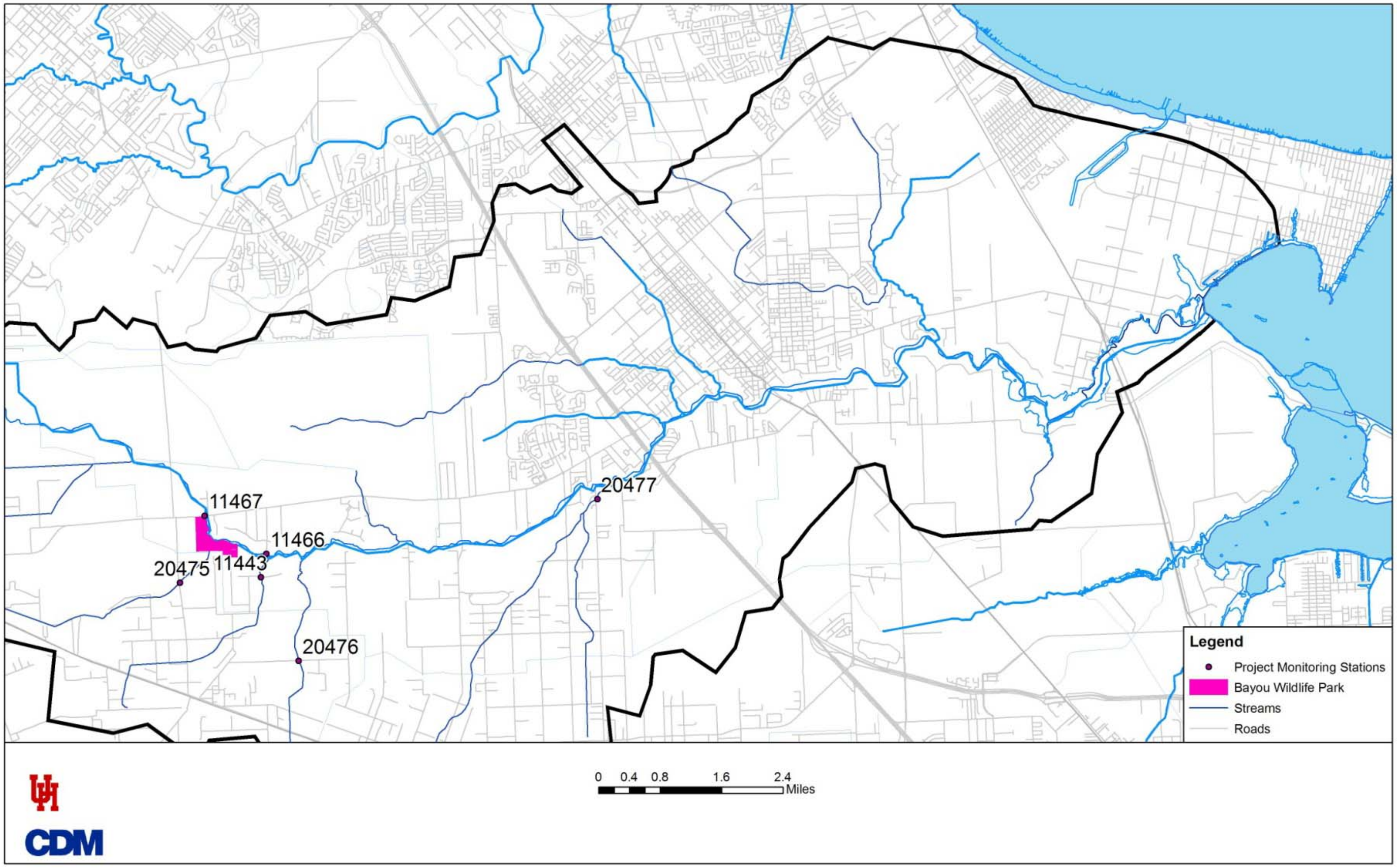


Figure 2-20 Project Monitoring Stations

Table 2-13 Bayou Wildlife Park Monitoring Data

Event	Date	Site	Enterococcus (MPN/ 100ml)	E.coli (MPN/ 100ml)
Wet Weather Event 1	10/7/2008	11467-1*	24,000	2,481
		11466-1*	77,010	120,330
		11467-2	38,730	17,329
		11466-2	18,600	1,553
Wet Weather Event 2	11/10/2008	11467-1*	NA	2,419
		11466-1*	16,070	19,863
	11/11/2008	11467-2	NA	17,329
		11466-2	12,997	17,329
		11467-3	NA	15,531
		11466-3	92,080	12,997
	11/12/2008	11466-4	23,100	10,462
		11467-4	NA	6,131
	11/13/2008	11467-5	NA	1,553
		11466-5	5,172	1,553
Geometric Mean- First Flush	10/7/2008 – 11/13/2008	11467 upstream of park	4,221	45,664
	10/7/2008 – 11/13/2008	11466 downstream of park	13,662	45,664

* First flush sample

2.4.2 Tributary Sampling

The goal of this task is to update existing water quality data and estimate tributary loads from a variety of land use types. In addition, tributary sampling will allow for comparison of tributaries that have and do not have WWTPs. The data collected during two wet weather events are presented in **Table 2-14**, with locations that were monitored also presented in **Figure 2-20**.

The findings from the monitoring indicate that dry weather concentrations of E. coli were typically very low for station 20475 (a geometric mean of 4 MPN/dL) while the majority of the samples were above the standard for station 20477 (a geometric mean of 168 MPN/dL). In wet weather, both stations exhibited very high bacteria concentrations, with all collected samples exhibiting concentrations above the water quality standard.

Table 2-14 Tributary Monitoring Data

Event	Date	Site	Enterococcus (MPN/ 100ml)	E.coli (MPN/ 100ml)
Dry weather	7/9/2008	20475	n/a	11
	7/14/2008	20477	38	234
	8/12/2008	20475	106	2
		20477	579	66
	8/29/2008	20475	n/a	3
		20477	6	308
Wet Weather Event 1	10/7/2008	20477-1	6,630	3,050
		20475-1	13,540	1,112
		20475-1	24,000	2,755
		20477-2	15,650	2,755
Wet Weather Event 2	11/10/2008	20475-1	n/a	548
		20477-1	697	1,076
	11/11/2008	20475-2	n/a	15,041
		20477-2	30,760	10,860
		20475-3	n/a	12,033

Event	Date	Site	Enterococcus (MPN/ 100ml)	E.coli (MPN/ 100ml)
		20477-3	24,192	n/a
	11/12/2008	20475-4	n/a	4,480
		20477-4	23,100	9,804
	11/13/2008	20475-5	n/a	345
		20477-5	1210	649

2.4.2 WWTF Sampling

The goal of this task is to understand the relationship, if any, between treated wastewater effluent and *E. coli* and enterococci levels downstream of the outfall. To accomplish this task, samples were collected at three wastewater outfalls during dry weather. The location of the monitored WWTFs are shown in **Figure 2-21**. Data from monitoring at the WWTFs in the watershed are shown in **Table 2-15**. The monitoring effort focused on collecting samples during dry weather at the plant outfall, to minimize effects of infiltration and inflow on plant treatment capabilities. In addition, WWTF effluents for accessible facilities in the watershed were monitored as were bacteria levels upstream and downstream of the effluent discharge location (when flow was present). As shown in **Table 2-15**, *E. coli* levels downstream of the plants ranged from 74 MPN/dL at the Galveston County WCID 1 plant to 866 MPN/dL at the Pine Colony plant while enterococci concentrations were noted to be 30 MPN/dL downstream of the Galveston County WCID 1 plant. Effluent concentrations ranged from 155,310 MPN/dl measured at Pine Colony to greater than 241,920 MPN/dL at Meadowlands, demonstrating that these plants were not adequately disinfecting effluent at the time of sample collection. Because of the high levels noted at Pine Colony on July 21, 2008, the facility was monitored again one month later. During the second visit, high levels of bacteria were still noted in the effluent and levels downstream of the effluent discharge point were measured at 866 MPN/dL. These data suggest that some WWTFs can contribute significant bacteria loading to Dickinson Bayou; however, this is not true for all WWTFs in the watershed as shown by the samples collected from Galveston County WCID#1. In 2010, both the Meadowland Utility and Pine Colony wastewater treatment facilities were under enforcement orders issued by the TCEQ for effluent violations. The TCEQ and the Dickinson Bayou Watershed Partnership are working with these facilities to improve their performance.

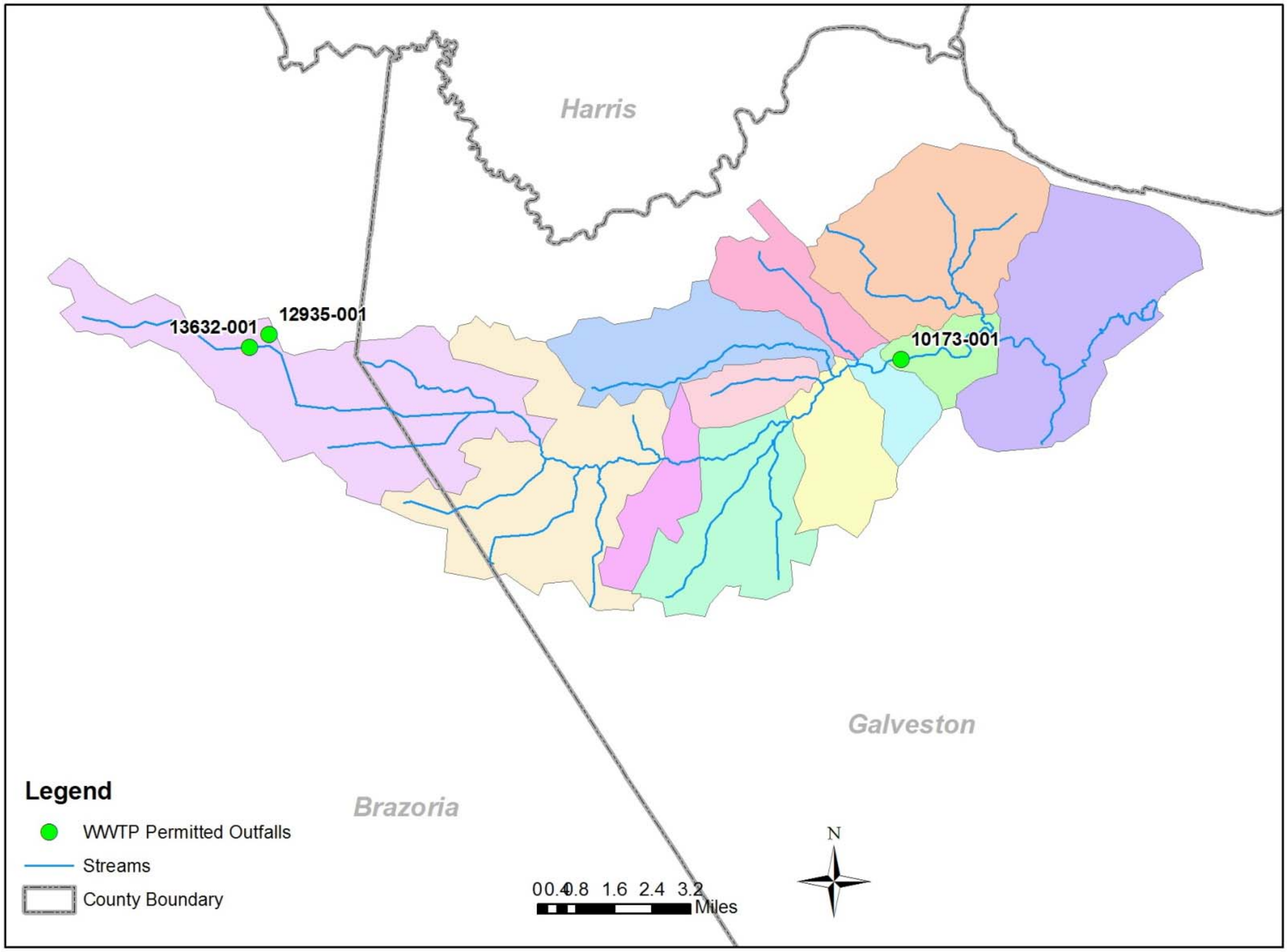


Figure 2-21 Location of Monitored WWTFs

Table 2-15 TMDL Water Quality Data- WWTFs

Date	Station	Assess-ment Unit	Plant Name	Time	Entero-coccus (MPN/ 100ml)	*E.coli* (MPN/ 100ml)	TSS (mg/L)	NH3 (mg/L)	TKN (mg/L)	NO2 & NO3 (mg/L)	Total Phospho-rus (mg/L)	Ortho-Phosphate (mg/L)
7/21/2008	10173-U	1103_02	Galveston County WCID 1 [a]	12:15	30	34	10.3	<0.1	2.4	0.13	0.39	0.27
7/21/2008	10173-D	1103_02	Galveston County WCID 1 [a]	12:40	30	74	11.8	<0.1	6.6	0.45	0.98	0.58
7/21/2008	12935-E	1104_02	Pine Colony [b]	14:00	141,360	241,920	53.3	6.7	9.5	0.28	4.51	4.07
8/27/2008	13632-E	1104_02	Meadowlands [b]	12:45	NA [d]	>241,920	2.5	6.5	13	1.44	15	6.24
8/27/2008	12935-E	1104_02	Pine Colony [c]	13:35	NA [d]	155,310	<1.0	1.4	6.8	3.14	5.5	2.08
8/27/2008	12935-D	1104_02	Pine Colony [c]	16:00	NA [d]	866	36	<0.1	1.9	1.18	0.46	0.245

Notes: U, D, E refer to the location of the station with relation to the Assessment Unit, U for Upstream, D for Downstream and E for effluent pipe; [a] No effluent sample, Effluent pipe submerged; [b] no upstream or downstream flow present; [c] no upstream flow present; [d] enterococci data were not collected on this date

2.4.3 Results and Evaluation of Pipe Outfall Reconnaissance

A two-day preliminary reconnaissance and pipe/source survey effort was undertaken during dry weather in the portions of Dickinson Bayou accessible via boat. The survey was conducted to identify dry weather discharges from pipes from urbanized areas along the main stem of Dickinson Bayou, identify potential sources of bacteria along the bayou and inspect potential sampling locations.

The pipe reconnaissance was conducted on May 7, 2008 and June 7, 2008. The survey identified eleven (11) pipes that terminate into the portion of Dickinson Bayou that was surveyed. Locations of the surveyed pipes is shown in **Figure 2-22**. Eight of these were submerged or partially submerged, preventing an assessment of dry weather discharges. The remaining three outfalls did not exhibit dry weather discharges on the day of the survey. The majority of the visible pipes looked to be storm water drainage from the street or residential property. Along with the storm water discharge pipes there are two wastewater treatment facilities on the section of Dickinson Bayou surveyed, but only one pipe was visible. This pipe was partially submerged so it was not possible to determine flow. **Table 2-16** shows the locations and detailed information of the pipes identified during the reconnaissance. As can be seen from the Table, no pipes were observed to be discharging at the time of the survey.

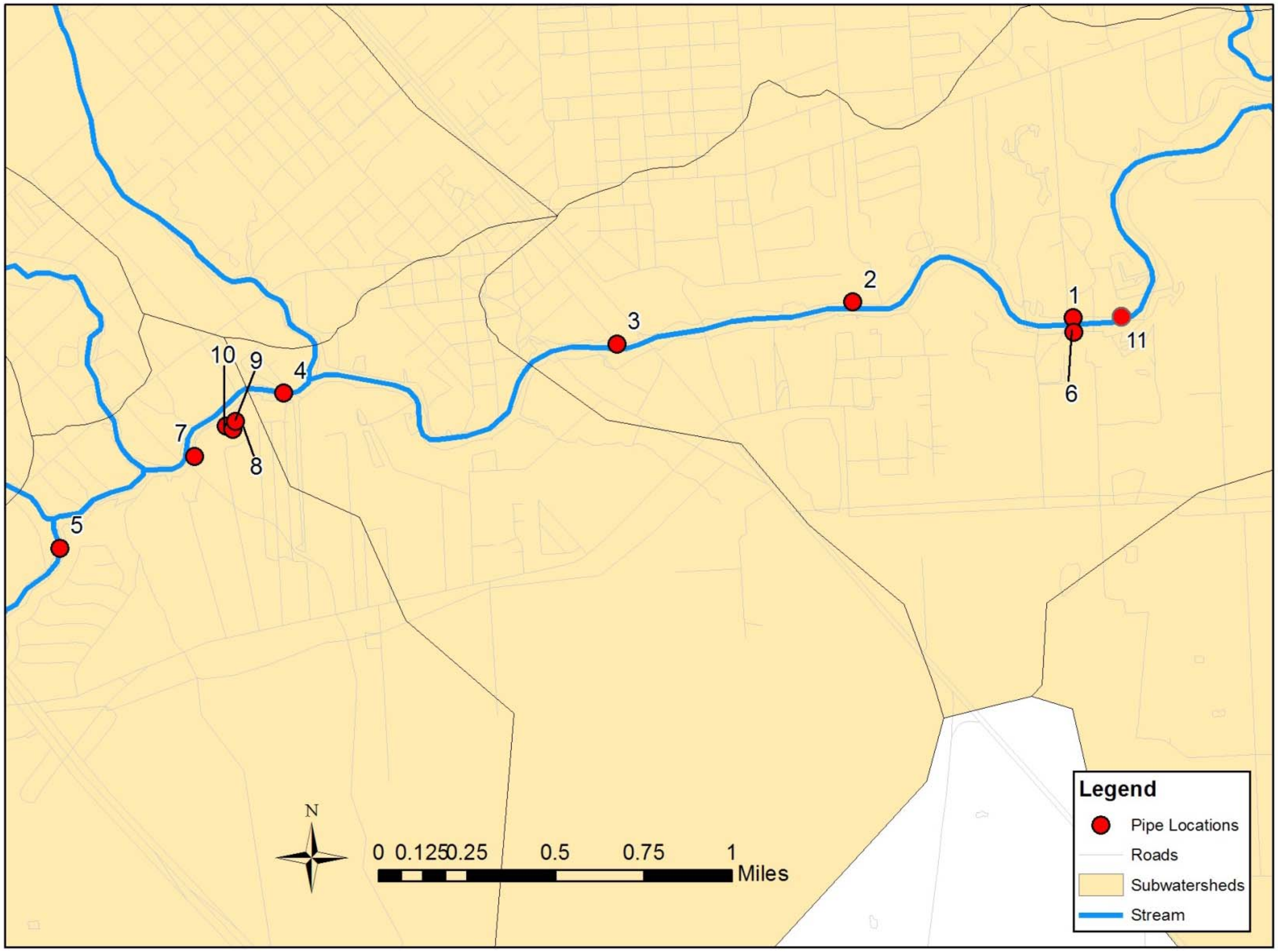


Figure 2-22 Pipe Reconnaissance Map, Dickinson Bayou

Table 2-16 Pipe Reconnaissance Results

Date	Map ID	Pipe ID	GIS Coordinate		Pipe Size (in)	Pipe Geo-metry	Pipe Material	Pipe Condition	Flow	Suspected Pipe Function	Comments
			North	West							
Northside											
5/7/08	11	N-OUT-1	29º27.148	95º01.124	32	Circle	Concrete	Good	No	Storm water	Residential property, bulk head wall, partially submerged, no flow
5/7/08	1	N-OUT-2	29º27 428	95º01.334	32	Circle	Concrete	Good	No	Storm water	Residential property, in the ground, grass covered lawn, partially submerged, no flow
5/7/08	2	N-OUT-3	29º27 492	95º01.955	4	Circle	PVC	Good	No	Private Property	Residential property, bulk head wall
5/7/08	3	N-OUT-4	29º27.415	95º02.626	64	Circle	Concrete	Good	Unk	WWTF	Submerged, Galveston Wastewater Treatment Plant
5/7/08	4	N-OUT-5	29º27.330	95º03.573	24	Circle	Concrete	Excellent	No	Storm Drain	Drain from street, runs through residential property
5/7/08	5	N-OUT-6	29º26.972	95º04.224	12	Circle	PVC	Good	No	Private Property	Residential property, drain from yard, bulk head wall
Southside											
5/7/08	6	S-OUT-1	29º27.393	95º01.334	32	Circle	Concrete	Good	No	Storm water	Residential property, bulk head wall, partially submerged, no flow
6/7/08	7	S-OUT-2	29º27.184	95º03.831	36	Circle	Corrugated PVC	Good	Unk	Storm water	Gated outflow, partially submerged, large flow necessary to open gate, residential grassland surrounding
6/7/08	8	S-OUT-3	29º27.255	95º03.739	3	Circle	PVC	Good	No	Residential Yard	Residential property, bulk head wall, partially submerged, no flow
6/7/08	9	S-OUT-4	29º27.247	95º03.721	3	Circle	PVC	Good	No	Residential Yard	Residential property, bulk head wall, partially submerged, no flow
6/7/08	10	S-OUT-5	29º27.265	95º03.712	3	Circle	PVC	Good	No	Residential Yard	Residential property, bulk head wall, partially submerged, no flow

CHAPTER 3:
WATER QUALITY TARGET

Dickinson Bayou and its associated tributaries are assigned a designated use of contact recreation. Safety of contact recreation is determined by indicator bacteria. For Dickinson Bayou, *E. coli* and enterococci are used as the indicator bacteria. These organisms are fecal bacteria that originate in the intestines of warm-blooded species (human and animal). While these bacteria do not directly cause illness in humans, the US EPA has determined their presence indicates a heightened risk of other harmful microbes in the water body (US EPA, 1986). In 2010 the TCEQ adopted revisions to the "Texas Surface Water Quality Standards." In the 2010 revision of the standards, the requirement for use of the single sample criterion for standards attainment was removed. In 2011 the EPA approved this change to the Texas Surface Water Quality Standards. The single sample criterion is still used by the TCEQ for screening purposes.

A summary of indicator bacteria and their relevant standards for the State of Texas are shown in **Table 3-1**. As shown in the table, there are three potential indicator bacteria, including fecal coliform, *E. coli* and enterococci. *E. coli* and enterococci are the preferred indicators by TCEQ for freshwater and tidal streams, respectively. Fecal coliform is used only when there are inadequate data available for the other parameters.

Table 3-1 Summary of Bacteria Standards

Indicator Bacteria	Long-term Geometric Mean Concentration	Single Sample Not to Exceed Concentration
Fecal coliform (cfu/dL)	200	400*
E. coli (MPN/dL)	126	394*
Enterococci (MPN/dL)	35	89*

cfu – colony forming units, MPN – most probable number

* As of 2010, only geometric mean criteria are used for assessment of standards attainment

As stated previously, the Dickinson Bayou was included in the State of Texas' Clean Water Act §303(d) list of impaired water bodies in 1996 because fecal indicator bacteria levels were observed to exceed the criteria established by the State of Texas to assure the safety of contact recreation. This impairment was expanded in 2002 to include four major tributaries of Dickinson Bayou (i.e., Bensons Bayou, Bordens Gully, Giesler Bayou and Gum Bayou). Presently, these water bodies remain on the State of Texas' list of impaired water bodies with the exception of Gum Bayou which was removed from the State of Texas 303(d) list in 2006 (Gum Bayou was added to the list again in the draft 2010 State of Texas 303(d) list).

The State of Texas evaluates water bodies on both a segment and Assessment Unit basis. For Dickinson Bayou, there are two segments defined for the watershed: the tidal portion, or Segment 1103, and the non-tidal portion, or Segment 1104. These segments are further delineated into subareas known as Assessment Units. The Assessment Units for Dickinson Bayou are shown in **Table 3-2**. There are a total of six Assessment Units contained within Segment 1103 while Segment 1104 contains four Assessment Units.

Table 3-2 Bacteria Standards by Assessment Unit

Description	Segment	Assessment Unit	Indicator Bacteria
Dickinson Bayou Tidal	1103	1103_02	Enterococci
	1103	1103_03	Enterococci
	1103	1103_04	Enterococci
Bensons Bayou	1103	1103A_01	Enterococci
Bordens Gully	1103	1103B_01	Enterococci
Geislers Bayou	1103	1103C_01	Enterococci
Gum Bayou	1103D	1103D_01	Enterococci
Dickinson Bayou Above Tidal	1104	1104_01	*E. coli*
	1104	1104_02	*E. coli*

CHAPTER 4: SOURCE ANALYSIS

To support TMDL development the sources of bacteria loading must be determined and analyzed. Sources of bacteria loading are categorized as point (permitted) or nonpoint (non-permitted) sources. Point sources are permitted through the National Pollution Discharge Elimination System (NPDES) program which, in Texas, is delegated by the USEPA to the state under the Texas Pollution Discharge Elimination System (TPDES) program.. All sources not permitted by the NPDES/TPDES are considered nonpoint sources. The following chapter discusses what is known regarding sources of bacteria, permitted and non-permitted, in the impaired water bodies of the Dickinson Bayou watershed.

4.1 Permitted Sources

Permitted sources, often known as point sources, are described as a discernable, confined, and discrete conveyance from which pollutants are or may be discharged to surface waters by the Code of Federal Regulations (40, §122.2). Under the Texas Water Code, TCEQ has adopted rules and procedures to issue permits to control the quantity and quality of discharges into or adjacent to waters of the state through the Texas Pollution Discharge Elimination System (TPDES) program. NPDES/TPDES-permitted facilities classified as point sources that may contribute to bacteria loading to water bodies in the Dickinson Bayou watershed include:

- TPDES municipal wastewater treatment facilities (WWTF);
- TPDES industrial WWTF;
- TPDES permitted storm water (municipal separate storm sewer systems) and;
- TPDES municipal solid waste facilities; and

4.1.1 Wastewater Treatment Facilities

As of January 2011, there are a total of nine TPDES-permitted wastewater treatment facilities that discharge to Dickinson Bayou or one its tributaries. These plants are described in **Table 4-1** and shown in **Figure 4-1**. Of these permitted facilities, four are domestic wastewater treatment facilities and five treat industrial wastewater, groundwater extracted from a landfill or stormwater. Only one plant, Galveston County WCID #1 (TPDES ID 10173-001), has a permitted flow of greater than 1 MGD and thus is considered a major facility. **Appendix A** provides a summary of self-reported flows by WWTF.

In addition to these 9 permits, the TCEQ has issued three additional permits to discharge treated wastewater into Dickinson Bayou Above Tidal (1104_02), Gum Bayou (1103D_01) and Dickinson Bayou Tidal (1103_01). As of January 2011, the facilities for which these TCEQ permits were issued have not been constructed. These permits are also described in **Table 4-1** and shown in **Figure 4-1**

As part of the TMDL monitoring, the outfalls of three of the four wastewater facilities treating domestic wastewater were sampled and analyzed for *E. coli* and enterococcus concentrations. The results of this sampling effort revealed problems with some facilities' compliance with permitted effluent limits (see Section 2.4.2). These compliance issues are being addressed by the TCEQ.

Table 4-1 TPDES Discharge Information for Dickinson Bayou

TCEQ Permit ID	NPDES ID	Assessment Unit	Permittee	Permitted Flow (MGD)	Average Flow (MGD)	Discharge Type	Date of First Permit Issuance	Status	SIC Code	SIC Description
00377-000	TX0003727	1103_02	Penreco	0.075	0.057	Process Wastewater, Stormwater	5/16/1975	Active	2999	Products of Petroleum and Coal., Not Elsewhere Classified
03416-000	TX0119458	1104_01	Waste Management of Texas, Inc.	n/a[2]	0.79	Groundwater	8/30/2005	Active	4953	Refuse System
03749-000	TX0112861	1103_01[1]	Hillman Shrimp & Oyster Co.	0.07	0.005	Process Wastewater	1/20/2004	Active	2092	Prepared Fresh or Frozen Fish and Seafoods
03479-000	TX0108367	1103_01[1]	Sea Lion Technology	n/a[2,3]	0.058	Domestic Wastewater	11/30/1999	Active	2869	Industrial Inorganic Chemicals, not elsewhere classified
04086-000	TX0117757	1103_01[1]	Duratherm, Inc.	n/a[1]	0.431	Stormwater	12/1/1999	Active	4953	Recyclable Fuel
10173-001	TX0023655	1103_02	Galveston County WCID 1	4.8	2.759	Domestic Wastewater	5/22/1976	Active	4952	Domestic Sewage
12935-001	TX0095770	1104_02	Pine Colony	0.05	0.024	Domestic Wastewater	5/23/1985	Active	4952	Domestic Sewage
13632-001	TX0109886	1104_02	Meadowland Utility Corp	0.0234	0.009	Domestic Wastewater	9/10/2004	Active	4952	Domestic Sewage
14326-001	TX0124761	1103_01[1]	Via Bayou Inc	0.02	0.002	Domestic Wastewater	7/9/2002	Active	7033	Recreational Vehicle Parks and Campsites
14440-001*	TX0125873	1104_02	Brazoria County MUD	0.95[3]	n/a	Domestic Wastewater	3/23/2004	Active	4952	Domestic Sewage
14570-001*	TX0127248	1103D_01[1]	Marlin Atlanta White Ltd	0.5	n/a	Domestic Wastewater	n/a	na	4952	Domestic Sewage

Abbreviations: MGD - million gallons per day, NPDES - National Pollutant Discharge Elimination System, SIC - standard industrial code, TCEQ - Texas Commission on Environmental Quality, WWTF - wastewater treatment plant, WWTF - wastewater treatment facility n/a - not available

Notes: [1] Discharges or permitted to discharge to an assessment unit that is not 2008 303(d) -isted; [2] Permitted for intermittent flow, [3] Located in Dickinson Bayou watershed but discharge goes to Galveston Bay, *Permit granted, facility not yet built

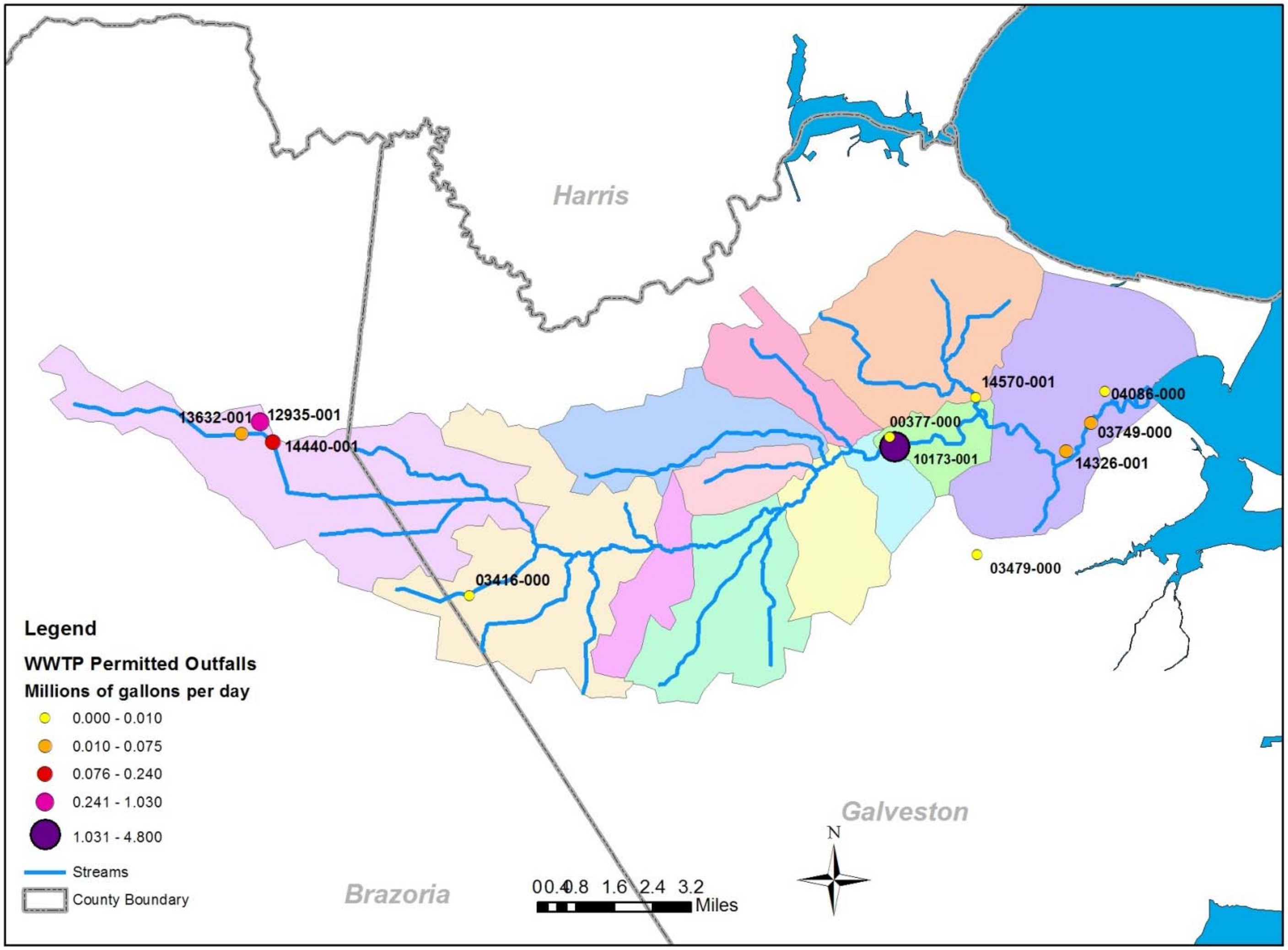


Figure 4-1 **TPDES-Permitted Facilities in the Dickinson Bayou Watershed**

4.1.2 TPDES-Regulated Storm Water

Phase II of the National Pollutant Discharge Elimination System (NPDES) storm water program was issued in 1999. This program requires regulated small Municipal Separate Storm Sewer System (MS4) discharges in urbanized areas, as well as small MS4s outside the urbanized areas that are designated by the permitting authority, to obtain NPDES coverage for their storm water discharges. A small MS4 is considered to be any MS4 not already covered by the Phase I storm water program, which covered urbanized areas with greater than a population of 100,000.

In the Dickinson Bayou watershed, there are a total of eight Phase II MS4 permittees who are covered under the TCEQ general permit. These permitted entities are listed in **Table 4-2**. The permittees include a total of three cities, one county and four drainage districts. It is important to note that only certain portions of the Dickinson Bayou watershed are covered by urbanized areas (UA) as designated by the USEPA; only those areas within the UA are considered to be MS4 permitted areas of the watershed (Figure 4.2). These UAs include the greater City of Houston and Texas City metropolitan areas.

Table 4-2 Summary of Storm Water Permittees

Permit Number	Permittee	Area (acres)
TXR040148	Brazoria County Conservation and Reclamation No. 3	9,462
TXR040271	City of Dickinson	4,158
TXR040249	City of League City	14,435
TXR040024	City of Texas City	4,631
TXR040364	Galveston County	5,494
TXR040067	Galveston County Consolidated Drainage District	6,022
TXR040203	Galveston County Drainage District No. 1	18,547
TXR040203	Galveston Country Drainage District No. 2	5,448

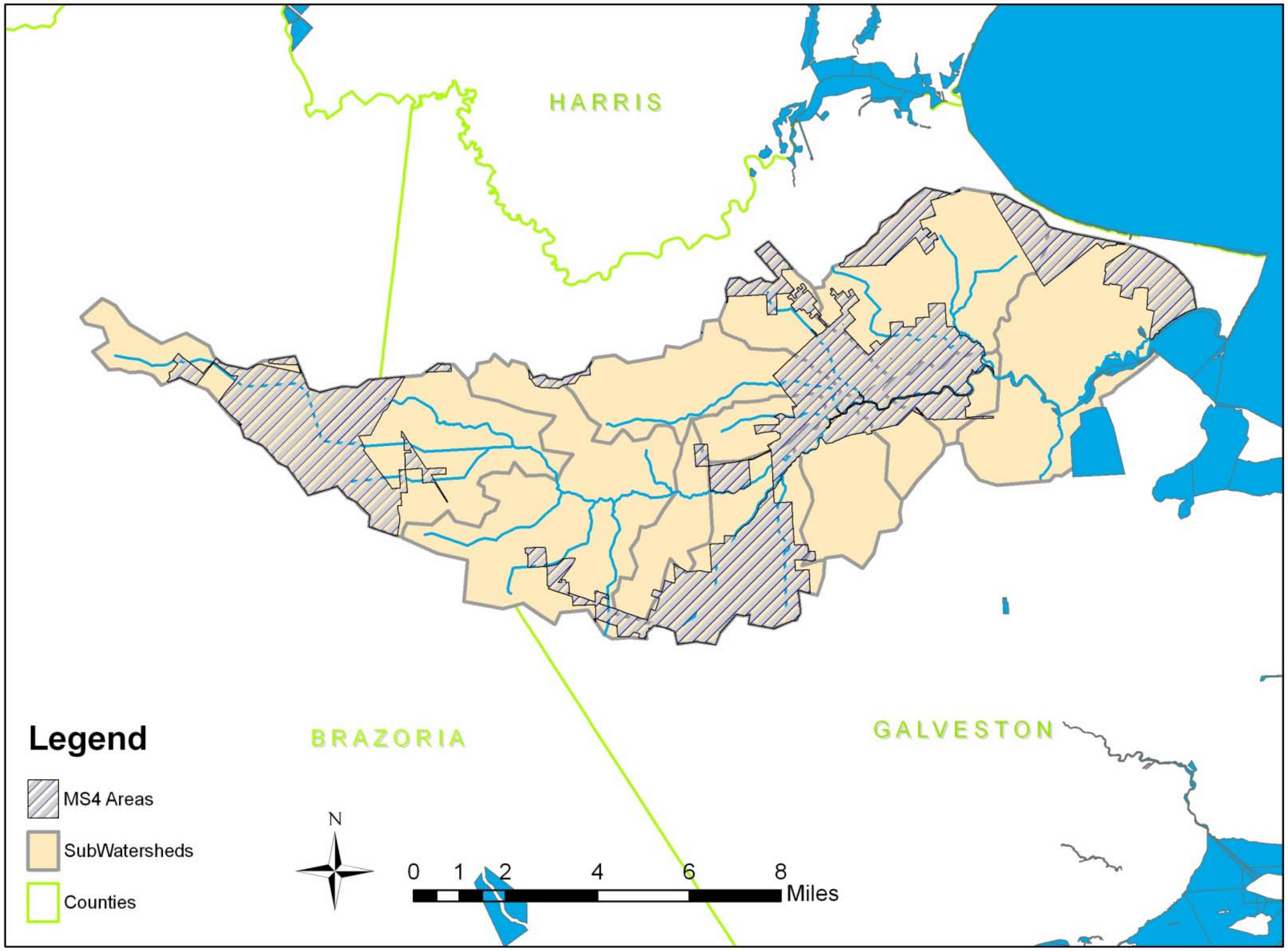


Figure 4-2 Designated MS4 Urbanized Areas within the Dickinson Bayou watershed

4.1.3 Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are releases of untreated wastewater, including domestic, commercial, and industrial wastewater and are permit violations that must be addressed by the responsible TPDES permittee. These releases usually occur as the result of a break, stoppage, or exceedance of capacity in the sanitary sewer conveyance system. If not directly discharged into the bayou, the overflows will typically drain to the storm water conveyance system which then carries the overflows to the bayou.

SSO data obtained from Galveston County for WWTF Galveston County WCID No. 1 are shown in **Table 4-3** and are summarized in tabular format for the project area in **Table 4-4**. SSO locations are presented in **Figure 4-3**. A total of 28 SSOs were reported during the period between May 17, 2002 and September 16, 2008 for the Galveston County WCID 1 WWTF within the Dickinson Bayou watershed. Flows associated with these SSOs range from 200 gallons to 96,580 gallons. Typical causes for the SSOs included heavy rainfall, infiltration and inflow (I/I) and lift station (LS) malfunction or failure. To better evaluate the SSOs, the individual events were classified as “Wet” or “Dry” based on the prior 3-day rainfall in the area. If the 3-day antecedent rainfall was greater than 0.1 inches, the SSO was considered to be associated with a rainfall event; otherwise the SSO was considered a dry weather SSO. Two SSOs occurred because of Hurricane Ike in September 2008 and were classified as wet weather SSOs, even though antecedent rainfall conditions were consistent with dry weather. This is because the precipitating cause of the SSO was power failure associated with Hurricane Ike. Based on the weather classification, the majority of the SSOs reported by Galveston County are those associated with wet weather conditions. However, dry weather SSOs may also impact bayou water quality, especially during “base flow” situations. For the impaired Assessment Units addressed in this TMDL document, SSOs were only reported in Assessment Units 1103_02, 1103C_01 and 1103A_01. SSOs were reported to the TCEQ only by one permitted entity in the Dickinson Watershed, GCWCID#1.

Table 4-3 Sanitary Sewer Overflows in Dickinson Bayou Watershed

Address	Event Date	Total Volume (Gallons)	Excursion Cause	Location	SSO Condition	Assessment Unit
Manhole 570 Georgia&FM517	5/17/02	75000	Heavy Rains	Storm Drain	Wet	1103_02
Hwy 3 & Central St	5/17/02	57000	Heavy Rains	Storm Drain	Wet	1103_02
2617 Branding Iron Dr	9/11/02	5000	LS Malfunction	Unknown	Wet	1103_02
5118 39th	10/29/02	2000	I/I From Rainfall	Ditch	Wet	1103_02
5125 39th	10/29/02	2000	I/I From Rainfall	Ditch	Wet	1103_02
5118 39th	10/30/02	2000	Heavy Rains	Storm Drain	Wet	1103A_01
4220 Scenic Dr	12/4/02	500	Heavy Rainfall	Storm Drain	Wet	1103A_01
4318 Country Club	12/4/02	500	Heavy Rainfall	Storm Drain	Wet	1103_02
Hwy 3 & Central St	12/4/02	500	Heavy Rainfall	Storm Drain	Wet	1103_02
2201 Oleander Dr	5/14/03	200	Contractor Error	Dickinson Bayou	Dry	1103_02
FM 517 & Timber	10/27/04	5000	Lift Station Down	Storm Drain	Dry	1103A_01
2920 Colonial Dr	9/24/06	500	LS Power Outage	Ground	Dry	1103C_01
C Club Ln & Dickinson Bay	9/26/06	96580	Failed Coupling	Dickinson Bayou	Wet	1103_02
Hwy 3 & Central	10/17/06	9000	Heavy Rain	Storm Drain	Dry	1103A_01
Deats & Timber	10/26/06	8400	Heavy Rain	Storm Drain	Dry	1103_02
Ecret Lift Station	10/27/06	36000	Broken Line	Dickinson Bayou	Wet	1103_02
2800 California Ave	12/6/06	2400	LS Pump Failure	Ditch	Dry	1103_02
Yupon & Deats Rd	1/4/07	4800	Rain	Ditch	Dry	1103A_01
2201 Oleander Dr	3/9/07	300	LS Down	Ditch	Dry	1103_02
Hwy 3 & Central St	3/14/07	2400	Power Outage/Rain	Storm Sewer	Dry	1103A_01
4503 Mariners Mooring St	5/7/07	1200	LS Failure	Ditch	Wet	1103_02
4503 Mariners Mooring St	5/27/07	1400	LS Failure Due To Lighting	Ditch	Wet	1103_02
4503 Mariners Mooring	8/16/07	1920	Lightning/ LS Failure	Ditch	Wet	1103_02

Address	Event Date	Total Volume (Gallons)	Excursion Cause	Location	SSO Condition	Assessment Unit
St						
4660 Country Club Dr	12/27/07	2400	Power Failure	Ditch	Wet	1103_02
4503 Mariners Mooring St	1/16/08	2400	LS Fuse Tripped	Ditch	Wet	1103_02
Lininger LS	1/19/08	12000	Crack In Force Main	Ditch	Dry	1103_02
Country Club LS	9/15/08	50000	Hurricane Ike	Ground	Wet	1103_02
4503 Mariners Mooring St	9/16/08	5000	Hurricane Ike	Unknown	Wet	1103_02

Notes: SSO – sanitary sewer overflow, LS – lift station, I/I – infiltration and inflow

Table 4-4 Summary of Sanitary Sewer Overflows by Assessment Unit

Assessment Unit	No. of Overflow		Date		Amount (gallons)		
	Wet	Dry	Min.	Max.	Min.	Max.	Total
1103_02	16	5	5/17/02	9/16/08	200	96,580	362,200
1103A_01	2	4	10/30/02	3/14/07	500	9,000	24,200
1103C_01	0	1	9/24/06	9/24/06	500	500	500

4.1.4 Concentrated Animal Feeding Operations

There are no permitted CAFOs located within the study area. See discussion in **Section 4.2.2** for further discussion on livestock sources in the watershed.

4.2 Non-permitted Sources

There are several types of non-permitted sources of bacteria that may impact Dickinson Bayou. These include malfunctioning on-site sewage facilities, livestock/agriculture, pets and wildlife.

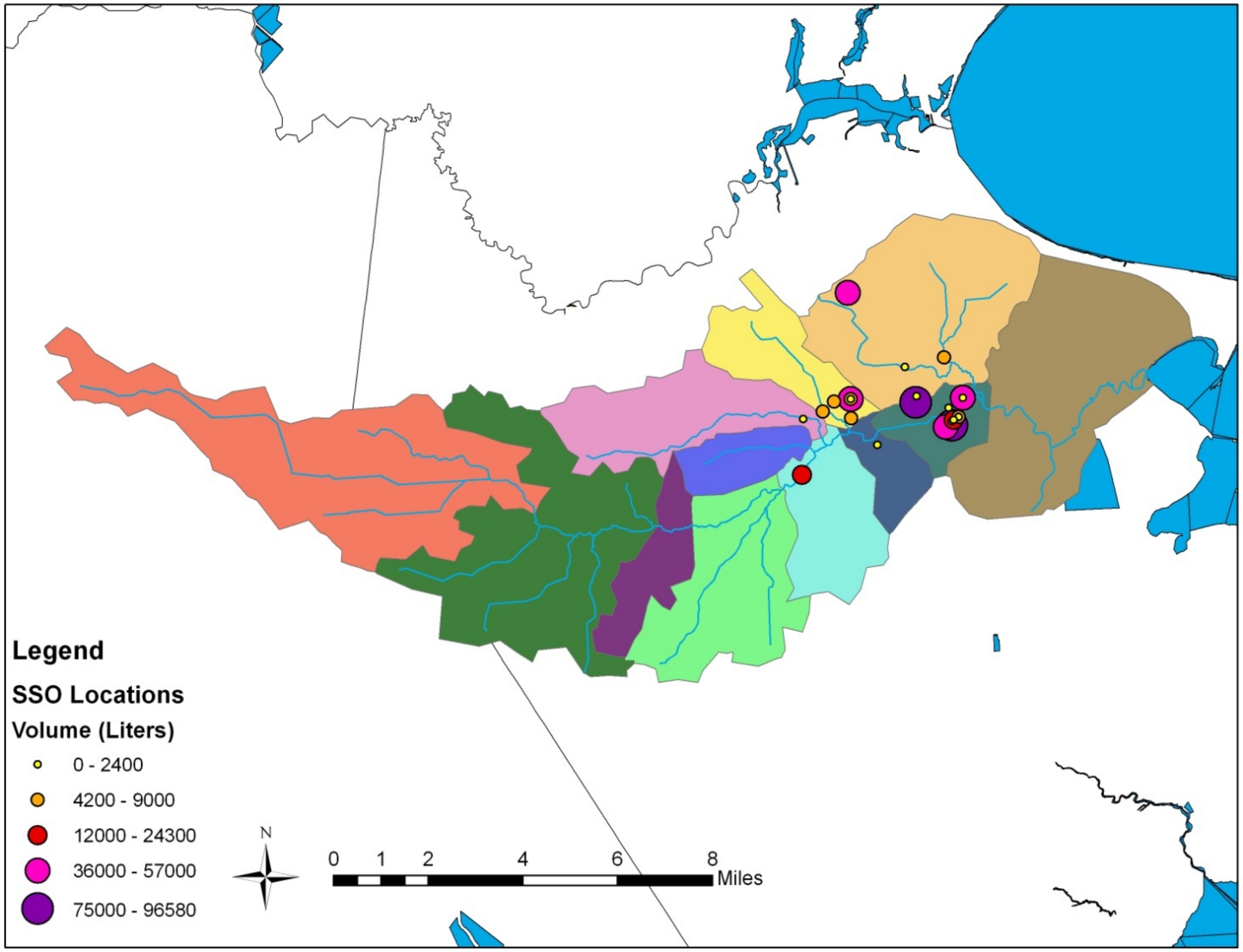


Figure 4-3 SSO Occurrences in Dickinson Bayou Watershed

4.2.1 On-site Sewage Facilities

Failing onsite sewage facilities (OSSFs) can be a source of fecal pathogens and indicator bacteria loading to streams and rivers. Indicator bacteria loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface discharge or from transport by storm water runoff. While most septic systems are located outside city and drainage district boundaries; there are several older neighborhoods in these regions that remain on septic systems. It is important to note that malfunctioning septic systems are unauthorized discharges - not unregulated sources.

The number of OSSFs in the HSPF sub-watersheds associated with each assessment unit was determined for the Dickinson Bayou based on the following information: (1) A survey of OSSF permits in the greater Houston-Galveston area conducted by H-GAC in 2008 and 2009 and the location of these permits is shown in **Figure 4-4**, (2) OSSF estimates derived from 1990 census data, and (3) permitted septic systems reported in the On-line Activity Reporting System (OARS) reported between 1991 and 2008. The H-GAC dataset was supplemented with data from the 1990 census and OARS to reflect the estimated total number of OSSFs installed/permitted in the watershed between 1990 and 2010.

The assumptions regarding septic system failure rates, typical septic tank specifications used for this analysis are summarized in **Table 4-5**. A failure rate of 25% was applied to OSSFs newer than the year 2000 and 35% was applied for OSSFs older than 2000. Based on these assumptions, a total of 1,546 failing OSSFs were estimated for the entire Dickinson Bayou watershed as of 2010 as shown in **Table 4-6**.

Bacteria loads from OSSFs were simulated in the HSPF model through the use of the watershed build-up/wash-off process. The size of the septic system was used to estimate a typical area on a subwatershed basis that would be associated with septic systems. Then, associated bacteria loading rates were estimated from literature values and assigned to those areas. The loading estimates were then adjusted within the range of values reported in the literature to match the edge-of-field runoff concentrations for the septic system bacteria source (Baird *et al.*, 1996, Pitt *et al.*, 2004, McCarthy *et al.*, 2006, Storm Water Joint Task Force, 2002).

Table 4-5. Assumptions for OSSF Calculations

Assumptions	Value	Reference
Septic failure rate for septic systems installed later than 2000	25%	(GCHD 2000)
Septic failure rate for septic systems prior to 2000	35%	National Menu of Best Management Practices for Stormwater Phase II
Size of typical septic system = $\frac{Aerobic\ Tank\ Capacity}{Septic\ Tank\ Effluent\ Loading\ rate}$	2000 sf	TCEQ Rules (Chapter 285, OSSF Rules)
Aerobic tank capacity for a typical 3-bedroom house (< 2501 Sq.ft)	400 gpd	TCEQ Rules (Chapter 285, OSSF Rules)
Septic tank effluent loading rate for class III soils for Texas	0.2 gpd/sf	TCEQ Rules (Chapter 285, OSSF Rules)
State of Texas requires that the loading rate should not exceed	1.2 gpd/sf	TCEQ Rules (Chapter 285, OSSF Rules)

Table 4-6. Number of failing OSSFs by Assessment Unit

Assessment Unit	Number of OSSFs	Number of Failing OSSFs
1103_01	155	49
1103_02	973	310
1103_03	13	4
1103_04	1,495	476
1103A_01	48	15
1103B_01	51	16
1103C_01	44	14
1104_01	754	240
1104_02	1,324	422

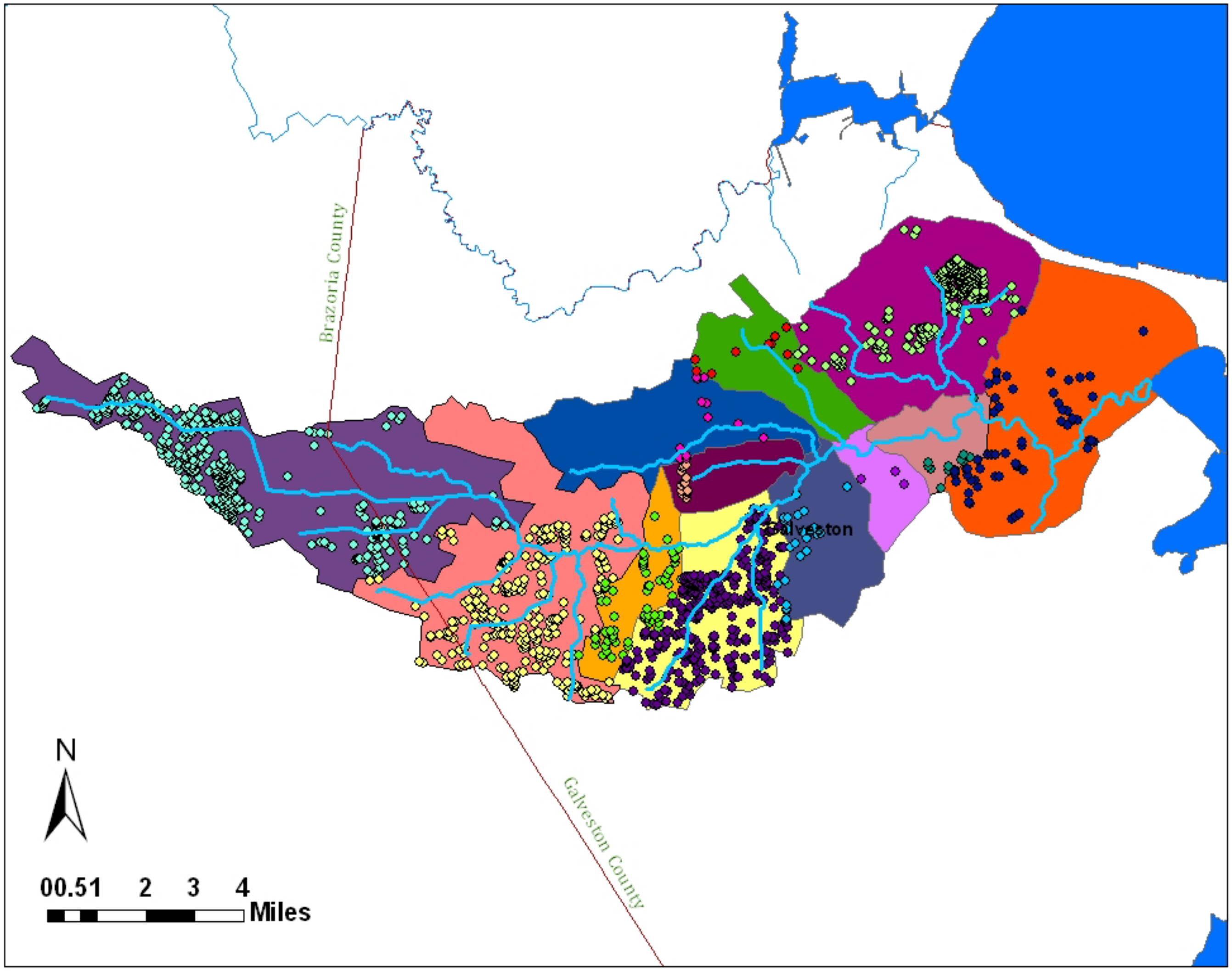


Figure 4-4. On-Site Sewage Facilities in Dickinson Bayou Watershed (H-GAC, 2009)

4.2.2 Livestock Contributions

Livestock can be a source of bacteria to surface water bodies. The United States Department of Agriculture (USDA) conducts the Census of Agriculture every 5 years on the county level and these data provided the basis of the animal agriculture population estimates used in this study (USDA, 2002). Using 2005 land use maps from the Multi-Resolution Land Characteristics Consortium (MRLC), the total area of pastureland was estimated in the watershed, as well as for Brazoria and Galveston County. The number of animals per unit area of pasture and grassland for Brazoria and Galveston was determined and applied to the area of the pastureland and grassland in the watershed within the respective counties. This produced livestock population estimates for the study area.

Livestock population estimates are listed in **Table 4-7**. As the table shows, a direct comparison of per capita numbers indicates the largest animal type of livestock is poultry, specifically those produced for eggs (i.e., layers). Cattle and calves followed by horses and ponies make up the next largest per capita animal types. However, a per capita comparison of animal types has limited utility. It is more useful to convert per capita numbers into animal units using animal unit equivalents, which are simply the animal population numbers multiplied by the ratio of the mean animal weights for each animal type to the mean weight of cattle (Animal Equivalents = Animal Population * Mean Animal Weight / Mean Weight of Cattle). Utilizing this method, cattle make up about 63% of animal units in the watershed with horses another 26% of animal units; all 7 poultry types combined only make up 1% of animal units in the watershed. The subwatershed for Assessment Unit 1104_02 was determined to have the highest number of livestock (per capita and in animal units), with the dominant per capita animal being layers (i.e., chickens) and the dominant type by animal units being cattle. The animal equivalent estimates are included in **Table 4-8**.

While the overall largest per capita livestock animal type is poultry layers, it is important to note that according to TCEQ confined animal feeding operation (CAFO) permit records and TSSWCB Water Quality Management Plan records, there are no known poultry AFOs/CAFOs in Galveston or Brazoria Counties. As such, it is reasonable to conclude that all of the poultry identified in **Tables 4-7** and **4-8** are associated with "backyard" poultry and egg operations. These types of operations fill niche markets not serviced by the large-scale commercial poultry industry, such as hobby/pet enthusiasts, 4-H and FFA programs, farmers markets and organic free-range, heirloom/heritage breeds, and cultural/ethnic markets.

Fecal coliform loadings from livestock were calculated based on estimates from literature sources, including US EPA (2000), American Society of Agricultural Engineers (1998, 2003), Zeckoski *et al*. (2005), and Benham *et al*. (2005). The resulting fecal coliform values were converted to *E. coli* values using a conversion factor based on the criteria found in the Texas Surface Water Quality Standards (126 MPN/dL to 200 cfu/dL). **Table 4-9** shows the estimated number of fecal coliform (cfu) generated per day per animal type. These estimates are not a precise accounting of the livestock in the watershed but they demonstrate that livestock may be a potential source of bacteria.

Table 4-7. Livestock Population Estimates by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit								Total Animals
	1103_02	1103_03	1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02	
Cattle And Calves	350	15	394	35	22	78	283	788	1,965
Layers	596	25	671	60	37	132	482	1,343	3,346
Horses And Ponies	143	6	161	14	9	32	115	322	802
Goats	104	4	117	11	7	23	84	235	585
Hogs And Pigs	37	2	41	4	2	8	30	83	207
Sheep And Lambs	14	1	16	1	1	3	12	32	80
Pullets	52	2	58	5	3	11	42	116	289
Broilers	10	0	11	1	1	2	8	22	55
Turkeys	12	1	14	1	1	3	10	27	69
Ducks	17	1	19	2	1	4	14	38	96
Geese	6	0	7	1	0	1	5	13	33
Other Poultry	57	2	64	6	4	13	46	128	320
Bison	4	0	4	0	0	1	3	9	21
Captive Deer	7	0	7	1	0	1	5	15	36
Donkey	12	1	13	1	1	3	10	27	68
Rabbits	17	1	19	2	1	4	14	38	96
Total Animals	1,438	61	1,616	145	90	319	1,163	3,236	8,068

Table 4-8. Livestock Animal Equivalents by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit								Total Animal Equivalent Conversion	Total Animal Equivalents (MPN/day)
	1103_02	1103_03	1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02		
Cattle And Calves	350	15	394	35	22	78	283	788	1.000	1,965
Layers	2.4	0.1	2.7	0.2	0.1	0.5	1.9	5	0.004	13
Horses And Ponies	142	5.9	160	14	9	32	114	319	0.991	795
Goats	15	0.6	16	1.6	1.0	3.2	12	33	0.141	82
Hogs And Pigs	26	14	29	2.8	1.4	5.6	21	58	0.698	145
Sheep And Lambs	1	0.1	1	0.1	0.1	0.2	0.7	1.9	0.059	4.8
Pullets	0.4	0.0	0.4	0.0	0.0	0.1	0.3	0.8	0.007	2.0
Broilers	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.002	0.1
Turkeys	0.2	0.0	0.2	0.0	0.0	0.0	0.1	0.4	0.015	1.0
Ducks	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.003	0.3
Geese	0.2	0.0	0.2	0.0	0.0	0.0	0.1	0.4	0.030	1.0
Other Poultry	0.3	0.0	0.4	0.0	0.0	0.1	0.3	0.7	0.006	1.8
Bison	8.8	0.0	8.8	0.0	0.0	2.2	6.6	20	2.203	46
Captive Deer	1.9	0.0	1.9	0.3	0.0	0.3	1.3	4.0	0.264	10
Donkey	6.9	0.6	7.4	0.6	0.6	1.7	5.7	15	0.573	39
Rabbits	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.2	0.004	0.4
Total Animal Eq.	554	24	621	55	34	124	447	1246	-	3,105

Table 4-9. Livestock Bacteria by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit (FC production counts/day)								FC Production (count/ animal/day)	EC Production (count/ animal/day)	Total EC Produced (MPN/ day)
	1103_02	1103_03	1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02			
Cattle And Calves	4.38E+13	1.88E+12	4.93E+13	4.38E+12	2.75E+12	9.75E+12	3.54E+13	9.85E+13	1.25E+11	7.88E+10	1.55E+14
Layers	8.34E+10	3.50E+09	9.39E+10	8.40E+09	5.18E+09	1.85 E+10	6.75E+10	1.88E+11	1.40E+08	8.82E+07	2.95E+11
Horses And Ponies	6.01E+10	2.52E+09	6.76E+10	5.88E+09	3.78E+09	1.34E+10	4.83E+10	1.35E+11	4.20E+08	2.65E+08	2.12E+11
Goats	1.25E+12	4.80E+10	1.40E+12	1.32E+11	8.40E+10	2.76E+11	1.01E+12	2.82E+12	1.20E+10	7.56E+09	4.42E+12
Hogs And Pigs	4.00E+11	2.16E+10	4.43E+11	4.32E+10	2.16E+10	8.64E+10	3.24E+11	8.96E+11	1.08E+10	6.80E+09	1.41E+12
Sheep And Lambs	1.68E+11	1.20E+10	1.92E+11	1.20E+10	1.20E+10	3.60E+10	1.44E+11	3.84E+11	1.20E+10	7.56E+09	6.05E+11
Pullets	1.35E+10	5.19E+08	1.50E+10	1.30E+09	7.78E+08	2.85E+09	1.09E+10	3.01E+10	2.59E+08	1.63E+08	4.72E+10
Broilers	8.90E+08	0.00E+00	9.79E+08	8.90E+07	8.90E+07	1.78E+08	7.12E+08	1.69E+09	8.90E+07	5.61E+07	3.08E+09
Turkeys	1.12E+0-	9.30E+07	1.30E+09	9.30E+07	9.30E+07	2.79E+08	9.30E+08	2.51E+09	9.30E+07	5.86E+07	4.04E+09
Ducks	4.13E+10	2.43E+09	4.62E+10	4.86E+09	2.43E+09	9.72E+09	3.40E+10	9.23E+10	2.43E+09	1.53E+09	1.47E+11
Geese	2.94E+11	0.00E+00	3.43E+11	4.90E+10	0.00E+00	4.90E+10	2.45E+11	6.37E+11	4.90E+10	3.09E+10	1.02E+12
Other Poultry	7.75E+09	2.72E+08	8.70E+09	8.16E+08	5.44E+08	1.77E+09	6.26E+09	1.74E+10	1.36E+08	8.57E+07	2.74E+10
Bison	5.00E+11	0.00E+00	5.00E+11	0.00E+00	0.00E+00	1.25E+11	3.75E+11	1.13E+12	1.25E+11	7.88E+10	1.65E+12
Captive Deer	3.50E+09	0.00E+00	3.50E+09	5.00E+08	0.00E+00	5.00E+08	2.50E+09	7.50E+09	5.00E+08	3.15E+08	1.13E+10
Donkey	5.04E+09	4.20E+08	5.46E+09	4.20E+08	4.20E+08	1.26E+09	4.20E+09	1.13E+10	4.20E+08	2.65E+08	1.80E+10
Rabbits	4.13E+10	2.43E+09	4.62E+10	4.86E+09	2.43E+09	9.72E+09	3.40E+10	9.23E+10	2.43E+09	1.53E+09	1.47E+11
Total	4.66E+13	1.97E+12	5.24E+13	4.64E+12	2.88E+12	1.04E+13	3.77E+13	1.05E+14	1.25E+11	7.88E+10	1.65E+14

4.2.3 Wildlife and Exotic Contributions

Wildlife census figures were not available for the Dickinson Bayou watershed (e.g., from Texas Parks and Wildlife Department). However, an analysis of land use patterns in the watershed suggests wildlife is a probable source of fecal bacteria to Dickinson Bayou, especially in the far western and southeastern portions of the watershed.

The Texas coast serves as a primary breeding ground for myriad species of colonial birds. An aquatic habitat is essential for a complete life cycle of the colonial birds and thus these species may be a source of bacteria loading to the Dickinson Bayou watershed. Population estimates of colonial water birds in the Dickinson watershed were derived from the Texas Coastal Interactive Mapping application (National Biological Information Infrastructure, 2011). Wild deer (*Odocoileus virginianus texana*) are the most numerous big game animal in Texas and United States (Cook, 1992). The State of Texas has more wild deer than any other state, with state-wide populations ranging from three to four million. Based on the Quality Deer Management Association deer density map (2001), Dickinson Bayou watershed deer populations are estimated to range from less than 15 deer per square mile to 30-45 deer per square mile. These densities are consistent with those reported in the Bacteria TMDL for Orange County watersheds which reported between 20-50 deer per square mile in that study area.

Invasive and exotic animals have also been identified in the Dickinson Bayou watershed. The following discusses several of the key invasive and exotic species in the watershed.

Feral hogs (*Sus scrofa*) are a nuisance species with populations of more than 2 million across Texas, about 50 percent of all feral hogs in the United States. Feral hog populations have expanded dramatically because of their adaptability and high reproductive rate (Mapston, 2004). The Texas Agrilife Extension Service has an on-going Feral Hog Abatement Program that aims to reduce the population of feral hogs primarily through trapping programs. Feral hog population estimates are available from Texas Agrilife for the State of Texas (2011). This study reported that the 95% confidence interval for the average feral hog density was between 1.33 hogs per square mile to 2.45 hogs per square mile. The average of these two values, 1.89 hogs per square mile, was applied to the Dickinson Bayou watershed. Estimates for Dickinson Bayou watershed were quantified by multiplying the feral hog density and the assessment unit area. Nutria (*Myocastor coypus*) are large South American rodents that were imported in 1899 for fur production. Nutria are known to be found in coastal areas from Texas to Delaware and can be observed in the forested riparian zones upstream and downstream of urbanized areas in the Dickinson Bayou watershed. A TMDL study for fecal coliform bacteria conducted in Terrebonne Basin, Louisiana identified nutria as a significant source of fecal coliform to Bayou Pointe au Chien (subsegment 120605) and Lost Lake/Four League Bay (subsegment 120708) (US EPA 2007), however no estimates on nutria population or their fecal coliform production are available.

Capybara (*Hydrochoerus hydrochaeris*) is a large South American rodent and is primarily a grazer with a digestive capacity that matched a sheep. These rodents are believed to have once escaped from a local petting zoo but have since captured. The presence of capybara in the Dickinson watershed has been reported periodically in the past; however, there is no reliable quantitative source of information about their population, which if existent, is thought to be low. Hence, the contribution of fecal production from capybara was considered to be negligible in Dickinson Bayou.

Finally, a number of exotic animals are present at the Bayou Wildlife Preserve, an 81-acre, privately-owned, animal wildlife park located approximately 2.5 miles upstream of the tidal boundary. The preserve receives over 35,000 visitors annually, who tour the facility via specially built trams that drive around the park. The park houses approximately 400 exotic animals, including ostrich, emu, camels, rhinoceros, giraffe, buffalo, zebra, water buffalo and wildebeest. Exotic animal estimates used in the TMDL analysis were based on animal totals reported during a site visit to the wildlife preserve. **Table 4-10** shows the estimated number of colonial birds, feral hogs and exotic animals in the subwatersheds associated with each Assessment Unit. **Table 4-11** shows the amount of *E. coli* (MPN) generated per day by animal type for each assessment Unit.

Table 4-10. Wildlife, Invasive and Exotic Animal Populations by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit								Total Animals
	1103_02	1103_03	1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02	
Snowy Egret	10	1	12	3	1	2	6	10	45
Tricolored Heron	9	1	12	2	1	2	6	9	42
White Ibis	72	6	89	19	7	13	42	72	320
White-faced Ibis	1	0	1	0	0	0	0	1	3
Brown Pelican	4	0	5	1	0	1	2	4	17
Least Tern	4	0	5	1	0	1	2	4	17
Royal Tern	75	6	92	20	8	13	43	74	331
Sandwich Tern	13	1	16	3	1	2	8	13	57
Wild Deer	392	35	490	122	47	81	290	709	2,166
Feral Hog	31	2	38	8	3	5	18	30	135
Other exotic species	0	0	0	0	0	0	400	0	400
Total Animals	219	17	270	57	21	39	527	217	1,367

Table 4-11. Wildlife, Invasive and Exotic Animal Bacteria Production by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit (FC count/day)								FC Production (count/ animal/day)	EC Production (count/ animal/day)	Total EC Produced (MPN/ day)
	1103_02	1103_03	1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02			
Snowy Egret	1.29E+11	1.00E+10	1.59E+11	3.38E+10	1.31E+10	2.26E+10	7.51E+10	1.28E+11	1.29E+10	8.14E+09	3.59E+11
Tricolored Heron	1.22E+11	9.54E+09	1.51E+11	3.22E+10	1.25E+10	2.15E+10	7.14E+10	1.21E+11	1.29E+10	8.14E+09	3.42E+11
White Ibis	9.33E+11	7.27E+10	1.15E+12	2.45E+11	9.52E+10	1.64E+11	5.44E+11	9.25E+11	1.29E+10	8.14E+09	2.60E+12
White-faced Ibis	6.69E+09	5.21E+08	8.26E+09	1.76E+09	6.83E+08	1.17E+09	3.90E+09	6.63E+09	1.29E+10	8.14E+09	1.87E+10
Brown Pelican	5.25E+10	4.09E+09	6.48E+10	1.38E+10	5.35E+09	9.21E+09	3.06E+10	5.20E+10	1.29E+10	8.14E+09	1.46E+11
Least Tern	5.46E+10	4.26E+09	6.75E+10	1.44E+10	5.57E+09	9.59E+09	3.19E+10	5.41E+10	1.29E+10	8.14E+09	1.52E+11
Royal Tern	9.63E+11	7.50E+10	1.19E+12	2.53E+11	9.82E+10	1.69E+11	5.61E+11	9.54E+11	1.29E+10	8.14E+09	2.68E+12
Sandwich Tern	1.68E+11	1.31E+10	2.08E+11	4.42E+10	1.72E+10	2.95E+10	9.81E+10	1.67E+11	1.29E+10	8.14E+09	4.69E+11
Wild Deer	5.06E+12	4.48E+11	6.33E+12	1.57E+12	6.11E+11	1.05E+12	3.75E+12	9.15E+12	5.00E+11	8.14E+09	1.76E+13
Feral Hog	3.96E+11	3.08E+10	4.89E+11	1.04E+11	4.04E+10	6.95E+10	2.31E+11	3.92E+11	1.08E+10	6.80E+09	1.10E+12
Bayou Wildlife Park	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.17E+12	0.00E+00	1.20E+10	7.56E+09	3.25E+12
Total	2.82E+12	2.20E+11	3.49E+12	7.42E+11	2.88E+11	4.96E+11	6.81E+12	2.80E+12	-	-	1.11E+13

4.2.4 Domestic Pets

Domesticated animals and pets, namely dogs and cats, are potential sources of indicator bacteria to Dickinson Bayou. The number of dogs and cats in the study area was estimated by assuming a density of dogs and cats per household, with 0.632 dogs per household and 0.713 cats per household (American Veterinary Medical Association, 2007). The number of households in the watershed was determined from the US Census housing projections for 2000 at the tract level (US Census, 2000). As shown in **Table 4-12**, the estimated number of dogs ranges from 328 in Assessment Unit 1103B_01 to 4,262 in Assessment Unit 1103_02. For cats, the estimated totals range from 371 in Assessment Unit 1103B_01 to 4,262 in Assessment Unit 1103_03. For cats, the estimated totals range from 371 in Assessment Unit 1103B_01 to 4,809 in Assessment Unit 1103_03. The load associated with these pets was estimated using loading estimates from the same sources used for livestock and is shown in **Table 4-13**.

Table 4- 12. Domestic Pet Populations by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit								Total Animals
	1103_02	1103_03	1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02	
Dogs	368	2,966	4,262	1,872	328	884	1,389	2,337	14,406
Cats	415	3,347	4,809	2,112	371	997	1,567	2,637	16,255
Total Pets	783	6,312	9,071	3,984	699	1,881	2,956	4,974	30,661

Table 4-13 Domestic Pet Daily *E. coli* Production by Assessment Unit in Dickinson Bayou

Type of Animal	Assessment Unit (FC counts/day)								FC Production (count/ animal/day)	EC Production (count/ animal/day)	Total EC Produced (MPN/day)
	AU 1103_02	AU 1103_03	AU 1103_04	1103A_01	1103B_01	1103C_01	1104_01	1104_02			
Dogs	1.21E+12	9.79E+12	1.41E+13	6.18E+12	1.08E+12	2.92E+12	4.58E+12	7.71E+12	3.30E+09	2.08E+09	3.00E+13
Cats	2.24E+11	1.81E+12	2.60E+12	1.14E+12	2.00E+11	5.38E+11	8.46E+11	1.42E+12	5.40E+08	3.40E+08	5.53E+12
Total Pets	1.44E+12	1.16E+13	1.67E+13	7.32E+12	1.28E+12	3.46E+12	5.43E+12	9.14E+12	-	-	3.55E+13

4.3 Bacteria Re-growth and Die-off

The load estimates presented in Chapter 4 do not reflect the effects of re-growth or die-off on the bacteria loading. In Chapter 5, water quality model results are presented which do account for die-off. They also consider re-growth to some extent, as the die-off rate can be considered the net difference between growth and decay.

CHAPTER 5:
MODELING APPROACH AND METHODS

One essential component of a TMDL is to establish a linkage, or relationship, between pollutant sources and pollutant concentrations in the impaired water body. Using this linkage, it is possible to determine the capacity of the water body to assimilate bacteria loadings while still supporting its designated use. Historically a wide range of modeling approaches have been implemented to assess TMDL endpoints and required wasteload and load allocation reductions. Most models have similar capabilities but are suited to evaluating different types of watersheds, depending upon the water quality parameters to be evaluated, time and spatial scales of interest, extent of available data and other site specific conditions. In addition, model applications vary significantly in terms of the economic expense and technical complexity required to adequately determine a TMDL that is scientifically defensible.

For this project, a Load Allocation Methodology Review was completed to identify the best approach for this watershed through the use of screening criteria (University of Houston and CDM, 2008). The model selected for use in the tidal portion of Dickinson Bayou was a coupled watershed/receiving water modeling strategy via HSPF combined with a tidal prism model. HSPF has been accepted as the technical basis for numerous TMDL evaluations in Texas. The tidal prism model was used in the USEPA approved Clear Creek TMDL for the tidal portion of Clear Creek. In addition, past TMDL projects in Virginia have shown that a well-established link can be developed between these two models to provide a seamless framework where bacteria fate and transport can be simulated. For the non-tidal portion of the watershed, load duration curve (LDC) analyses were used to specify loadings. The LDC approach is discussed in **Chapter 6**.

5.1 HSPF

Hydrological Simulation Program – Fortran (HSPF) is a highly regarded and widely used watershed modeling software. First developed in the 1970s, it is now in its twelfth version (Bicknell *et al*., 2001). HSPF offers deterministic, continuous modeling of runoff and pollutant mobilization using a large array of lumped parameters derived from watershed-specific information such as land use, subwatershed boundaries, rainfall, stream geometry and capacity, bacteria loading rates, 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 on an hourly or daily basis. HSPF also offers a simple one-dimensional receiving water model to simulate in-stream processes such as sediment resuspension and bacterial die-off.

The HSPF model developed in this work serves two purposes: (1) supply in-stream flows for the non-tidal portion of Dickinson Bayou to support the development of load duration curves to specify the total maximum daily load for Assessment units 1104_01 and 1104_02 in Segment 1104; and (2) provide an upper boundary condition for flow and water quality to the Tidal Model and provide runoff volume and pollutant loads to the Tidal Model from tidal subwatersheds. The Tidal Prism Model is described in **Section 5.2**.

The HSPF model requires a significant amount of input data and requires information to describe the Dickinson Bayou watershed, including:

- Delineation of Subwatershed areas;
- Meterologic and Physical Watershed Data;
- Hydrologic characteristics; and
- Bacteria loading for various sources within the watershed.

Each of these items will be discussed in the following sub-sections. The sections will describe the general development of the HSPF model.

5.1.1 HSPF Subwatersheds

As HSPF is a lumped parameter model, subwatersheds that define drainage areas with similar characteristics must be defined. As described previously, these subwatersheds were defined as part of the HSPF modeling process used during the development of a dissolved oxygen TMDL for Dickinson Bayou and no changes have been made to their boundaries.

A plot of the subwatersheds used in the study is presented in **Figure 5-1**. As shown in the figure, there are a total of twelve subbasins which are simulated in HSPF. Subbasin 12 and a portion of subbasin 11, correspond to the non-tidal portion of Dickinson Bayou (Segment 1104). The remaining watersheds were used to provide input into the tidal model described in **Section 5.2**.

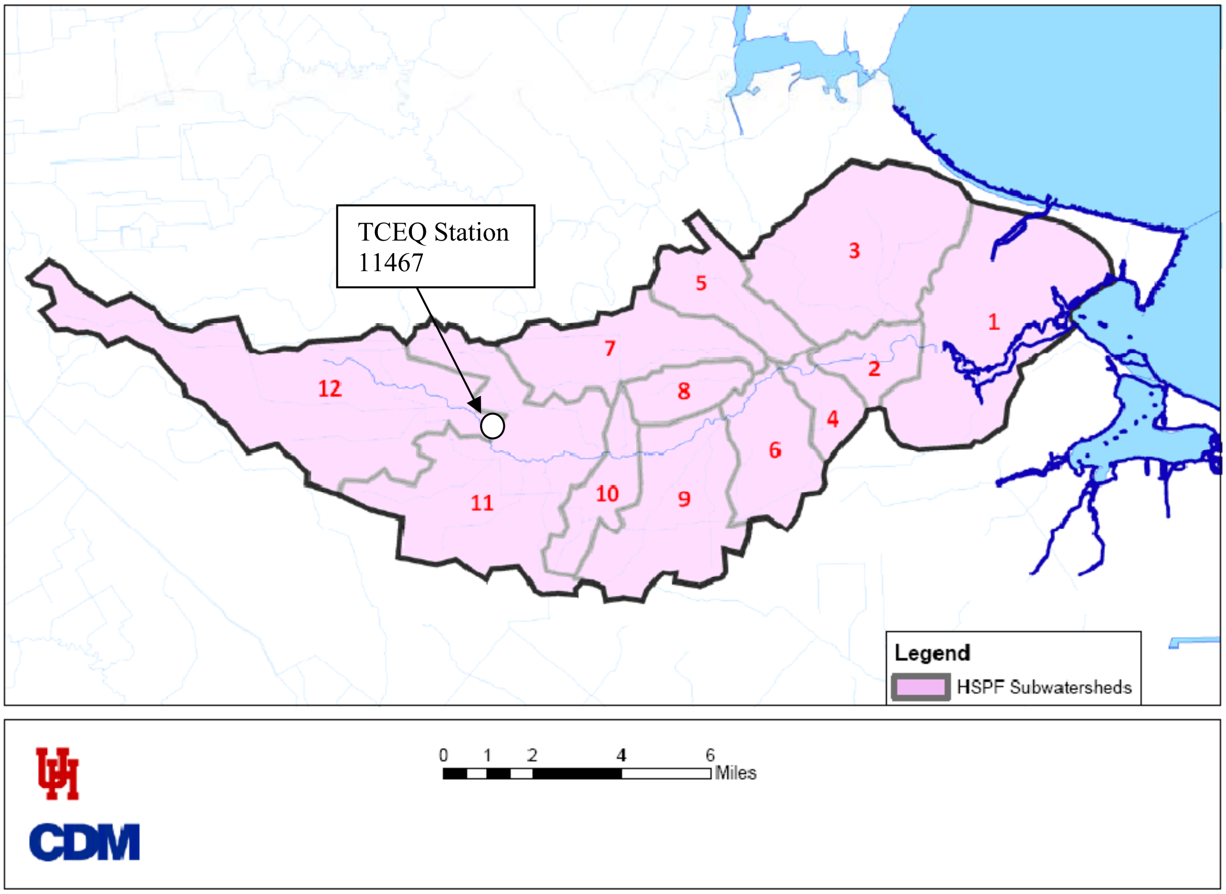


Figure 5-1 HSPF Subwatersheds

5.1.2 Meterologic and Watershed Data

HSPF has a large number of meterologic inputs required in order to execute, including precipitation, potential evapotranspiration, air temperature, dew point, solar radiation, cloud cover, and wind speed. A total of three meteorological stations were used for these data and include Houston National Weather Service Office (NWSO - Cooperative #414333), Houston Clover Field (Weather Bureau Army-Navy [WBAN] #12975) and Galveston Scholes field (Cooperative #413430). The simulation time period of the HSPF model runs from June 1, 1999 through December 31, 2008.

As mentioned previously, rain gauges in the watershed are quite sparse. As such, the Houston NWSO rainfall gauge was used as the primary rainfall gauge for almost all of watershed and supplemented, when missing data occurred, with information from Houston Clover Field. The rainfall data for the Houston NWSO gauge was available on a daily basis only; thus data from Houston Clover Field and Galveston Scholes field were used to disaggregate the daily rainfall in WDMUtil, a utility program included with the 2005 Windows version of HSPF (WinHSPF). A plot of the gauge coverage for the watershed is shown in **Figure 5-2**. The map demonstrates that only one subwatershed, subbasin 12, relies on Houston Clover field for rainfall data. All other gauges use the Houston NWSO gauge.

Other watershed information that were used in the set-up of the HSPF model included soils and land use. Soils and land use data presented in **Chapter 2** provide the basis for the information included in the model. Soils data from STATSGO were used to define infiltration parameters as well as sediment parameters. Land use data from H-GAC (2002) were used throughout the model to define pervious and impervious land areas, vegetation and numerous hydrologic and bacteria loading parameters. The land use from H-GAC was modified to reflect pasture/hay land use from the National Land Cover Dataset (USGS, 1992) as a subcategory of the H-GAC grassland classification.

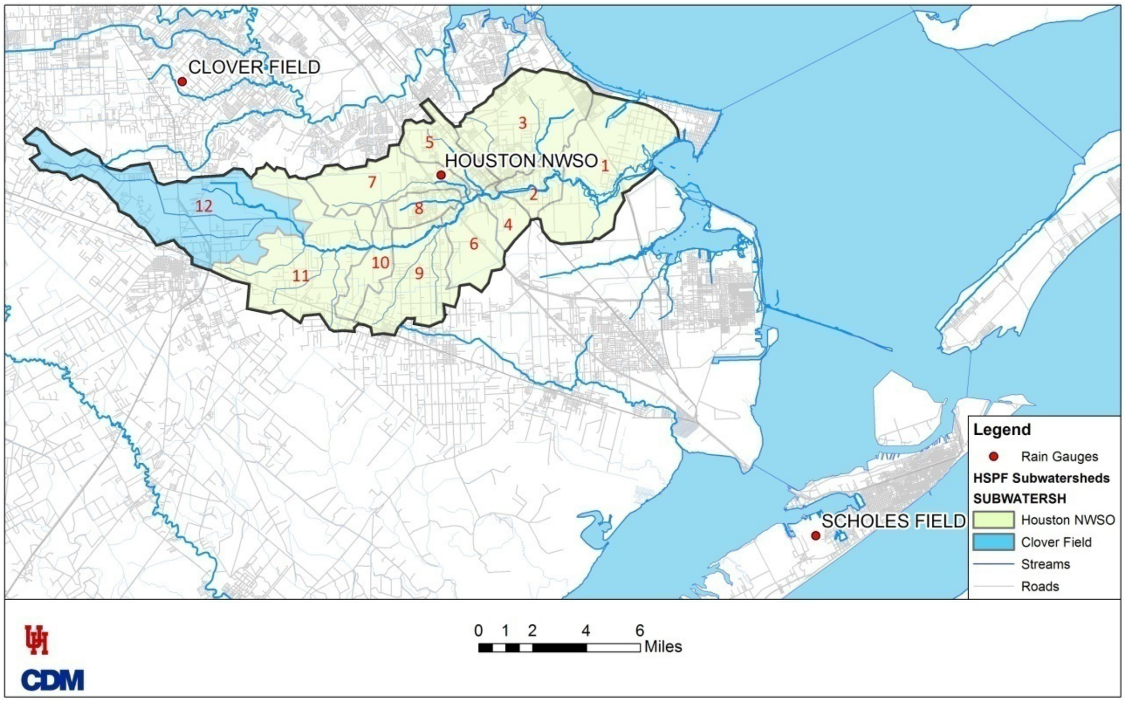


Figure 5-2 Rain Gauges for Dickinson Bayou Modeling

5.1.3 Hydrologic Characteristics

Hydrologic set-up and calibration for HSPF relies on a large amount of data to specify stream characteristics as well as matching the water balance observed in the model with measurements observed in the stream. Much of the hydrology and hydraulics for the Dickinson Bayou HSPF model were determined from data available from the USGS, including stream lengths, rating tables as well as stream and watershed slopes.

The Dickinson Bayou watershed does not have a continuous stream gauge to use for calibration. Instead, flow from a nearby stream, Chocolate Bayou, was transformed by adjusting for differences in WWTF discharges and drainage areas to create a synthetic flow times series for Dickinson Bayou. A map showing the location of the Chocolate

Bayou watershed is presented in **Figure 5-3**. The resulting synthetic flow time series for Subbasin 11 is presented in **Figure 5-4**.

During the process of working with the synthetic flows, it became apparent that the intricacies of weather, rainfall and development patterns in Chocolate Bayou were not entirely representative of those in the Dickinson Bayou watershed. As such, the calibration process for the HSPF model as it is normally understood was not possible for Dickinson Bayou because the synthetic flow time series was used as a substitute for measured flow.

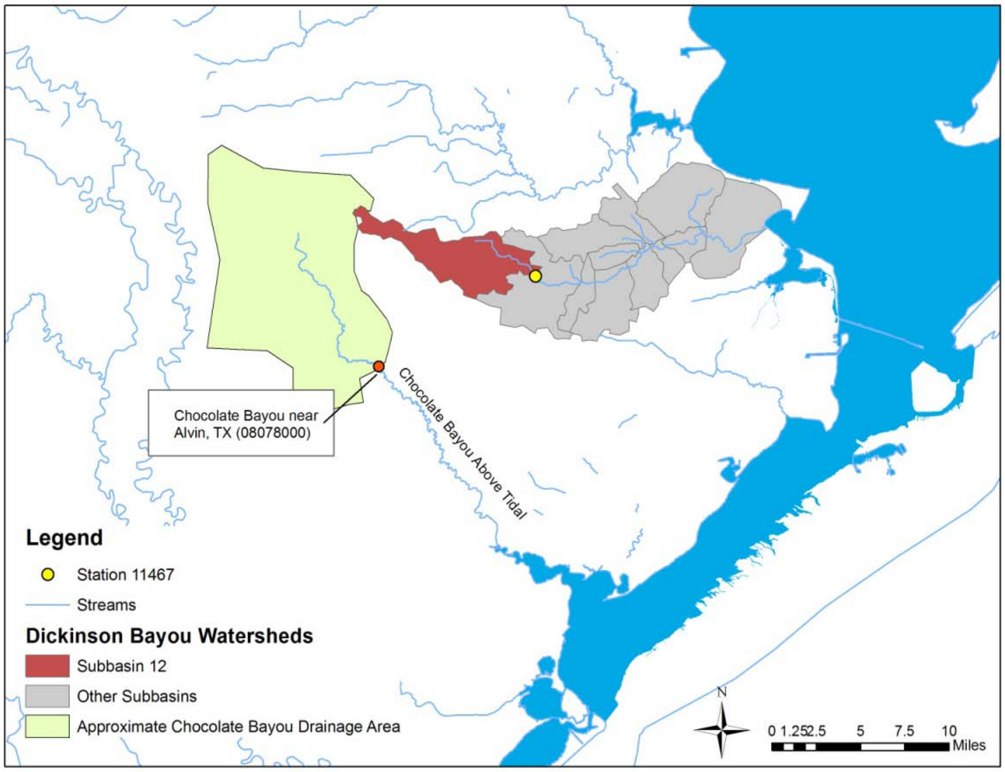


Figure 5-3 Chocolate Bayou Drainage Area Location

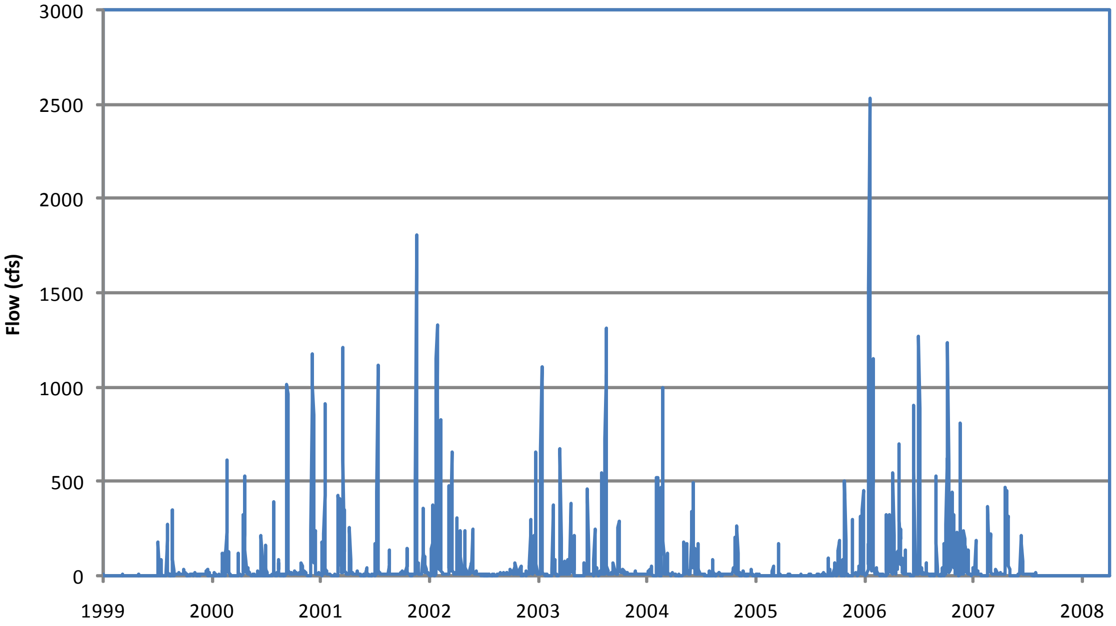


Figure 5-4 Synthetic Flow Data for Reach 11

Nonetheless, the Dickinson Bayou HSPF model was tested against the synthetic flow data to obtain the best fit possible in Subbasin 11. The model was tested against the synthetic data between June 1, 1999 through December 31, 2004 with the validation period being January 1, 2005 through December 31, 2008. An example of the model calibration is presented in **Figure 5-5**. The plot demonstrates that the model occasionally exhibits a hydrograph that is not present in the synthetic data; this discrepancy is likely due to the use of synthetic data where rainfall patterns may not coincide exactly with those in Dickinson Bayou. Another comparison is presented in **Figure 5-6** which shows flow duration curves for modeled and synthetic flows at Reach 11. This plot demonstrates that, in terms of frequency patterns, the modeled and synthetic flow distributions are quite similar in nature.

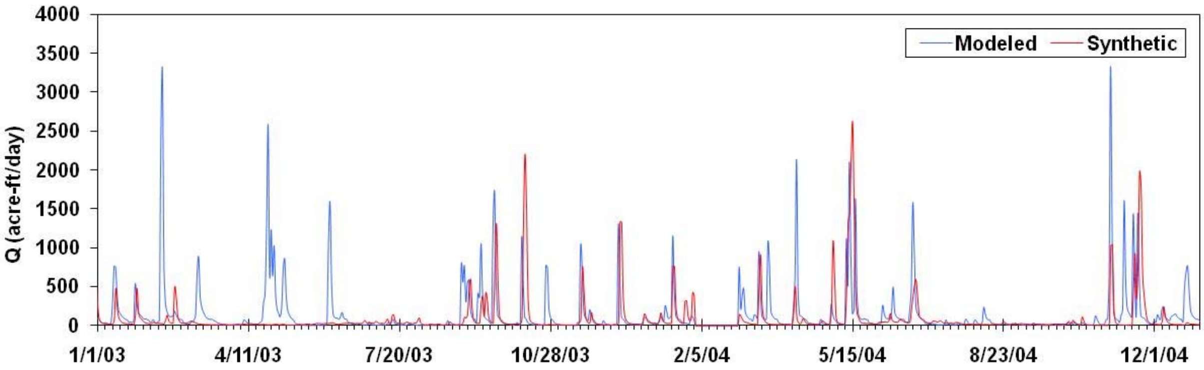


Figure 5-5 Flow Comparison for 2004

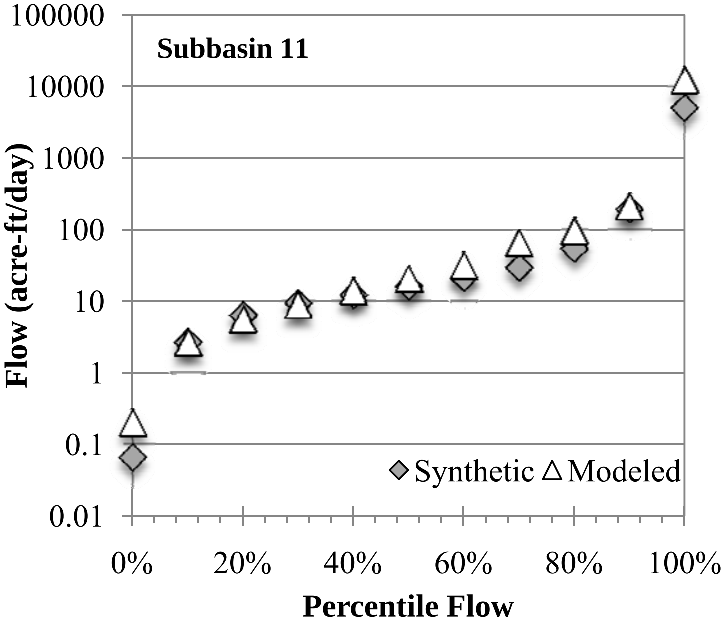


Figure 5-6 Flow Duration Curve for Synthetic and Modeled Flows, Reach 11

5.1.4 Bacteria Data

The simulation of water quality, specifically bacteria concentrations in simulated flows, was included in the HSPF model to provide runoff loads to the tidal prism model.

Bacteria loading inputs in HSPF consisted of WWTFs loading and watershed loading from accumulation/wash-off. SSOs were not included in the HSPF model since none were identified in the non-tidal portion of the watershed; SSOs in the tidal portion of the watershed were incorporated into the tidal prism/box model.

Bacteria loading for WWTFs was specified using measurements collected in the Dickinson Bayou watershed. Plants that were not monitored used the net mean(?) *E. coli* concentration associated with the Galveston County WCID No. 1 (10173-001), 40 MPN/dL; this value was also used for Pine Colony (KC Utilities) WWTF (12935-001).

The other primary source of bacteria loading in the HSPF model is accumulation (build-up) and wash-off. Development of the accumulation/wash-off coefficients in the model first focused on estimating the number of animals in the watershed and their associated bacteria loading potential from literature values, which were detailed previously in **Chapter 2**. The loading estimates were then adjusted within the range of values reported in the literature to match the edge-of-field runoff concentrations from each land use to literature EMCs (Baird *et al*., 1996, Pitt *et al*., 2004, McCarthy *et al*., 2006, Stormwater Joint Task Force, 2002).

The results of the *E. coli* EMC testing are presented in **Table 5-1**. All EMCs were adjusted to be within the literature value ranges, except for pasture land. Pasture EMCs are higher than those specified in the literature because it was assumed that all livestock were associated with pastureland. The EMC estimate for pasture land from the literature, on the other hand, is more representative of land without the influence of livestock. The EMC concentration is also consistent with other TMDLs, such as the Willamette Basin TMDL where the agricultural bacteria EMC was 1.3 times that of the residential/urban EMCs (State of Oregon Department of Environmental Quality, 2006).

Table 5-1 EMC Results for HSPF

Land Use	Literature Range		Houston Value	Calibrated EMC (MPN/dL)
Malfunctioning Septic Systems	50,000	500,000	n/a	289,692
Low Density Residential	33,630	63,357	26,963-52,342*	38,563
High Density Residential	101	73,836	26,963-52,342*	75,896
Commercial, Industrial, Transportation	730	44,632	16,918-105,158	35,568
Barren	44,632		44,632	46,475
Natural	2,500	7,200	2,500	3,357
Cultivated	2,500		2,500	3,522
Pasture	2,500		2,500	96,986**

* includes both high and low density residential

** Literature values for pasture do not include livestock runoff; calibrated EMC value does.

Another key calibration process focused on matching in-stream concentrations at TCEQ monitoring station 11467, located at the outlet of Reach 12 and shown on **Figure 5-1**. Obtaining a good fit between the observed in-stream *E. coli* levels in Dickinson Bayou and those in the model focused primarily on adjusting bacteria die-off coefficients. The calibrated value was determined to be 1.0 per day in the model which is within the typical range reported in the literature.

Limited data were available for calibration at TCEQ monitoring station 11467; only 48 data points were available between December 2001 and November 2008. Because of this limited data availability, calibration focused on the entire period record at Station 11467. A comparison of modeled and observed values is presented in **Figure 5-**

7. The figure demonstrates that the model reproduces the range of bacteria concentrations observed during the period of record at the station. It is important to note that although the HSPF model was tested and adjusted using observed in-stream bacteria concentrations, the TMDL and TMDL load allocations are determined using the LDC method and tidal prism approach.

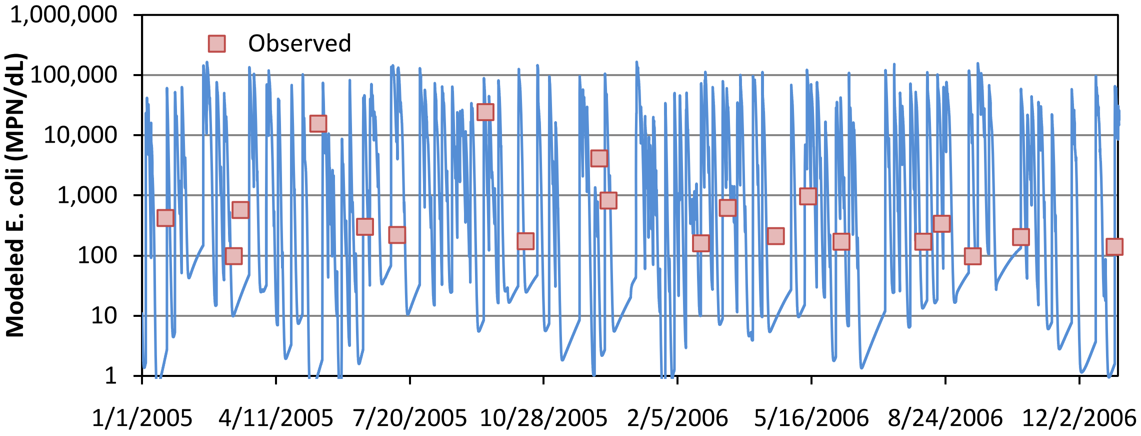


Figure 5-7. Bacteria Calibration Plot at station 11467

5.2 Tidal Modeling

Tidal prism models (TPMs) or box models 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 (1951), and several TPMs have been developed and refined to apply the concept towards water quality modeling of a variety of constituents, including bacteria (Kuo *et al*, 1988; Shen *et al*., 2005; Kuo *et al*., 2005). Tidal prism models 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 *et al*, 1988; Shen *et al*., 2005; Kuo *et al*., 2005; Wang *et al*., 2005).

Data requirements are fairly low for tidal prism models compared to some other mechanistic receiving water models, but generally they can only be used for smaller tidal basins and estuaries since one of the key assumptions is that the tide rises and falls simultaneously throughout each modeled segment. Other key input parameters include bathymetric data, such as water depth and surface area.

To simulate enterococci in the tidal portion of the watershed, a time-variable tidal prism box model was developed in Microsoft Excel for the same simulation period as the HSPF model, June 1, 1999 through December 31, 2008. The period June 1, 1999 through November 5, 2001 was used for the TMDL calculations presented in this report because the land use, bathymetry and boundary condition data are representative of that same time period. The tidal prism box model 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 tidal prism box model is shown in **Figure 5-8**. 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, WWTF and SSOs. Die-off and tidal exchange represent the two potential sinks of enterococci in the tidal box model.

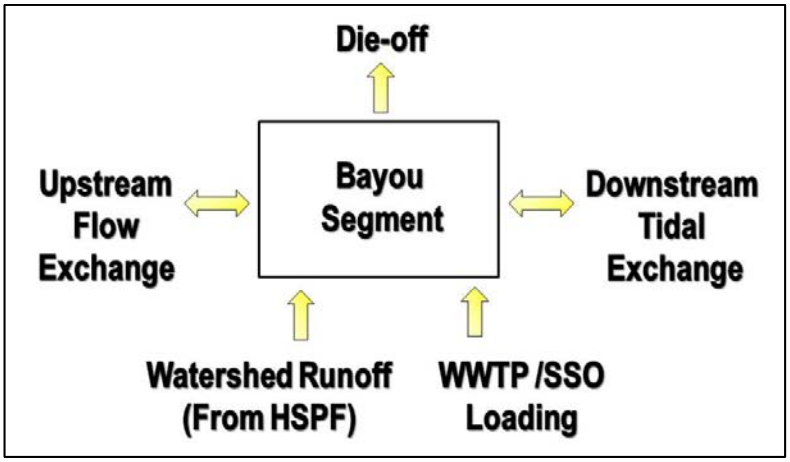


Figure 5-8. Tidal Prism Box Model Conceptual Model

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

1. The presence of a TCEQ monitoring station;
2. The presence of an Assessment Unit boundary; or
3. 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 5-9**. As shown in the figure, there are a total of 18 model segments in the tidal prism box model, with five segments associated with tributaries.

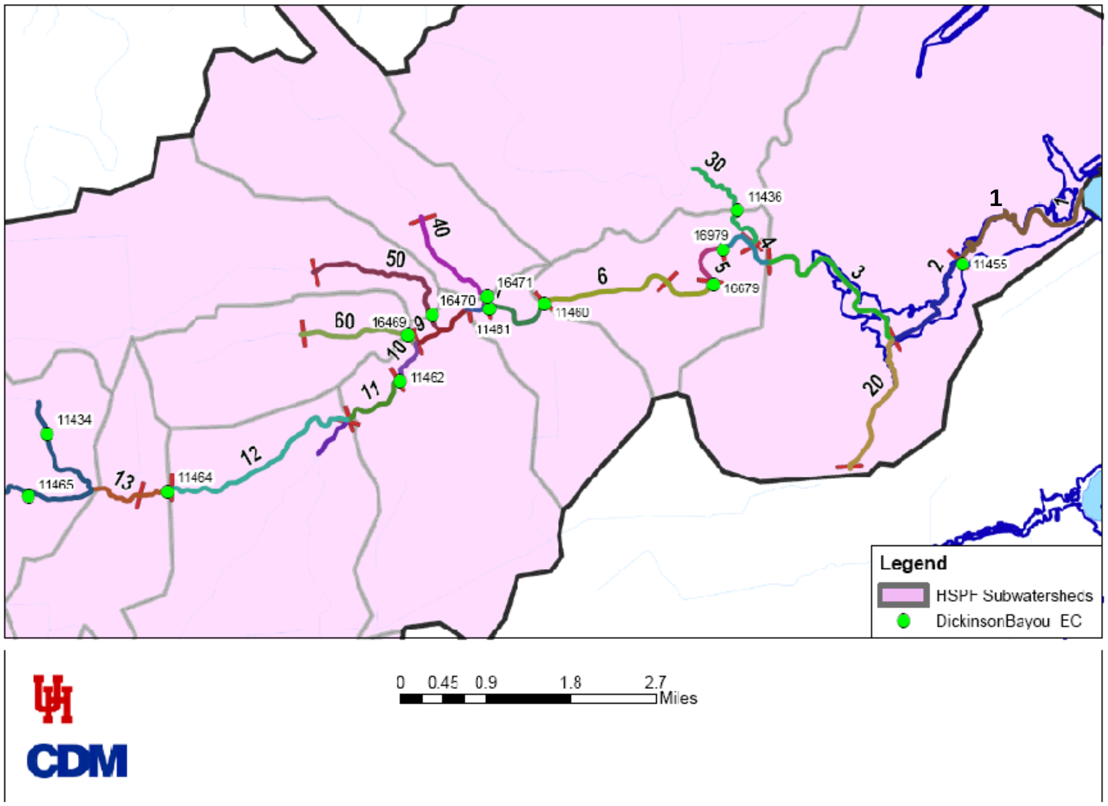


Figure 5-9. Tidal Prism Box Model Segmentation

5.2.1 Hydraulics

The changes in volume associated with change in water level as a result of tidal fluctuations is a critical component that must be accounted for in the tidal prism box model. The volumes generated and used in the tidal prism model are based on stream cross-sections collected by the USGS in the late 1990's. These cross-sections, while not detailed, provide the best available data upon which to base the volume calculations. Alternative means of calculating volumes, such as use of a HEC-2 model, would have relied on even older data to specify this critical parameter. When and if newer and more detailed data become available (such as LiDAR elevations), they may be used to refine the model and potentially yield improvements in the overall hydraulic simulation of the tidal prism box model.

To define the volumes, the first step is to define a tidal boundary condition. For the Dickinson Bayou model, the tidal boundary was developed using a combination of USGS measurements and Eagle Point (NOAA station 8771013) tide data. Tide data were collected briefly by the USGS from December 2000 through August 2001 at Dickinson Bayou where it crosses Highway 3 in the watershed. Because this tide gauge was located directly in the project watershed, it was used as the basis for the tide boundary. To fill in the large gaps where USGS did not collect data in the simulation period, a correlation between Eagle Point tide data and the USGS tide data was developed and used to adjust the Eagle Point data to be representative of a Dickinson Bayou tide elevation time series. After water levels were determined, they were used in conjunction with the cross-sectional area and length of the segment to calculate the volume at various locations throughout the tidal portion of Dickinson Bayou. As shown in the conceptual model, the tidal prism box model also receives input of flow from WWTF discharges, SSOs, the upstream boundary condition from the non-tidal portion of the watershed (based on HSPF flows) as well as watershed runoff from the HSPF model. These inputs were included as point sources to each segment of the tidal prism model. For the calibrated model, WWTF discharges were based on monthly flows reported in PCS while SSO discharges were based on average flows of SSOs in each segment provided by Galveston County.

The model was tested with salinity which acts as a conservative tracer to confirm the adequacy of the model hydraulics as well as the simulated freshwater inflows and tidal exchange. A plot of the average salinity concentrations longitudinally along the bayou are presented in **Figure 5-10**. The overall average error at all locations over the simulation period between observed and modeled salinities was 17%. Based on the salinity model runs, the model hydraulics are sufficient to simulate the hydrodynamics of the tidal segment of Dickinson Bayou with a satisfactory level of accuracy.

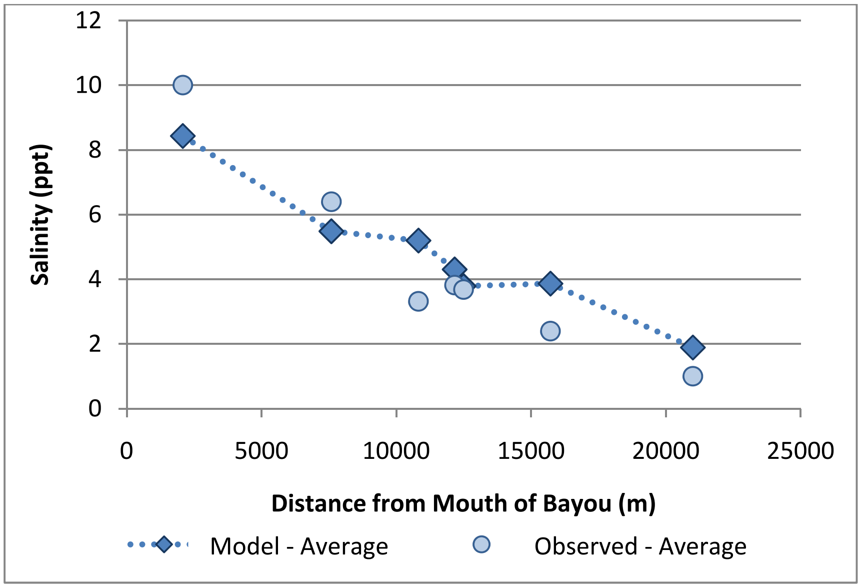


Figure 5-10. Longitudinal Profile of Simulated and Observed Salinity in Dickinson Bayou

5.2.2 Bacteria Simulation

To simulate bacteria, the tidal prism box model must account for several sources of bacteria as detailed in the conceptual model. These enterococci sources and sinks includes WWTFs, SSOs, and HSPF inflow, as well as upstream boundary conditions (obtained from the HPSF simulation), downstream boundary conditions and reductions as a result of die-off.

Boundary conditions are an important consideration in the tidal prism box model. The downstream boundary condition in the tidal prism box model was specified using observed data from TCEQ monitoring station 15219. This station is close to the outlet of Dickinson Bayou and generally has concentrations near the detection limit with an average concentration between 10 and 13 MPN/dL during the period it was monitored between May 8, 1997 and July 27, 2005. The upstream boundary condition used for the tidal prism box model was defined using *E. coli* concentrations simulated by HSPF entering the tidal portion of the Dickinson Bayou watershed; these *E. coli* concentrations were transformed into enterococci using a ratio of the geometric mean standards, or 35 / 126.

Additional sources of bacteria to the model included the inflows from runoff in the tidal subwatersheds that were simulated by HSPF. Like the upstream boundary condition, all *E. coli* concentrations simulated in the HSPF model were transformed into enterococci concentrations using a ratio of the geometric mean standards, or 35 / 126. The transformed bacteria concentrations were input into the tidal prism box model as point sources into each model segment.

WWTF discharges were also treated as point sources into the tidal prism box model. The enterococci concentration assigned to each facility was the net mean value measured during sampling at the Galveston County WCID No. 1 facility, which was 8.3 MPN/dL when transformed using the ratio of standards to enterococci. Similarly, the SSO discharges were assigned typical enterococci concentrations associated with SSOs ($3.1\text{x}10^5$ MPN/dL) reduced by 72% to reflect a delivery ratio as specified in the US EPA Report on Combined and Sanitary Sewer Overflows (2004). **Table 5-2** presents a summary of the flows and loads that were used in the tidal model.

Table 5-2. Summary of WWTF and Sanitary Sewer Overflow discharges in Tidal Prism Model

Model Segment	Source	Self-Reported Average WWTF Flow (MGD)[2]	SSO Flow (m^3/hr)	Assigned Con-centration (MPN/dL)	Average Load (MPN/day)
1	Duratherm Asset Acquisition Corp	0.431	-	8.3	3.01E+08
	Hillman Shrimp & Oyster Co.	0.005	-	8.3	6.28E+05
2	Via Bayou RV Resort WWTF	0.002	-	8.3	6.28E+05
4	Sanitary sewer overflows (SSOs)	-	3.01E-05	310,840	2.24E+06
5	SSOs	-	7.22E-04	310,840	0.00E+00
6	Galveston County WCID #1	2.759	-	8.3	1.74E+09
	Penreco - Dickinson TX Plant	0.057	-	8.3	1.79E+07
	SSOs	-	7.47E-04	310,840	5.57E+07
7	SSOs	-	3.04E-03	310,840	2.27E+08
11	SSOs	-	3.04E-03	310,840	2.27E+08
20	Sea Lion Technology	0.058	-	8.3	1.82E+07
30	Marlin Atlantis White	n/a[1]	-	n/a[1]	n/a[1]
	SSOs		13.1	310,840	9.77E+11
40	SSOs		6.86E-02	310,840	1.02E+09
50	SSOs		7.74E-03	310,840	2.89E+08

Note [1] The USEPA PCS database does not report flow for this WWTF; [2] average flow reported between November 1999 and February 2007;

The tidal prism model was tested against observed enterococci concentrations for the time period between June 1, 1999 through November 5, 2001. To match modeled concentrations to observations, the bacteria decay rates were adjusted between 0.25 and 2.0 per day, within typical literature values (Bowie *et al*., 1985; Beaudeau *et al*., 2001; Liu et al., 2006). Although SSO data were not available for this time period, SSO loading was also included in one segment where frequent SSOs were observed between 2002 and 2008 to match in-stream loading at that reach.

The results were compared against observed enterococci at all locations where monitoring data were available along the main stem of the bayou as well as at tributary outlets. **Table 5-3** shows a comparison of geometric means between the model and observed values at TCEQ monitoring stations, which are shown in **Figure 5-11**. As can be seen from the table, the comparison between observed and modeled geometric means ranges from -40% to 138%, with average errors between observed and modeled values being 30%.

A longitudinal plot of the modeled and observed concentrations was also prepared using the geometric means and is presented in **Figure 5-12.** The plot demonstrates there is very good agreement throughout most of the watershed between the model and observed values. Around river meter 11,000 there is some overestimation of the observed value while at approximately river meter 13,000 the model underestimates the observed enterococci concentration to some extent.

Table 5-3. Comparison of Model and Observed Geometric Means for Tidal Prism Box Model

Station/Reach	Observed Geometric Mean	Modeled Geometric Mean	Error
11455/Reach 2	6.0	6.3	51%
16979/Reach 5	28.0	33.4	19%
16679/Reach 6	10.2	19.1	56%
11460/Reach 7	56.1	63.1	13%
11461/Reach 8	160.5	115.2	-28%
11462/Reach 11	76.9	87.5	14%
11464/Reach 13	71.3	69.2	-3%
11436/Reach 30	5831.5	15010	157%
16471/Reach 40	75.8	412.5	-81%
16470/Reach 50	95.8	98.9	-3%
16469/Reach 60	171.0	48.0	72%

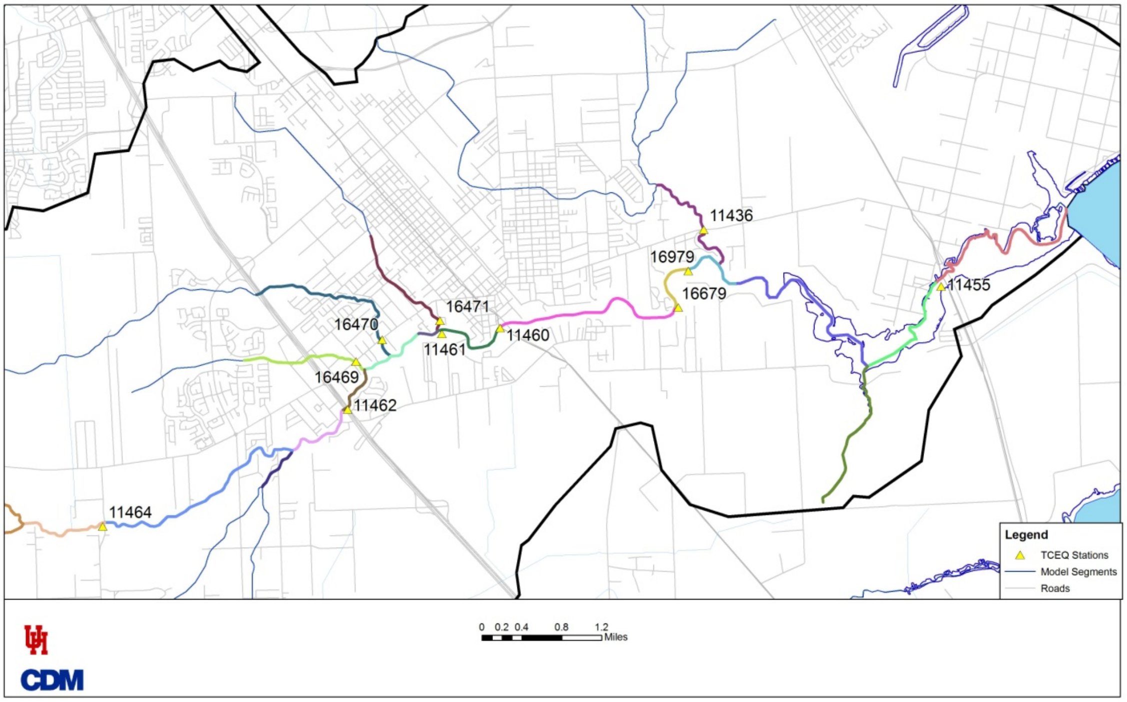


Figure 5-11. Monitoring Station Locations Used for Tidal Prism Box Model Comparison

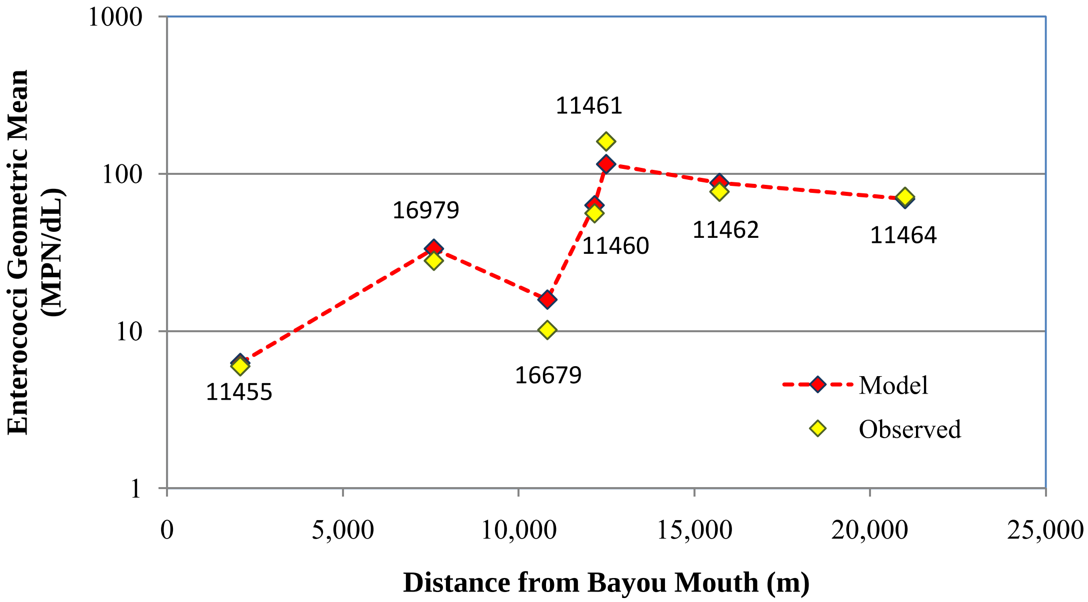


Figure 5-12. Longitudinal Profile of Simulated and Observed Enterococci in Dickinson Bayou

5.3 TMDL Calculations

The TMDLs for the tidal AUs were calculated using the tidal prism model. The TMDLs were calculated based on flows for each AU simulated in the tidal prism for the period from June 1, 1999 through November 5, 2001 multiplied by the water quality standard of 35 MPN/dL. The median of the load for each segment was used to specify the TMDL. Observed loads were calculated at the outlet of each AU as the median of the enterococci loads associated with flow downstream in the bayou. The calculated loads are summarized in **Table 5-4**. To meet the TMDLs in the tidal segments, reductions in source loadings are required. The required reductions for the tidal segments are presented in the Table and range from 0.00E+00 in 1103_02 to 1.14E+12 in 1103_04.

Table 5-4. Summary of TMDL and Observed Loads

Stream Name	Assessment Unit	TMDL (MPN/day)	Observed Load (MPN/day)	Reduction Required(MPN/day)
Dickinson Bayou Tidal	1103_04	6.74E+10	1.21E+12	1.14E+12
	1103_03	9.41E+10	1.31E+11	3.72E+10
	1103_02	2.41E+11	1.11E+11	0.00E+00
Bensons Bayou	1103A_01	9.26E+09	1.54E+10	6.14E+09
Bordens Gully	1103B_01	1.65E+09	2.14E+09	4.95E+08
Geisler Bayou	1103C_01	4.14E+09	6.00E+09	1.85E+09

CHAPTER 6: LOAD DURATION CURVE ANALYSES

Load duration curves (LDCs) are graphs of the frequency distribution of loads of pollutants in a stream. The basic steps to generate LDCs involve:

- preparing flow duration curves (FDC) – the Hydrologic Simulation Program-Fortran (HSPF) model was used to generate flow records that have incorporated the permitted flow for WWTFs at the monitoring stations chosen for analysis;
- identifying the critical flow range from the FDCs to define the loading reductions necessary to attain the appropriate TMDL water quality target – the mid-range flow regime (20th-80th percentile range) was chosen as most representative and protective of the contact recreation use in Dickinson Bayou Above Tidal (i.e., swimming is not expected to occur at high flows due to safety concerns nor at very low flows due to a lack of sufficient depth in the Above Tidal portion of the bayou);
- converting the flow duration curves to Load Duration Curves (LDCs);
- estimating existing indicator bacteria loading in the receiving water using ambient water quality data collected at the stations selected for analysis;
- interpreting LDCs to derive TMDL elements—Waste Load Allocation (WLA), Load Allocation (LA), Margin of Safety (MOS), and load reduction goals.

The following section presents a summary of the methodology used to develop flow duration curves for Dickinson Bayou.

6.1 Flow Duration Curves

A continuous historical flow record is not available for Dickinson Bayou due to a lack of flow gauging stations in the bayou and thus, historical flows were simulated using a watershed model, the Hydrologic Simulation Program –Fortran (HSPF). The model was calibrated using physical information about the bayou and its watershed collected between June 1, 1999 and December 31, 2004. The calibration process for the HSPF model, as it is normally understood, was not possible for Dickinson Bayou as flow gauge data were not available; therefore, a synthetic flow time series was substituted and used for model calibration. The HSPF model of the Dickinson Bayou watershed was also used to support the tidal prism/mass balance model discussed in more detail in **Appendix B**.

It is important to note that, in accordance with accepted practice, the simulated flows for the FDC reflect contributions from WWTFs using permitted flow. The simulated hourly flows from the HSPF model simulating full permitted flow from WWTFs were converted to daily values to calculate a Flow Duration Curve (FDC) at the outlet of each AU. FDCs are graphs of the frequency distribution of flow in streams. The flow exceedance frequency (x-value of each point) is obtained by determining the percent of flow that equals or exceeds the measured or calculated flow associated with a specific location in a stream. The generated FDCs for Dickinson Bayou Above Tidal are shown in **Figures 6-1** and **6-2**.

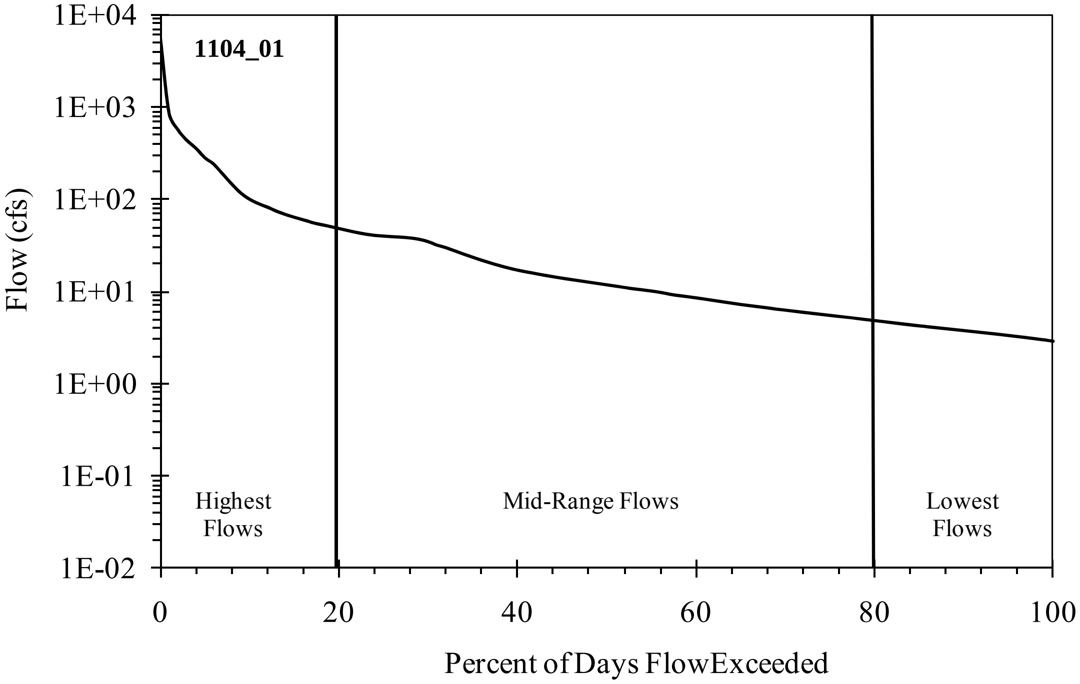


Figure 6-1. Flow Duration Curve for Assessment Unit 1104_01

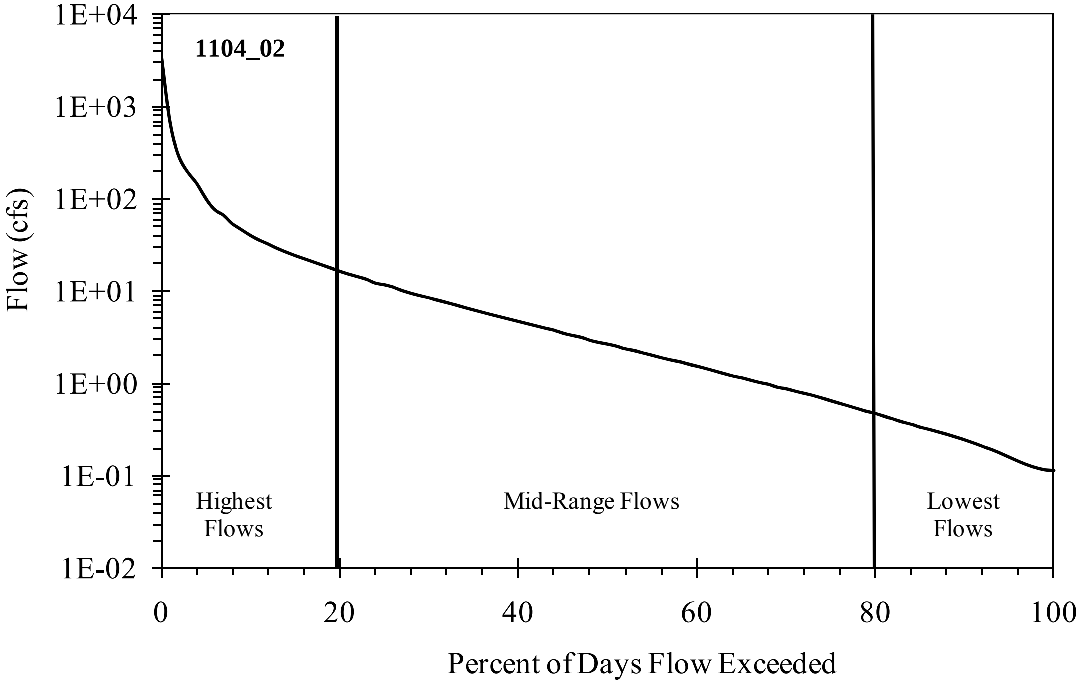


Figure 6-2. Flow Duration Curve for Assessment Unit 1104_02

The historical flow was separated into three flow regimes:

- 0 to 20th percentile: Highest flows;
- 20th to 80th percentile: Mid-range flows; and
- 80th to 100th percentile: Lowest flows.

The mid-range flow regime was chosen as the critical flow range for the calculation of the TMDLs because it is thought to be most representative and protective of the contact recreation use in Dickinson Bayou Above Tidal, as the average water depth in this part of the bayou is less than half of a meter during low flows (80th-100th percentile range) and contact recreation is not advisable due to safety concerns at the highest flow (0-20th percentile flow regime). The 20-80 percentile flow range also encompasses the largest portion of flow frequencies of the FDC.

Once the flow duration curves were prepared, the next step in the TMDL process was to develop load duration curves.

6.2 Load Duration Curve Analysis

Load duration curves are similar in appearance to flow duration curves; however, instead of flows, values are expressed in terms of an indicator bacteria load in MPN/day. The flow for each percentile between 0 and 100 (at 1 percentile intervals) was multiplied by the water quality standard, as shown in **Equation 6-1,** to derive the load duration curve (LDC). Flows used in the LDC analysis are based on HSPF simulations previously described that incorporate the permitted flow for WWTFs in the segment. For these LDCs, the water quality target was set at the *E. coli* geometric mean water quality criterion. An explicit margin of safety was incorporated into the analysis by reducing the assimilative capacity of the stream by 5%, hence the overall water quality target shown in the LDC is 120 MPN/dL rather than the geometric mean criterion of 126 MPN/dL. The calculated LDC is then used to specify the total maximum daily load (TMDL) at any given flow condition.

Equation 6-1

$$\text{LDC} = \text{swqs} * (1\text{-MOS}) * \text{flow} * \text{unit conversion factor}$$

where:

swqs (surface water quality standard) = 126 MPN/100mL *E. coli*

flow (cfs) = flow at each percentile

MOS = 0.05; and

unit conversion factor = 24,465,758 $100 mL \cdot s/cfs \cdot day$.

The measured *E. coli* values were paired with simulated flows occurring on the date of sample collection (using the HSPF model with permitted WWTF flow to generate the flows) to calculate an instantaneous bacteria load (E. coli concentration * instantaneous flow) and plotted on the LDC.

In addition to observed bacteria loads, WWTFs were also included in the LDC analysis. The permitted flows were used to calculate the wasteload allocations (WLAs) for WWTF in the AUs. The loading associated with these facilities is referred to as the waste load allocation (WLA) and was calculated using **Equation 6-2**.

Equation 6-2

$$\text{WLA}_{\text{WWTF}} = \tfrac{1}{2} * \text{swqs} * \text{flow} * \text{unit conversion factor}$$

where:

swqs (surface water quality standard) = 126 MPN/100mL *E. coli*

flow (10^6 gal/day) = permitted WWTF flow; and

unit conversion factor = 37,854,120 100mL/10^6gal.

The WLA_{WWTF} does not include wastewater loads associated with anticipated future growth. The future WWTF loads are calculated separately and are added to the LDC load to derive the TMDL.

6.3 Load Duration Curve Analysis Results

The following section provides a summary of LDC analysis results for the two freshwater Assessment Units in Dickinson Bayou, 1104_01 and 1104_02.

6.3.1 Assessment Unit 1104_01

Shown in **Figure 6-3** is the LDC developed for Assessment Unit 1104_01. The indicator bacteria data used to develop the LDC was obtained from the closest TCEQ indicator bacteria sampling locations, station 11465 (Dickinson Bayou at Jack Beaver), using data collected by the TCEQ routine monitoring from July 10, 2000 through May 17, 2001. One permitted WWTF, TPDES permit number 03416-000 (Waste Management of Texas) is included in this segment. Thus a waste load allocation (WLA) was included for this facility located near a tributary contributing to the Above-tidal segment of Dickinson Bayou. Since this facility is permitted to discharge intermittently, with no specific flow limit, the LDC was derived using the average annual discharge volume multiplied by the water quality standard of 63 MPN/dL (i.e., one-half of the water quality standard of 126 MPN/dL). The LDC indicates that *E. coli* concentrations typically exceed the long-term geometric mean water quality standard in this Assessment Unit in the highest flow range.

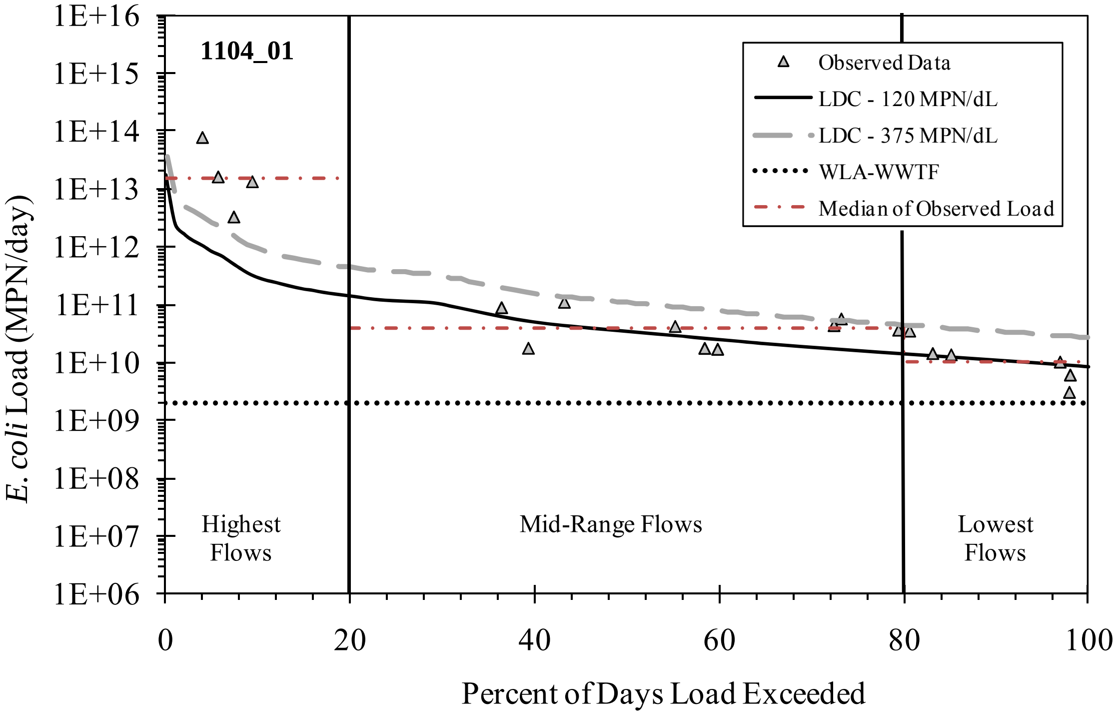


Figure 6-3 Load Duration Curve for *E. coli* in Assessment Unit 1104_01

Shown in **Table 6-1** is a summary of flow, existing loads, LDC and margin of safety for AU 1104_01 for all three flow conditions. The existing *E. coli* loads in the bayou ranged from 1.01E+10 under the lowest flow regime to 1.50E+13 MPN/day under the highest flow regime. The calculated LDC ranged from 1.10E+10 MPN/day to 3.21E+11 MPN/day.

Table 6-1. Load allocations and reductions for Segment 1104_01

Condition	0-20%	20-80%	80-100%
Median Flow (cfs)	109.49	11.83	3.74
Target Concentration (MPN/dL)[1]	119.7	119.7	119.7
Observed Load, Median (MPN/day)	1.50E+13	3.90E+10	1.01E+10
LDC, Median (MPN/day)	3.21E+11	3.46E+10	1.10E+10
Margin of Safety Load, Median (MPN/day)	1.69E+10	1.82E+09	5.76E+08
Required Reduction (MPN/day)	1.47E+13	4.37E+09	0.00E+00

Note: [1] Reflects a 5% margin of safety on the 126 MPN/dL contact recreation standard

6.3.2 Assessment Unit 1104_02

The LDC for Assessment Unit 1104_02 is presented in **Figure 6-4**. The indicator bacteria data used to develop LDC was obtained from the closest TCEQ monitoring station located at the outlet of AU 1104_02, station 11467 (Dickinson Bayou at FM 517), and includes data collected by the TCEQ during routine monitoring from June 16, 2001 through December 2, 2008. A total of three permitted WWTFs, TPDES permit numbers 12935-001, 13632-001 and 14440-001 are included for these facilities in **Figure 6-4** using the same methodology as for Assessment Unit 1104_01.

In the lower percentile flows, Segment 1104_02 can become effluent dominated. When the stream is effluent dominated, the load value on the LDC falls below the WLA_{WWTF}. In these situations, the WWTF load allocation value is plotted on the LDC in place of the (lower) LDC load. Under these conditions, it is assumed that the WWTFs are compliant with permit requirements and, therefore, their discharges will not result in criterion exceedances. It should noted that, because of this assumption, the LDC median load for the lowest flow regime cannot be used to directly calculate the LDC or margin of safety.

Figure 6-4 shows that *E. coli* concentrations are distributed above the LDC, indicating that frequent exceedances of the contact recreation standard, primarily in the mid-range and high flow conditions. The required load reductions, based on comparing the observed load and calculated LDC, are presented in **Table 6-2** and range from 0.00E+00 MPN/day under the lowest flow condition to 4.85+11 MPN/day under the highest flow condition. The mid-range flow was used to calculate the TMDL, as it represents the average conditions in the watershed and the conditions most likely to support contact recreation.

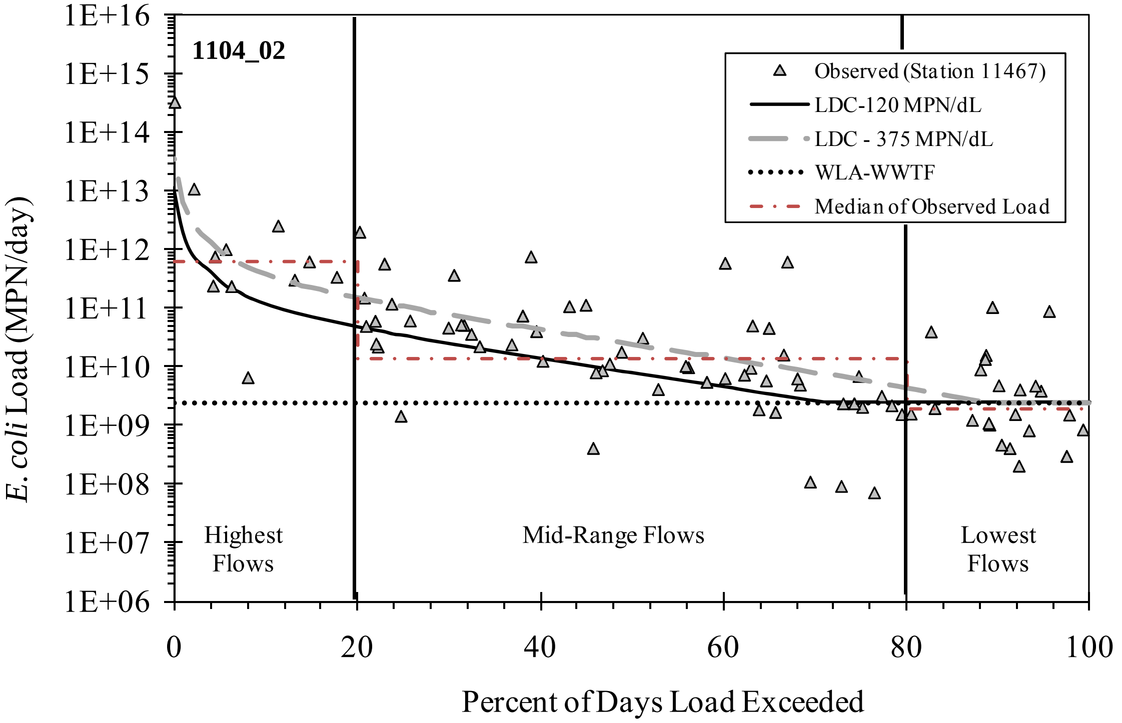


Figure 6-4 Load Duration Curve for *E. coli* in Assessment Unit 1104_02

Table 6-2 Load allocations and reductions for Segment 1104_02

Condition	0-20%	20-80%	80-100%
Median Flow (cfs)	43.35	2.67	0.24
Target Concentration (MPN/dL)[1]	119.7	119.7	119.7
Existing Load, Median (MPN/day)	6.12E+11	1.42E+10	1.95E+09
LDC, Median (MPN/day)[2]	1.27E+11[2]	7.81E+09	2.44E+09
Margin of Safety, Median (MPN/day)	6.68E+09	4.11E+08	3.64E+07
Load Reduction (MPN/day)	0.00E+00	6.37E+09	4.85E+11

Note: [1] Reflects a 5% margin of safety on the 126 MPN/dL contact recreation standard; [2] effluent dominated condition and therefore, equation A-1 cannot be used to calculate LDC directly from presented median flow

CHAPTER 7: TMDL CALCULATIONS

A bacteria TMDL represents the capacity of a water body to assimilate indicator bacteria. Typically, there are several possible allocation strategies that would 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 load duration curve method for Dickinson Bayou Above Tidal; and
2) The mass balance method using a tidal prism/box model for Dickinson Bayou Tidal, Bensons Bayou, Bordens Gully, and Giesler Bayou.

The TMDL equation, modified to accommodate additional factors, is expressed as shown in **Equation 7-1**. The TMDL, $\Sigma WLA_{WWTF,}$ FG and MOS allocations are set by flow, the contact recreation criterion, permitted wastewater flow, estimates of future wastewater flow and a margin of safety percetnage (5%) to account for uncertainty in the analysis. The load that remains after subtracting $\Sigma WLA_{WWTF,}$ MOS, and FG is allocated to the $\Sigma WLA_{\text{Storm Water}}$ and ΣLA. Permitted storm water sources ($\Sigma WLA_{\text{Storm Water)}}$ are allocated according to the proportion of the Assessment Unit designated as an urbanized area, as previously described, and the remaining load is allocated to the load allocation (ΣLA).

Equation 7-1

$$TMDL = \Sigma WLA_{WWTF} + \Sigma WLA_{\text{storm water}} + \Sigma LA + MOS + FG$$

where:

ΣWLA_{WWTF} = waste load allocation (permitted WWTF);

$\Sigma WLA_{\text{storm water}}$ = waste load allocation (permitted storm water);

LA = load allocation (non-permitted nonpoint source contributions);

MOS = margin of safety; and

FG = future growth.

This chapter describes the each of the components of this equation in more detail.

7.1 Wasteload Allocations - WWTFs

Waste load allocations (WLA) are established for point sources, such as WWTFs using **Equation 7-2**. As shown in the equation, the WLA for dischargers in the non-tidal portion of the watershed was calculated using one-half of the *E. coli* concentration of 126 MPN/dL (i.e., 63 MPN/dL) multiplied by the permitted flow. Similarly, for the tidal portion of the watershed, one-half the enterococcus concentration of 35 MPN/dL (i.e., 17 MPN/dL) was used to calculate the WLA. For WWTFs without permitted flow data (i.e., 03416-000 and 03479-000), the average annual reported flow for the WWTFs was used to calculate assigned a WLA.

Equation 7-2

$$WLA_{WWTF} = \tfrac{1}{2} * swqs * flow * \text{unit conversion factor}$$

where:

swqs (surface water quality standard) = 126 MPN/100mL *E. coli* or 35 MPN/100 mL enterococci;
flow (10^6 gal/day) = permitted flow; and
unit conversion factor = 37,854,120 100mL/10^6gal.

Table 7-1 presents a summary of the WWTFs in the Dickinson Bayou watershed as well as their flow characteristics and bacteria allocations. Consideration of future growth and its impacts on the WLA are discussed in a later section and in Appendix B.

Table 7-1. Waste load Allocation for WWTFs in Dickinson Bayou Watershed

Assessment Unit	TPDES ID	Facility name	Permitted Flow (MGD)	Average Self-Reported Flow (MGD)	*E. coli* Load (MPN/day)	Enterococci Load (MPN/day)
1104_01	03416-000	Waste Management Of Texas	n/a[1]	0.829[1]	1.97E+09	n/a[2]
1104_02	13632-001	Meadowland Utility	0.023	0.009	5.48E+07	n/a[2]
1104_02	14440-001	Brazoria County MUD No. 24	0.95	n/a [4]	2.26E+09	n/a[2]
1104_02	12935-001	Pine Colony	0.05	0.026	1.19E+08	n/a[2]
1103_02	00377-000	Penreco	0.075	0.057	n/a[2]	4.96E+07
1103_02	10173-001	Galveston County WCID No. 1	4.8	2.759	n/a[2]	3.18E+09
1103D_01	14570-001	Marlin Atlantis White, Ltd.	0.5	n/a [4]	n/a[2]	3.31E+08
1103_01	03749-000	Hillman Shrimp & Oyster Co.	0.07	0.005	n/a[2]	4.63E+07
1103_01	04086-000	Duratherm Inc.	n/a[3]	0.091	n/a[3]	n/a[3]
1103_01	14326-001	Via Bayou RV Park	0.02	0.002	n/a[2]	1.32E+07
1103_01	03479-000	Sea Lion Technology, Inc.	n/a[3]	0.058	n/a[3]	n/a[3]

[1] No permitted flow specified; average daily flow from monthly self-reports was used to calculate WLA; average flow reported between November 1999 and February 2007:

[2] Load calculated only for *E. coli* (in Segment 1104) or enterococci (in Segment 1103);

[3] The industrial process associated with facilities is not considered a source of indicator bacteria warranting a WLA;

[4] Flows not reported in period that was evaluated for averaging

Abbreviations: MGD – million gallons per day; MPN – most probable number; MUD – municipal utility district; TPDES – Texas Pollutant Discharge Elimination System; WCID – water control and improvement district

7.2 Wasteload Allocations – MS4s

Storm water discharges from MS4 areas are considered permitted point sources. Therefore, the WLA calculations must also include an allocation for permitted storm water discharges. A simplified approach for estimating the WLA for MS4 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 storm water loading.

The percentage of each Assessment Unit's subwatershed that is under a TPDES MS4 permit is used to estimate the amount of the overall runoff load that should be allocated as the permitted storm water contribution in the $\text{WLA}_{\text{Storm water}}$ component of the TMDL. **Table 7-2** summarizes the percentage of each Assessment Unit's subwatershed that is designated as an urbanized area. The proportions of the Assessment Unit subwatershed areas included in urbanized areas range from 2 % to 48%.

The percentages shown in **Table 7-2** are used to derive the $\text{WLA}_{\text{Storm water}}$ values as shown in **Equation 7-2**.

Equation 7-2

$$\text{WLA}_{\text{storm water}} = (\text{TMDL} - \Sigma\text{WLA}_{\text{WWTF}} - \text{MOS} - \text{FG}) * \text{PctMS4}$$

where:

$\text{WLA}_{\text{storm water}}$ (MPN/day) = permitted storm water WLA;
TMDL (MPN/day) = maximum allowable load (MPN/day);
$\Sigma\text{WLA}_{\text{WWTF}}$ (MPN/day) = permitted WWTF WLA;
FG (MPN/day) = WWTF future growth WLA;
PctMS4 (%) = Percentage of the Assessment Unit permitted for MS4 Storm water;
LA (MPN/day) = load allocation; and
MOS (MPN/day) = 5% margin of safety.

Table 7-2. Percentages of Each Assessment Unit Designated as an Urbanized Area

Assessment Unit	Area under MS4 (acres)	Total sub-watershed area (acres)	Percentage of Assessment Unit Permitted for Storm Water
1104_01	485	7,689	6%
1104_02	5,378	13,065	41%
1103_04	5,232	16,295	32%
1103_03	26	9,806	27%
1103_02	4,524	13,192	34%
1103_01	181	9,806	2%
1103A_01	1,675	3,466	48%
1103B_01	484	1,346	36%
1103C_01	613	2,315	26%
Total	18,837	68,160	28%

7.3 Load Allocations

The load allocation is the sum of loading from all nonpoint sources. It is calculated as shown in **Equation 7-3**.

Equation 7-3

$$LA = TMDL - \Sigma WLA_{WWTF} - \Sigma WLA \text{ storm water} - MOS$$

where:

LA (MPN/day) = load allocation; and
TMDL (MPN/day) = maximum allowable load (MPN/day);
ΣWLA_{WWTF} (MPN/day) = permitted WWTF WLA;
ΣWLA storm water (MPN/day) = permitted storm water WLA;
MOS (MPN/day) = 5% margin of safety.

7.4 Margin of Safety

Although there is a large degree of uncertainty in many model parameters used for this study, observed data have been used when available and when not available, conservative assumptions have been implemented. Section 303(d) of the CWA requires

TMDLs to incorporate "a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality."

For this TMDL, an explicit 5% margin of safety has been incorporated into both the LDCs and tidal prism modeling. The TMDL for the freshwater segment used a 5% margin of safety because of the limited amount of data for some sampling locations as well as the lack of measured flow data within the watershed.

7.5 Allowance for Future Growth

In Chapter 2, data from the TWDB were presented that demonstrates, on average, growth of 20% across the project study area is expected between 2000 and 2020. A methodology for addressing future growth is presented in **Appendix B** of this technical guidance document.

7.6 Seasonality

TMDLs are required to consider the potential impact of seasonal or annual variation in loadings, especially where significant contributions are made by runoff-drive bacteria sources. As described in **Chapter 2**, there are no apparent trends over time, either seasonally or annually, at any monitoring station within Dickinson Bayou.

7.7 TMDL Calculations

As shown in **Table 7-3**, for Assessment Units 1104_01 and 1104_02, the Above tidal portion of Dickinson Bayou, the calculated *E. coli* TMDL ranged from 1.04E+10 MPN/day to 3.70E+10 MPN/day. The waste load allocation ranged from 1.97E+09 to 2.44E+09 MPN/day for WWTFs and 2.06E+09 to 2.21E+09 MPN/day for permitted storm water. The load allocations for sub-watersheds associated with Assessment Units 1104_01 and 1104_02 ranged from 3.16E+09 to 3.06E+10 MPN/day.

For the tidal Assessment Units, which include 1103A_01, 1103B_01, 1103C_01, 1103_02, 1103_03, and 1103_04 the enterococci TMDL ranged from 1.65E+09 to 2.41E+11 MPN/day. Waste load allocations for Assessment Units in the Tidal segment and Tidal tributaries were established at 3.22E+ 09MPN/day. Permitted storm water waste load allocations for Assessment Units in the tidal portion of Dickinson Bayou and in tidal tributaries ranged from 5.64E+08 to 3.06E+10 MPN/day and load allocations for these Assessment Units ranged from 1.00E+09 to 2.21E+11 MPN/day.

Table 7-3. TMDL Allocation for Dickinson Bayou Watershed (in MPN/day)

Stream Name	Assess-ment Unit	Indicator Bacteria	TMDL[1]	WLA_{WWTF}[2]	$WLA_{storm\ water}$[3]	LA[4]	MOS[5]	Future Growth[6]
Dickinson Bayou Above Tidal	1104_01	*E. coli*	3.70E+10	1.97E+09	2.06E+09	3.06E+10	1.82E+09	5.28E+08
	1104_02	*E. coli*	1.04E+10	2.44E+09	2.21E+09	3.16E+09	4.11E+08	2.19E+09
Bensons Bayou	1103A_01	Enterococci	9.26E+09	0.00E+00	4.25E+09	4.55E+09	4.63E+08	0.00E+00
Bordens Gully	1103B_01	Enterococci	1.65E+09	0.00E+00	5.64E+08	1.00E+09	8.25E+07	0.00E+00
Geislers Bayou	1103C_01	Enterococci	4.14E+09	0.00E+00	1.04E+09	2.89E+09	2.07E+08	0.00E+00
Dickinson Bayou Tidal[7]	1103_02	Enterococci	2.41E+11	3.22E+09	4.17E+09	2.21E+11	1.21E+10	8.03E+08
	1103_03	Enterococci	9.41E+10	0.00E+00	3.06E+10	5.87E+10	4.70E+09	0.00E+00
	1103_04	Enterococci	6.74E+10	0.00E+00	1.72E+10	4.68E+10	3.37E+09	0.00E+00

[1] TMDL calculated as sum of WLA_{WWTF}, $WLA_{Storm\ Water}$, LA, MOS and Future growth (includes full permitted flow)

[2] WLA_{WWTF} is sum of permitted loads discharging to impaired Assessment Units

[3] $WLA_{Storm\ Water}$ is TMDL minus the sum of WLA_{WWTF}, MOS and Future growth multiplied by the percentage of the Assessment Unit watershed covered by MS4 permits

[4] LA is TMDL minus the sum of WLA_{WWTF}, $WLA_{Storm\ Water}$, MOS and Future growth

[5] MOS is a 5% margin of safety which is applied to the TMDL

[6] Future growth accounts for population growth through 2050 in permitted WWTF discharges

[7] Because it is not included on the 303(d) List, a TMDL has not been specified for Assessment Unit 1103_01

CHAPTER 8: PUBLIC PARTICIPATION

Over the course of the Dickinson Bayou TMDL, public participation has played a large role. Members of the project stakeholder group include government, permitted facilities, agriculture, business, environmental and community interests in the Dickinson Bayou watersheds. A total of three meetings were held: December 2007, April 2008, and October 2009, to present both project status reports from the TCEQ as well as updates on the technical aspects of the project. The meetings were held at project milestones and were also used to solicit input and feedback from the stakeholders. Stakeholder input was invaluable as it provided local insight to the project staff. This stakeholder group was also active in preparing a watershed protection plan for Dickinson Bayou and an implementation plan associated with this TMDL.

Websites housed at the TCEQ (http://www.tceq.texas.gov/waterquality/tmdl/80-dickinsonbayoubacteria.html) and the Texas Coastal Watershed Program (http://www.dickinsonbayou.org) provide access to meeting summaries, presentations, ground rules and a list of stakeholder group members. The websites were frequently update to ensure that absent stakeholders and the public were informed of meetings and their findings.

CHAPTER 9:

REFERENCES

American Society of Agricultural Engineers. ASAE 1998. Manure production and characteristics. D384.1.

American Society of Agricultural Engineers. ASAE 2003. Manure production and characteristics. D384.1.

American Veterinary Medical Association. 2007. Market Research Statistics: U.S. Pet Ownership – 2007. http://www.avma.org/reference/marketstats/ownership.asp. Accessed June 2009.

Baird, C., M. Jennings, D. Ockerman, T. Dybala. 1996. "Characterization of Nonpoint Sources and Loadings to Corpus Christi Bay National Estuary Program Study Area." CCBNEP-05. Corpus Christi Bay National Estuary Program, Corpus Christi.

Benham, B.L., K.M. Brannan, G. Yagow, R.W. Zeckoski, T.A. Dillaha, S. Mostaghimi, J.W. Wynn. 2005. Development of Bacteria and Benthic Total Maximum Daily Loads: A Case Study, Linville Creek, Virginia." Journal of Environmental Quality. 34(5): 1860-1872.

Beaudeau, P., Toussett, N., Bruchon, F., Lefevre, A., and Taylor, H.D. 2001 "In Situ Measurement and Statistical Modeling of Escherichia coli Decay in Small Rivers." Water Research, 35(13), 3168-3178.

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., T.H. Jobes, and A.S. Donigian, Jr. 2001. Hydrological Simulation Program - Fortran (HSPF). User's Manual for Release 12. U.S.

EPA National Exposure Research Laboratory, Athens, GA, in cooperation with U.S. Geological Survey, Water Resources Division, Reston, VA.

Bowie, George L, William B. Mills, Donald B. Procella, Carrie L. Campbell, James R. Pagenkopf, Gretchen L. Rupp, Kay M. Johnson, Peter W.H. Chan, Steven A. Gherini. 1985. Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling. EPA 660/3-85-040. USEPA. Athens, GA.

Cook, Robert L. 1992. Learn About Whitetails. http://www.tpwd.state.tx.us/publications/pwdpubs/media/pwd_lf_w7000_0007.pdf. Accessed April 2011.

Crenwelge, Gerald W., Edward L. Griffin, and Janet K. Barker. 1988. Soil Survey of Galveston County, Texas. United States Department of Agriculture Soil Conservation Service. Available online at http://soils.usda.gov/survey/online_surveys/texas/. Accessed July 2009.

H-GAC. 2002. 2002 Land Cover Data Set. http://www.h-gac.com/rds/land_use/default.aspx. Accessed June 2009.

H-GAC. 2008. 2008 Land Cover Data Set. http://www.h-gac.com/rds/land_use/default.aspx. Accessed June 2009

Ketchum, B.H. 1988. The exchanges of fresh and salt water in tidal estuaries. Journal of Marine Research. 10:18-38.

Kuo, A.Y., and B.J. Neilson. 1988. A Modified Tidal Prism Model for Water Quality in Small Coastal Embayments. *Wat. Sci. Tech.,* Vol 20, pp. 133-142.

Kuo, A.T., K. Park, S.-C. Kim, and J. Lin. 2005. A Tidal Prism Water Quality Model for Small Coastal Basins. Coastal Management, Vol. 33, pp. 101-117.

Liu, L., M. S. Pharnikumar, S. L. Molloy, R.L. Whitman, D.A. Shively, M.B. Nevers, D.J. Schwab, J.B. Rose. 2006. Modeling the transport and inactivation of E. coli and enterococci in the near-shore region of Lake Michigan. Environmental Science and Technology. 40(16): 5022-5028.

McCarthy, D.T., V.G. Mitchell, A. Deletic, C. Diaper. 2006. "*Escherichia coli* Levels in Urban Stormwater." 7th WSUD & 4th UDM Conerence Proceedings, Melbourne Australia.

National Biological Information Infrastructure 2005. Texas Coastal Interactive Mapping Application. <http://maps.harc.edu/waterbirds/> Accessed on March 21, 2011.

NCDC. 2002, Climatography of the United States No. 85: Divisional Normal and Standard Deviations of Temperature, Precipitation, and Heating and Cooling Degree Days 1971-2000 (and previous normal periods). National Climatic Data Center/NESDIS/NOAA, Asheville, North Carolina.

Natural Resource Conservation Service (NRCS). 2006. STATSGO2 Database. http://soils.usda.gov/survey/geography/statsgo/. Accessed July 2007.

Quality Deer Management Association. 2011. Whitetail Map Guide. <http://www.i-maps.com/Qdma/frame/default1024_ie.asp?C=48449&LinkID=0&NID=0&cmd=map&TL=100000&GL=010100&MF=11000

Pitt, R., A. Maestre, R. Morquecho. 2004. "National Stormwater Database (version 1.1)." University of Alabama, Tuscaloosa, AL.

Shen, J., S. Sun, and T. Wang. 2005. Development of the Fecal Coliform Total Maximum Daily Load Using Simulation Program C^{++} and Tidal Prism Model in Estuarine Shellfish Growing Areas: A Case Study in the Nassawadox Coastal Embayment, Virginia. *Journal of Environmental Science and Health*, Vol. 40, pp. 1791-1807.

State of Oregon Department of Environmental Quality. 2006. Willamette Basin Total Maximum Daily Load Appendix A: Bacteria Technical Appendix. http://www.deq.state.or.us/WQ/TMDLs/docs/willamettebasin/willamette/appxabacteria.pdf. Accessed November 2009.

Stormwater Management Joint Task Force. 2002. "Annual Report for the National Pollutant Discharge Elimination System." City of Houston, Harris County Flood Control District, Texas Department of Transportation.

TCEQ 2010. Draft 2010 Texas Integrated Report for Clean Water Act Sections 305(b) and 303(d) http://www.tceq.texas.gov/compliance/monitoring/water/quality/data/10twqi/10twqi

TCEQ 2008a. Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data. <www.tceq.state.tx.us/assets/public/compliance/monops/water/04twqi/04_guidance.pdf>.

TCEQ 2008b. Eighteen Total Maximum Daily Loads for Bacteria in Buffalo and Whiteoak Bayous and Tributaries.

TCEQ 1996. Texas Water Quality Inventory and 303(d) List. <www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/305_303.html>.

TCEQ 2002. Texas Water Quality Inventory and 303(d) List. <www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/305_303.html>.

TCEQ 2000. Texas Surface Water Quality Standards, 2000 update, 30 TAC 307. <www.tceq.state.tx.us/permitting/water_quality/wq_assessment/standards/WQ_standards_2000.html>.

Texas Agrilife Extension (2009). State of the Watershed. http://www.dickinsonbayou.org/watersheds/wp/DBWPPStateofWatershed2009.pdf.pdf Accessed July 2009.

Texas Agrilife. 2011. Feral Hog Statewide population growth and density. http://feralhogs.tamu.edu/files/2011/05/FeralHogFactSheet.pdf. Accessed May 2011.

Texas State Demographers Office. 2008. Estimates of the Total Populations of Counties and Places in Texas for July 1, 2007 and January 1, 2008. < http://txsdc.utsa.edu/download/pdf/ estimates/2007_txpopest_county.pdf> Accessed June 2009 and February 2010.

TWDB. 2006. Population and Water Demand Projections: 2006 Regional Water Plan & 2007 State Water Plan Projections Data. http://www.twdb.state.tx.us/wrpi/data/data.htm. Accessed June 2009.

TWDB. 2010. Population and Water Demand Projections: 2006 Regional Water Plan & 2007 State Water Plan Projections Data. http://www.twdb.state.tx.us/wrpi/data/data.htm. Accessed June 2009.

USGS. 1992. National Land Cover Dataset. http://landcover.usgs.gov/natllandcover.php

University of Houston and CDM. 2007. Total Maximum Daily Loads for Fecal Bacteria in the Dickinson Bayou Final Historical Data Review and Analysis Report.

University of Houston and CDM. 2007. Total Maximum Daily Loads for Fecal Bacteria in the Dickinson Bayou Load Allocation Methodology Review.

University of Houston and Parsons. 2008. Technical Support Document: Bacteria Total Maximum Daily Loads for the Clear Creek Watershed, Houston, Texas (1101, 1101b, 1101d, 1102, 1102a, 1102b, 1102c, 1102d, 1102e).

USDA. 2007. Agriculture Census. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Census_by_State/Texas.index.asp. Accessed June 2009.

US EPA. 1986. "Ambient Water Quality Criteria for Bacteria." EPA 440/4-84-002. US EPA, Washington, D.C.

US EPA. 2004. "Report to Congress: Impacts and Control of CSOs and SSOs." EPA 833-R-04-001, US EPA, Washington, D.C.

US EPA. 2000. "Bacterial Indicator Tool User's Guide." EPA 832-B-01-003. US EPA, Washington, D.C.

Wang, T., J. Shen, S. Sun, and H.V. Wang. 2005. Fecal Coliform Modeling in Small Coastal Waters Using a Linked Watershed and Tidal Prism Water Quality Model: A Preliminary Study in Jarrett Bay, North Carolina. Prepared for Proceedings of the Conference on Watershed Management to Meet Water Quality Standards and Emerging TMDL. ASAE Publication Number 701P0105, ed. P.W. Gassman.

Zeckoski, R.W., B.L. Benham, S.B. Shah, M.L. Wolfe, K.M. Brannan, M. Al-Smadi, T.A. Dillaha, S. Mostaghimi, C.D. Heatwole. 2005. "BSLC: A Tool for Bacteria Source Characterization for Watershed Management." Applied Engineering in Agriculture. 21(5): 879-889.

Appendix A

Summary of Self-Reported Flows in Dickinson Bayou

Table A-1 Summary of Self-Reported Flows (MGD) in Dickinson Bayou

Reporting Month	TX0109886	TX0108367	TX0095770	TX0003727	TX0023655	TX0112861	TX0117757	TX0119458	TX0124761
Nov-99	0.00557			0.049	1.698719				
Decr-99	0.0057		0.0353	0.052	2.285076				
Jan-00	0.00545	0.03511	0.0353	0.049	2.058776				
Feb-00	0.00578	0.01556	0.0321	0.049	2.143901				
Mar-00	0.00633	0.03457	0.0291	0.049	2.056756				
Aprl-00	0.006	0.05385	0.0291	0.053	2.676307				
May-00	0.0083	0.07533	0.0311	0.061	2.942013				
Jun-00	0.0047	0.02146	0.0311	0.046	1.870873				
Jul-00	0.004	0.04767	0.0321	0.054	1.747806				
Aug-00	0.0057	0.02048	0.0422	0.049	1.783664				
Sepr-00	0.0075	0.07723	0.0387	0.055	2.10804		0.07		
Oct-00	0.0075	0.05152	0.0291	0.05	2.167778		0.08		
Nov-00	0.0115	0.09545	0.0568	0.066	4.701169		0.08		
Dec-00	0.008	0.07294	0.0291	0.06	2.815292		0.08		
Jan-01	0.008	0.0759	0.0353	0.055	4.422843		0.08		
Feb-01	0.0069	**0.0759**	0.0321	0.056	2.475453		0.08		
Mar-01	0.015	0.05201	0.02395	0.058	2.184907		0.14	0.28	
Apr-01	0.013	0.0501	0.0237	0.055	1.857526		0.14	1.35	
May-01	0.0112	0.0255	0.0291	0.062	3.97868		0.14	4.03	
Jun-01	0.013	0.091635	0.0306	0.062	1.912865		0.14	2.8	
Jul-01	0.0069	0.02379	0.04	0.065	2.99606		0.07	3.17	
Aug-01	0.0053	0.02379	0.04	0.065	3.99642		0.126	0.8	
Sep-01	0.009	0.09395	0.061	0.059	2.93613		0.122	0.74	
Oct-01	0.012	0.06915	0.0412	0.067	3.432674		0.133	1.02	
Nov-01	0.0106	0.06133	0.046	0.057	5.393156		0.288	0.42	
Dec-01	0.022	0.0605	0.043	0.067	3.299835		0.72	1.74	
Jan-02	0.0181	0.06522	0.0357	0.061	2.110081		0.42	0	
Feb-02	0.0114	0.0202	0.026	0.056	2.750467		0.42	0	
Mar-02	0.0072	0.02386	0.0266	0.054	2.83628		0.42	0.91	
Apr-02	0.0046	0.05271	0.0318	0.063	2.722804		0.14	2.03	
May-02	0.01	0.10227	0.025	0.065	3.2696		0.15	2.44	
Jun-02	0.016	0.04741	0.0255	0.068	3.32442		0.13	0.37	
Jul-02	0.0166	0.09437	0.0335	0.061	4.613309		0.13	0.57	
Aug-02	0.015	0.12349	0.04	0.053	5.36653		0.072	2.87	
Sep-02	0.019	0.0767	0.03	0.055	3.553606		0.072	0.55	
Oct-02	0.0233	0.11546	0.024	0.074	4.638157		0.126	1.07	
Nov-02	0.018	0.0579	0.034	0.062	3.706872		0.126	0.24	
Dec-02	0.02	0.05922	0.03	0.06	4.24924		0.141	1.05	
Jan-03	0.0178	0.03945	0.04	0.07	2.8894			0.45	0.00158
Feb-03	0.01	0.05287	0.031	0.056	2.25039			0.02	0.00158

Reporting Month	TX0109886	TX0108367	TX0095770	TX0003727	TX0023655	TX0112861	TX0117757	TX0119458	TX0124761
Mar-03	0.012	0.022	0.027	0.052	2.13969			0.14	0.0015
Apr-03	0.0037	0.02663	0.019	0.056	2.38627			1.46	0.000754
May-03	0.006	0.0182	0.013	0.064	2.81454			0.3	0.0017
Jun-03	0.009	0.055229	0.014	0.051	3.11656		0.04	1.494	0.001
Jul-03	0.01	0.04759	0.016	0.044	5.3003		0.04	0.5	0.0015
Aug-03	0.009	0.11771	0.013	0.06	3.50128		0.07	0.144	0.001405
Sep-03	0.018	0.15577	0.014	0.061	3.60301		0.06	1.937	0.00017
Oct-03	0.015	0.0664	0.018	0.07	3.46354		0.06	0.569	0.0022
Nov-03	0.0233	0.06486	0.014	0.078	4.71211		0.06	0.5	0.0017
Dec-03	0.012	0.0595	0.016	0.066	5.35917		0.04	0.144	0.013
Jan-04	0.015	0.06052	0.005	0.055	2.29066		0.04	0.197	0.0018
Feb-04	0.012	0.04322	0.015	0.053	2.08847	0.0078	0.05	0.234	0.00186
Mar-04	0.0108	0.03328	0.017	0.045	2.74038	0.0076	0.03	0.337	0.0016
Apr-04	0.011	0.03404	0.014	0.052	2.66422	0.0076	0.03	1.477	0.0013
May-04	0.0122	0.06889	0.014	0.049	2.31876	0.007194	0.03	0.719	0.001595
Jun-04	0.013	0.06889	0.013	0.044	2.56539	0.005367	0.05	5.537	0.0015
Jul-04	0.007	0.03484	0.0116	0.055	2.72944	0.0004	0.05	1.117	0.002
Aug-04	0.007	0.03244	0.0122	0.049	3.01203	0.0008	0.05	0.275	0.0012
Sep-04	0.005	0.03129	0.014	0.048	4.71545	0.004166	0.05	0.127	**0.0012**
Oct-04	0.004	0.03934	0.0142	0.046	2.15349	0.0008	0.04	0.277	0.00198
Nov-04	0.016	0.0768	0.0132	0.048	3.36943	0.0085	0.04	0.397	0.0036
Dec-04	0.007	0.3714	0.016	0.052	2.96797	0.00706	0.03	0.867	0.0021
Jan-05	0.008	0.02874	0.0147	0.052	3.1393	0.006	0.03	0.357	0.0015
Feb-05	0.008	0.03369	0.015	0.048	2.099509	0.0055	0.03	0.837	0.0021
Mar-05	0.009	0.03369	0.018	0.073	2.042115	0.00648	0.03	0.127	0.0021
Apr-05	0.0073	0.0284	0.016	0.05	1.375603	0.006166	3	0.182	0.0016
May-05	0.0073	0.0284	0.018	0.047	1.487248	0.008	0.04	0.207	0.0017
Jun-05	0.006	0.014513	0.0126	0.051	1.499554	0.00763	0.04	0.127	0.0019
Jul-05	0.006	0.03757	0.021	0.055	1.417925	0.00587	0.04	0.257	0.0014
Aug-05	0.006	0.10414	0.09	0.062	1.443252	0.000806	0.04	0.207	0.0014
Sep-05	0.0064	0.06689	0.016		2.20581	0.000806	0.04	0.127	0.0014
Oct-05	0.003	0.03198	0.022		1.929119	0.000806	0.04	0.317	0.0015
Nov-05	0.004	0.04736	0.022		1.59478	0.005267	0.04	0.127	0.0015
Dec-05	0.002	0.03139	0.02		1.23405	0.005064	0.04	0.467	0.0017
Jan-06	0.003	0.04461	0.016		1.11364	0.00871	0.03	0.397	0.002
Feb-06	0.005	0.02917	0.022		1.199254	0.00639	0.03	0.527	0.0022
Mar-06	0.004	0.01833	0.023		1.685734	0.007581	0.03	0.127	0.002
Apr-06	0.0024	0.03438	0.027		1.93548	0.00823	0.04	0.127	0.0064
May-06	0.003	0.08387	0.023		3.288703	0.00603	0.04	0.127	0.0014
Jun-06	0.003	0.08297	0.023		2.06764	0.00263	0.04	1.27	0.0014
Jul-06	0.003	0.05681	0.023		1.659404	0.00263	0.03	0.747	0.0013
Aug-06	0.003	0.06972	0.024		3.063639	0.0008	0.04	2.357	0.0012
Sep-06	0.004	0.05304			1.33121	0.00087	0.04	2.357	0.0012

Reporting Month	TX0109886	TX0108367	TX0095770	TX0003727	TX0023655	TX0112861	TX0117757	TX0119458	TX0124761
Oct-06	0.007	0.14446			1.63478	0.0007	0.04	0.127	0.0014
Nov-06	0.003	0.02422			3.20701	0.0065	0.04	0.127	0.0014
Dec-06	0.004	0.03326			1.87474	0.004774	0.04	0.127	0.0013
Jan-07	0.006	0.06138			4.422843	0.0054	0.04	0.254	0.0012
Feb-07	0.003	0.01902			2.475453	0.0079	0.04	0	0.0014
Average:	0.009	0.058	0.026	0.057	2.759	0.005	0.091	0.829	0.002

🟪

🟨

🟧 **value**

Appendix B- Future Growth Analysis

Methodology

The methodology used to predict future growth to 2050 is based on the approach used in the Clear Creek TMDL report. This appendix describes the procedure used for the growth prediction.

Municipal Wastewater Projections

Municipal wastewater flow projections are based on the population difference between the 2010 population estimate from the Texas Water Development Board (TWDB) and the 2050 population estimate. If a WWTF was located within a city, the population growth for that city was used to project future WWTF flows; otherwise, county population projections were used. **Table B-1** presents the population estimates between 2010 and 2050 for cities and counties in the Dickinson Bayou watershed.

Table B-1 Summary of Population Estimates for Dickinson Bayou Watershed

City/County	2000 U. S. Census Population	2010 Population Estimate	2050 Population Estimate	Percent Increase (2000-2050)
Alvin	21,413	23,231	30,375	42%
Dickinson	17,093	19,955	24,921	46%
Friendswood	29,037	32,353	38,107	31%
League City	45,444	53,546	67,613	49%
Manvel	3,046	3,046	3,046	0%
Santa Fe	9,548	10,141	11,170	17%
Texas City	41,521	41,891	42,534	2%
Galveston County	250,158	268,714	300,915	20%
Brazoria County	241,767	285,850	459,078	90%

Next, the per capita permitted flow for each city in the watershed was determined for 2010. To do this, permitted flows were obtained for all WWTFs within the cities. A summary of the WWTFs used to calculate the total flow by city is shown in **Table B-2** and a summary of the per capita flow by city is shown in **Table B-3**. Using the calculated per capita flow, the future permitted flow for 2050 was projected and is also included in **Table B-3**.

Table B-2 Summary of Permitted Flows by City

City or County	TCEQ Permit ID	NPDES ID	Permittee	Assessment Unit	Permitted Flow (MGD)
Dickinson	14570-001	TX0127248	Marlin Atlantis White Ltd	1103_02	0.5
Dickinson	10173-001	TX0023655	Galveston County WCID 1	1103_02	4.8
League City	10568-003	TX0071447	City of League City	n/a	0.66
League City	10568-005	TX0071447	City of League City	n/a	7.5
Santa Fe	10174-001	TX0023671	Galveston County WCID No. 8	n/a	1.5
Texas City	14326-001	TX0124761	Via Bayou RV Park	1103_02	0.02
Texas City	10375-001	TX0023949	City of Texas City	1103_04	12.4

Table B-3 Per Capita Flow by City

City	Per capita Gallons Per Day	Total permitted flow (MGD) - 2010	Total permitted flow (MGD) - 2050
Dickinson	2.41E-04	4.80	5.99
League City	1.52E-04	8.16	10.30
Texas City	3.19E-04	13.37	13.58
Santa Fe	1.48E-04	1.50	1.65

For WWTFs within city limits, the amount of the city's flow made up by the facility was determined and is shown in **Table B-4.** For example at Galveston County WCID #1, the permitted flow is 4.8 MGD in 2008. As shown in **Table B-3**, the total permitted flow in the City of Dickinson is 4.8 MGD and thus the facility comprises 100% of the City of Dickinson's permitted flow. Then, the calculated future permitted flow for the city is multiplied by the percentage of the city's flow handled by the WWTF to arrive at the 2050 permitted flow for the facility.

For WWTFs not located within a city, a slightly different approach was taken. In this case, the growth expected between 2010 and 2050 for the county was used to estimate the projected flows for the facility. For example, the Meadowland WWTF (TPDES ID 13632-001) is located in Brazoria County which is expected to grow by 90% between 2010 and 2050. Therefore, the 2008 permitted flow was increased by 90% to reflect this growth and is calculated to be 0.044 MGD.

Table C-4 Summary of Future Permitted Flows by WWTF

TCEQ Permit	Permittee	City/Location of Outfall	2008 Permitted Flow (MGD)	% of city flow	% growth in county	2050 Permitted Flow - All
10173-001 G	alveston County WCID #1	Dickinson 4.	800	100%	n/a^3 5.	995
14570-001 M	arlin Atlantis White, Ltd.	Dickinson 0	.5^2 33	%	n/a^3 1.	998
14326-001	Via Bayou RV Park	Texas City	0.020	0.15%	n/a^3 0.	020
14440-001 Br	azoria County MUD No. 24	Brazoria Co.	0.95	n/a^1 90	%	1.804
12935-001	Pine Colony	Brazoria Co.	0.050	n/a^1 90	%	0.095
13632-001 Me	adowland Utility	Brazoria Co.	0.0234	n/a^1 90	%	0.044

[1] Facility not located within city limits
[2] Facility not yet in operation
[3] City flow used to predict population growth

Industrial Wastewater Projections

For industrial facilities, the expected increase in industrial water demand calculated by the TWDB between 2010 and 2050 was used to estimate future WWTF discharges. A summary of the water demands is presented in **Table B-5** for Dickinson Bayou watershed. As shown in the Table, increases of 27% to 36% are expected in the watershed.

Table B-5 Summary of Future Industrial Water Demands for Dickinson Bayou Watershed

County	2010 Water Demand (acre-ft)	2050 Water Demand (acre-ft)	% increase in industrial water use
Galveston 4	1,005	51,967	27%
Brazoria 2	60,239	354093	36%

Next, the permitted flow for each industrial facility was multiplied by the growth in industrial water demand expected for the county in which it is located to determine the 2050 permitted flow; the values were obtained from TWDB. A summary of projected industrial permitted flows is presented in **Table B-6**. Permitted flows from industrial facilities are expected to range between 0.025 MGD to 1.051 MGD in 2050.

Table B-6 Summary of Permitted Industrial WWTF Discharges in 2050

TCEQ ID	Facility name	County	Permitted Flow (MGD)	2050 Permitted Flow (MGD)
03416-000	Waste Management Of Texas Inc	Galveston	0.829[1]	1.051
03479-000	Sea Lion Technology, Inc.	Galveston	0.020	0.025
04086-001	Duratherm, Inc.	Galveston	0.091[1]	0.115
00377-000	Penreco	Galveston	0.075	0.095
03749-001	Hillman Shrimp & Oyster Co.	Galveston	0.070	0.089

Notes:

[1] Intermittent flow, average reported flow used instead

[2] Permitted flow not available