Proposed for Public Comment, May 2008

Nine Total Maximum Daily Loads for Bacteria in Clear Creek and Tributaries

Segments 1101, 1101B, 1101D, 1102, 1102A, 1102B, 1102C, 1102D, and 1102E

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Executive Summary

This document describes total maximum daily loads (TMDLs) for indicator bacteria for Clear Creek Tidal (1101) and Clear Creek Above Tidal (1102), the two main segments of the Clear Creek watershed. In addition to those two segments, several tributaries including Chigger Creek, Robinson Bayou, Cowart Creek, Mary's Creek/North Fork Mary's Creek, Hickory Slough, Turkey Creek, and Mud Gully (Segments 1101B, 1101D, 1102A, 1102B, 1102C, 1102D, and 1102E, respectively), have concentrations of indicator bacteria that exceed the criteria used to evaluate attainment of the contact recreation use. The segments included in this TMDL were first identified as having an impairment to the contact recreation use on the *1996, 2002, and 2006 Texas Water Quality Inventory and 303(d) List* (Table 1).

Using the *Escherichia coli* (*E. coli)* indicator, if the minimum sample requirement for minimum number of samples is met, the contact recreation use is not supported when:

- the geometric mean of all *E. coli* samples exceeds 126 counts per 100 milliliter (mL)
- and/or individual samples exceed 394 counts per 100 mL more than 25 percent of the time.

Using the Enterococci indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all Enterococci samples exceeds 35 counts per 100 mL
- and/or individual samples exceed 89 counts per 100 mL more than 25 percent of the time.

Using the fecal coliform indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all fecal coliform samples exceeds 200 counts per 100 mL
- and/or individual samples exceed 400 counts per 100 mL more than 25 percent of the time.

The Clear Creek watershed encompasses approximately 180 square miles of land located just southeast of the city of Houston, Texas. Approximately 40 percent of the watershed lies within Brazoria County, 35 percent lies within Harris County, 20 percent is within Galveston County, and 5 percent of the watershed lies within Fort Bend County. The eastern and central portions of the watershed are primarily urban and residential, with some commercial and industrial uses. The western and southern parts of the watershed include rural and agricultural land uses which continue to transition over time from cultivated and woody land to developed land.

Data the Texas Commission on Environmental Quality (TCEQ) analyzed from the assessment period of November 29, 2000, through December 28, 2006, showed 32 of the 36 sampling locations in the impaired segments exceeded the indicator bacteria concentrations for the current contact recreation standard.

In Clear Creek Tidal, seven of the nine sampling locations exceed the Enterococci criterion. The geometric mean for Enterococci ranged from 15 to 974 counts/100mL and individual sample concentrations exceeded the criterion in 0 percent to 100 percent of the samples.

At all four sampling locations in Chigger Creek, the *E. coli* or fecal coliform single sample criterion is exceeded. Geometric mean (geomean) concentrations of *E. coli* ranged from 85 to 260 counts/100mL and individual sample concentrations exceeded the criterion in 18 percent to 34 percent of the samples.

In Robinson Bayou, the two sampling locations exceed the Enterococci, *E. coli*, and fecal coliform criterion. The geometric mean for Enterococci ranged from 158 to 1191 counts/100mL and individual sample concentrations exceeded the criterion in 63 percent to 93 percent of the samples.

At 9 of the 10 sampling locations in Clear Creek Above Tidal, the single sample criteria established for *E. coli* or fecal coliform (either or both) are exceeded. The geometric mean of *E. coli* concentrations ranged from 51 to 358 counts/100mL and individual sample concentrations exceeded the criterion in 5 percent to 42 percent of the samples.

In Cowart Creek, all four sampling locations exceed the single sample criteria established for *E. coli* or fecal coliform (either or both). The geometric mean of *E. coli* concentrations ranged from 56 to 314 counts/100mL and individual sample concentrations exceeded the criterion in 9 percent to 45 percent of the samples.

Of the three sampling locations in Mary's Creek/North Fork Mary's Creek, only the most-downstream sampling location exceeds the single sample criterion established for fecal coliform. Fifty-five percent of the samples exceed the fecal coliform criterion, and 24 percent of the samples exceed the *E. coli* criterion. The geometric mean of *E. coli* ranged from 51 to 231 counts/100mL and individual sample concentrations exceeded the criterion in 8 percent to 24 percent of the samples.

In Hickory Slough, the single sampling location exceeded both *E. coli* and fecal coliform single sample criterion (35 percent and 29 percent, respectively). The geometric mean of *E. coli* at the sampling location is 159 counts/100mL.

At the sampling location in Turkey Creek, both *E. coli* and fecal coliform exceeded the single sample criterion (73 percent and 30 percent, respectively). The geometric mean of *E. coli* at the single sampling location is 97 counts/100mL.

In Mud Gully, fecal coliform exceeded the single sample criterion at the two sampling locations (85 percent and 50 percent). The geometric mean of fecal coliform at the two sampling locations ranged from 743 to 1340 counts/100mL.

The most probable sources of indicator bacteria within the entire watershed are non-compliant wastewater treatment facility (WWTF) discharges, storm water runoff from municipal separate storm sewer systems (MS4s), sanitary sewer overflows, dry weather discharges (illicit discharges) from storm sewers, failing on-site sewer facilities, and runoff from areas not part of an MS4.

For the freshwater segments (Chigger Creek, Clear Creek Above Tidal, Cowart Creek, Mary's Creek/North Fork Mary's Creek, Hickory Slough, Turkey Creek, and Mud Gully), a load duration curve analysis identified the maximum percent reduction goal for each segment. The mass balance, tidal prism method was used to determine the load capacity, current loads, and percent reduction goals for Clear Creek Tidal and Robinson Bayou, and in the tidally influenced portions of select tributaries to Clear Creek Tidal.

The percent reduction goals based on the geometric mean criterion for the nine segments of the Clear Creek watershed ranged from 25 percent to 97 percent for the highest flow conditions and from 25 percent to 91 percent over all flow conditions.

The waste load allocation for wastewater treatment facilities was established as the permitted flow times the geometric mean of the indicator bacteria criterion. Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard. The TMDL calculations in this report will guide determination of the assimilative capacity of each stream under changing conditions, including future growth. Wastewater discharge facilities will be evaluated case-by-case.

Introduction

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

In simple terms, a TMDL is a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. TMDLs are the best possible estimates of the assimilative capacity of the water body for a pollutant under consideration. A TMDL is commonly expressed as a load with units of mass per period of time, but may be expressed in other ways. TMDLs must also estimate how much the pollutant load must be reduced from current levels in order to achieve water quality standards.

The TMDL Program is a major component of Texas' overall process for managing the quality of its surface waters. The program addresses impaired or threatened streams, reservoirs, lakes, bays, and estuaries (water bodies) in, or bordering on, the state of Texas. The primary objective of the TMDL Program is to restore and maintain the beneficial uses—such as drinking water supply, recreation, support of aquatic life, or fishing—of impaired or threatened water bodies. This TMDL addresses impairments to the contact recreation use due to exceedances of the indicator bacteria criteria in Clear Creek Tidal, Clear Creek Above Tidal, Chigger Creek, Robinson Bayou, Cowart Creek, Mary's Creek/North Fork Mary's Creek, Hickory Slough, Turkey Creek, and Mud Gully.

Section 303(d) of the Clean Water Act and the implementing regulations of the U.S. Environmental Protection Agency (EPA) in Title 40 of the Code of Federal Regulations, Part 130 (40 CFR 130) describe the statutory and regulatory requirements for acceptable TMDLs. The EPA provides further direction in its *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA 1991). This TMDL document has been prepared in accordance with those regulations and guidelines.

The TCEQ must consider certain elements in developing a TMDL; they are described in the following sections:

- Problem Definition
- Endpoint Identification
- Source Analysis
- Linkage Analysis
- Seasonal Variation
- Margin of Safety
- Pollutant Load Allocation
- Public Participation
- Implementation and Reasonable Assurance

The commission adopted this document on Month, Day, Year. Upon EPA approval, these TMDLs will become an update to the state's Water Quality Management Plan.

Problem Definition

The segments included in this TMDL were first identified as having an impairment to the contact recreation use on the *1996, 2002, and 2006 Texas Water Quality Inventory and 303(d) List* (Table 1). Clear Creek and its tributaries have both freshwater segments and tidally influenced segments. Clear Creek is classified as two separate water bodies, Clear Creek Tidal, and Clear Creek Above Tidal. The tidal influence within Clear Creek creates a median high tide level of 2.0 feet and reaches an average of 3.3 feet above sea level annually during peak tide (USACE 1985).

Figure 1 is a location map showing the water bodies and their contributing watersheds that are addressed in this TMDL report. The delineation of each watershed is derived from 2005 geographic information system (GIS) data files created for the Tropical Storm Allison Recovery Project (TSARP) provided by Harris County Flood Control District (HCFCD). Using the TSARP GIS file produces in watershed delineations that are slightly different from the historic delineations based on TCEQ GIS files associated with classified segments (Segments 1101 and 1102). However, the use of TSARP drainage areas provides finer resolution and results in delineations that accurately represent the watersheds contributing to each classified and unclassified segment.

Table 1. TMDL Segments and First Year on 303(d) List

Segment Number	Segment Name	Type	First Year Listed
1101	Clear Creek Tidal	Tidal	1996
1101B	Chigger Creek	Freshwater	2002
1101D	Robinson Bayou	Tidal	2006
1102	Clear Creek Above Tidal	Freshwater	1996
1102A	Cowart Creek	Freshwater	2002
1102B	Mary's Creek/ North Fork Mary's Creek	Freshwater	2002
1102C	Hickory Slough	Freshwater	2006
1102D	Turkey Creek	Freshwater	2006
1102E	Mud Gully	Freshwater	2006

The standards for water quality are defined in the *Texas Surface Water Quality Standards* (TCEQ 2000). The specific uses assigned to the nine segments included in this report are contact recreation, aquatic life, general, and fish consumption. The criteria for assessing attainment of the contact recreation use are expressed as the number of indicator bacteria per hundred milliliters (100 mL) of water. The number of colony-forming units may not exceed certain concentrations in a single sample, nor as a geometric mean of all samples.

As described in the TCEQ's "2004 Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data" (TCEQ 2004), the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. *E. coli* for freshwater and Enterococci in tidal water are now the preferred indicator bacteria for assessing the contact recreation use, but fecal coliform bacteria may be used when there is insufficient *E. coli* or Enterococci data, since fecal coliform was the preferred indicator in the past. For this project *E. coli* data were used for data analysis and modeling to support TMDL development for Clear Creek above Tidal, Chigger Creek, Cowart Creek, Mary's Creek/North Fork Mary's Creek, and Hickory Slough. Fecal coliform data were used for data analysis and modeling to support TMDL development for Turkey Creek, and Mud Gully. Fecal coliform, *E. coli,* and Enterococci data were used in analysis and modeling to develop TMDLs for Clear Creek Tidal and Robinson Bayou.

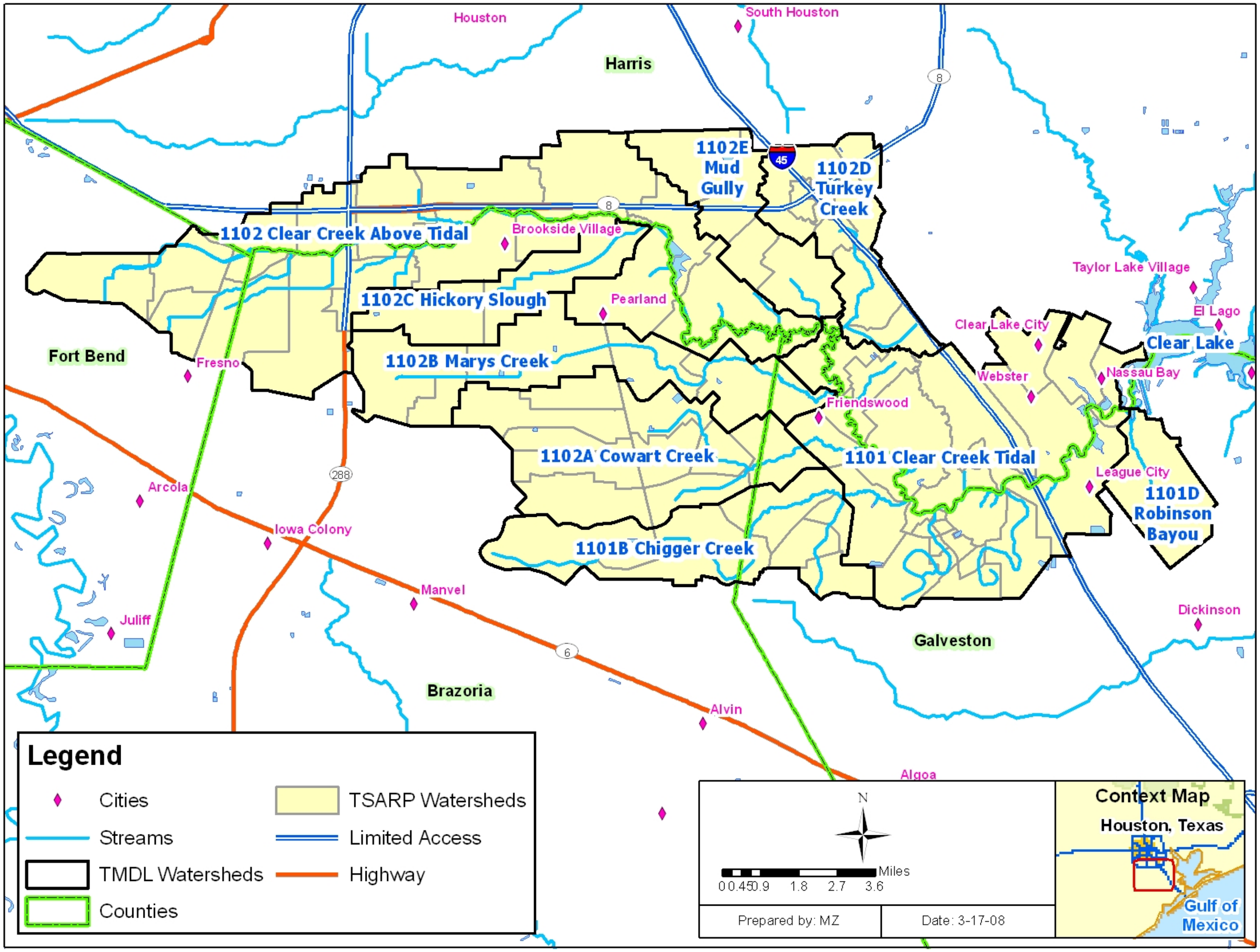


Figure 1. Clear Creek Watershed

Using the *E. coli* indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all *E. coli* samples exceeds 126 counts per 100 mL;
- and/or individual samples exceed 394 counts per 100 mL more than 25 percent of the time.

Using the Enterococci indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all Enterococci samples exceeds 35 counts per 100 mL;
- and/or individual samples exceed 89 counts per 100 mL more than 25 percent of the time.

Using the fecal coliform indicator, if the minimum sample requirement is met, the contact recreation use is not supported when:

- the geometric mean of all fecal coliform samples exceeds 200 counts per 100 mL;
- and/or individual samples exceed 400 counts per 100 mL more than 25 percent of the time.

Data the TCEQ analyzed from the assessment period of November 29, 2000, through December 28, 2006, showed 32 of the 36 sampling locations in the impaired segments exceeded the indicator bacteria concentrations for the contact recreation standard (Table 2).

Bacteria concentrations are expressed as either colony forming units (cfu) or most probable number (MPN) depending on the type indicator bacteria and the type of test used to analyze the sample. The MPN is a statistical estimate of the actual number of colony-forming units in a water sample. Throughout this document, indicator bacteria concentrations will be referred to as “counts” rather than using the two different units. Most of the analyses for *E. coli* and Enterococci are in MPN but some older analyses are in cfu.

Ambient Indicator Bacteria Concentrations

Table 2 summarizes indicator bacteria data for all sampling locations in each segment for the period of record of 1990 through 2006. In most cases, *E. coli* and Enterococci measurements do not exist prior to 2000. There are 134 *E. coli* samples throughout Clear Creek Tidal that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. At seven of the nine sampling locations, 25 percent or more of the samples exceed the Enterococci criterion established for this water body. The geometric mean for Enterococci ranged from 15 to 974 counts/100mL and individual sample concentrations exceeded the criterion in 0 percent to 100 percent of the samples. This indicates conditions of widespread and persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use. However, it should be noted that five sampling locations (11447, 15458, 16573, 16575, and 16577) have less than 10 samples. Sampling locations that meet or exceed criteria are distributed throughout the length of Clear Creek Tidal. Sampling locations are shown in Figure 2.

There are 100 *E. coli* samples throughout Chigger Creek that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. At three sampling locations, more than 25 percent of the samples exceed the single sample criterion established for *E. coli* and fecal coliform. Only 18 percent of *E. coli samples* at station 16472 exceeded the criterion. Geomean concentrations of *E. coli* ranged from 85 to 260 counts/100mL and individual sample concentrations exceeded the criterion in 18 percent to 34 percent of the samples. This indicates conditions of widespread and persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use. One of these four sampling locations does have a small (<10) sample set.

Table 2. Summary of Criteria and Assessment Data – 1990-2006

Seg	ID	Indicator Bacteria	Geometric Mean Criterion counts/ 100mL	Geometric Mean Concentration counts/ 100mL	Single Sample Criterion counts/ 100mL	Number of Samples	Number of Samples Exceeding Single Sample Criterion	Percent of Samples Exceeding Single Sample Criterion
Clear Creek Tidal								
1101	11446	FC	200	282	400	41	18	44%
		EC	126	24	394	5	0	0%
		ENT	35	50	89	45	13	29%
	11447	FC	200	290	400	51	19	37%
		EC	126	39	394	7	0	0%
		ENT	35	56	89	3	1	33%
	11448	FC	200	451	400	88	33	38%
		EC	126	128	394	11	2	18%
		ENT	35	974	89	19	19	100%
	15458	FC	200	332	400	47	20	43%
		EC	126	108	394	4	1	25%
		ENT	35	15	89	3	0	0%
	16572	FC	200	130	400	29	6	21%
		EC	126	193	394	2	1	50%
		ENT	35	19	89	20	5	25%
	16573	FC	200	84	400	29	4	14%
		EC	126	3229	394	1	1	100%
		ENT	35	24	89	8	0	0%
	16575	FC	200	235	400	40	13	33%
		EC	126	21	394	5	0	0%

Seg	ID	Indicator Bacteria	Geometric Mean Criterion counts/ 100mL	Geometric Mean Concentra-tion counts/ 100mL	Single Sample Criterion counts/ 100mL	Number of Samples	Number of Samples Exceeding Single Sample Criterion	Percent of Samples Exceeding Single Sample Criterion
		Clear Creek Tidal, continued						
1101, cont.		ENT	35	49	89	5	3	60%
	16576	FC	200	253	400	40	13	33%
		EC	126	33	394	11	0	0%
		ENT	35	314	89	30	23	77%
	16577	FC	200	222	400	40	10	25%
		EC	126	56	394	12	1	8%
		ENT	35	490	89	1	1	100%
Chigger Creek								
1101 B	16472	FC	200	319	400	41	15	37%
		EC	126	90	394	28	5	18%
	16493	FC	200	824	400	38	23	61%
		EC	126	260	394	41	14	34%
	17072	FC	200	193	400	14	5	36%
		EC	126	173	394	22	7	32%
	17078	FC	200	160	400	8	3	38%
		EC	126	85	394	9	3	33%
Robinson Bayou								
1101 D	16475	FC	200	824	400	40	27	68%
		EC	126	267	394	10	5	50%
		ENT	35	158	89	27	17	63%
	16486	FC	200	3061	400	32	26	81%
		EC	126	165	394	11	4	36%
		ENT	35	1191	89	15	14	93%
Clear Creek above Tidal								
1102	11449	FC	200	461	400	39	18	46%
		EC	126	51	394	20	1	5%
	11450	FC	200	833	400	53	31	58%
		EC	126	358	394	52	22	42%
		ENT	35	92	89	11	6	55%
	11451	FC	200	458	400	31	15	48%
		EC	126	146	394	27	9	33%

Seg	ID	Indicator Bacteria	Geometric Mean Criterion counts/ 100mL	Geometric Mean Concentration counts/ 100mL	Single Sample Criterion counts/ 100mL	Number of Samples	Number of Samples Exceeding Single Sample Criterion	Percent of Samples Exceeding Single Sample Criterion
	Clear Creek Above Tidal, continued							
1102, cont.	11452	FC	200	381	400	63	27	43%
		EC	126	170	394	57	18	32%
	14229	FC	200	435	400	56	30	54%
		EC	126	161	394	27	10	37%
	17073	FC	200	185	400	25	9	36%
		EC	126	75	394	18	4	22%
	17074	FC	200	348	400	29	13	45%
		EC	126	75	394	36	7	19%
	17076	FC	200	368	400	30	10	33%
		EC	126	189	394	25	5	20%
	17077	FC	200	210	400	30	8	27%
		EC	126	79	394	25	4	16%
	17079	FC	200	117	400	22	2	9%
		EC	126	99	394	38	6	16%
Cowart Creek								
1102 A	11425	FC	200	628	400	17	9	53%
		EC	126	314	394	29	13	45%
	11426	FC	200	354	400	13	4	31%
		EC	126	259	394	13	5	38%
	16477	FC	200	520	400	40	19	48%
		EC	126	102	394	11	3	27%
	16478	FC	200	777	400	23	14	61%
		EC	126	56	394	11	2	9%
Mary's Creek/North Fork Mary's Creek								
1102 B	16473	FC	200	711	400	40	22	55%
		EC	126	231	394	41	10	24%
	17917	FC	200	119	400	14	1	7%
		EC	126	85	394	23	2	9%
	17918	FC	200	46	400	14	1	7%
		EC	126	51	394	24	2	8%

Seg	ID	Indicator Bacteria	Geometric Mean Criterion counts/ 100mL	Geometric Mean Concentra-tion counts/ 100mL	Single Sample Criterion counts/ 100mL	Number of Samples	Number of Samples Exceeding Single Sample Criterion	Percent of Samples Exceeding Single Sample Criterion
Hickory Slough								
1102 C	17068	FC	200	267	400	31	11	35%
		EC	126	159	394	45	13	29%
Turkey Creek								
1102 D	17069	FC	200	2196	400	15	11	73%
		EC	126	97	394	10	3	30%
Mud Gully								
1102 E	17070	FC	200	1340	400	20	17	85%
		EC	126	54	394	11	2	18%
	17071	FC	200	743	400	12	6	50%
		EC	126	48	394	12	1	8%

EC = *E. coli*, FC = fecal coliform; ENT = Enterococci; Seg = Segment Number; ID = Station Number

Highlighted stations are tidally influenced stations on freshwater segments. Load duration curve analysis cannot be applied to sampling locations that are tidally influenced; therefore, these stations will be part of the TMDL analysis associated with Clear Creek Tidal, Segment 1101.

There are 42 *E. coli* samples throughout Robinson Bayou that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. Seventeen of the 27 samples (63 percent) collected at the sampling location 16475 and 14 of the 15 samples (93 percent) collected at sampling location 16486 used to assess this water body exceed the Enterococci criterion. Geometric means ranged from 158 to 1191 counts/100mL. This indicates persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use. The sampling locations are located in the lower and middle reaches of Robinson Bayou.

There are 325 *E. coli* samples throughout Clear Creek Above Tidal that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. At nine of the 10 sampling locations, more than 25 percent of the samples exceed the single sample criterion established for either *E. coli* or fecal coliform, or both. The geometric mean of *E. coli* concentrations ranged from 51 to 358 counts/100mL and individual sample concentrations exceeded the criterion in 5 percent to 42 percent of the samples. This data analysis indicates conditions of widespread and persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use. Sampling locations that meet or exceed criteria are distributed throughout the length of Clear Creek Above Tidal.

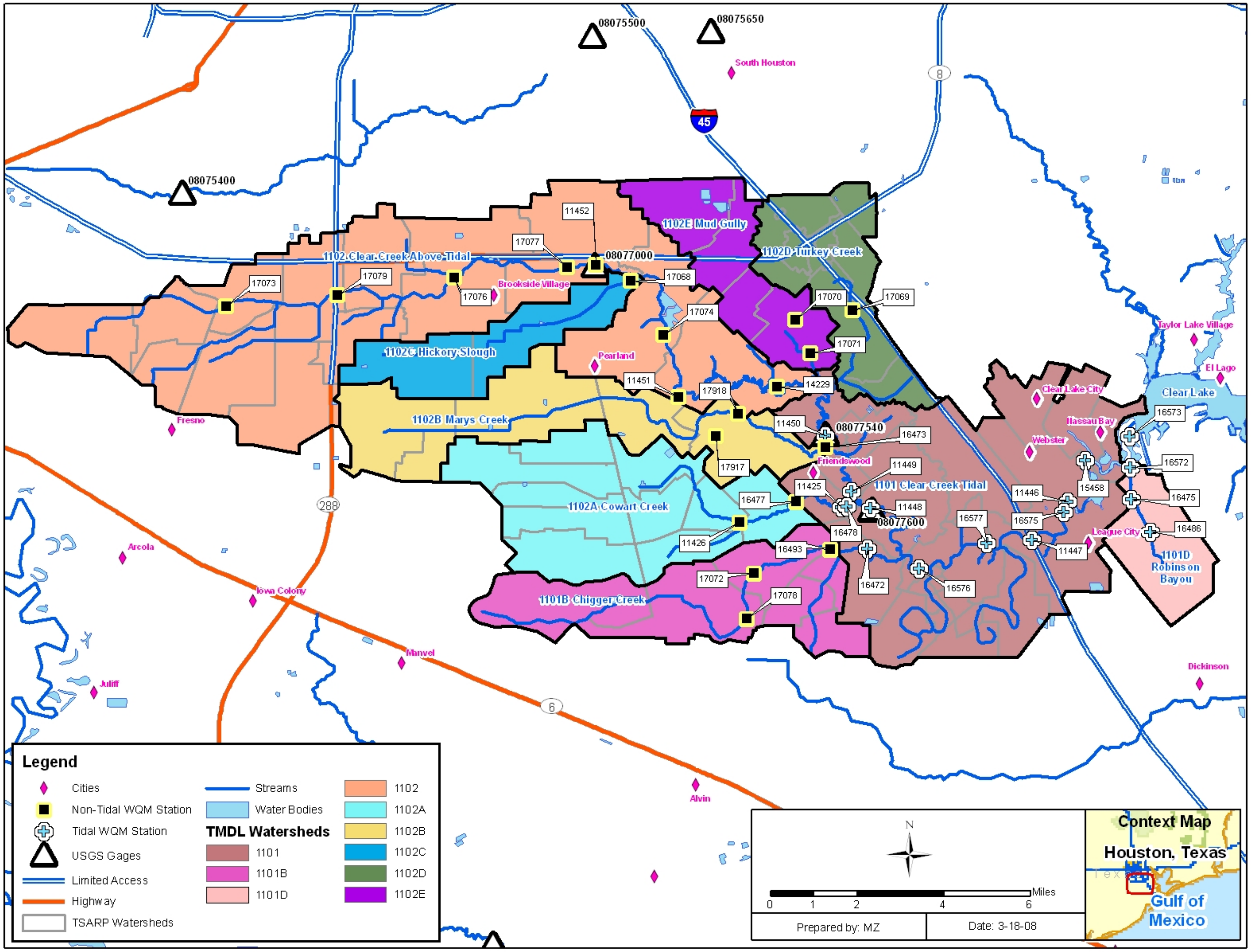


Figure 2. Clear Creek Watershed Sampling Locations

There are 64 *E. coli* samples throughout Cowart Creek that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. At all four sampling locations, more than 25 percent of the samples exceed the single sample criterion established for either *E. coli* or fecal coliform, or both. The geometric mean of *E. coli* concentrations ranged from 56 to 314 counts/100mL and individual sample concentrations exceeded the criterion in 9 percent to 45 percent of the samples. This data analysis indicates conditions of widespread and persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use.

There are 88 *E. coli* samples throughout Mary's Creek/North Fork Mary's Creek that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. Of the three sampling locations, only the most downstream exceeds the single sample criterion established for fecal coliform. Fifty-five percent of the samples exceed the fecal coliform criterion, and 24 percent of the samples exceed the *E. coli* criterion. However, the geometric means for both indicators are exceeded. The geometric mean of *E. coli* ranged from 51 to 231 counts/100mL and individual sample concentrations exceeded the criterion in 8 percent to 24 percent of the samples. This may indicate conditions of localized but persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use only in the downstream portion of the segment. An additional factor that complicates characterization of the impairment of contact recreation at this sampling location is the fact that this station is tidally influenced.

There are 45 *E. coli* samples throughout Hickory Slough that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. At sampling location 17068, both *E. coli* and fecal coliform exceeded the single sample criterion (35 percent and 29 percent, respectively). The geometric mean of *E. coli* at the single sampling location is 159 counts/100mL. Given the small size of this watershed, it is presumed that this station adequately represents conditions of persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use.

There is only one sampling location on Turkey Creek. Sampling location 17069 has 10 *E. coli* samples and 15 fecal coliform samples to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. Both *E. coli* and fecal coliform exceeded the single sample criterion (73 percent and 30 percent, respectively). The geometric mean of *E. coli* at this sampling location is 97 counts/100mL which supports the contact recreation use. The geometric mean of fecal coliform at this station is 2,196 counts/100mL which significantly exceeds the water quality criterion. These data indicate high concentrations of fecal coliform are present in the Turkey Creek watershed.

There are 32 *E. coli* samples throughout Mud Gully that were used to assess the extent of the indicator bacteria impairment and to determine TMDL pollutant load allocations. At sampling location 17070, fecal coliform exceeded the single sample criterion 85 percent of the time and at station 17071, fecal coliform exceeded the single sample criterion 50 percent of the time. The geometric means of fecal coliform at the two sampling locations ranged from 743 to 1340. Based on samples of the *E. coli* indicator, the contact recreation use is met at the two sampling locations in the segment. However, because there are a limited number of *E. coli* samples, fecal coliform data were used to determine the TMDL to protect the contact recreation use. The fecal coliform data indicate conditions of persistent elevated levels of indicator bacteria resulting in nonsupport of contact recreation use.

Watershed Overview

Clear Creek Tidal and Robinson Bayou are perennial tidal water bodies that terminate at Clear Lake. The remaining seven water bodies are freshwater. Clear Creek Above Tidal (1102) is the perennial freshwater part of Clear Creek that extends from Clear Creek Tidal into Fort Bend County. Chigger Creek is a perennial tributary of Clear Creek Tidal (1101). Cowart Creek and Mary's Creek/North Fork Mary's Creek are tributaries of Clear Creek Above Tidal. Cowart Creek is an intermittent water body with perennial pools and Mary's Creek/North Fork Mary's Creek is a perennial water body. The three remaining tributaries of Clear Creek Above Tidal are freshwater, perennial water bodies.

All of the water bodies addressed by these TMDLs are within the Clear Creek watershed. The Clear Creek watershed encompasses approximately 180 square miles of land located just southeast of the city of Houston, Texas. The Clear Creek watershed is part of the San Jacinto-Brazos Coastal Basin. The watershed feeds into Clear Lake (Segment 2425) which, in turn, feeds into Upper Galveston Bay (Segment 2421). Approximately 40 percent of the watershed lies within Brazoria County, 35 percent lies within Harris County, 20 percent is within Galveston County, and 5 percent of the watershed lies within Fort Bend County. The eastern and central portions of the watershed are primarily urban and residential, with some commercial and industrial uses.

The climate of the region is subtropical humid, with very hot and humid summers and mild winters (USACE 1985). The average daytime temperature in the summer is 34 degrees Celsius (93 degrees Fahrenheit) while the temperature averages between 4 and 16 degrees Celsius (39 to 61 degrees Fahrenheit) during the winter. Summer month rainfall is dominated by subtropical convection, winter months by frontal storms, and fall and spring months by combinations of these two (Burian 2005). Average annual rainfall from 1970 to 2000 based on the national data set from PRISM Group (PRISM Group 2006), is summarized in Table 3. Annual rainfall averages range from 51.77 inches in the Clear Creek Above Tidal watershed to 54.52 inches in the Robinson Bayou watershed.

Table 4 summarizes the percentages of the land use categories for the contributing watershed associated with each respective segment in the Clear Creek watershed. The specific land use/land cover data files were derived from the Change Analysis Program, Texas 2005 Land Cover Data (NOAA 2007). The land use categories are displayed in Figure 1. The primary land use category in all watersheds within the study area is developed land (between 39 percent and 82 percent). The second most prominent land use category is pasture/hay land which ranges between 5 percent and 28 percent. The western and southern parts of the watershed include rural and agricultural land use which continues to transition over time from cultivated and woody land to developed land.

The Clear Creek Tidal, Robinson Bayou, Mary's Creek/North Fork Mary's Creek, Hickory Slough, Turkey Creek, and Mud Gully watersheds are primarily urban with 51 percent to 82 percent developed land. Chigger Creek, Clear Creek Above Tidal, and Cowart Creek are less urbanized with 39 percent to 49 percent developed land.

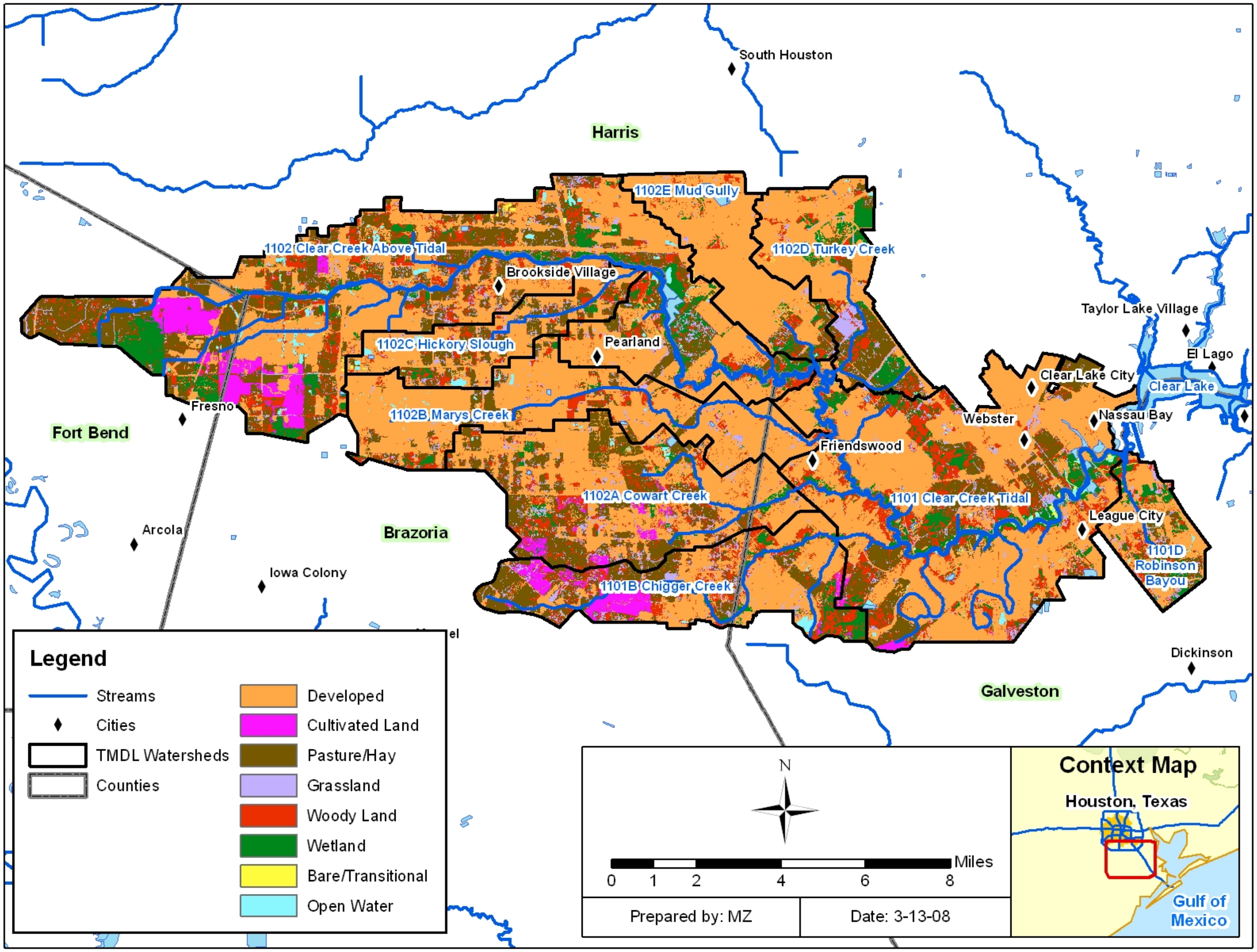


Figure 3. Clear Creek Watershed Land Use

Table 3. PRISM Annual Average Precipitation, 1970-2000

Segment Name	Segment ID	Average Annual Precipitation (Inches)
Clear Creek Tidal	1101	54.04
Chigger Creek	1101B	53.11
Robinson Bayou	1101D	54.52
Clear Creek above Tidal	1102	51.77
Cowart Creek	1102A	52.70
Mary's Creek/North Fork Mary's Creek	1102B	52.37
Hickory Slough	1102C	52.22
Turkey Creek	1102D	53.33
Mud Gully	1102E	53.02

Table 4. Summary of Watershed Characteristics

	Clear Creek Tidal	Chigger Creek	Robin-son Bayou	Clear Creek above Tidal	Cowart Creek	Mary's Creek/ North Fork Mary's Creek	Hickory Slough	Turkey Creek	Mud Gully
Segment	**1101**	**1101B**	**1101D**	**1102**	**1102A**	**1102B**	**1102C**	**1102D**	**1102E**
Aggregated Land Use Category (percent)									
Developed	58	39	51	41	49	79	54	57	82
Cultivated Land	0.6	10.3	0.0	5.5	3.2	0.0	0.0	0.0	0.0
Pasture/Hay	12.1	22.3	12.1	24.5	27.7	7.9	22.7	15.7	5.0
Grasslands/ Herbaceous	3.8	6.1	7.0	4.5	5.9	3.3	6.1	6.4	2.1
Woody Land	14	15	15	12	11	7.2	12	9.1	6.1
Open Water	1.9	0.9	0.7	1.5	0.4	0.6	2.2	0.3	1.5
Wetland	8.4	6.5	14	1.1	3.3	1.4	2.8	12	3.5
Bare/ Transitional	0.9	0.0	0.9	0.3	0.1	0.1	0.3	0.3	0.3
Other Characteristics									
Stream Length (miles)	12	9.8	1.4	30	6.4	10.9	10.4	3.0	2.7
Watershed Area (miles)	39.7	14.9	5.4	57.8	19.4	16.2	7.7	10.1	9.4

The study area has six incorporated cities within its watershed. Twelve independent utility districts and seven drainage districts are active within the watershed.

The six largest cities within the Clear Creek watershed are expected to increase in population by an average of 42.5 percent from 2000 to 2020, according to the Texas Water Development Board (TWDB) (Montgomery Watson America, Inc. 2000). Table 5 lists TWDB population growth estimates for these six cities from 2000 to 2020.

Table 5. Clear Creek Watershed Population Increases by City, 2000 to 2020

City	2000 Census Population	2010 Population	2020 Population	Growth Rate (2000-2020)
Brookside Village	1,960	2,282	2,618	34%
Friendswood	29,037	32,353	35,216	21%
League City	45,444	53,546	60,539	33%
Nassau Bay	4,170	Unknown	Unknown	0%
Pearland	37,640	66,049	83,462	112%
Webster	9,083	13,076	16,946	87%

Source: <www.twdb.state.tx.us/data/data.asp> (Jan 2008)

Projections last updated 04/17/2006

Endpoint Identification

All TMDLs must identify a quantifiable water quality target that indicates the desired water quality condition and provides a measurable goal for the TMDL. The TMDL endpoint also serves to focus the technical work to be accomplished and as a criterion against which to evaluate future conditions.

The endpoint for the TMDLs for freshwater segments is to maintain concentrations of *E. coli* below the geometric mean criterion of 126 counts/100 mL. The endpoint for the TMDLs for tidal (saltwater) segments is to achieve concentrations of Enterococci below the geometric mean criterion of 35 counts/100 mL. The tidal segments are Clear Creek Tidal and Robinson Bayou.

Source Analysis

Pollutants may come from several sources, both point and nonpoint. Point source pollutants come from sources that are regulated by permit under the Texas Pollutant Discharge Elimination System (TPDES). WWTFs, and storm water discharges from industries, construction, and the separate storm sewer systems of cities are considered point sources of pollution. Nonpoint source pollution originates from multiple locations, usually carried to surface waters by rainfall runoff, and is not regulated by permit under the TPDES.

Point Sources

All nine segments in the study area have TPDES-permitted sources. A significant portion of the study area (approximately 64 percent) is regulated under the TPDES storm water discharge permit jointly held by Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation.

WWTFs

The locations of the TPDES-permitted facilities that continuously discharge wastewater to surface waters addressed in these TMDLs are listed in Table 6 and displayed in Figure 4. There are 21 permitted outfalls for WWTFs in the Clear Creek watershed. There are no WWTFs located in the Chigger Creek or Robinson Bayou watersheds.

There are six WWTF dischargers in the Clear Creek Tidal (1101) watershed with a total permitted flow of 26.54 million gallons per day (MGD). These WWTFs include the City of Webster, City of Nassau Bay, and League City. In the Clear Creek above Tidal (1102) watershed, seven WWTF dischargers have a total of 12.91 MGD of permitted flow. The City of Pearland is the permittee for five of these discharges. The Cowart Creek (1102A) watershed has two permitted dischargers with a total of 0.084 MGD. These are small facilities serving a limited number of connections. There are three permitted dischargers in the Mary's Creek/North Fork Mary's Creek (1102B) watershed with a total permitted flow of 4.4 MGD. The City of Pearland is one of the major dischargers and the other is a Municipal Utility District. Hickory Slough (1102C), Turkey Creek (1102D), and Mud Gully (1102E) each have only one permitted WWTF. The permitted flow for the small WWTF in Hickory Slough is 0.075 MGD. The WWTFs in Turkey Creek and Mud Gully are operated by the City of Houston. The Turkey Creek facility has a permitted flow of 6.14 MGD and the Mud Gully facility has a permitted flow of 5.33 MGD. There are no WWTFs located in the Chigger Creek or Robinson Bayou watersheds.

Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are permit violations that must be addressed by the responsible TPDES permittee. SSOs most often result from blockages in the sewer collection pipes caused by tree roots, grease, and other debris. The TCEQ maintains a database of SSO data collected from wastewater operators in the Clear Creek watershed. One SSO database is collected by the City of Houston and the other is compiled from the remainder of the wastewater dischargers in the Clear Creek watershed (Rice 2005). The locations and magnitudes of all reported SSOs, and WWTF service area boundaries are displayed in Figure 5 and the data for events outside of the city of Houston are summarized in Table 7.

As shown by the data, there have been approximately 600 sanitary sewer overflows reported in the Clear Creek watershed between January 2000 and July 2005. For the portion of the Clear Creek watershed located in the City of Houston, estimated volumes were recorded for 130 of the reported events and averaged 2,950 gallons per event. For the regions of the Clear Creek watershed located outside of the City of Houston, estimated volumes were recorded for 425 of the events, and averaged 13,600 gallons per event. SSOs were reported in all nine segments of the study area.

Table 6. WWTF Dischargers in the Clear Creek Watershed

Segment Number	Segment Name	TPDES Number	Facility Name	Treatment Type	County	Current Permitted Flow (MGD)
1101	Clear Creek Tidal	10520-001	City of Webster	Cl	Harris	3.3
		10526-001	City of Nassau Bay	Cl	Harris	1.33*
		10526-001	City of Nassau Bay (outfall 2)	Cl	Harris	1.33*
		10568-003	City of League City	Cl	Galveston	0.66
		10568-005	City of League City	UV	Galveston	12
		11571-001	Gulf Coast Waste Disposal Authority	UV	Harris	9.25
1102	Clear Creek above Tidal	10134-002	City of Pearland	Cl	Brazoria	3.1
		10134-008	City of Pearland	UV	Brazoria	2.00
		10134-010	City of Pearland	Cl	Brazoria	2.50
		10134-010	City of Pearland (outfall 2)	Cl	Brazoria	2.00
		12295-001	City of Pearland	Cl	Brazoria	0.95
		12939-001	Harris County WCID 89	Cl	Harris	0.25
		13864-001	Fresno Manufacturing LLC	NA	Fort Bend	0.0084
1102A	Cowart Creek	12822-001	Walker Water Works Inc.	Cl	Brazoria	0.035
		13865-001	Forestaire Estates	Cl	Brazoria	0.049
1102B	Mary's Creek/North Fork Mary's Creek	10134-007	City of Pearland	UV	Brazoria	2.0
		12332-001	Brazoria County Mud No. 1	Cl	Brazoria	2.4
		12680-001	H & R Realty Investments LLC	Cl	Brazoria	0.012
1102C	Hickory Slough	12849-001	CMH Parks Inc.	Cl	Brazoria	0.075
1102D	Turkey Creek	10495-075	City of Houston	Cl	Harris	6.14
1102E	Mud Gully	10495-079	City of Houston	Cl	Harris	5.33

Source: TCEQ, August 2007

MGD = million gallons per day

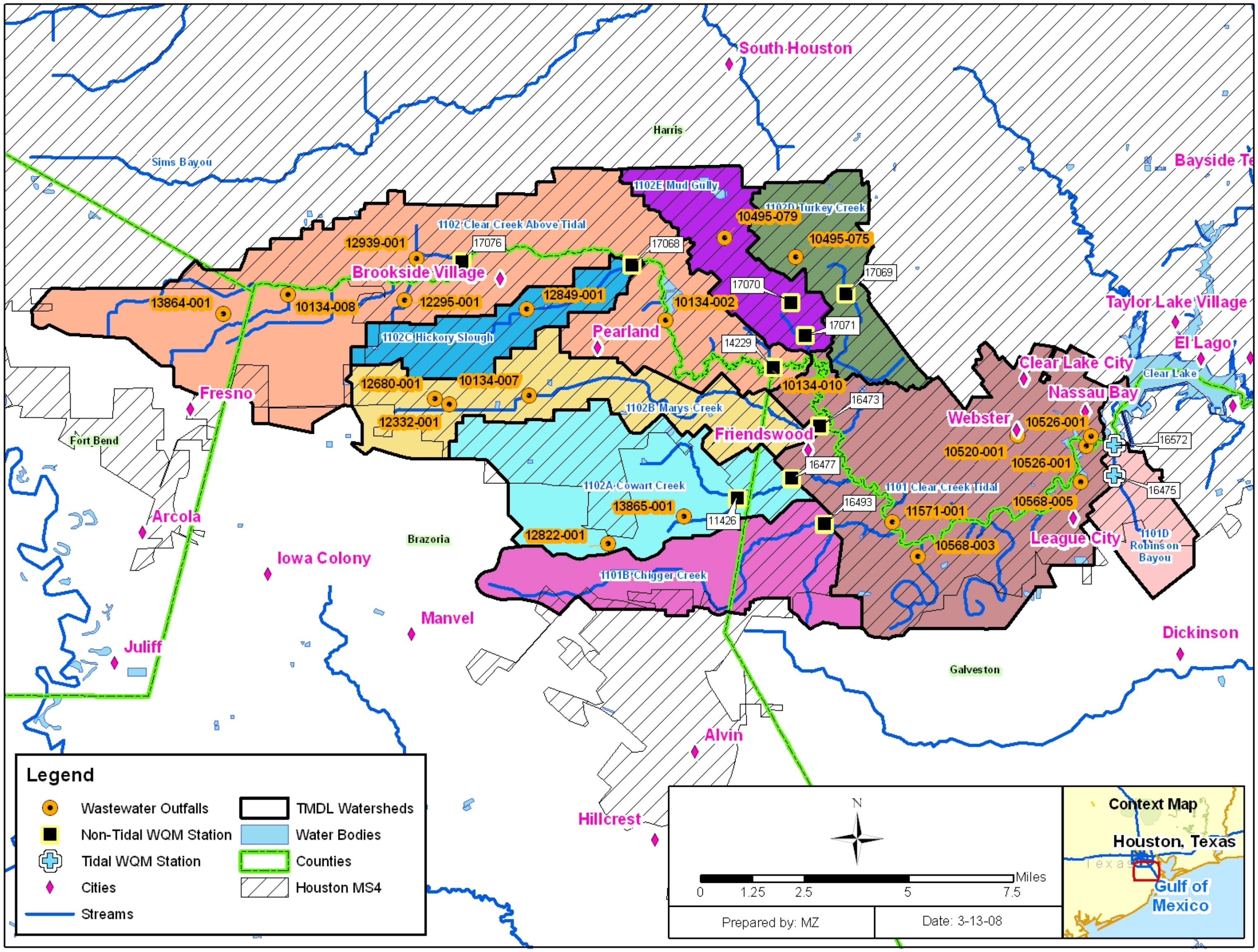
Treatment Type

Cl = Chlorination

UV= Ultraviolet Light

NA = Information Not Available From EPA Permit Compliance System Database

* The total flow from both outfalls combined cannot exceed 1.33 MGD



Source: The jurisdictional boundary of the Houston MS4 permit is derived from Urbanized Area Map Results for Texas which can be found at the EPA Web site. <http://cfpub.epa.gov/npdes/stormwater/urbanmapresult.cfm?state=TX>. No other information was available.

Figure 4. TPDES-Permitted Facilities in the Clear Creek Watershed

TPDES Regulated Storm Water

When evaluating waste load allocations and load allocations, a distinction must be made between storm water originating from an area under a TPDES regulated discharge permit and storm water originating from areas not under a TPDES regulated discharge permit. Storm water discharges fall into two categories:

1) storm water subject to permitting, which is any storm water originating from a TPDES Phase 1 or Phase 2 permitted-discharge urbanized area; and
2) storm water currently not subject to permitting, which is any storm water originating from any area outside a TPDES Phase 1 or Phase 2 permitted-discharge urbanized area.

Considerable portions of each watershed in the study area are covered under the City of Houston/Harris County discharge permit (TPDES Permit No. WQ0004685000). The jurisdictional boundary of the Houston MS4 permit is derived from Urbanized Area Map Results for Texas which is based on the 2000 U.S. Census and can be found at the EPA Web site: <http://cfpub.epa.gov/npdes/stormwater/urbanmapresult.cfm?state=TX>.

Under the City of Houston/Harris County storm water discharge permit, Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation are designated as co-permittees. These agencies do not have any monitoring points located on water bodies that drain into the Clear Creek watershed (Martin 2005). Therefore, there are no monitoring data available to characterize bacteria concentrations or loads from regulated storm water discharged to receiving waters in the Clear Creek watershed. Figure 4 displays the portion of the watershed that contributes indicator bacteria loads to the receiving waters from permitted and non-permitted storm water.

Table 8 lists the percentage of each watershed covered under the Houston MS4 permit.

Dry Weather Discharges/Illicit Discharges

In addition to permitted discharges of wastewater that can contribute indicator bacteria loads to Clear Creek receiving waters, indicator bacteria loads from both permitted and non-permitted storm water can enter the streams from permitted outfalls and illicit discharges under both dry and wet weather conditions. These discharges are known as dry weather or illicit discharges. These discharges are covered by a WWTF permit, or where applicable, by provisions of a an MS4 permit.

The Galveston County Health District (GCHD 2001) conducted a study in 2000 of the storm sewer discharges into Clear Creek and its tributaries. The objectives of this study were to locate all of the storm water outfalls, sample the dry weather flows for indicator bacteria, investigate any contaminated discharges, and locate and eliminate cross connections between the sanitary and storm sewer systems in the region. The Galveston County Health District study found that 385 of 1,140 storm water outfalls in the region had dry weather discharges and that 22 percent of these (83 outfalls) had fecal coliform concentrations greater than 1,000 counts/100 mL. These types of discharges contribute to instream impairments.

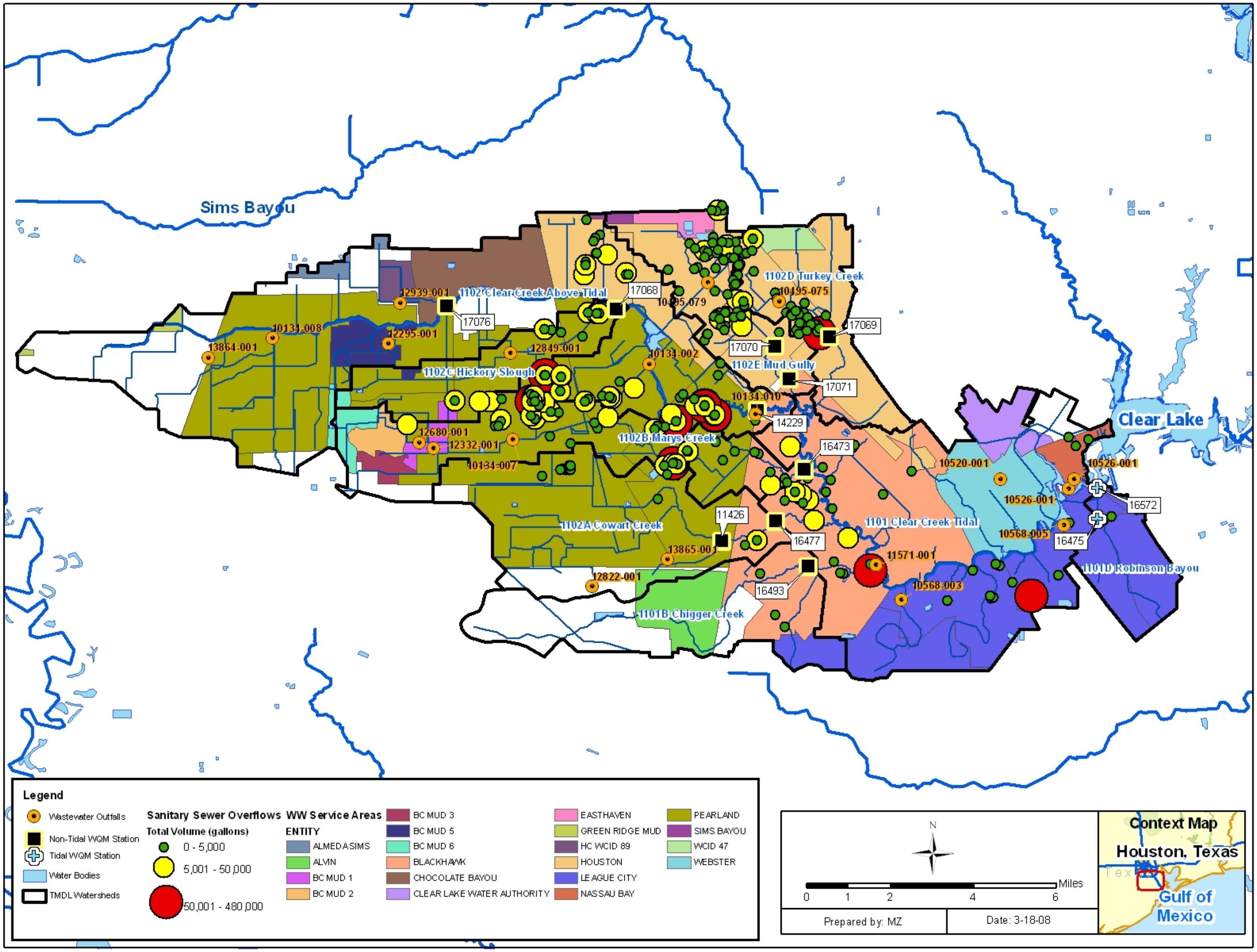


Figure 5. Sanitary Sewer Overflow Locations (January 2000 through July 2005)

Table 7. Sanitary Sewer Overflow Summary (January 2000 through July 2005)

Facility Name	Facility ID	Number of Overflows	Date Range		Amount (Gallons)	
			From	To	Min	Max
City of Pearland[1]	10134-001	8	06/28/2003	06/15/2004	1500	3,150
City of Pearland	10134-002	182	04/03/2000	07/15/2005	200	181,500
City of Pearland[1]	10134-003	48	09/15/2000	12/13/2001	200	68,100
City of Pearland	10134-007	25	10/05/2000	07/18/2005	100	63,000
City of Pearland	10134-010	86	05/17/2002	07/25/2005	200	180,000
Sagemont	10495-075	77	01/21/2000	08/24/2004	7	147,050
Sagemeadow UD	10495-079	85	01/07/2000	07/19/2005	5	25,240
City of Nassau Bay	10526-001	4	06/09/2001	06/28/2004	200	500
City of League City	10568-005	40	08/14/2000	05/10/2005	50	480,000
City of Webster	10520-001	1	11/24/2002	11/24/2002	N/A	N/A
Pilchers Property[1]	11572-001	1	03/13/2002	03/13/2002	20000	20,000
Gulf Coast Waste Disposal Authority[2]	11571-001	52	11/15/2000	07/22/2005	30	450,000
Brazoria Co Mud 5	12295-001	3	01/07/2001	04/12/2003	30	200
Brazoria Co Mud 2	12332-001	16	10/31/2000	09/18/2004	75	18,000
Brazoria Co Mud 19[1]	14135-001	3	12/10/2001	12/30/2002	2000	20,000

[1]Inactive Facility

[2]Facility name change provided by TCEQ, November 2007. Facility previously named Blackhawk/Friendswood

In 2005 and 2006, additional reconnaissance of pipe outfalls discharging directly into Clear Creek and its tributaries was performed. The creek banks were canvassed by walking, kayaking, or using a motorboat to identify pipes with an outfall directly into Clear Creek or its tributaries. The primary goals of this task were to document the location, diameter, global positioning system (GPS) coordinates, and drainage classification (flowing or not flowing) of all pipes that enter the water bodies of Clear Creek. Sampling of bacteria levels of observed discharges was not one of the tasks of this reconnaissance project.

This pipe reconnaissance identified a total of 440 pipes that are positioned to discharge into Clear Creek and its tributaries. Of these 440 pipes, 98 were observed as having visible flow. Figure 6 depicts the Clear Creek watershed and the pipe outfall locations identified in the 2005 and 2006 pipe reconnaissance. This figure differentiates between pipes observed that were not flowing and those that were flowing, and the location of TCEQ-permitted outfalls.

Table 8. Percentage of Permitted Storm Water in each Watershed

Segment	Receiving Stream	TPDES Number	Total Area (acres)	Area under MS4 Permit (acres)	Percent of Watershed under MS4
1101	Clear Creek Tidal	WQ0004685000	24,347	22,839	94%
1101B	Chigger Creek	WQ0004685000	9,526	4,127	43%
1101D	Robinson Bayou	WQ0004685000	3,481	2,281	66%
1102	Clear Creek above Tidal	WQ0004685000	33,084	22,891	69%
1102A	Cowart Creek	WQ0004685000	12,380	6,476	52%
1102B	Mary's Creek/North Fork Mary's Creek	WQ0004685000	10,375	9,317	90%
1102C	Hickory Slough	WQ0004685000	4,935	4,740	96%
1102D	Turkey Creek	WQ0004685000	6,482	6,482	100%
1102E	Mud Gully	WQ0004685000	6,009	6,009	100%

Nonpoint Sources

Nonpoint source (NPS) loading enters the impaired segment through distributed, unspecific locations and is usually not regulated. Nonpoint sources of indicator bacteria can emanate from wildlife, various agricultural activities, and agricultural animals, land application fields, urban runoff not covered by a permit, failing onsite sewage facilities (OSSFs), and domestic pets.

On-Site Sewage Facilities

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

It has been observed that OSSF failures are proportional to the adequacy of a state's minimum design criteria (Hall 2002). The 1995 American Housing Survey conducted by the U.S. Census Bureau estimates that, nationwide, 10 percent of occupied homes with OSSFs experience malfunctions during the year (U.S. Census Bureau 1995). A statewide study conducted by Reed, Stowe & Yanke, LLC (2001) reported that approximately 12 percent of the OSSFs in Harris County were chronically malfunctioning. Most studies estimate that the minimum lot size necessary to ensure against failure is roughly one-half to one acre (Hall 2002). Some studies, however, found that lot sizes in this range or even larger could

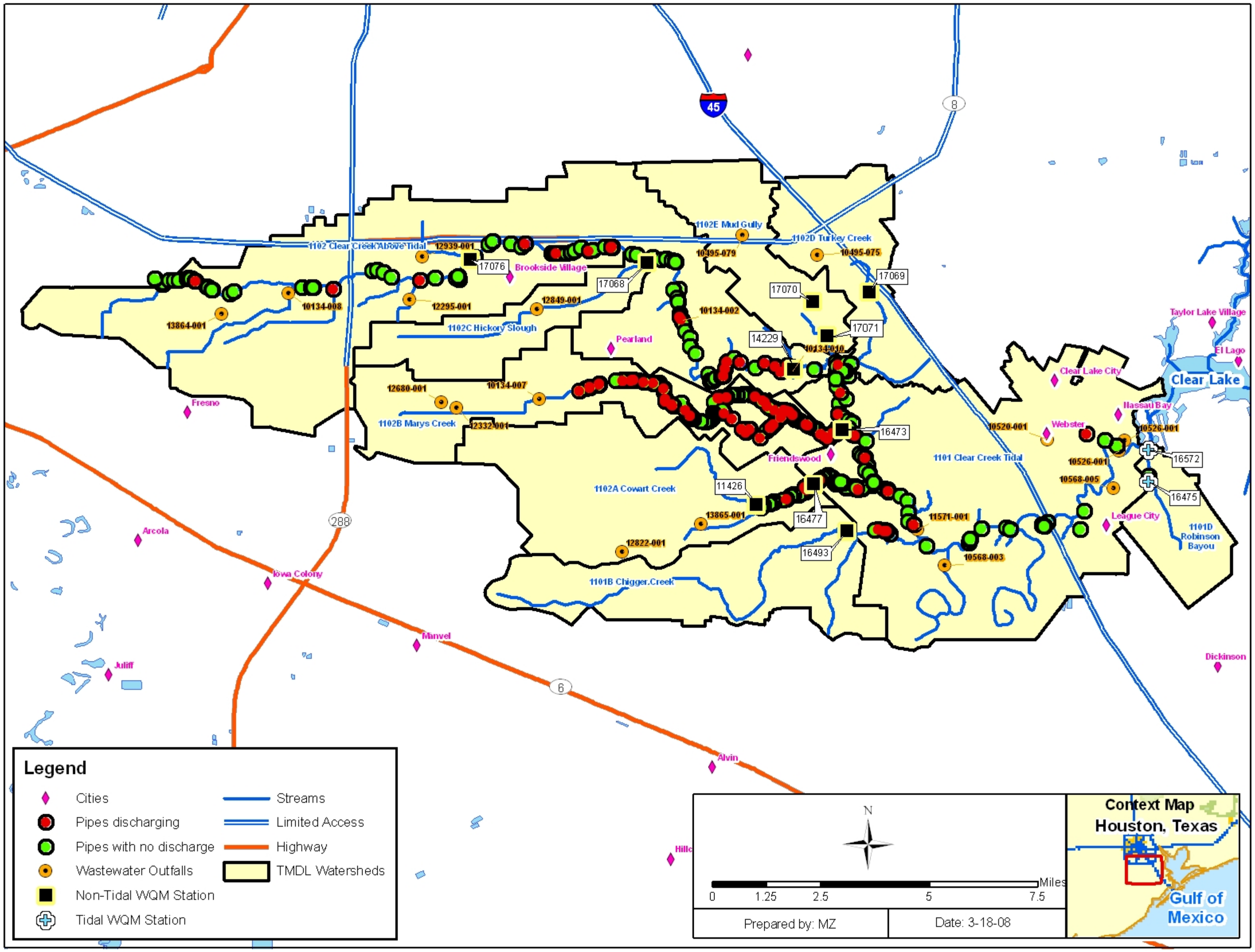


Figure 6. 2005-2006 Pipe Reconnaissance

still cause contamination of ground or surface water (University of Florida 1987). It is estimated that areas with more than 40 OSSFs per square mile (6.25 septic systems per 100 acres) can be considered to have potential failure problems (Canter and Knox 1985).

Only permitted OSSF systems are recorded by authorized county or city agents, therefore it is difficult to estimate the exact number of OSSFs that are in use in the study area. Table 9 lists the OSSF totals between 1992-2007 based on the 1990 U.S. Census and the number of OSSF permits obtained by authorized county or city agents. Permits are obtained to install or replace systems. However, some permits are obtained when an older failing system needs repair (H-GAC 2005). It is assumed that there are more OSSFs in each city or county listed in Table 9 which were installed prior to 1992.

Because the Clear Creek watershed covers only portions of each of the four counties listed in Table 9, specific steps were taken to estimate the proportion of OSSFs that exist within the Clear Creek watershed. The number of OSSFs was estimated for each watershed. The estimate of OSSFs was derived by using data from the 1990 U.S. Census (U.S. Census Bureau 2000) and a GIS shape file obtained from the Houston-Galveston Area Council (H-GAC) showing all areas where wastewater service currently exists. Figure 7 displays un-sewered areas that did not fall under the wastewater service areas. OSSFs were calculated using spatial GIS queries for areas not covered by wastewater service areas. OSSFs were assigned proportionally based on the percentage of the area falling outside a wastewater service area within each watershed. Finally, the OSSFs for each un-sewered area were then totaled by TMDL watershed. This approach gives an estimate of OSSFs in the watershed. Table 10 shows the estimated number of OSSFs calculated using this GIS method.

Harris County provided additional OSSF data for select portions of the study area. The subdivisions of Clear Creek Shores, Ski Ranch Estates, and Joseph A Dickinson Survey were listed as OSSF areas. There are 54 existing structures in these subdivisions; 33 have permits for OSSFs, and the remaining 21 are suspected to be failing. These estimates were also included in Table 10. It was suggested that these older systems are believed to discharge sewage directly into the drainage canals leading to Clear Creek. Figure 7 points out subdivisions that have been identified as having OSSFs, including the City of Brookside Village and the subdivisions of Clear Creek Shores, Ski Ranch Estates, and Joseph A Dickinson Survey (not shown in Figure 7).

Non-Permitted Agricultural Activities and Domesticated Animals

There are a number of non-permitted agricultural activities that can also be sources of indicator bacteria loading. Agricultural activities of greatest concern are typically those associated with livestock operations including cattle grazing (Drapcho and Hubbs 2002). The following are examples of livestock activities that can contribute to bacteria sources:

- Processed livestock manure is often applied to fields as fertilizer, and can contribute to indicator bacteria loading if washed into streams by runoff.
- Livestock grazing in pastures deposit manure containing indicator bacteria onto land surfaces. These bacteria may be washed into water bodies by runoff.
- Livestock that have direct access to water bodies can provide a concentrated source of indicator bacteria loading directly into streams.

Table 11 provides estimated numbers of selected livestock by watershed based on the 2002 Census of Agriculture conducted by U.S. Department of Agriculture (USDAUSDA 2002). The county-level estimated livestock populations were distributed among watersheds based on GIS calculations of pastureland per watershed, based on the Texas 2005 C-CAP Land Cover Data (NOAA 2007). If watersheds passed into multiple counties then the agricultural numbers were calculated separately by county and then summed for the entire watershed. Because the watersheds are generally much smaller than the counties, and livestock are not evenly distributed across counties or constant with time, these are rough estimates only. Cattle are the most abundant species of livestock in the study area, and often have direct access to the water bodies or their tributaries.

Table 9. Numbers of OSSF Permits Issued by Authorized County or City Agent

Year	City of Brookside Village	Brazoria	Fort Bend	Galveston	Harris	City of Pearland
1990 Census Totals	NA	25,772	9,721	12,733	44,120	NA
1992	6	177	113	134	243	
1993	16	499	252	319	651	1
1994	14	398	343	361	881	
1995	10	660	347	321	1,035	
1996	10	811	304	344	1,327	
1997	11	570	343	360	1,393	
1998	5	713	504	446	1,301	
1999		712	594	456	1,606	
2000		701	544	401	1,422	
2001		655	444	432	1,388	
2002		755	495	461	1,397	
2003		788	538	506	1,424	
2004		724	501	568	1,174	
2005		720	550	511	1,080	
2006		668	555	425	1,039	
2007*		112	281	224	498	
Total	**72**	**35,435**	**16,429**	**19,002**	**61,979**	**1**

Note: Data obtained from TCEQ On-Site Activity Reporting System

* data available up to 8/8/2007

NA: Not Available

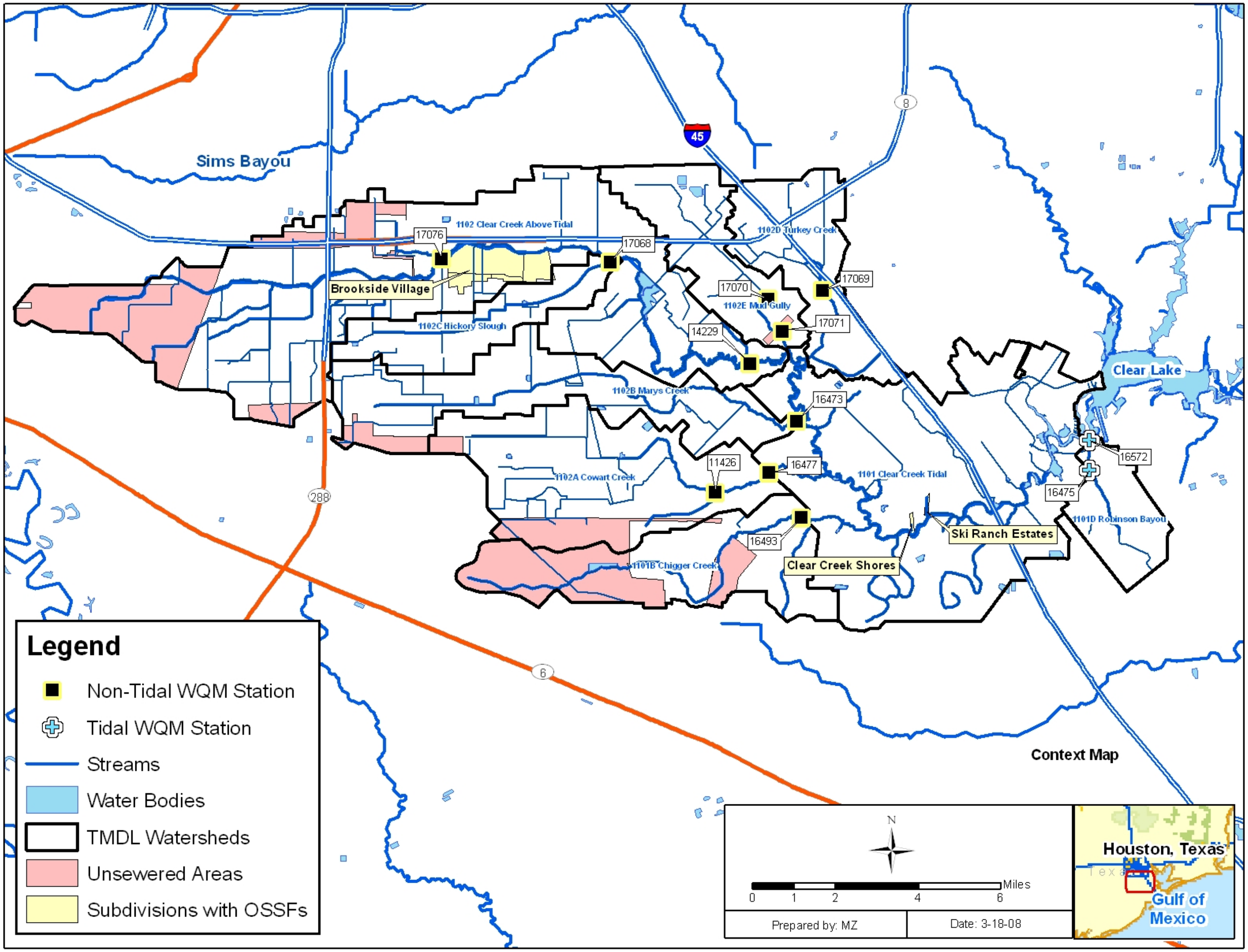


Figure 7. Un-Sewered Areas and Subdivisions with OSSFs

Table 10. Estimated Number of OSSFs per Watershed

Segment	Stream Name	OSSF Estimate using 1990 Census method	OSSF data from Harris County and OARS	Number of Failing OSSFs
1101	Clear Creek Tidal	9	54	21*
1101B	Chigger Creek	37		4
1102	Clear Creek above Tidal	420	72	59
1102A	Cowart Creek	22		3
1102B	Mary's Creek/North Fork Mary's Creek	12		1
1102C	Hickory Slough	1		0
1102D	Turkey Creek	0		0
1102E	Mud Gully	23		3
1101D	Robinson Bayou	0		0

OARS = Online Assessment Reporting System

* Twenty-one OSSFs are suspected to be failing from Clear Creek Shores, Ski Ranch Estates, and Joseph A Dickinson Survey.

Table 11. Livestock Estimates by Watershed

Segment Number	Segment Name	Cattle & Calves	Dairy Cows	Horses & Ponies	Sheep & Lambs	Hogs & Pigs	Ducks & Geese	Chickens & Turkeys
1101	Clear Creek Tidal	46	0	5	1	0	1	9
1101B	Chigger Creek	115	0	9	1	1	2	9
1102	Clear Creek above Tidal	37	0	2	0	1	0	62
1102A	Cowart Creek	8	0	1	0	0	0	1
1102B	Mary's Creek/North Fork Mary's Creek	595	0	34	5	19	5	771
1102C	Hickory Slough	583	0	29	6	22	3	971
1102D	Turkey Creek	802	9	93	14	9	21	163
1102E	Mud Gully	193	2	22	3	2	5	39
1101D	Robinson Bayou	306	0	25	1	3	7	24

The Texas AgriLife Extension Service was contacted in January 2007 to get feedback from local experts on whether the livestock numbers from the 2002 USDA Census of Agriculture reflect current livestock numbers in the Clear Creek watershed. County Extension

Agents in Galveston, Harris, and Brazoria Counties stated that overall the numbers of livestock animals have decreased since 2002 as grazing land continues to be developed. All stated that no manure application is occurring in the study area. It was also indicated that broilers (chickens) may have increased because of the increase in youth livestock programs such as Future Farmers of America and 4-H (Cranfill 2008). Livestock numbers and their contributions to bacteria loadings in the Clear Creek watershed are expected to decrease over time as more land is converted from grazing to developed, urban uses.

Wildlife and Unmanaged Animal Contributions

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

Domestic Pets

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

Table 12 summarizes the estimated number of dogs and cats for the watersheds of the study area.

Linkage Analysis

Establishing the potential relationship between instream water quality and the source of pollutant loadings is an important component in developing a TMDL. It allows for the evaluation of management options that will achieve the desired endpoint.

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

Table 12. Estimated Number of Pets in Each Watershed

Segment	Segment Name	Dogs	Cats
1101	Clear Creek Tidal	23,359	26,581
1101B	Chigger Creek	4,900	5,576
1102	Clear Creek above Tidal	16,860	19,186
1102A	Cowart Creek	6,254	7,116
1102B	Mary's Creek/North Fork Mary's Creek	12,493	14,216
1102C	Hickory Slough	5,798	6,597
1102D	Turkey Creek	11,947	13,595
1102E	Mud Gully	12,893	14,672
1101D	Robinson Bayou	4,799	5,461

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

Two methods of analysis were used for analyzing indicator bacteria loads and instream water quality. Load duration curve (LDC) analyses were used for the seven freshwater segments. A mass balance analysis was used for the two tidal segments.

Load Duration Curve Analysis

LDCs are similar in appearance to flow duration curves; however, the y-axis is expressed in terms of a bacteria load in counts/day. The curve represents the single sample water quality criterion for fecal coliform (400 counts/100 mL) or *E. coli* (394 counts/100 mL), expressed in terms of a load through multiplication by the flows historically observed at this site. Using the single sample water quality criterion to generate the LDC is necessary to display the allowable pollutant load in relation to the existing loads which are represented by existing ambient water quality samples. The basic steps to generate an LDC involve:

- preparing flow duration curves (FDC) for gauged and un-gauged sampling locations;
- estimating existing bacteria loading in the receiving water using ambient water quality data;
- using LDCs to identify the critical condition that will define loading reductions necessary to attain the contact recreation standard; and

- interpreting LDCs to derive TMDL elements – waste load allocation, load allocation, margin of safety, and percent reduction goals.

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

Equation 1

TMDL (counts/day) = criterion * flow in cubic feet per second (cfs) * unit conversion factor

where:

criterion = 400 counts /100 mL (Fecal coliform); or 394 counts/100 mL (*E. coli*)
unit conversion factor = 24,465,755 100 mL/ft3 * seconds/day

The flow exceedance frequency (x-value of each point) is obtained by determining the percent of historical observations that equal or exceed the measured or estimated flow. The lack of current, long-term flow data from within the study area necessitated that flows be estimated for Clear Creek above Tidal, Chigger Creek, Cowart Creek, Mary's Creek, Hickory Slough, Turkey Creek, and Mud Gully. Therefore, USGS gauge station 08075400 (Sims Bayou at Hiram Clarke Street, Houston, Texas), which is located outside the watershed, was chosen to conduct flow projections to establish estimated flows for each of these freshwater segments.

The period of record for flow data used from this station was 1996 through 2006. Historical observations of bacteria concentration are paired with flow data and are plotted on the LDC. The indicator bacteria load (or the y-value of each point) is calculated by multiplying the indicator bacteria concentration (counts or counts/100mL) by the instantaneous flow in cubic feet per second (cfs) at the same site and time, with appropriate volumetric and time unit conversions. Indicator bacteria loads that exceed water quality criteria fall above the water quality criterion line.

LDCs display the maximum allowable load over the complete range of flow conditions by a line using the calculation of flow multiplied by the single sample water quality criterion. Using LDCs, a TMDL can be expressed as a continuous function of flow, equal to the line, or as a discrete value derived from a specific flow condition. A detailed description of the LDC method is included in Appendix A.

Load Duration Curve Results

There are no permitted WWTF discharges on Chigger Creek so no additions to the naturalized projected flow were necessary. The LDC for Chigger Creek segment 1101B (Figure 8) is based on *E. coli* bacteria measurements at sampling location 16493 (Chigger Creek at FM 528 Bridge). The percent reduction goal is calculated so that the geometric mean for *E. coli* is met under all flow conditions. The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion during mid-range and high flow conditions. This analysis also indicates that most of the *E. coli* observations in the highest flow range were wet weather influenced.

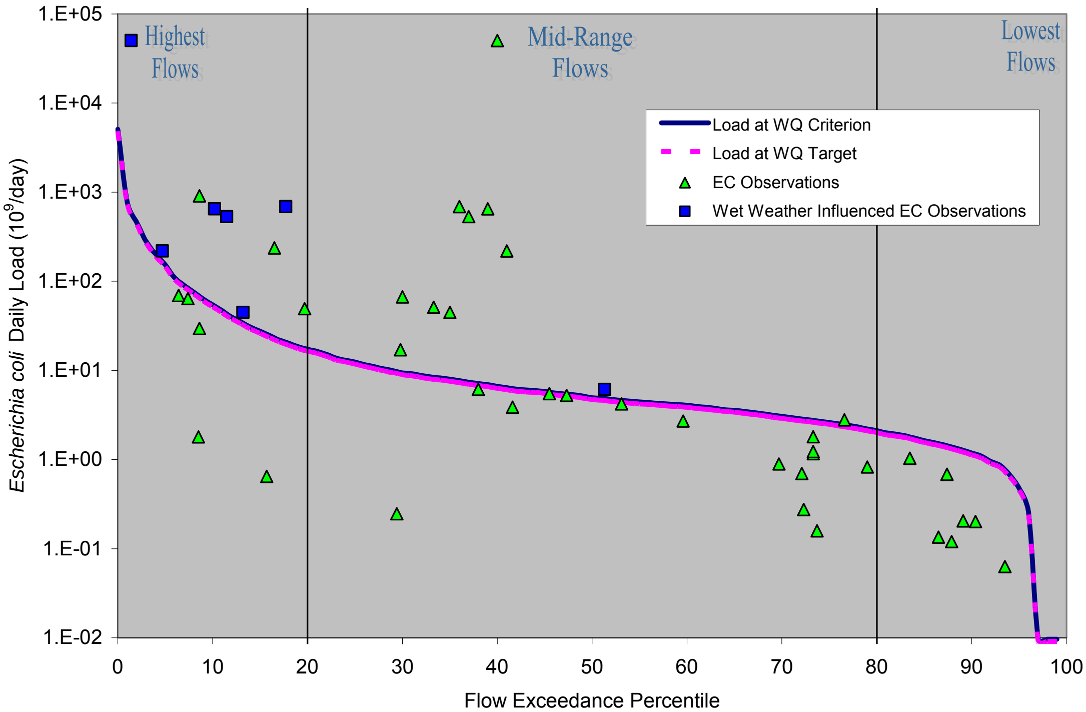


Figure 8. Load Duration Curve for E. coli in Chigger Creek (1101B)

Because WWTF discharges occur in Clear Creek Above Tidal, average monthly WWTF flows obtained from daily monitoring reports (DMRs) were added to the naturalized projected flows. DMR data was not available for two of the WWTFs (TX0032743 and TX0119750) located in the watershed. To compensate for the lack of flow data for these two dischargers, one-half of the facility design flow was added to the naturalized projected flow. The LDC for Clear Creek Above Tidal segment 1102 (Figure 9) is based on *E. coli* bacteria measurements at sampling location 14229 (Clear Creek at Dixie Farm Road). The percent reduction goal is calculated so that geometric mean criterion for contact recreation is met under all flow conditions. The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion under most flow conditions. This analysis also indicates that wet weather influenced *E. coli* observations are found under mid-range and high flow conditions.

Because WWTF discharges occur in Cowart Creek, average monthly WWTF flows obtained from DMRs were added to the naturalized projected flows. The LDC for Cowart Creek segment 1102A (Figure 10) is based on *E. coli* bacteria measurements at sampling location 16477 (Cowart Creek at Sunset Drive). The percent reduction goal is calculated so that the geometric mean criterion for contact recreation is met under all flow conditions. The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion primarily during the highest flow conditions, indicative of storm water sources. This is also demonstrated by the wet weather influenced *E. coli* samples occurring during the highest flow conditions.

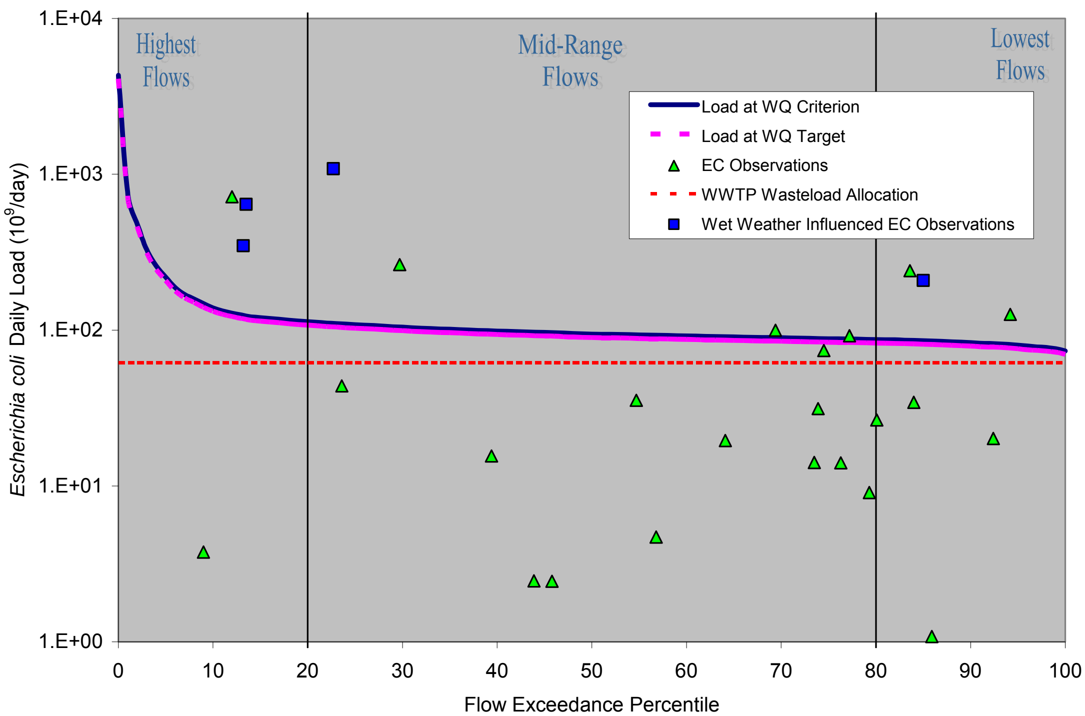


Figure 9. Load Duration Curve for E. coli in Clear Creek Above Tidal (1102)

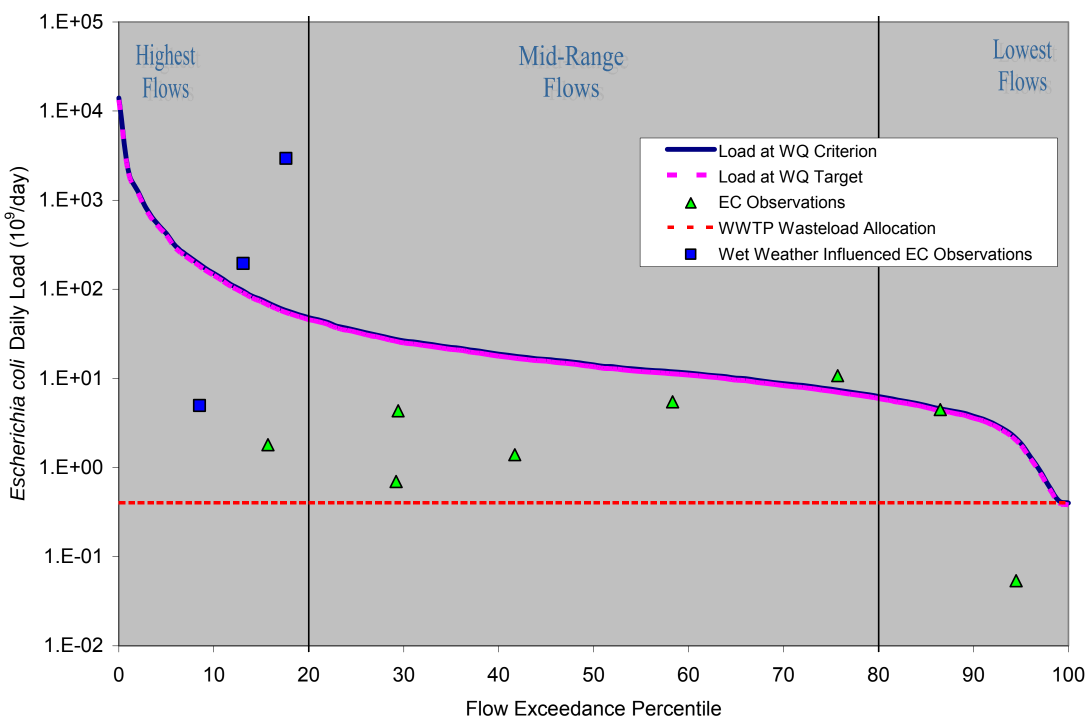


Figure 10. Load Duration Curve for E. coli in Cowart Creek (1102A)

Because WWTF discharges occur in Mary's Creek/North Fork Mary's Creek, average monthly WWTF flows obtained from DMRs were added to the naturalized projected flows. The LDC for Mary's Creek/North Fork Mary's Creek segment 1102B (Figure 11) is based on *E. coli* bacteria measurements at sampling location 16473 (Mary's Creek at Mary's Crossing). The percent reduction goal is calculated so that the geometric mean criterion for contact recreation is met under all flow conditions. The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion during high and mid-range flow conditions. Wet weather influenced bacteria samples exceeded mainly during higher flow conditions. This LDC presents some atypical characteristics where the WWTFs provide continuous flows above the 90th percentile. In cases such as this, stream flow above the 90th percentile is entirely composed of effluent. It is assumed that the WWTFs are compliant with permit requirements and therefore their discharges will not result in criteria exceedances.

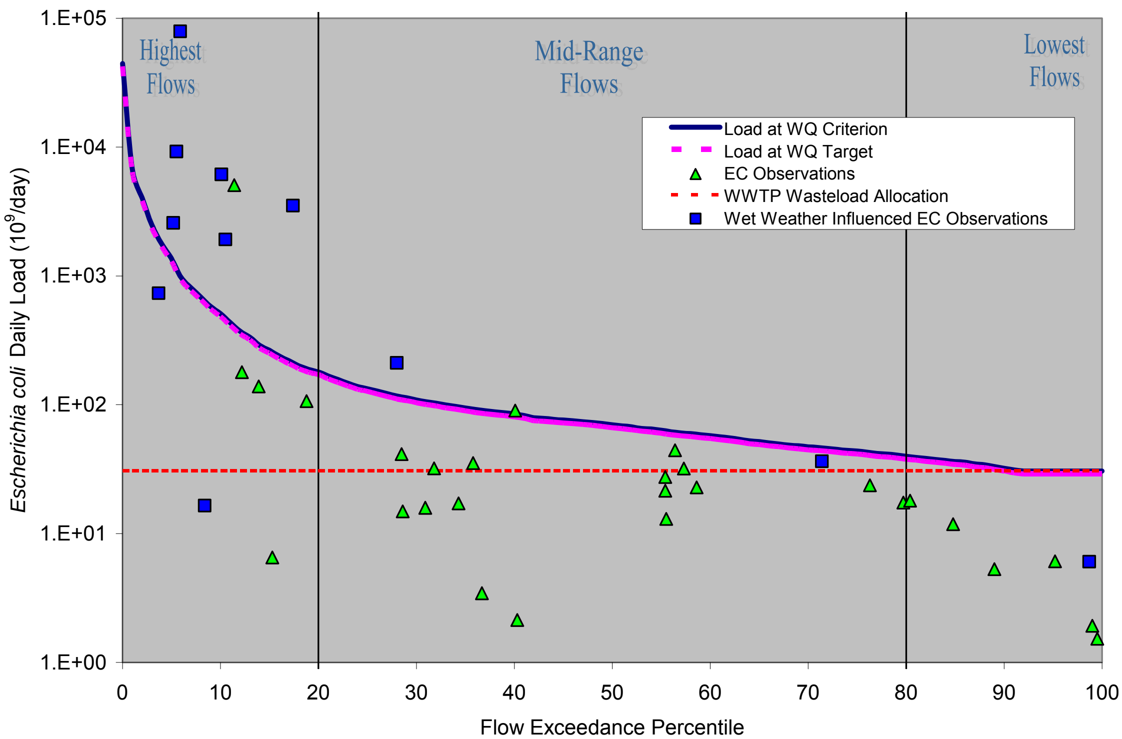


Figure 11. Load Duration Curve for E. coli in Mary's Creek/North Fork Mary's Creek (1102B)

Because WWTF discharges occur in Hickory Slough, average monthly WWTF flows obtained from DMRs were added to the naturalized projected flows. The LDC for Hickory Slough segment 1102C (Figure 12) is based on *E. coli* bacteria measurements at sampling location 17068 (Hickory Slough at Robinson Drive). The percent reduction goal is calculated so that the geometric mean criterion for contact recreation is met under all flow conditions. The LDC indicates that *E. coli* levels exceed the instantaneous water quality criterion during all flow conditions. Wet weather influenced bacteria samples exceeded mainly during higher flow conditions.

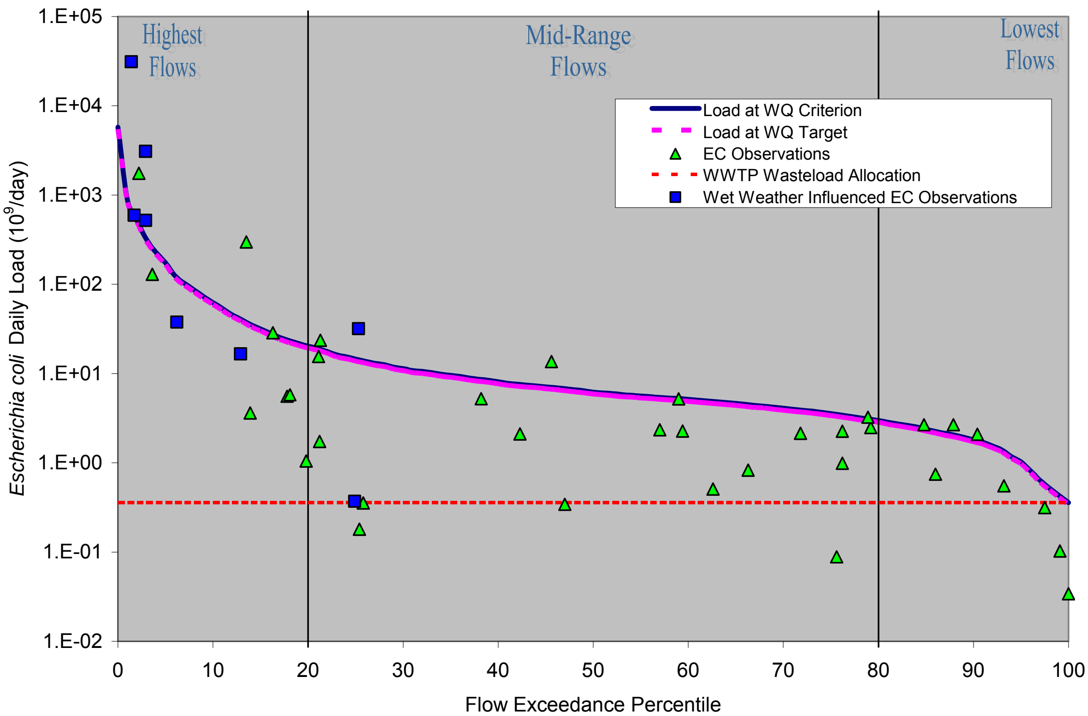


Figure 12. Load Duration Curve for E. coli in Hickory Slough (1102C)

Because WWTF discharges occur in Turkey Creek, average monthly WWTF flows obtained from DMRs were added to the naturalized projected flows. The LDC for Turkey Creek segment 1102D (Figure 13) is based on fecal coliform bacteria measurements at sampling location 17069 (Turkey Creek at Dixie Farm Road). The percent reduction goal is calculated so that the geometric mean criterion for contact recreation is met under all flow conditions. The LDC indicates that fecal coliform levels sometimes exceed the instantaneous water quality criterion during mid-range flow conditions.

Because WWTF discharges occur in Mud Gully, average monthly WWTF flows obtained from DMRs were added to the naturalized projected flows. The LDC for Mud Gully segment 1102E (Figure 14) is based on fecal coliform bacteria measurements at sampling location 17071 (Mud Gully at Dixie Farm Road). The percent reduction goal is calculated so that the geometric mean criterion for contact recreation is met under all flow conditions. The LDC indicates that fecal coliform levels exceed the instantaneous water quality criterion during all flow conditions. Wet weather influenced bacteria samples exceeded mainly during higher flow conditions.

Mass Balance Analysis—Tidal Prism Method

A time-varying tidal prism modeling approach with a moderate level of spatial resolution was used to simulate the tidal segments of Clear Creek. The tidal prism is the volume of water between low and high tide levels or between the high tide elevation and the bottom of the tidal waterway. Load calculations were developed for a series of reaches within

Clear Creek Tidal and Robinson Bayou, as well as the tidal portions of the major tributaries discharging to Clear Creek Tidal.

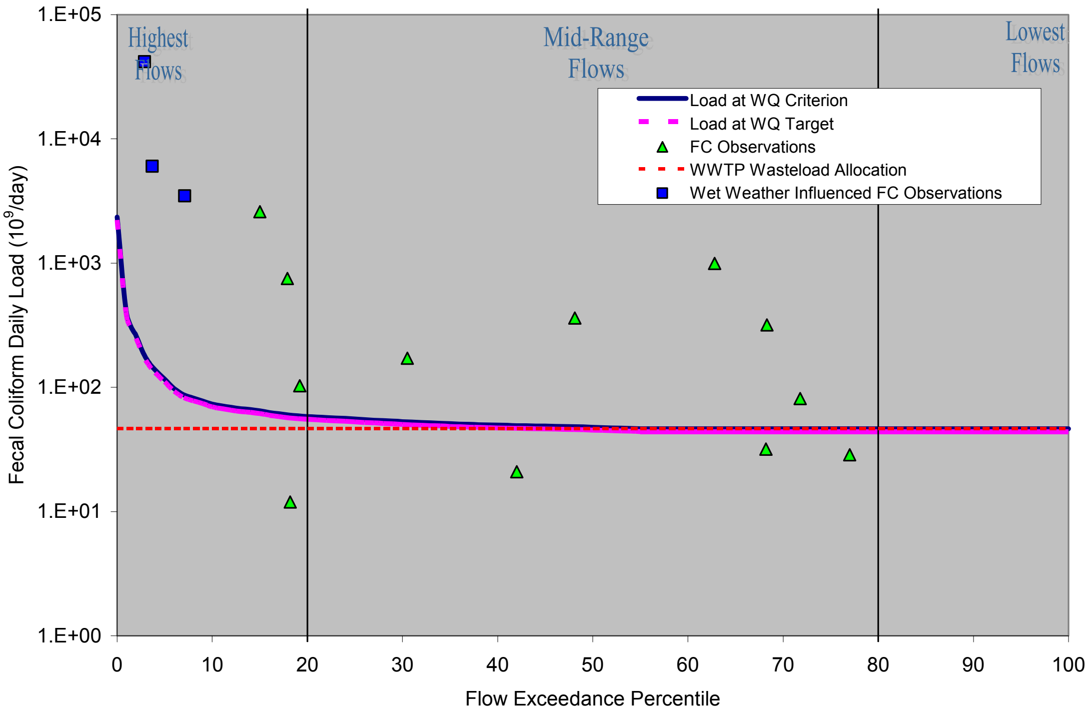


Figure 13. Load Duration Curve for Fecal coliform in Turkey Creek (1102D)

The model incorporates the three mechanisms through which Enterococci loadings enter the impaired systems:

1) rain-induced freshwater inputs (i.e. runoff),
2) direct point source discharges, and
3) tidally influenced loadings, which are introduced during the diurnal tidal fluctuations that occur in the system.

The model assumes that Enterococci are removed with the net estuarine flow out from the tidal system and via biodegradation and die-off. It is also assumed that biodegradation and die-off exceed potential bacteria contributions from re-growth. A generalized schematic of the source and sink terms for the tidally influenced impaired water bodies is presented in Figure 15.

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

Equation 2

$$\frac{dV}{dt} = Q_u + Q_f - Q_d$$

where*:*

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

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

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

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

The average Enterococci concentrations measured at each of the water quality monitoring stations along Clear Creek Tidal and Robinson Bayou were used to define the initial conditions in each model reach. The geometric mean of Enterococci concentrations measured in Clear Lake station 16571 (12 counts/100 mL) was used to set the downstream boundary concentration of Enterococci. Enterococci levels in runoff, tributaries, and WWTFs were estimated as described Appendix B.

The model was calibrated by varying the decay rate by reach and adjusting this decay rate within the bounds of reported rates until the model accurately reproduced the temporal and spatial distribution of observed Enterococci within the system. Sinton, *et al*. (1994) and Davies-Colley, *et al*. (1998) reported decay rates between 0.12 and 40 day^{-1}, Anderson, *et al*. (2005) reported rates between 0.73 and 2.1 day^{-1}, and Kay, *et al*. (2005) measured decay rates between 2.2 and 8.5 day^{-1}. Final decay rates applied to the model ranged from 0.7 to 3.6 day^{-1}, which is within the ranges reported in the literature. The decay rates were not varied temporally because insufficient data were available to estimate the seasonal variation in decay rates.

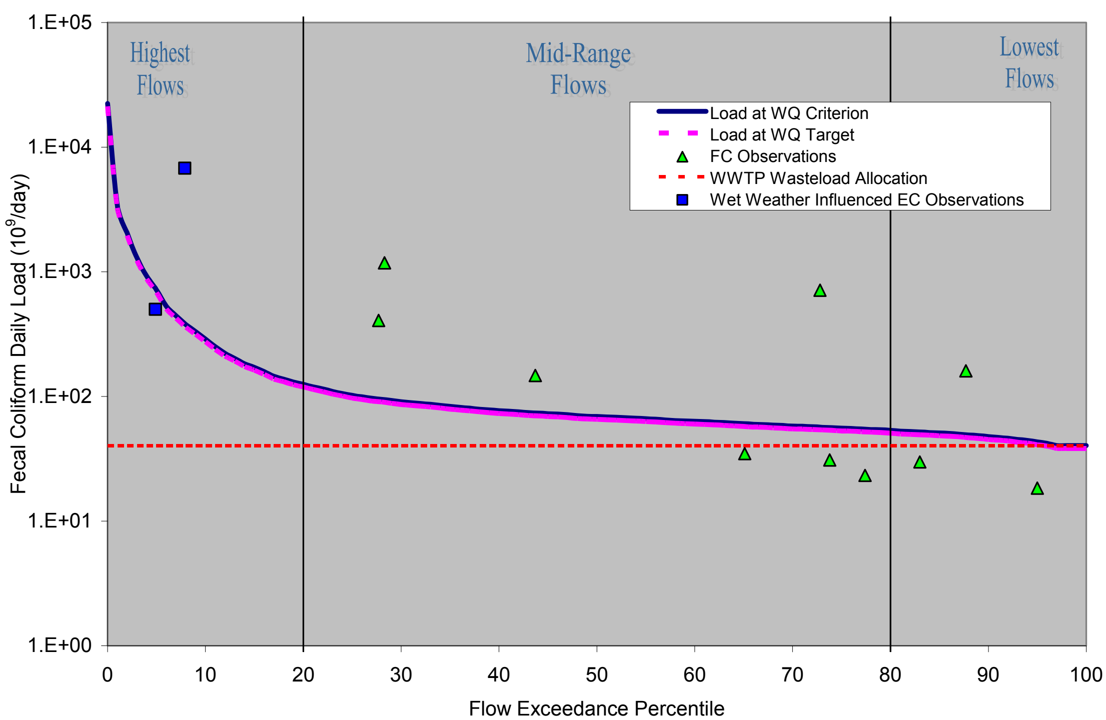


Figure 14. Load Duration Curve for Fecal Coliform in Mud Gully (1102E)

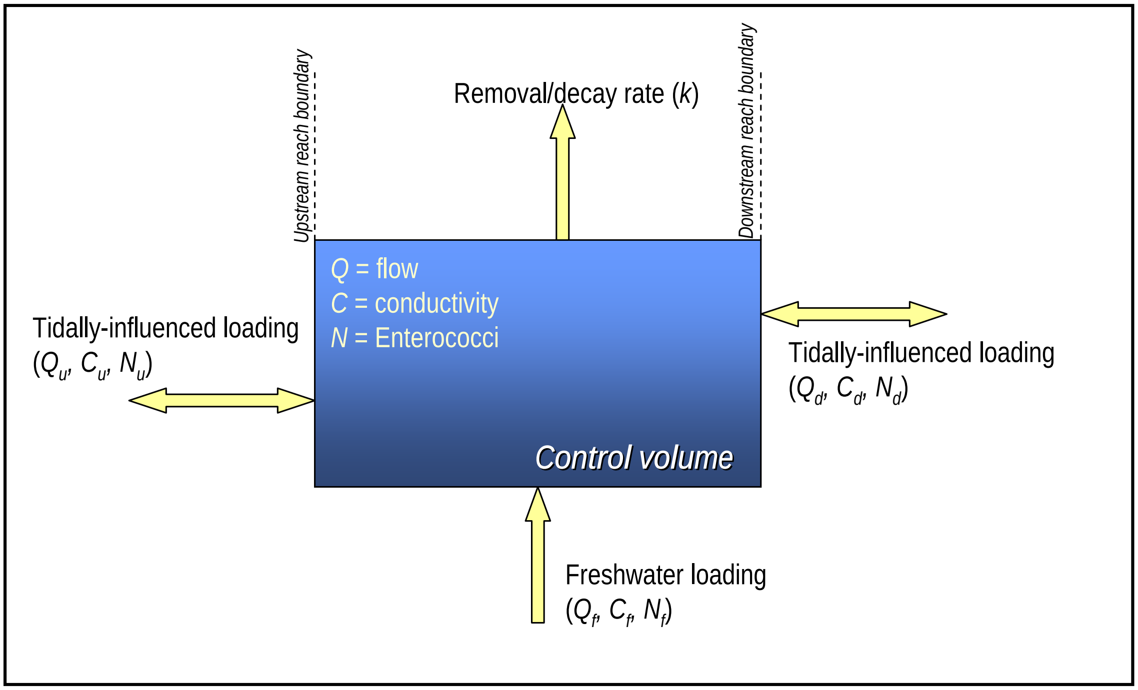


Figure 15. Conceptual Model for Sources and Sinks of Enterococci

Figure 16 presents a comparison of measured and modeled Enterococci concentrations along the main stem of Clear Creek. As can be seen, the model reasonably predicts the spatial distribution of Enterococci along the creek. For the tidal prism model, indicator bacteria data (including fecal coliform and *E. coli*), from 2000 through 2006 for a given station were used to compare to modeled values. Fecal coliform and *E. coli* data were converted to Enterococci concentrations using calculated ENT/FC and ENT/EC ratios (0.27 and 0.34, respectively), as described in Appendix B. A detailed description of the tidal prism method is included in Appendix B.

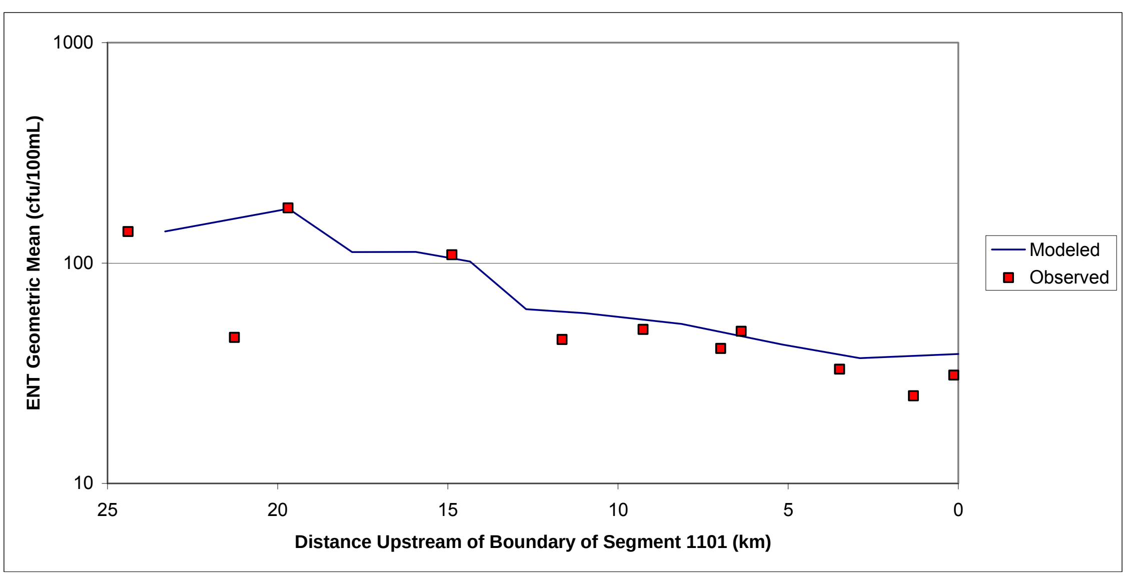


Figure 16. Longitudinal Profile of Enterococci Concentrations

Margin of Safety

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

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

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

The TMDLs for freshwater segments incorporate an explicit MOS by setting a more stringent target for indicator bacteria loads that is 5 percent lower than the geometric mean criterion. The explicit margin of safety was used because of the limited amount of data for some of the sampling locations. For contact recreation, this equates to a geometric mean of 190 counts/100 mL for fecal coliform, and 120 counts/100 mL for *E. coli*. The net effect of the TMDL with a MOS is that the assimilative capacity or allowable pollutant loading of each water body is slightly reduced. The TMDLs for the freshwater streams in this report incorporate an explicit MOS by using a LDC developed using 95 percent of the geometric mean criterion. For the tidal segments, the MOS was also explicit. But in this case, the MOS was based on allowable loading not concentration. After the tidal prism model calculated the total assimilative capacity for Enterococci (the TMDL), 5 percent of the allowable load was computed as the MOS.

Pollutant Load Allocation

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

Equation 3

$$\text{TMDL} = \Sigma\text{WLA} + \Sigma\text{LA} + \text{MOS}$$

where:

WLA = waste load allocation (permitted or point source contributions)
LA = load allocation (non-permitted or nonpoint source contributions)
MOS = margin of safety

As stated in 40 CFR, §130.2(1), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For fecal coliform, *E. coli*, or Enterococci bacteria, TMDLs are expressed as colony-forming units per day, where possible, or as a percent reduction goal, and represent the maximum one day load the stream can assimilate while still attaining the surface water quality standards.

For the Clear Creek watershed, two different methods were used to quantify allowable pollutant loads, percent reduction goals, and specific TMDL allocations for point and nonpoint sources:

1) the load duration curve method for freshwater streams, and
2) a mass balance method using a tidal prism for tidal streams.

Pollutant load allocations and percent reduction goals for the tidally influenced segments were developed using the tidal prism, mass balance method. Pollutant load allocations and percent reduction goals for the freshwater segments were developed using the LDC method.

In most cases TMDL calculations, associated allocations, and percent reduction goals are established for the most-downstream sampling locations in each watershed. This establishes a distinct TMDL for each 303(d) listed water body. The most-downstream sampling locations for each water body are listed in Table 13.

Table 13. Sampling Locations Used to Establish TMDL

Segment	Sampling Location	Description
Clear Creek Tidal	16572	Clear Creek Tidal at the Mouth of Robinson Bayou, approx. 100 ft from the sign for Preserve Lakeside Luxury Subdivision
Chigger Creek	16493	Chigger Creek at FM528 Bridge in Friendswood
Robinson Bayou	16475	Robinson Bayou at FM270 in League City
Clear Creek above Tidal	14229	Clear Creek at Dixie Farm Road (FM 1959) near Friendswood
Cowart Creek	16477	Cowarts Creek at Sunset Drive in Friendswood
Mary’s Creek/North Fork Mary’s Creek	16473	Mary’s Creek at Mary's Crossing in North Friendswood
Hickory Slough	17068	Hickory Slough at Robinson Drive in Pearland
Turkey Creek	17069	Turkey Creek at Dixie Farm Road in Friendswood
Mud Gully	17071	Mud Gully at Dixie Farm Road, SW of IH45 in Friendswood

Load Reductions

To calculate the bacteria load at the criteria for non-tidal segments, the flow rate at each flow exceedance percentile is multiplied by a unit conversion factor (24,465,755 100 mL/ft^3 * seconds/day) and the criterion specific to each indicator bacteria. This calculation produces the maximum bacteria load in the stream without exceeding the instantaneous criterion over the range of flow conditions. In the case of fecal coliform or *E. coli* for freshwater streams, the allowable geometric mean concentrations in the surface water quality standards are the TMDL. Fecal coliform and *E. coli* are plotted in relation to flow exceedance percentiles as an LDC. The x-axis indicates the flow exceedance percentile, while the y-axis is expressed in terms of a bacteria load.

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

The LDC approach recognizes that the assimilative capacity of a water body depends on the flow, and that maximum allowable loading varies with flow condition. Existing loading, and load reductions required to meet the TMDL water quality target can also be calculated under different flow conditions. For the tidal segments, existing loading is calculated as the average daily input load (permitted and non-permitted runoff and WWTFs) for the simulation period (1/01/2000 to 9/30/2006).

Selecting the most-downstream sampling location for each 303(d) listed water body as the location for establishing a TMDL is the most logical approach since TMDLs are most effective when established at the watershed scale. However, in some instances limiting TMDL calculations to the most-downstream sampling location may not always result in the pollutant load reductions necessary to achieve the contact recreation standard throughout a watershed. Thus it is sometime necessary to evaluate multiple sampling locations on a given water body to determine which portion of the watershed requires the largest percent reduction goal to achieve and maintain the contact recreation standard. This analysis did demonstrate that percent reduction goals at select upstream sampling stations (highlighted in Table 14) were greater than the reductions calculated for the most-downstream stations in the watersheds.

Table 14 presents the percent reduction goals necessary to achieve the contact recreation standard for select indicator bacteria for each 303(d) listed freshwater stream in the study area, as derived from the LDCs. Percent reduction goals for each 303(d) listed freshwater stream in the study area are based on data analysis using the geometric mean criterion since it is anticipated that achieving the geometric mean over an extended period of time will likely ensure that the single sample criterion will also be achieved. Because the geometric mean criterion is considered more stringent, the TMDL for each of these sampling locations is determined by selecting the highest percent reduction goal calculated for the geometric mean criterion. Attainment of contact recreation standard in response to TMDL implementation will be based on results measured at each of the sampling locations listed in Table 14.

The sampling location requiring the highest percent reduction based on the geometric mean criterion was chosen for each freshwater stream. The most-downstream stations were not always found to require the highest percent reductions. Sampling locations located in the upstream portions of Clear Creek above Tidal, Cowart Creek, and Mud Gully were found to require higher percent reductions than the most-downstream stations.

The TMDL percent reduction goals for Clear Creek above Tidal, Cowart Creek, Chigger Creek, Mary's Creek/North Fork Mary's Creek, and Hickory Slough will be based on the geometric mean criterion for *E. coli*. The TMDL percent reduction goals for Mud Gully and Turkey Creek will be based on the geometric mean criterion for fecal coliform. This is because Mud Gully and Turkey Creek both have limited *E. coli* data and both were included on the 303(d) list for exceedances of the fecal coliform criterion.

The highest percent reductions for each stream are found in Table 14. Appendix A summarizes the methodology used to calculate percent reduction goals for sampling locations using the geometric mean criterion. In Appendix A, Tables A-2 through A-11 summarizes the pollutant load allocations and percent reduction goals for each flow regime. The highest percent reduction goals for each segment were typically found to occur in the flow regime with the highest flows (0–20th percentile). The percent reduction goals range from 67 to 96 percent. However, the overall percent reduction goals range from 25 to 91 percent.

Table 14. TMDL Percent Reductions Required to Meet the Contact Recreation Standard for Freshwater Segments in the Clear Creek Watershed

Segment	Sampling Location	Stream Name	Indicator Bacteria Species	Highest Reduction		Overall Reduction
				Percent Reduction	Corresponding Flow Regime	
1101B	16493	Chigger Creek	*E. coli*	86%	Highest flows	54%
1102	14229	Clear Creek above Tidal	*E. coli*	83%[a]	Highest flows	37%[a]
1102A	16477	Cowart Creek	*E. coli*	89%[b]	Highest flows	54%[b]
1102B	16473	Mary's Creek/North Fork Mary's Creek	*E. coli*	85%	Highest flows	48%
1102C	17068	Hickory Slough	*E. coli*	67%	Highest flows	25%
1102D	17069	Turkey Creek	Fecal coliform	96%	Highest flows	91%
1102E	17071	Mud Gully	Fecal coliform	91%[c]	Highest flows	86%[c]

a = highest percent reduction was calculated based on WQ data at WQM station 17076

b = highest percent reduction was calculated based on WQ data at WQM station 11426

c = highest percent reduction was calculated based on WQ data at WQM station 17070

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

The percent reduction goals that are required to meet the standard for contact recreation in Clear Creek Tidal and its major tributaries are illustrated in Figures 17 and 18. The required load reductions were calculated at the end of the reach containing the sampling location, and the load reductions for the segment are those from the reach requiring the greatest load reductions. From the variety of pollutant reduction scenarios for Clear Creek Tidal displayed in Figure 17, it is apparent that the loading upstream of station 11448 (Reach B) requires a much larger reduction than the remaining length of the main stem. Consequently, the scenario “Final” in Figure 17 recommends a 97 percent reduction for reaches A and B and a 45 percent reduction goal for the remaining downstream reaches of Clear Creek Tidal. Required load reductions ranged from 28 percent in Chigger Creek (Reach M) to 97 percent in Magnolia Creek Table 15.

Waste Load Allocation

TPDES-permitted facilities are allocated a daily wasteload calculated as their permitted discharge flow rate multiplied by the instream geometric mean water quality criterion. In other words, the facilities are required to meet instream criteria at their points of discharge. Table 16 summarizes the waste load allocation (WLA) for the TPDES-permitted facilities within the study area. The allocated loads are calculated for fecal coliform, *E. coli*, and Enterococci. The WWTFs are subject to the limits for the indicator bacteria in their permits. The WWTFs will not be subject to all listed indicator bacteria.

The WLA for each facility (WLA_{WWTF}) is derived from the following equation.

Equation 4

$$WLA_{WWTF} = \text{criterion} * \text{flow} * \text{unit conversion factor}$$

where:

criterion = 35, 200, and 126 counts/100mL for Enterococci, fecal coliform, and *E. coli* respectively

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

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

When multiple TPDES facilities occur within a watershed, loads from individual WWTFs are summed and the total load for continuous point sources is included as part of the WLA_{WWTF} component of the TMDL calculation for the corresponding segment. When there are no TPDES WWTFs discharging into the contributing watershed of a sampling location then WLA_{WWTF} is not applicable. The assimilative capacity of streams increases as the amount of flow increases so future WWTF discharges will be required to conform to Equation 4. Increases in flow allow for increased loadings. Compliance with the WLA_{WWTF} will be achieved by adhering to the indicator bacteria discharge limits and disinfection requirements of TPDES permits.

WLA calculations must also include an allocation for permitted storm water discharges (WLA_{MS4}). Given the limited amount of data available and the complexities associated

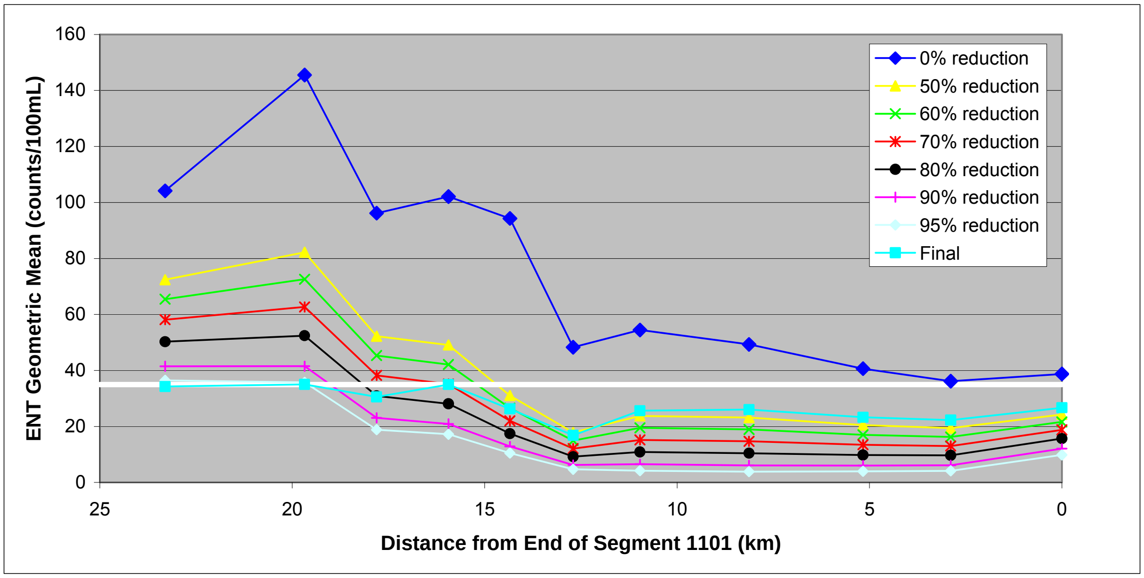


Figure 17. Clear Creek Tidal: Reductions in Relation to the Geometric Mean Criterion

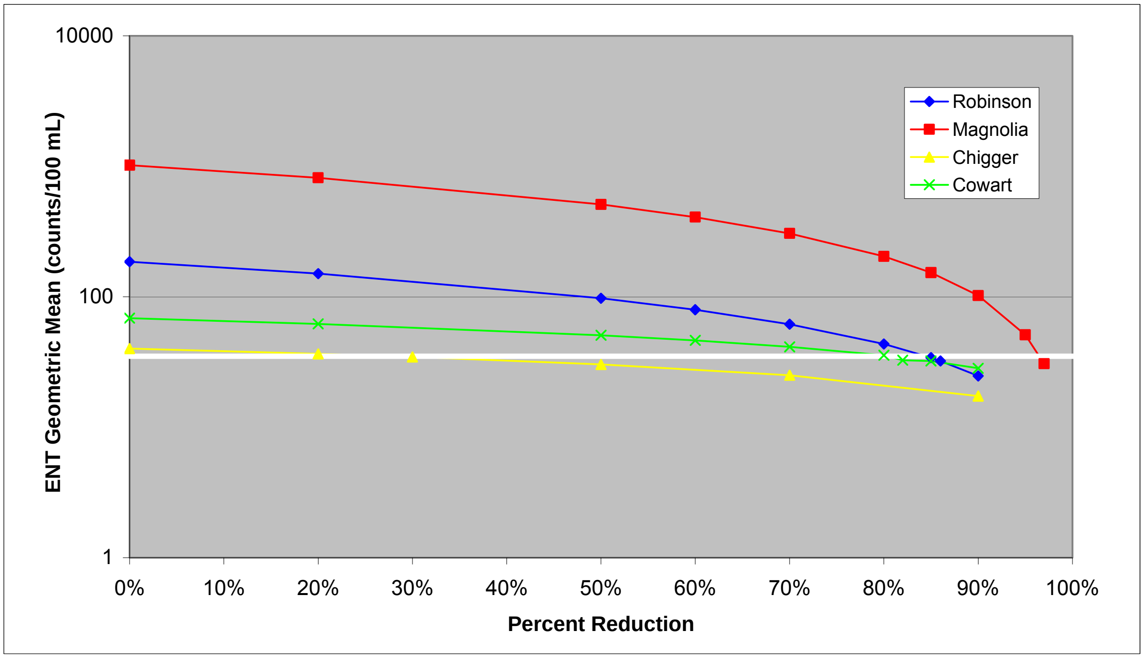


Figure 18. Major Tributaries to Clear Creek Tidal: Reductions in Relation to the Geometric Mean Criterion

Table 15. TMDL Percent Reductions Required to Meet the Contact Recreation Standard for Tidal Segments in the Clear Creek Watershed

Segment	Sampling Location	Stream Name	Indicator Bacteria Species	Percent Reduction Required
1101	16572	Clear Creek Tidal (Reaches A through K, Tributaries A through E, and TribOne)a	Enterococci	49%[b]
	16611	Magnolia Creek (Reach N and Magnolia Creek above Tidal)	Enterococci	97%
1102A	11425	Cowart Creek (Reach L) [a]	Enterococci	82%
1101B	16472	Chigger Creek (Reach M) [a]	Enterococci	28%
1101D	16475	Robinson Bayou (Reaches O and P and Robinson Bayou above Tidal)	Enterococci	86%

[a] The reductions are calculated assuming that the upstream freshwater segment (addressed using LDC) meet the WQS for EC (126 counts/100mL). This concentration was multiplied by the 0.34 ENT/EC ratio to obtain incoming Enterococci concentrations (42 counts/100mL)

[b] Corresponds to a 97% reduction in loading upstream of station 11448 and 45% thereafter.

with simulating rainfall runoff and the variability of storm water loading a simplified approach for estimating the WLA_{MS4} for areas was used in the development of these TMDLs. For both the LDC and tidal prism method, the percentage of each watershed that is under a TPDES MS4 permit is used to estimate the amount of the overall runoff load that should be dedicated as the permitted storm water contribution in the WLA_{MS4} component of the TMDL. The difference between the total storm water runoff load and the portion allocated to WLA_{MS4} constitutes the LA component of the TMDL (direct nonpoint runoff).

For the freshwater streams, the flow dependent calculations for the MS4 portion of the WLA were derived using LDC and the MS4 percentages found in Table 8. The flow dependent calculations for the portion of the WLA assigned to permitted storm water are provided in Appendix C. For the tidal segments, any runoff occurring within the boundaries of an MS4 permit was considered a point source contribution and was included in the WLA calculation. The allowable load from all storm water runoff ($LA_{Stormwater}$) was calculated as the maximum allowable load (TMDL) minus the margin of safety minus the load allocated to WWTFs (WLA_{WWTF}). The resulting load ($LA_{Stormwater}$) was split into WLA_{MS4} component (permitted) and LA component (non-permitted) using the percent of the drainage areas within the tidal prism model covered by MS4 permits provided in Table 17.

The TCEQ intends to implement these individual WLAs through the permitting process as either monitoring requirements or effluent limitations. However, there may be a more economical or technically feasible means of achieving the goal of improved water quality and circumstances may warrant changes in individual WLAs after this TMDL is adopted. Therefore, these individual WLAs are non-binding until implemented via a separate TPDES permitting action, which may involve preparation of a "Water Quality Management Plan Update." Regardless, all permitting actions will demonstrate compliance with the TMDL.

Table 16. Waste load Allocations for TPDES-Permitted WWTF

Receiving Water	TPDES Number	Facility Name	Final Permitted Flow (MGD)	Daily Load		
				Fecal coliform	E. coli	Enterococci
Clear Creek Tidal (1101)	10520-001	City of Webster	3.30	2.50E+10	1.57E+10	4.37E+09
	10526-001	City of Nassau Bay	1.33	1.01E+10	6.34E+09	1.76E+09
	10526-001	City of Nassau Bay	1.33[a]	0[b]	0[b]	0[b]
	10568-003	City of League City	0.66	5.00E+09	3.15E+09	8.74E+08
	10568-005	City of League City	12.0	9.08E+10	5.72E+10	1.59E+10
	11571-001	Gulf Coast Waste Disposal Authority	9.25	7.00E+10	4.41E+10	1.23E+10
Clear Creek above Tidal (1102)	10134-002	City of Pearland	4.5	3.41E+10	2.15E+10	
	10134-008	City of Pearland	2.00	1.51E+10	9.54E+09	
	10134-010	City of Pearland	2.50	1.89E+10	1.19E+10	
	10134-010	City of Pearland	2.00	1.51E+10	9.54E+09	
	12295-001	City of Pearland	0.95	7.19E+09	4.53E+09	
	12939-001	Harris County WCID 89	0.95	7.19E+09	4.53E+09	
	13864-001	Fresno Manufacturing LLC	0.0084	6.36E+07	4.01E+07	
Cowart Creek (1102A)	12822-001	Walker Water Works Inc.	0.035	2.65E+08	1.67E+08	
	13865-001	Forestaire Estates	0.049	3.71E+08	2.34E+08	
Mary's Creek/North Fork Mary's Creek (1102B)	10134-007	City of Pearland	4.0	3.03E+10	1.91E+10	
	12332-001	Brazoria County Mud No. 1	2.4	1.82E+10	1.14E+10	
	12680-001	H & R Realty Investments LLC	0.012	9.08E+07	5.72E+07	
Hickory Slough (1102C)	12849-001	CMH Parks Inc.	0.075	5.68E+08	3.58E+08	
Turkey Creek (1102D)	10495-075	City of Houston	6.14	4.65E+10	2.93E+10	
Mud Gully (1102E)	10495-079	City of Houston	5.33	4.04E+10	2.54E+10	

[a] The total of both outfalls combined cannot exceed 1.33 MGD

[b] Total allocated load included in outfall 01 (previous row)

Table 17. Percentage of Permitted Storm Water in each Tidal Drainage Area

Segment	Receiving Stream	TPDES Number	Total Area (acres)	Area under MS4 (acres)	Percent of Watershed under MS4
1101	Clear Creek Tidal (Reaches A through K, Tributaries A through E, and TribOne)	WQ0004685000	19,961	18,456	92%
	Magnolia Creek (Reach N and Magnolia Creek above Tidal)	WQ0004685000	1,895	1,895	100%
1102A	Cowart Creek (Reach L)	WQ0004685000	865	865	100%
1101B	Chigger Creek (Reach M)	WQ0004685000	1,625	1,625	100%
1101D	Robinson Bayou (Reaches O and P and Robinson Bayou above Tidal)	WQ0004685000	3,481	2,281	66%

The commission understands that this TMDL is, by definition, the total of the sum of the waste load allocation, the sum of the load allocation, and the margin of safety. Changes to individual WLAs may be necessary in the future in order to accommodate growth or other changing conditions. These changes to individual WLAs do not ordinarily require a revision of the actual TMDL; instead, changes will be made through updates to the TCEQ's Water Quality Management Plan. Any future changes to effluent limitations will be addressed through the permitting process and by updating the WQMP.

Load Allocation

Load allocations for freshwater segments can be calculated under different flow conditions as the water quality target load (TMDL) minus the WLA. The LA is represented by the area under the LDC but above the WLA. The LA at any particular flow exceedance is calculated as shown in the following equation.

Equation 5

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

where:

LA = allowable load from non-permitted sources
$TMDL$= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
ΣWLA_{MS4} = sum of all MS4 loads
MOS = margin of safety

For tidally influenced segments, the load allocation is also calculated using Equation 5.

TMDL Calculations

Table 18 summarizes the estimated maximum allowable loads of *E. coli* and fecal coliform for the freshwater segments. For the tidal stream segments, Table 19 summarizes the estimated maximum allowable loads of Enterococci that will ensure the contact recreation standard is met. These are calculated from the tidal prism model based on average percent reductions from total existing loading (WWTFs, runoff and tributaries) to the water body (Table 15). Table 19 includes WLA, LA, and MOS calculations.

Allowance for Future Growth

Compliance with these TMDLs is based on keeping the indicator bacteria concentrations in the selected waters below the limits that were set as criteria for the individual sites. Future growth of existing or new point sources is not limited by these TMDLs as long as the sources do not cause indicator bacteria to exceed the limits. The assimilative capacity of streams increases as the amount of flow increases. Increases in flow allow for additional indicator bacteria loads if the concentrations are at or below the contact recreation standard. Wastewater discharge facilities will be evaluated case-by-case.

To account for the high probability that new additional flows from WWTF may occur in any of the segments, a provision for future growth was included in the TMDL calculation by estimating permitted flows to year 2050 using population projections completed by the Texas Water Development Board. A summary of the employed methodology is included in Appendix D. For freshwater segments, the projected WWTF permitted flows were added to the flows from runoff to build the $TMDL_{Future}$ for various flows. For the tidally influenced segments, loads calculated using the projected flows and a 35 counts/100mL concentration were input in the tidal prism model along with all the other existing loads. The loads were then reduced by different percentages until the contact recreation standard was met in all the reaches. The reduced loads were then added to calculate the assimilative capacity or $TMDL_{Future}$. In both cases, the LA_{WWTF} for future population growth is the difference between the $TMDL_{Future}$ and the TMDL calculated using current conditions.

Seasonal Variation

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

Analysis of the available data for *E. coli* showed that about 37 percent of the stations exhibited higher geometric mean concentrations for the warmer months than the cooler months. In addition, only 3 out of 46 stations depicted statistical differences in single sample concentrations between the warmer and cooler periods. For Enterococci, a majority of the stations either did not have any data nor had inadequate data to conduct an analysis. For the stations analyzed, 50 percent of the stations had higher geometric means during the warmer

Table 18. Fecal coliform and E. coli TMDL Calculations for Freshwater Segments

Seg-ment	Sampling Location	Stream Name	Indicator Bacteria Species	TMDL[a] (counts/day)	WLA_{WWTF}[c] (counts/day)	WLA_{MS4}[d] (counts/day)	LA[f] (counts/day)	MOS[g] (counts/day)	$TMDL_{Future}$[b] (counts/day)	$WLA_{WWTF-Future}$[e] (counts/day)
1101B	16493	Chigger Creek	*E. coli*	1.74E+10	NA	7.16E+09	9.37E+09	8.70E+08	1.75E+10	5.25E+07
1102	14229	Clear Creek above Tidal	*E. coli*	4.44E+10	6.16E+10	NA	0	2.22E+09	1.32E+11	8.73E+10
1102A	16477	Cowart Creek	*E. coli*	4.83E+10	4.01E+08	2.38E+10	2.17E+10	2.41E+09	4.87E+10	3.94E+08
1102B	16473	Marys Creek	*E. coli*	1.63E+11	3.06E+10	1.12E+11	1.27E+10	8.15E+09	2.27E+11	6.42E+10
1102C	17068	Hickory Slough	*E. coli*	1.99E+10	3.58E+08	1.78E+10	7.37E+08	9.97E+08	2.06E+10	7.06E+08
1102D	17069	Turkey Creek	Fecal Coliform	3.66E+10	4.65E+10	NA	0	1.83E+09	8.14E+10	4.48E+10
1102E	17071	Mud Gully	Fecal Coliform	1.45E+11	4.04E+10	8.02E+10	1.68E+10	7.23E+09	1.79E+11	3.49E+10

[a] Sum of WWTF, WLA MS4, MOS, and LA that result in attainment of the geometric mean criterion.

[b] Sum of WWTF with projected permitted flows for 2050, storm water runoff, and tributary loads discharging directly to the WQ segment that result in attainment of the geometric mean criterion.

[c] Sum of loads from the WWTF discharging to the segment. Individual loads are calculated as permitted flow * 200 (FC) or 126 (EC) counts/100mL*conversion factor (Table 17).

[d] WLA_{MS4} = (TMDL – MOS – WWTF WLA)*(percent of drainage area covered by MS4 permits).

[e] Difference between $TMDL_{Future}$ and the TMDL

[f] LA = TMDL – MOS –WLA_{WWTF} –WLA_{MS4}

[g] MOS = TMDL x 0.05

NA= Allocation not applicable at this time. New WWTF must comply with Equation 4.

Table 19. Enterococci TMDL Calculations for Tidal Segments

Segment	Stream Name	TMDL[a] (counts per day)	WLA_{WWTF}[c] (counts per day)	WLA_{MS4}[d] (counts per day)	LA[f] (counts per day)	MOS[g] (counts per day)	$TMDL_{Future}$[b] (counts per day)	$WLA_{WWTF-Future}$[e] (counts per day)
1101	Clear Creek Tidal (Reaches A through K, Tributaries A through E, and TribOne)	9.37E+12	3.43E+10	8.16E+12	7.09E+11	4.69E+11	9.39E+12	2.11E+10
	Magnolia Creek (Reach N and Magnolia Creek above Tidal)	8.19E+10	8.74E+08	7.69E+10	0	4.09E+09	1.09E+11	2.74E+10
1102A	Cowart Creek (Reach L)	1.60E+11	NA*	1.52E+11	0	7.98E+09	1.60E+11	0**
1101B	Chigger Creek (Reach M)	7.16E+11	NA*	6.80E+11	0	3.58E+10	7.16E+11	0**
1101D	Robinson Bayou (Reaches P and O and Robinson Bayou above Tidal)	1.26E+11	NA*	7.88E+10	4.06E+10	6.28E+09	1.80E+11	5.44E+10

[a] Sum of WWTF, storm water runoff, and tributary loads discharging directly to the WQ segment that result in attainment of the geometric mean criterion

[b] Sum of WWTF with projected permitted flows for 2050, storm water runoff, and tributary loads discharging directly to the WQ segment that result in attainment of the geometric mean criterion

[c] Sum of loads from the WWTF discharging to the segment. Individual loads are calculated as permitted flow*35 counts/100mL*conversion factor (Table 16)

[d] $WLA_{MS4} = (TMDL - MOS - WLA_{WWTF})$*percent of drainage area covered by MS4 permits

[e] Difference between $TMDL_{Future}$ and the TMDL

[f] $LA = TMDL - MOS - WLA_{WWTF} - WLA_{MS4}$

[g] MOS = 0.05*TMDL

* NA – Allocation not applicable at this time. New WWTF must comply with Equation 4

** Growth for this watershed is addressed in the non-tidal portion (LDC) months as compared to the cooler months. Only one out of six stations showed statistically significant differences between concentrations for the warmer and cooler months.

Public Participation

Public meetings to present the status of the study and to discuss the available results were conducted. Notices of meetings were posted on the TMDL program's Web calendar and sent to all available interested groups and individuals. Two weeks prior to scheduled meetings, media releases were initiated and the public was formally invited to attend. To ensure that absent members and the public were informed of past meetings and pertinent material, a project Web page was established to provide meeting summaries, presentations, ground rules, and a list of steering committee members at <www.tceq.state.tx.us/ implementation/water/tmdl/68-clearcreekbacteria.html>.

The TCEQ maintains an inclusive public participation process. From the inception of the investigation, the project team sought to ensure that stakeholders were informed and involved. Communication and comments from the stakeholders in the watershed strengthen TMDL projects and their implementation.

The first public meeting for the Clear Creek Bacteria TMDL was held on April 5, 2006. The meeting introduced the TMDL process, identified the impaired segments and the reason for the impairment, a review of historical data, described potential sources of indicator bacteria within the watershed, and began the formation of the stakeholder group.

The second public meeting was held on September 21, 2006. The technical team presented the status of the project by reviewing historical data, listing the data that had been collected by the project team, discussed the different types of land use within the watershed, population increases to the year 2020, and potential sources of indicator bacteria within the watershed were also listed. Future plans were also presented which included more water quality sampling to assist with the development of LDCs and mass balance model.

The third public meeting was held on February 7, 2007. The presentation included an overview of the project, a list of completed activities including intensive surveys for flow and water quality, pipe reconnaissance, storm water runoff and wastewater discharge sampling. Bacteria sources in the watershed were also discussed, including septic systems, livestock and permitted WWTFs. Future tasks were also summarized which included completion of LDCs/mass balance and load calculations and allocations segment-by-segment.

On November 15, 2007, a fourth public meeting was held at the University of Houston–Clear Lake campus. At this meeting, the formal stakeholders group was identified and approved. Also at this meeting, the two different technical approaches that would be used to calculate TMDLs were summarized: the LDC method for freshwater streams, and a mass balance approach using tidal prism for the two tidal streams. After presenting data limitations to conducting a pollutant source assessment, stakeholders provided suggestions for how some of the data gaps might be addressed in the future. TCEQ also introduced a proposed strategy for moving from TMDL development into TMDL implementation. Opportunities and constraints of executing TMDL development and TMDL implementation on concurrent tracks were discussed by TCEQ and the stakeholders.

On March 6, 2008, a fifth public meeting was held at the University of Houston–Clear Lake campus. At this meeting, a presentation summarized the findings of the pollutant source assessment and the preliminary TMDL calculations based on LDCs and the tidal prism approach. TCEQ personnel also discussed options for how stakeholders of the Clear Creek watershed could participate in and initiate the TMDL implementation process. The TCEQ intends to initiate development of an implementation plan in summer 2008.

Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

1) **a TMDL**, which determines the maximum amount of pollutant a water body can receive in a single day and still meet applicable water quality standards, and
2) **an Implementation Plan**, which is a detailed description and schedule of the regulatory and voluntary management measures necessary to achieve the pollutant reductions identified in the TMDL.

The TCEQ is committed to developing Implementation Plans (I-Plans) for all TMDLs adopted by the commission and to ensuring the plans are implemented. I-Plans are critical to ensure water quality standards are restored and maintained. They are not subject to EPA approval.

In December 2007, stakeholders in the Houston/Harris County area initiated an effort to develop an area-wide I-Plan to address indicator bacteria sources throughout the greater Houston/Harris County area. This effort will include all of the water bodies that have been listed as impaired for contact recreation because of high indicator bacteria concentrations (Table 20). The TCEQ expects to complete the area-wide I-Plan, which will include the Clear Creek watershed, in 2009 or 2010.

Table 20. Watersheds Included in Houston/Harris County Implementation Plan

Watershed	Number of Segments	Counties
Clear Creek	9	Harris, Fort Bend, Galveston, Brazoria
Buffalo & Whiteoak Bayous	18	Harris, Wallis, Fort Bend
Sims Bayou	3	Harris, Fort Bend
Brays Bayou	5	Harris, Fort Bend
Halls Bayou	4	Harris
Greens Bayou	5	Harris
Eastern Houston	10	Harris
Lake Houston	14	Harris, Montgomery, Liberty, San Jacinto

The TCEQ works with stakeholders to develop the strategies summarized in the I-Plan. I-Plans may use an adaptive management approach that achieves initial loading allocations from a subset of the source categories. Adaptive management allows for development or refinement of methods to achieve the environmental goal of the plan.

Periodic and repeated evaluations of the effectiveness of implementation methods assure that progress is occurring, and may show that the original distribution of loading among sources should be modified to increase efficiency. This adaptive approach provides reasonable assurance that the necessary regulatory and voluntary activities to achieve the pollutant reductions will be implemented.

Implementation of the TMDL

Together, the TMDL and I-Plan direct the correction of unacceptable water quality conditions in an impaired surface water. A TMDL identifies a total loading from the combination of point sources and nonpoint sources that allows attainment of the water quality standards. An I-Plan specifically identifies the required or voluntary implementation actions that will be taken to achieve the pollutant loading goals of the TMDL.
Regulatory actions identified in the I-Plan could include:

- adjustment of an effluent limitation in a wastewater permit,
- a schedule for the elimination of a certain pollutant source,
- identification of any nonpoint source discharge that would be regulated as a point source,
- a limitation or prohibition for authorizing a point source under a general permit, or
- a required modification to a storm water management program (SWMP) and pollution prevention plan (PPP).

Strategies to optimize compliance and oversight are identified in an I-Plan when necessary. Such strategies may include additional monitoring and reporting of effluent discharge quality to evaluate and verify loading trends, adjustment of an inspection frequency or a response protocol to public complaints, and escalation of an enforcement remedy to require corrective action of a regulated entity contributing to an impairment.

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Appendix A – Load Duration Curve Method

Using Load Duration Curves to Develop TMDLs

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

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

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

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

Development of Flow Duration Curves

Flow duration curves (FDCs) serve as the foundation of Load Duration Curves (LDCs) and are graphical representations of the flow characteristics of a stream at a given site. FDCs utilize the historical hydrologic record from stream gauges to forecast future recurrence frequencies. While many sampling locations throughout Texas do not have long-term flow data, there are various methods that can be used to estimate flow frequencies at un-gauged stations or gauged stations missing flow data. The most basic method to estimate flows at an un-gauged site involves 1) identifying an upstream or downstream flow gauge; 2) calculating the contributing drainage areas of the un-gauged sites and the flow gauge; and 3) calculating daily flows at the un-gauged site by using the flow from an acceptable nearby gauged site multiplied by the drainage area ratio. More than one upstream flow gauge may also be considered.

Flow duration curves are a type of cumulative distribution function. The flow duration curve represents the fraction of flow observations that exceed a given flow at the site of interest. The observed flow values are first ranked from highest to lowest then, for each observation, the percentage of observations exceeding that flow is calculated. The flow value is read from the y-axis, which is typically on a logarithmic scale since the high flows would otherwise overwhelm the low flows. The flow exceedance frequency is read from the x-axis, which is numbered from 0 to 100 percent, and may or may not be logarithmic. The lowest measured flow occurs at an exceedance frequency of 100 percent indicating that flow has equaled or exceeded this value 100 percent of the time, while the highest measured flow is found at an exceedance frequency of 0 percent. The median flow occurs at a flow exceedance frequency of 50 percent.

While the number of observations required to develop a flow duration curve is not rigorously specified, a flow duration curve is usually based on more than 5-years of observations, and encompasses inter-annual and seasonal variation. Ideally, the drought of record and flood of record are included in the observations. For this purpose, the long-term flow gauging stations operated by the USGS are utilized. The lack of current, long-term flow data from within the study area necessitated that flows be estimated for Clear Creek Above Tidal, Chigger Creek, Cowart Creek, Mary's Creek, Hickory Slough, Turkey Creek, and Mud Gully. Therefore, USGS gauge station 08075400 (Sims Bayou at Hiram Clarke Street, Houston, Texas), which is located outside the watershed, was chosen to conduct flow projections to establish estimated flows for each of these freshwater segments. The period of record for flow data used from this station was 1996 through 2006.

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

Figures A-1 through A-7 present the FDC developed for the downstream sampling location used for calculating the TMDLs of each freshwater stream in this report using the flow projection method.

Figure A-1 represents the FDC for Chigger Creek, segment 1101B at sampling location 16493. There are no permitted WWTF discharges on Chigger Creek so there are no additions to the synthesized flow.

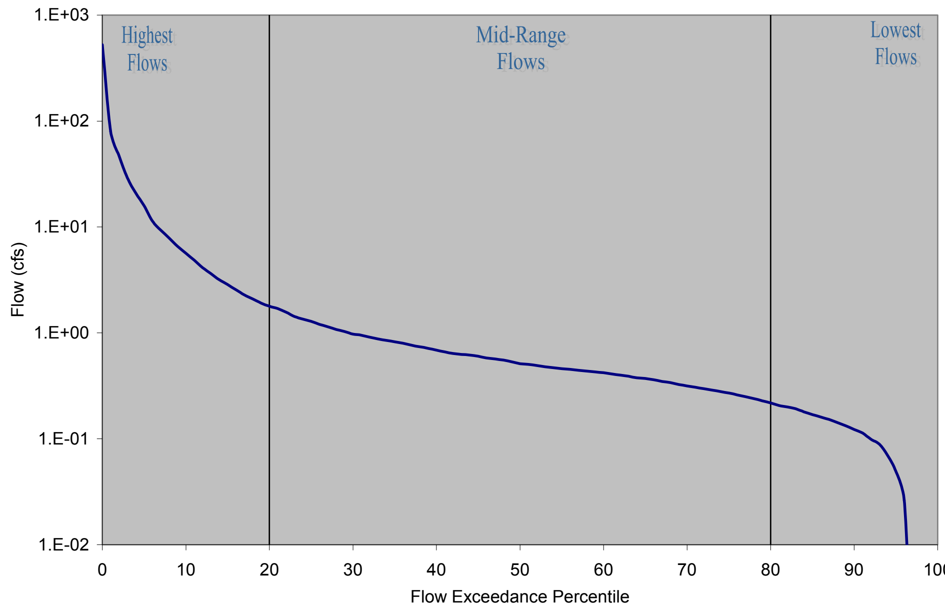

Figure A-1. Flow Duration Curve for Chigger Creek (1101B)

Figure A-2 represents the FDC for Clear Creek Above Tidal segment 1102 at sampling location 14229. Because WWTF discharges occur in Clear Creek Above Tidal, average monthly WWTF flows obtained from DMRs were added to the projected natural flows. DMR data was not available for two of the WWTFs (TX0032743 and TX0119750) located in the watershed. To compensate for the lack of flow data for these two dischargers, one-half of the facility design flow was added to the synthesized flow.

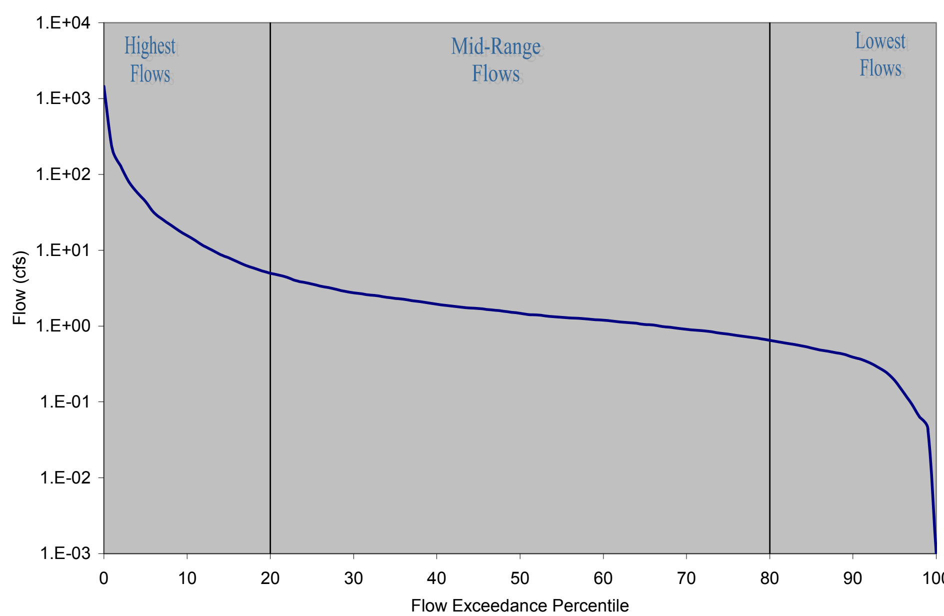

Figure A-2. Flow Duration Curve for Clear Creek Above Tidal (1102)

Figure A-3 represents the FDC for Cowart Creek segment 1102A at sampling location 16477. Because WWTF discharges occur in Cowart Creek, average monthly WWTF flows obtained from DMRs were added to the synthesized flows.

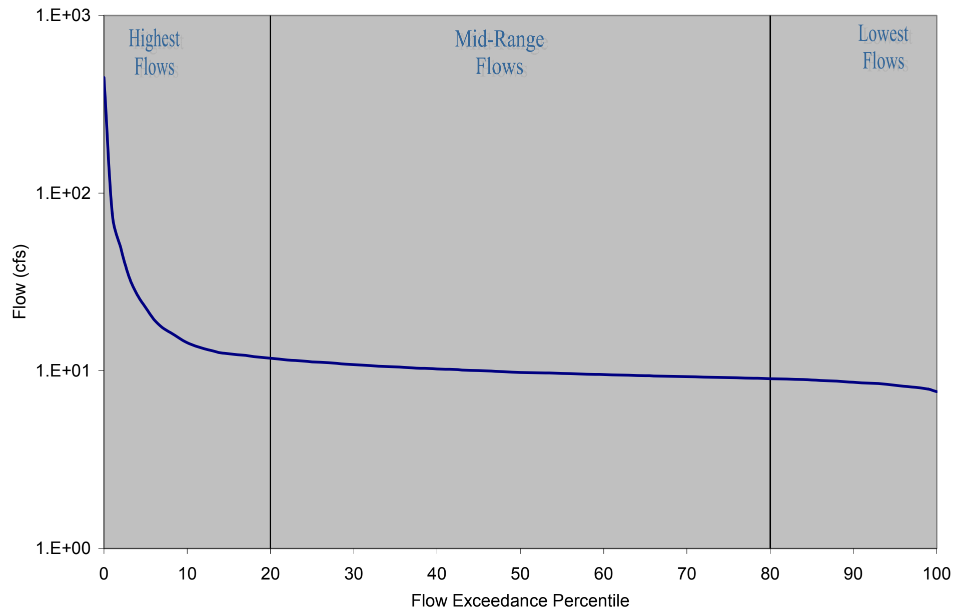

Figure A-3. Flow Duration Curve for Cowart Creek (1102A)

Figure A-4 represents the FDC for Mary's Creek/North Fork Mary's Creek segment 1102B at sampling location 16473. Because WWTF discharges occur in Mary's Creek, average monthly WWTF flows obtained from DMRs were added to the synthesized flows.

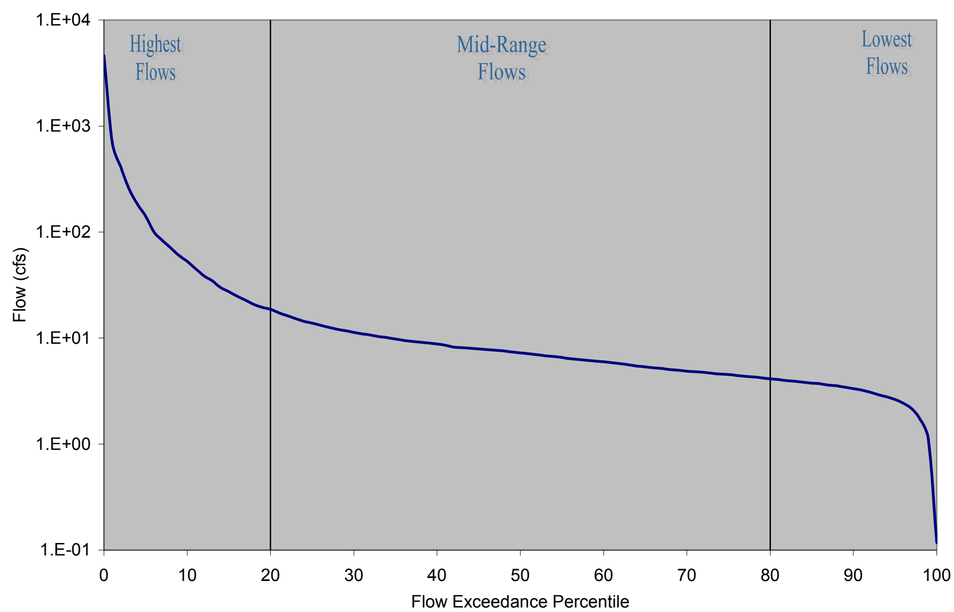

Figure A-4. Flow Duration Curve for Mary's Creek/North Fork Mary's Creek (1102B)

Figure A-5 represents the FDC for Hickory Slough segment 1102C at sampling location 17068. Because WWTF discharges occur in Hickory Slough, average monthly WWTF flows obtained from DMRs were added to the synthesized flows.

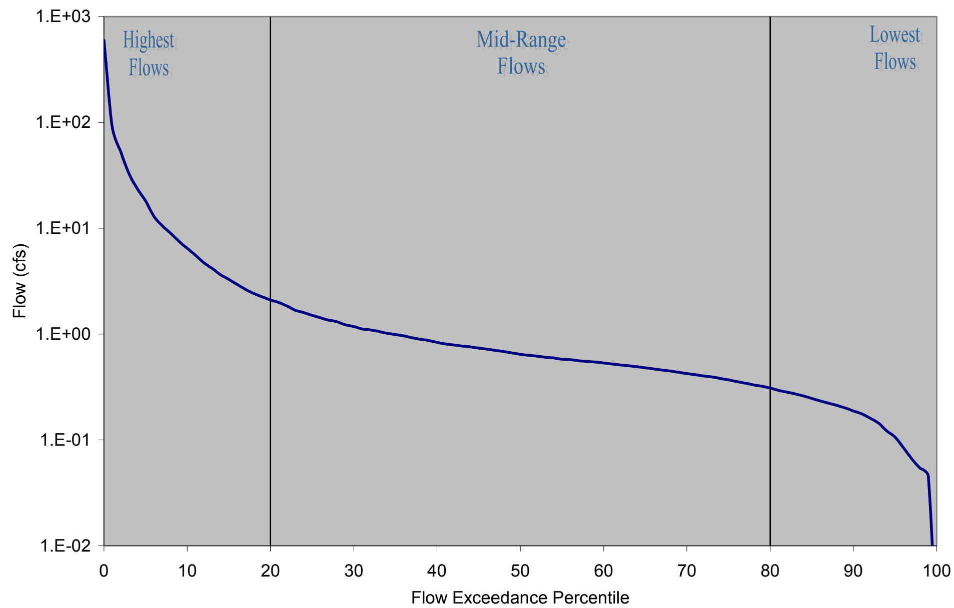

Figure A-5. Flow Duration Curve for Hickory Slough (1102C)

Figure A-6 represents the FDC for Turkey Creek, segment 1102D at sampling location 17069. Because WWTF discharges occur in Turkey Creek, average monthly WWTF flows obtained from DMRs were added to the synthesized flows.

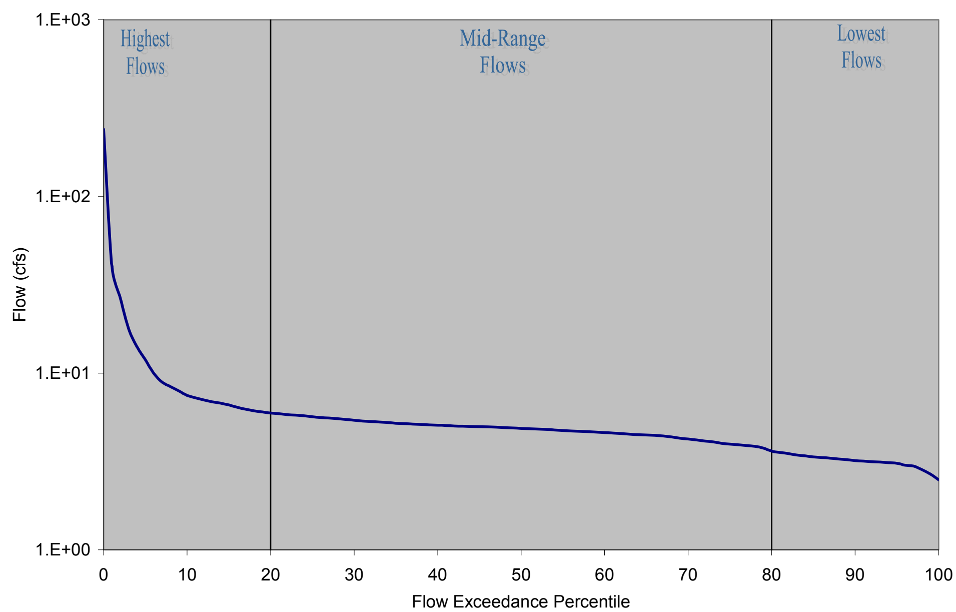

Figure A-6. Flow Duration Curve for Turkey Creek (1102D)

Figure A-7 represents the FDC for Mud Gully, segment 1102E at sampling location 17071. Because WWTF discharges occur in Mud Gully, average monthly WWTF flows obtained from DMRs were added to the synthesized flows.

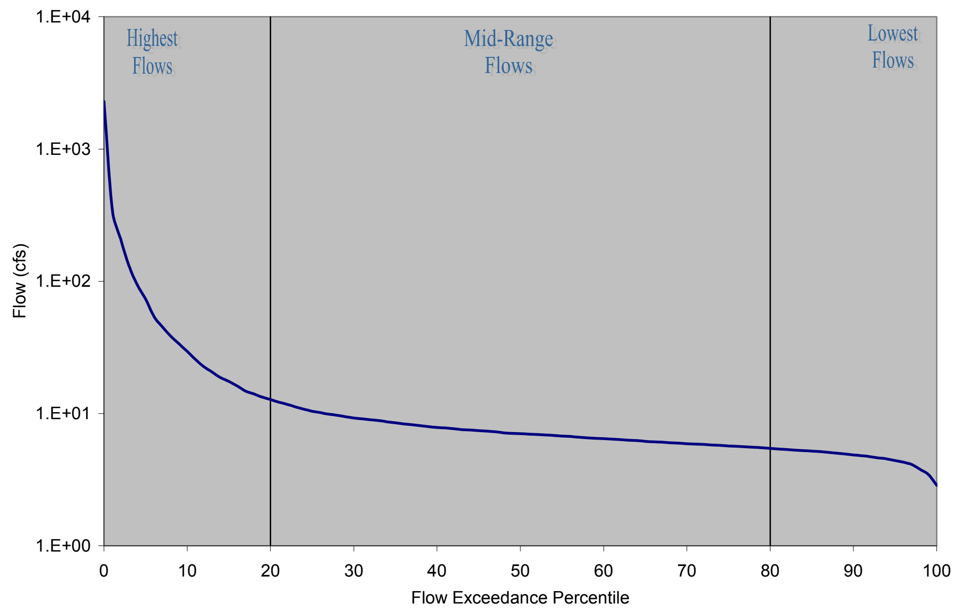

Figure A-7. Flow Duration Curve for Mud Gully (1102E)

FDCs can be subdivided into hydrologic condition classes to facilitate the diagnostic and analytical uses of flow and LDCs. The hydrologic classification scheme utilized in this application is described as follows.

Table A-1. Hydrologic Classification Scheme

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

Some instantaneous flow measurements were available from various agencies. These were not combined with the daily average flows or used in calculating flow percentiles, but were matched to bacteria grab measurements collected at the same site and time. When available, these instantaneous flow measurements were used in lieu of the daily average flow to calculate instantaneous bacteria loads.

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

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

Equation A-1

Point Source Loading = monthly average flow (mgd) * geomean of indicator bacteria concentration * unit conversion factor

where:

unit conversion factor = 37,854,120 100mL/million gallons (mg)

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

Development of Bacteria TMDLs for Freshwater Streams Using Load Duration Curves

The final step in the TMDL calculation process involves a group of additional computations derived from the preparation of LDCs. Using the single sample water quality criterion to generate the LDC is necessary to display the allowable pollutant load in relation to the existing loads which are represented by existing ambient water quality samples.

Step 1: Generate Bacteria LDCs

LDCs are similar in appearance to flow duration curves; however, the ordinate is expressed in terms of a bacteria load in counts/day. The curve represents the instantaneous water quality criterion for fecal coliform (400 counts/100mL) or *E. coli* (394 counts/100mL), expressed in terms of a load through multiplication by the continuum of flows historically observed at this site. The basic steps to generating an LDC involve:

- obtaining daily flow data for the sampling location of interest from the USGS;
- sorting the flow data and calculating flow exceedance percentiles for the time period and season of interest;
- obtaining the water quality data;

- matching the water quality observations with the flow data from the same date;
- display a curve on a plot that represents the allowable load multiplied by the actual or estimated flow at the SWQS for each respective indicator;
- multiplying the flow by the observed water quality parameter concentrations to calculate daily loads; then
- plotting the flow exceedance percentiles and daily load observations in a load duration plot.

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

Equation A-2

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

where:

criterion = 400 counts /100mL (Fecal coliform); or 394 counts/100mL (*E. coli*) and
unit conversion factor = 24,465,755 100mL/ft3 * seconds/day

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

Figure A-8 provides a schematic representation of where permitted and non-permitted sources of pollution occur throughout the entire hydrograph for a typical stream. This figure shows that runoff typically contributes pollutant loads during high flow to mid-range flow conditions. However, flows do not always correspond directly to runoff events. For instance, high flows may occur in dry weather and runoff influence may be observed with low or moderate flows.

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

Equation A-3

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

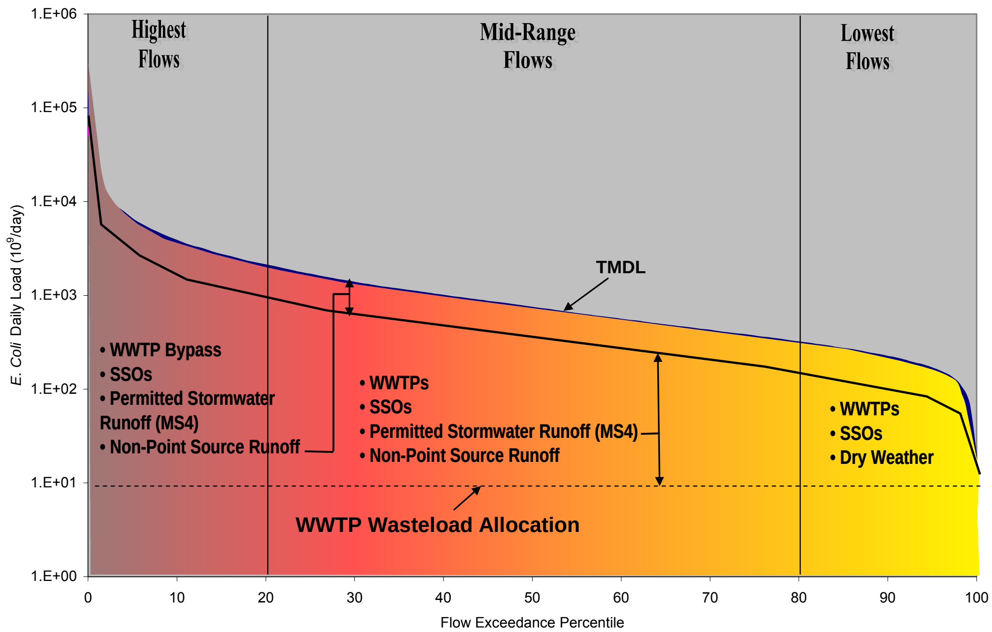

Figure A-8. LDC Schematic Diagram – Interpreting Sources and Loads

where:

S = potential maximum retention after runoff begins (inches)
CN =average curve number for the watershed

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

Step 2: Develop LDCs with MOS

The MOS may be defined explicitly or implicitly. A LDC depicting slightly lower estimates than the TMDL is typically developed to incorporate a MOS into the TMDL calculations. A typical explicit approach would reserve some fraction of the TMDL (*e.g.*, 5 percent) as the MOS. In an implicit MOS approach, conservative assumptions used in developing the TMDL are relied upon to provide an MOS to assure that surface water quality standards are attained.

For the TMDLs in this report, an explicit MOS of 5 percent of the TMDL value (5 percent of the instantaneous water quality criterion) has been selected to slightly reduce assimilative capacity in the watershed.

Step 3: Calculate WLA

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

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

WLA for WWTF

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

Equation A-4

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

where:

criterion = 200/100mL (Fecal coliform); 126/100mL (E. coli); or 35/100mL (Enterococci)
flow (mgd) = permitted flow
unit conversion factor = 37,854,120 100mL/mgd

WLA for NPDES/TPDES MS4s

Given the lack of data and the complexity of quantifying bacteria concentrations or loads associated with wet weather events, calculating the WLA for MS4 discharges must be derived in a manner similar to that used for all other non-permitted nonpoint sources. In other words, it must be derived from the overall LA or the area under the TMDL curve and above the WLA established for WWTFs. Rather than one discrete value, which is practical for WWTF discharges, the WLA calculations for permitted storm water discharges must be expressed as different maximum loads allowable under different flow conditions. Therefore, the percentage of a watershed that is under MS4 jurisdiction is used to estimate the load that should be allocated as the permitted storm water load. For example, the area of the City of Houston/Harris County permitted MS4 discharge in the project area is estimated to be 14,753 acres, 46 percent of the Clear Creek Above Tidal (Segment 1102) watershed. Therefore, 46 percent of the LA calculated at any flow condition will be designated as the WLA for the City of Houston/Harris County permitted storm water discharge. The WLA for MS4s can be expressed as a value for each flow exceedance frequency.

Step 4: Calculate LA

Load Allocations for freshwater segments can be calculated under different flow conditions as the water quality target load (TMDL) minus the WLA. The LA is represented by the area under the LDC but above the WLA. The LA at any particular flow exceedance is calculated as shown in the following equation.

Equation A-5

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

where:

LA = allowable load from non-permitted sources
$TMDL$= total allowable load
ΣWLA_{WWTF} = sum of all WWTF loads
ΣWLA_{MS4} = sum of all MS4 loads
MOS = margin of safety

Step 5: Estimate WLA Load Reduction

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

Step 6: Estimate LA Load Reduction

A percent reduction goal will be calculated for the geometric mean criterion for each segment. Load reduction estimates are calculated for each sampling location. After existing loading estimates are computed for each indicator bacteria, nonpoint load reduction estimates for each sampling location are calculated by using the difference between estimated existing loading and the allowable load expressed by the LDC (TMDL-MOS). For each of the three flow regimes, existing loads were determined by calculating the median flow (10^{th}, $50^{th,}$ and 90^{th} flow exceedance percentile) and the geometric mean concentration of the historical bacteria data. For example, for the $0\text{-}20^{th}$ percentile flow range, the flow corresponding to the 10^{th} percentile was used. The geometric mean of the indicator bacteria samples within the $0\text{-}20^{th}$ flow percentile range was then multiplied by the 10^{th} flow exceedance percentile to determine the existing load. Tables A-2 through A-11 show the load allocations and required reductions for each of the three flow ranges. The critical load allocations and reductions are shown in bold. Overall, percent reduction goals were also calculated for the most-downstream station of each segment. In this case, all indicator bacteria data from flow exceedance percentiles of 0 through 100 were used to calculate the geometric mean and the percent reduction goal was derived using the formula of:

$$\frac{\text{Geometric Mean of Indicator Bacteria Data} - \text{Water Quality Target} \times 100}{\text{Geometric Mean of Indicator Bacteria Data}}$$

Table A-2. Load Allocations and Reductions for Chigger Creek (1101B)

Station 16493			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	5.6	0.51	0.12
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	1.15E+02	2.78E+00	1.48E-01
TMDL (Q*C) (10^9 org/day)	1.74E+01	1.58E+00	3.78E-01
MOS (Q*C*0.05) (10^9 org/day)	8.70E-01	7.91E-02	1.89E-02
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	1.65E+01	1.50E+00	3.59E-01
Load Reduction (10^9 org/day)	9.82E+01	1.28E+00	0
Load Reduction (%)	**85.6%**	46.0%	0%
Overall Load Reduction* (%)	54%		

* - Overall load reduction calculated only for station at the most-downstream location

Table A-3. Load Allocations and Reductions for downstream Clear Creek above Tidal (1102)

Station 14229			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	14.4	9.79	8.62
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	1.66E+02	2.81E+01	3.78E+01
TMDL (Q*C) (10^9 org/day)	4.44E+01	3.02E+01	2.66E+01
MOS (Q*C*0.05) (10^9 org/day)	2.22E+00	1.51E+00	1.33E+00
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	4.22E+01	2.87E+01	2.52E+01
Load Reduction (10^9 org/day)	1.24E+02	0	1.26E+01
Load Reduction (%)	**74.6%**	0%	33.3%
Overall Load Reduction* (%)	37%		

* - Overall load reduction calculated only for station at the most-downstream location

Table A-4. Load Allocations and Reductions for upstream Clear Creek above Tidal (1102)

Station 17076			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	3.1	1.18	0.69
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	5.30E+01	3.62E+00	NA
TMDL (Q*C) (10^9 org/day)	9.69E+00	3.64E+00	2.13E+00
MOS (Q*C*0.05) (10^9 org/day)	4.84E-01	1.82E-01	1.06E-01
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	9.20E+00	3.46E+00	2.02E+00
Load Reduction (10^9 org/day)	4.38E+01	1.58E-01	NA
Load Reduction (%)	**82.6%**	4.4%	NA

Table A-5. Load Allocations and Reductions for upstream Cowart Creek (1102A)

Station 11426			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	12.6	1.19	0.32
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	3.23E+02	6.88E+00	1.20E+00
TMDL (Q*C) (10^9 org/day)	3.88E+01	3.68E+00	9.96E-01
MOS (Q*C*0.05) (10^9 org/day)	1.94E+00	1.84E-01	4.98E-02
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	3.69E+01	3.50E+00	9.46E-01
Load Reduction (10^9 org/day)	2.86E+02	3.38E+00	2.54E-01
Load Reduction (%)	**88.6%**	49.1%	21.2%

Table A-6. Load Allocations and Reductions for downstream Cowart Creek (1102A)

Station 16477			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	15.7	1.48	0.39
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	7.66E+01	2.62E+00	5.90E-01
TMDL (Q*C) (10^9 org/day)	4.83E+01	4.55E+00	1.20E+00
MOS (Q*C*0.05) (10^9 org/day)	2.41E+00	2.27E-01	6.00E-02
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	4.59E+01	4.32E+00	1.14E+00
Load Reduction (10^9 org/day)	3.07E+01	0	0
Load Reduction (%)	**40.1%**	0%	0%
Overall Load Reduction* (%)	54%		

* - Overall load reduction calculated only for station at the most-downstream location

Table A-7. Load Allocations and Reductions for Mary's Creek (1102B)

Station 16473			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	52.9	7.25	3.34
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	1.05E+03	2.18E+01	9.24E+00
TMDL (Q*C) (10^9 org/day)	1.63E+02	2.23E+01	1.03E+01
MOS (Q*C*0.05) (10^9 org/day)	8.15E+00	1.12E+00	5.15E-01
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	1.55E+02	2.12E+01	9.78E+00
Load Reduction (10^9 org/day)	8.98E+02	5.57E-01	0
Load Reduction (%)	**85.3%**	2.6%	0%
Overall Load Reduction* (%)	48%		

* - Overall load reduction calculated only for station at the most-downstream location

Table A-8. Load Allocations and Reductions for Hickory Slough (1102C)

Station 17068			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	6.5	0.64	0.19
Target, 0.95*C (org/100mL)	120	120	120
Existing Load (10^9 org/day)	5.70E+01	1.65E+00	5.64E-01
TMDL (Q*C) (10^9 org/day)	1.99E+01	1.98E+00	5.79E-01
MOS (Q*C*0.05) (10^9 org/day)	9.97E-01	9.92E-02	2.90E-02
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	1.89E+01	1.89E+00	5.50E-01
Load Reduction (10^9 org/day)	3.81E+01	0	1.34E-02
Load Reduction (%)	**66.8%**	0%	2.4%
Overall Load Reduction* (%)	25%		

* - Overall load reduction calculated only for station at the most-downstream location

Table A-9. Load Allocations and Reductions for Turkey Creek (1102D)

Station 17069			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	7.5	4.87	3.21
Target, 0.95*C (org/100mL)	190	190	190
Existing Load (10^9 org/day)	9.53E+02	1.09E+02	NA
TMDL (Q*C) (10^9 org/day)	3.66E+01	2.38E+01	1.57E+01
MOS (Q*C*0.05) (10^9 org/day)	1.83E+00	1.19E+00	7.84E-01
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	3.48E+01	2.27E+01	1.49E+01
Load Reduction (10^9 org/day)	9.18E+02	8.60E+01	NA
Load Reduction (%)	**96.3%**	79.2%	NA
Overall Load Reduction* (%)	91%		

* - Overall load reduction calculated only for station at the most-downstream location

Table A-10. Load Allocations and Reductions for upstream Mud Gulley (1102E)

Station 17070			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	24.0	6.55	4.69
Target, 0.95*C (org/100mL)	190	190	190
Existing Load (10^9 org/day)	1.19E+03	2.43E+02	5.18E+01
TMDL (Q*C) (10^9 org/day)	1.18E+02	3.21E+01	2.30E+01
MOS (Q*C*0.05) (10^9 org/day)	5.88E+00	1.60E+00	1.15E+00
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	1.12E+02	3.05E+01	2.18E+01
Load Reduction (10^9 org/day)	1.08E+03	2.13E+02	3.00E+01
Load Reduction (%)	**90.6%**	87.5%	57.9%

Table A-11. Load Allocations and Reductions for downstream Mud Gulley (1102E)

Station 17071			
Flow Regime %	**0-20%**	**20-80%**	**80-100%**
Median Flow, Q (cfs)	29.5	7.04	4.86
Target, 0.95*C (org/100mL)	190	190	190
Existing Load (10^9 org/day)	9.94E+02	1.45E+02	4.41E+01
TMDL (Q*C) (10^9 org/day)	1.45E+02	3.45E+01	2.38E+01
MOS (Q*C*0.05) (10^9 org/day)	7.23E+00	1.72E+00	1.19E+00
Allowable Load at Water Quality Target, TMDL-MOS (10^9 org/day)	1.37E+02	3.27E+01	2.26E+01
Load Reduction (10^9 org/day)	8.56E+02	1.12E+02	2.15E+01
Load Reduction (%)	**86.2%**	77.4%	48.7%
Overall Load Reduction* (%)	86%		

* - Overall load reduction calculated only for station at the most-downstream location

Appendix B – Tidal Prism Method

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

Modeling Approach

A time-variable tidal prism modeling approach with a moderate level of spatial resolution was used to simulate the bacterial indicator loads and establish TMDLs for the tidal segments of the Clear Creek watershed. The tidal prism is the volume of water gained in a tidal stream between low and high tide levels. Load calculations were developed for a series of reaches within Clear Creek tidal and Robinson Bayou, as well as the portions of the major tributaries discharging to Clear Creek tidal that periodically are influenced by tidal fluctuations. The model incorporates the three primary mechanisms through which Enterococci loadings and water enter the impaired systems:

i) rain-induced freshwater inputs via upstream reaches and tributaries or direct runoff,
ii) direct point source discharges, and
iii) tidally influenced loadings, which are introduced during the diurnal tidal fluctuations that occur in the system.

The model assumes that Enterococci are removed with the net estuarine flow from the system and via net decay. A generalized schematic of the source and sink terms of each impaired water body (1101, 1101D) is presented in Figure B-1.

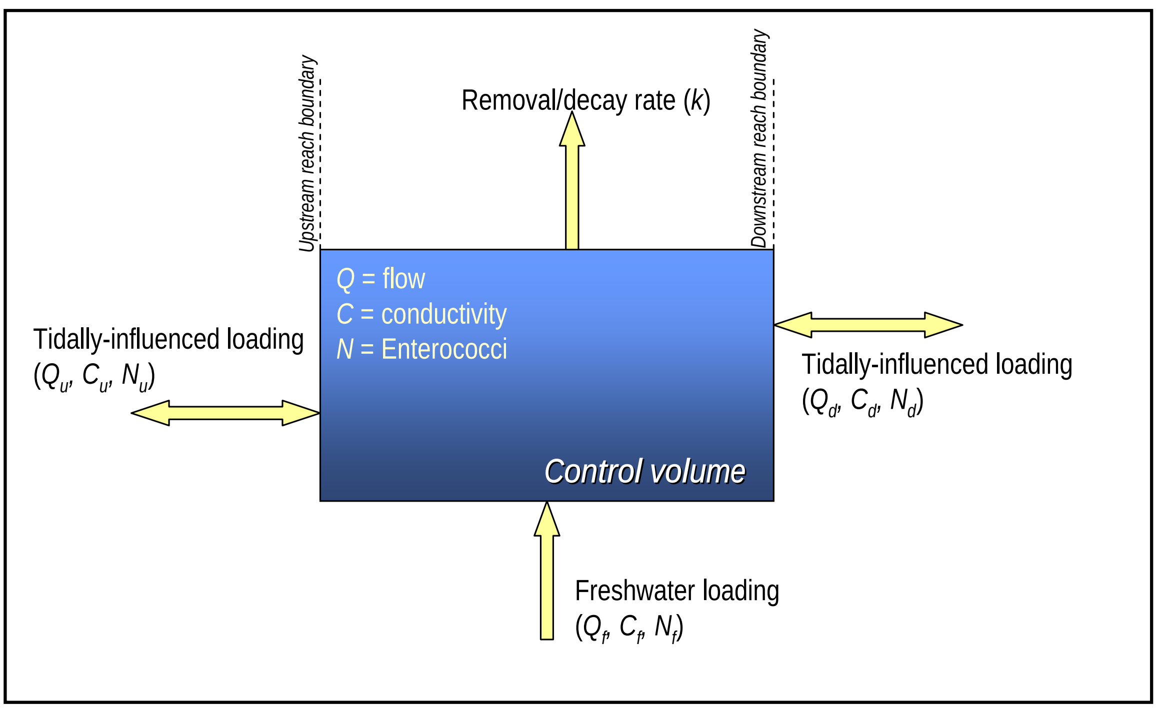

Figure B1. Conceptual Model for Sources and Sinks of Enterococci in a Control Volume

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

Equation B1

$$\frac{dV}{dt} = Q_u + Q_f - Q_d$$

where:

Q_u = volume of water crossing the upstream boundary of the reach [m^3/hr]
Q_d = volume of mixed water crossing the downstream boundary of the reach [m^3/hr]
Q_f = volume of freshwater inflow (runoff, tributaries, and WWTFs) discharging along the reach [m^3/hr],
dV/dt = change in volume of the reach with time [m^3/hr]

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

Step 1: Define Reaches

Clear Creek Tidal, Segment 1101, was divided into eleven reaches (Figure B-2). The tidal prism model includes reaches for Robinson Bayou, a tidal tributary of Clear Creek Tidal, and portions of freshwater tributaries Cowart Creek, Chigger Creek, and Magnolia Creek. A small downstream reach of Clear Creek Above Tidal (Reaches A and B) is also incorporated into the tidal prism model because it is tidally influenced. An effort was made to ensure that model reaches were of similar size.

Data from Tropical Storm Allison Recovery Project (TSARP) models were used to calculate cross-sectional areas for the boundaries of each main stem reach. Cross-sectional areas for small tributaries were estimated using LiDAR (Light Detection and Ranging) 2-foot contour elevation data collected in 2001 provided by TSARP.

Step 2: Establishing Tributary Inflows and Loads

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

Inflows from Non-Tidal Tributaries to Tidal Model Reaches

Estimated daily inflows from non-tidal (freshwater) tributary streams to the tidal model reaches were derived from the drainage area ratio method. These daily inflows were then disaggregated to hourly time series for the modeled period (2000 through 2006).

Enterococci Loads from Upstream Freshwater Segments

Indicator bacteria concentrations measured at the most-downstream sampling locations on non-tidal tributaries—including Mary's Creek/North Fork Mary's Creek (16473), Chigger Creek (16493), Cowart Creek (16477), and Clear Creek Above Tidal (14299)—were used to estimate Enterococci loads to the tidal prism model. For most of the sampling locations on these tributaries, only *E. coli* or fecal coliform data were available. Therefore, Enterococci concentrations were estimated from *E. coli* or fecal coliform data using Enterococci/*E. coli* or Enterococci/fecal coliform conversion ratios, based on data collected by the City of Houston and H-GAC for their Alternate Indicator Study (Running 2007). The median Enterococci/*E. coli* and Enterococci/fecal coliform ratios were 0.34 and 0.27, respectively. For dates with no historical water quality data

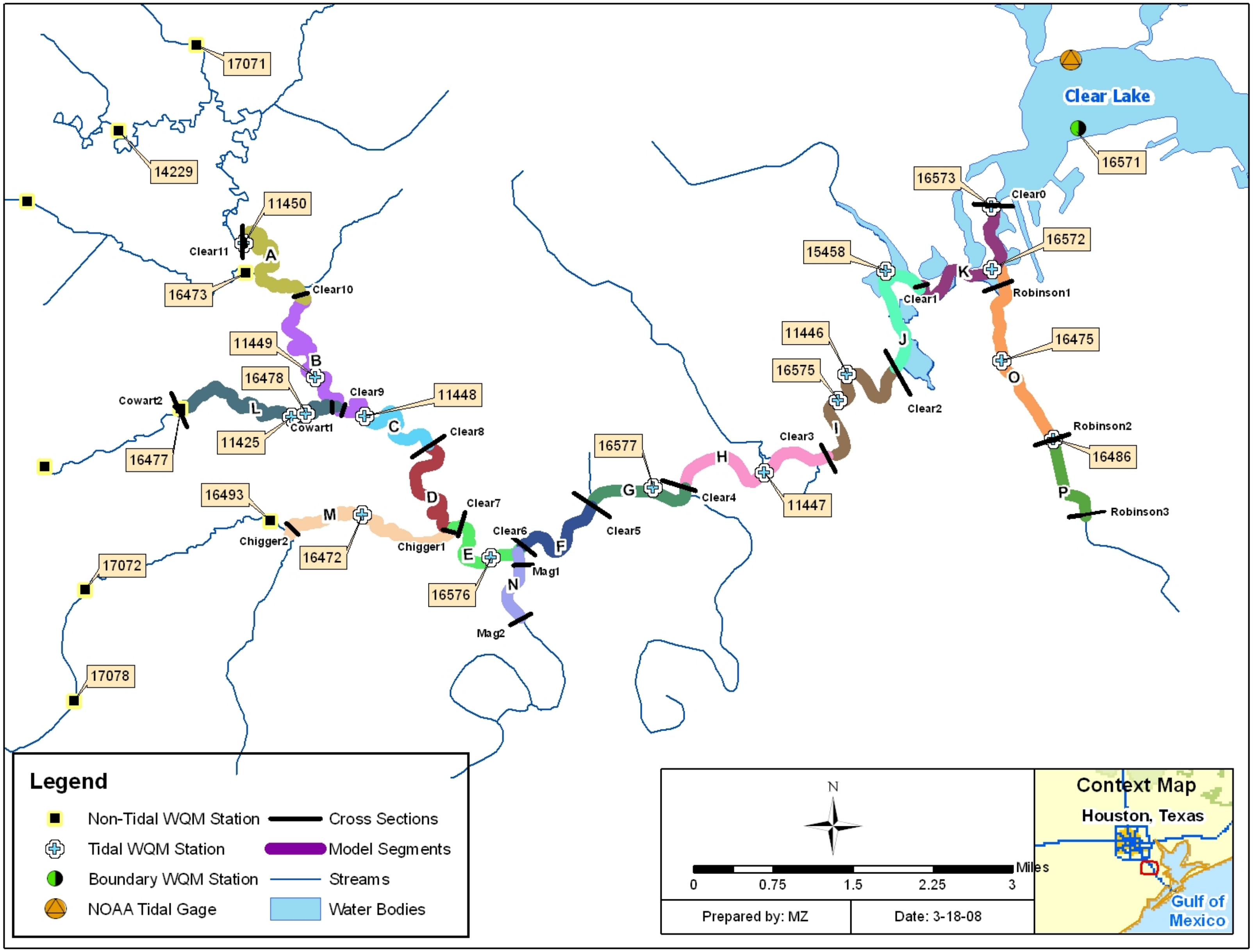

Figure B-2. Schematic of Clear Creek Tidal Reaches

Table B-1. Summary of Tributary Inflows and Loads to the Tidal Prism Model

Interface	Average Flow (m3/day)	Average Flow (cfs)	Average Enterococci Load (counts/day)
Clear Creek above Tidal (Reach A-K)	74,900	30.60	6.49E+10
Cowart Creek (Reach L)	26,700	10.90	2.17E+10
Chigger Creek (Reach M)	9,610	3.93	1.04E+10
Magnolia Creek (Reach N)	10,100	4.11	2.19E+12
Robinson Bayou (Reach P)	374	0.15	2.67E+10
Mary's Creek/ North Fork Mary's Creek (Reach A)	91,900	37.60	1.33E+11
Tributary A (Reach A)	2,830	1.16	4.28E+11
Tributary B (Reach G)	152	0.06	2.19E+10
Tributary One (Reach G)	16,100	6.58	2.31E+12
Tributary C (Reach H)	4,140	1.69	6.27E+11
Tributary D (Reach H)	4,260	1.74	6.46E+11
Tributary E (Reach J)	37,000	15.10	5.60E+12

available, the geometric mean of the observed values of each respective station was used. For Magnolia Creek, Robinson Bayou and Tributary One, the load time series were developed using the geometric means of the data collected during the 2006 Intensive Surveys (stations 16611, 16486, and 18818, respectively) for low flows (defined as flows lower than the 60th percentile), while the geometric means of the storm water data collected for the same locations were used for high flows. For Tributaries A through E for which no bacterial indicator data were available, the overall geometric means of the intensive surveys and the storm water sampling were used for low and high flows, respectively. Tributary load input datasets for Enterococci are summarized in Table B-1.

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

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

Permitted Sources: Continuous Point Source Dischargers (WWTFs)

Six TPDES-permitted WWTFs that continuously discharge wastewater are located in the Clear Creek Tidal Watershed. To be consistent with estimating bacterial indicator loads under the LDC method, average monthly flows from DMRs were again used to estimate fecal coliform loads from discrete point sources as inputs to the tidal prism model. Loads were calculated using maximum monthly geometric mean data for fecal coliform when available from TCEQ, then converted to estimates to Enterococci loads using the 0.27 Enterococci/fecal coliform ratio). *E. coli* data collected from a select group of WWTFs by Harris County in November 2007 were also used if no other data was available to characterize the bacteria concentrations in wastewater effluent. A summary of these data are shown in Table B-2.

Table B-2. Summary of Existing WWTF Loads in Model

Model Reach	TPDES Permit Number	Flow (average self reported) m^3/day	Flow (average self reported) MGD	Enterococci Concentration (counts/100mL)	Enterococci Load (counts/day)
D	11571-001	20,222	5.343	28[a]	5.66E+09
I	10520-001	5,169	1.366	0.5[b]	2.58E+07
J	10526-001	2,303	0.608	1[b]	2.30E+07
J	10568-005	23,356	6.170	13[a]	3.04E+09
K	10526-001	2,618	0.692	1[b]	2.62E+07
N	10568-003	1,450	0.383	4[a]	5.80E+07

[a] Maximum value of monthly self-reported fecal coliform geomeans times 0.27 (Enterococci/fecal coliform ratio)

[b] Maximum *E. coli* data from Harris County, 2007 times 0.34 (Enterococci/ *E. coli* ratio)

Permitted and Non-permitted Storm Water Runoff

Storm water runoff loads discharging directly to the model reaches were input to the model for the days on which a rain event occurred (as indicated by the closest Harris County Office of Emergency Management (HCOEM) gauge to each segment). Drainage areas were estimated using TSARP subwatersheds displayed in Figure B-3. Daily Enterococci runoff loads were calculated using land cover information from the C-CAP Texas 2005 Land Cover Data, and the amounts of rainfall recorded for the simulation period.

The amount of runoff for each drainage area was calculated using the National Resource Conservation Service (NRCS) runoff curve number method (NRCS 1986). The NRCS runoff equation is as follows.

Equation B-2

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

where:

Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)
I_a = initial abstraction (in).

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

Equation B-3

$$I_a = 0.2S$$

thus,

Equation B-4

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

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

Equation B-5

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

CN values range from 0 to 100 and are based on land cover and soil group. For this runoff calculation, all subwatersheds were assumed to be in soil group D (silt and clay) that generally has low infiltration rates. Land coverage data developed by C-CAP were aggregated from 22 categories into the six land-cover categories listed in Table B-3. The classification system and their corresponding runoff curve numbers are included in Table B-3.

Event mean concentrations (EMCs) for Enterococci were estimated based on fecal coliform EMCs obtained from the Storm Water Management Joint Task Force in 2002. The Enterococci to fecal coliform ratio (0.27) was applied to obtain Enterococci EMCs for different land cover categories. The Enterococci concentrations used for the tidal prism model are included in Table B-3

Average storm water runoff loads from the contributing subwatershed of each reach are summarized in Table B-4. The total average daily load from runoff into Clear Creek Tidal (including the tidal portions of the major tributaries) was estimated to be 1.11 $\times 10^{13}$ /day; the total for Robinson Bayou was estimated to be 8.71 $\times 10^{11}$ /day.

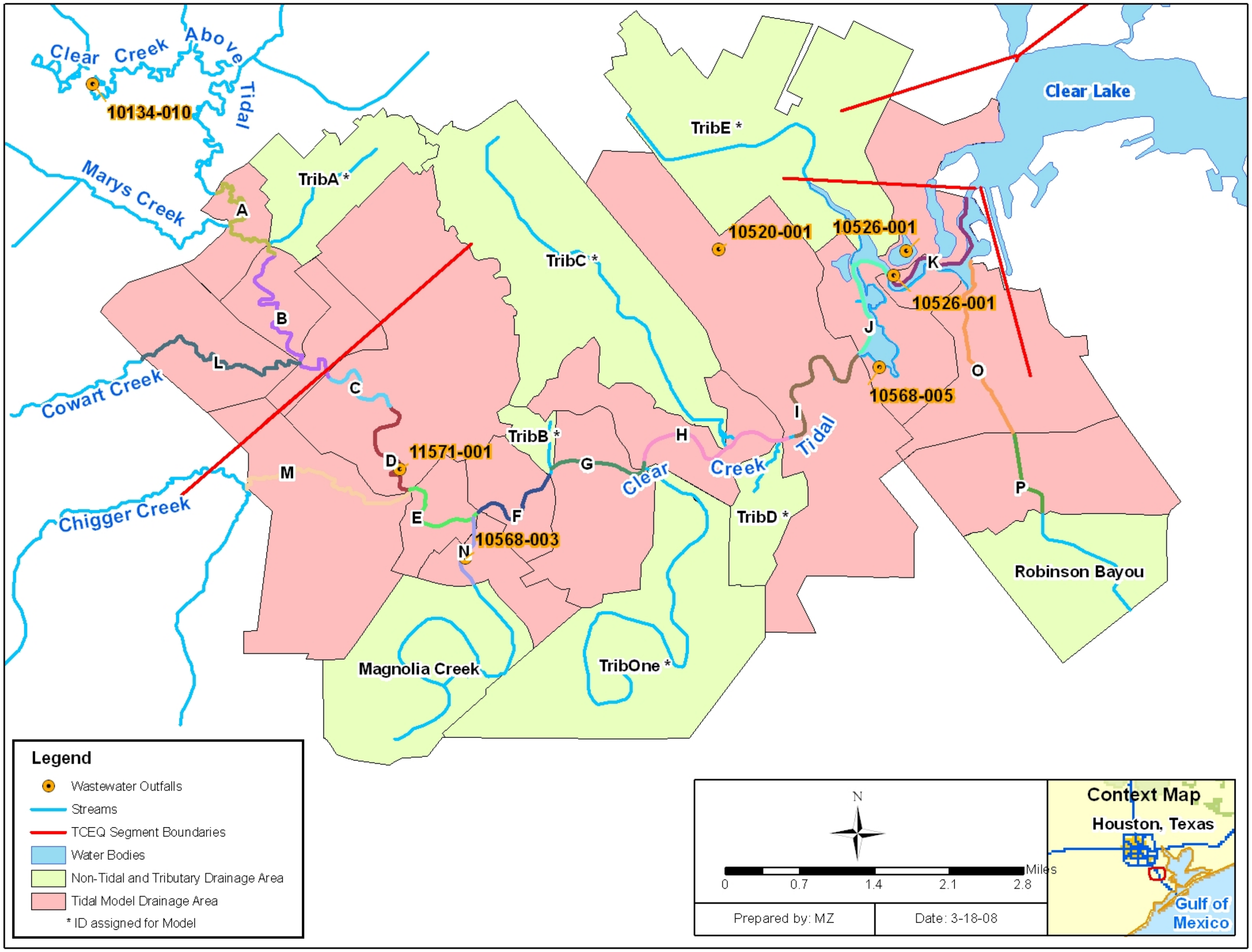

Figure B-3. Drainage Areas for the Tidal Prism Model Reaches

Table B-3. Runoff Curve Numbers for the Clear Creek Watershed

Land Cover Code	Land Cover Description	CN	Enterococci EMCs (counts/100mL)
1	Developed	92[a]	18,000
2	Grass/Agriculture	80[b]	700
3	Woodland	77[c]	400
4	Open Water	0	0
5	Wetlands	0	0
6	Transitional/Bare	89[d]	12,000

[a] Obtained from C-CAP Medium-Intensity Developed

[b] Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Pasture, grassland, or range- continuous forage for grazing (Good condition)

c Obtained from C-CAP Mixed Forest

d Obtained from "Urban Hydrology for Small Watersheds." Natural Resources Conservation Service, Technical Release 55, June 1986. Open space (lawns, parks, golf courses, cemeteries, etc.) Poor condition (grass cover <50 percent)

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

Reach	Average Flow (m^3/day)	Average Flow (cfs)	Average Enterococci Load (counts/day)
A	1,930	0.79	2.70E+11
B	4,840	1.98	7.75E+11
C	8,320	3.40	1.21E+12
D	7,680	3.14	1.12E+12
E	1,690	0.69	1.69E+11
F	1,850	0.76	1.46E+11
G	6,300	2.58	9.16E+11
H	4,180	1.71	3.57E+11
I	20,400	8.34	2.64E+12
J	6,510	2.66	1.05E+12
K	475	0.19	5.91E+10
L	5,620	2.30	8.87E+11
M	9,330	3.81	9.94E+11
N	3,360	1.37	5.39E+11
O	259	0.11	2.77E+10
P	5,750	2.35	8.43E+11

Note: Variable daily loads were input into the model. The loads presented here are the averages over the simulation period (01/01/2000 to 09/30/2006).

Step 4: Estimate Tidal Flow

Tidal flows for each reach were computed as the tidal exchange over the course of one hour, and were estimated as the difference in volume between two consecutive time steps (Equation B-1). To calculate volumes, one-hour gauge data for the simulation period of 1/01/2000 – 09/30/2006 were downloaded from the Texas Coastal Ocean Observation Network Station 502 at Clear Lake <http://lighthouse.tamucc.edu/overview/502>. After adjusting cross-sectional areas to reflect tidal elevation, the hourly volumes for each reach were calculated as the average of the cross-sectional areas at the downstream and upstream reach boundaries times the length of the reach.

Step 5: Verify Flow Balance Using Conductivity

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

Equation B-6

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

where:

V_t = volume of reach at time step t [m^3]
V_{t-1}= volume of reach at time step t-1 [m^3]
V_f= freshwater volume [m^3]
V_{in},V_{out}= tidally influenced volumes for time step t [m^3]
C_t= conductivity in the reach [µS/cm]
C_f= conductivity in the freshwater inputs [µS/cm]
C_{in}, C_{out} = conductivity of the tidally influenced flows [µS/cm]

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

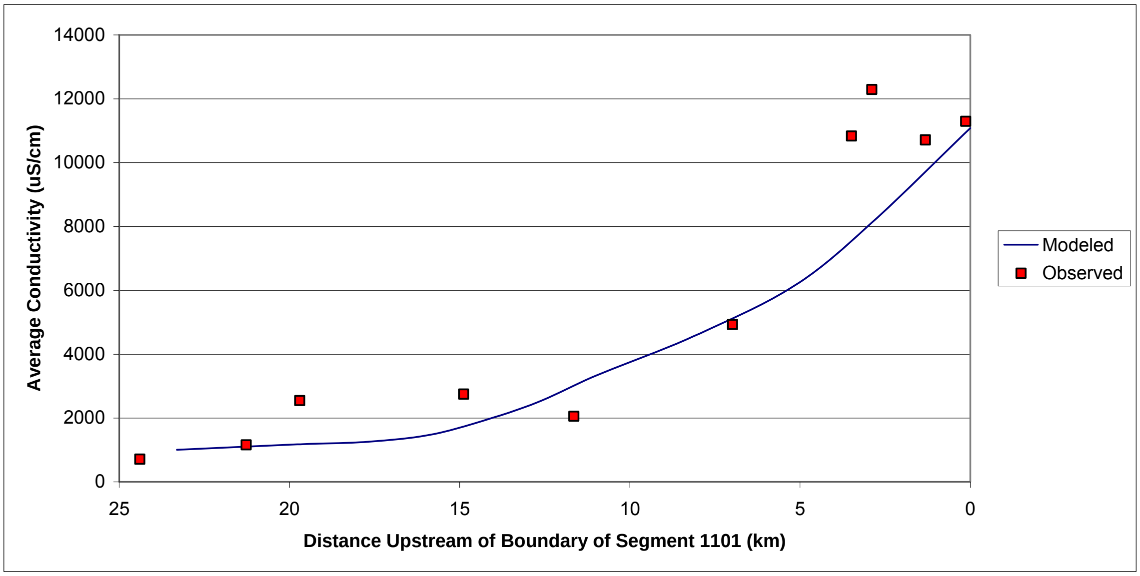

Figure B-4. Longitudinal Profile of Average Conductivity

Step 6: Perform Mass Balance on Enterococci Levels

Upon validation of the flow balance, a mass-balance on Enterococci for each reach can be computed as follows:

Equation B-7

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

where:

N_t = Enterococci level in the reach [counts/100mL]
N_f = Enterococci level in the freshwater flow [counts/100mL]
N_{in}, N_{out} = Enterococci level in tidally influenced flow [counts/100mL]
k = Enterococci first-order decay rate [hr^{-1}]

The average Enterococci concentrations measured at each of the water quality monitoring stations along Clear Creek Tidal and Robinson Bayou were used to define the initial conditions in each model reach. The geometric mean of Enterococci levels measured in Clear Lake station 16571 (12 counts/100mL) was used to set the downstream boundary concentration of Enterococci. Enterococci levels in runoff, tributaries, and WWTFs were estimated as described in Steps 2 and 3.

The model was calibrated by varying the decay rate by reach and adjusting this decay rate within the bounds of reported rates until the model reasonably reproduced the temporal and spatial distribution of observed Enterococci within the system. Sinton, *et al*. (1994) and Davies-Colley, *et al*. (1998) reported decay rates between 0.12 and 40 day^{-1}, Anderson, *et al*. (2005) reported rates between 0.73 and 2.1 day^{-1}, and Kay, *et al*. (2005) measured decay rates between 2.2 and 8.5 day^{-1}. Final decay rates applied to the model ranged from 0.7 to 3.6 day^{-1}, which is within the ranges reported in the literature. The decay rates were not varied temporally because insufficient data were available to estimate the seasonal variation in decay rates.

Figure B-5 presents a comparison of measured and modeled Enterococci geometric mean concentrations along the main stem of Clear Creek. As can be seen, the model reasonably predicts the spatial distribution of Enterococci along the creek. It is noted that all the bacteria historical data (including fecal coliform and *E. coli*) for a given station were used to compare to modeled values. Fecal coliform and *E. coli* data were converted to Enterococci concentrations using respectively the 0.27 and 0.34 ratios as previously described.

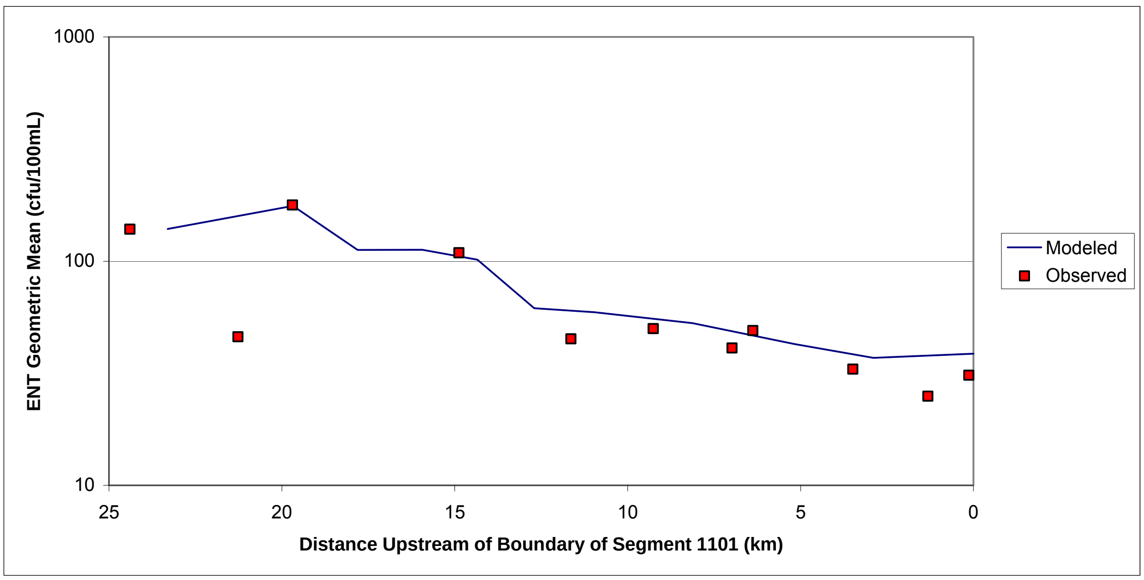

Figure B-5. Longitudinal Profile of Enterococci Concentrations (Geometric Means)

As mentioned earlier, six TPDES-permitted WWTFs discharge to Clear Creek Tidal, Segment 1101. For these continuous dischargers, the WLA_{WWTF} is computed as the product of the permitted flow and the criteria for each bacterial indicator, as prescribed in the TPDES permit. Storm water runoff can contribute both permitted and non-permitted sources of bacteria which must also be accounted for in the TMDL allocations. Any storm water runoff originating from the area of a watershed under the jurisdiction of an MS4 permit is considered a point source contribution and is therefore included as part of the WLA calculation as the WLA_{MS4}. The WLA will be split into the WLA_{WWTF} and WLA_{MS4} components. To be consistent with the LDC method, the estimated loading from storm water runoff within each drainage area is separated into storm water loading from MS4s and storm water loading from non-permitted areas. This is done by using the percentage of each drainage area covered by the MS4 permit. An explicit MOS of 5 percent of the criterion is also included in the TMDL calculation. The storm water loading from non-permitted areas is considered the LA. Therefore, another way of expressing the LA from non-permitted storm water runoff is calculated as the TMDL minus the margin of safety minus the WLA (sum of WWTF and MS4).

Percent reduction goals were calculated by changing the loads in the tidal prism model until all the reaches have concentrations lower than or equal to the 35 counts/100mL criterion for ENT. It is noted that the loads coming from upstream freshwater segments, addressed with LDCs, were assumed to be in compliance with the 126 counts/100 mL criterion for EC or 42 counts/100 mL for ENT if the 0.34 ratio is used.

Appendix C – Methodology to Estimated WWTF Permitted Flows in the Future

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

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

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

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

3. **Calculation of flows by watershed**
   - Add up the flows discharging to a given water body (Table C-5).
   - Use the projected flow to recalculate LDCs or to re-run the tidal prism model for future conditions.

Table C-1. TWDB Population Projections

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

Table C-2. Total Permitted Flows by City

Permit	Permittee	Segment	Use Population Projection For	Permitted Flow (MGD)
12332-001	Brazoria County MUD 1	1102	Brazoria County MUD 1	2.4
10005-001	City of Alvin	2432	City of Alvin	5
14440-001	R. West Development Co Inc	1104	City of Alvin	0.24
12935-001	K C Utilities	1104	City of Alvin	0.05
12822-001	Walker Water Works Inc	1102	City of Alvin	0.035
14039-001	Walker Water Works Inc	2432	City of Alvin	0.056
10134-002	City of Pearland	1102	City of Pearland	4.5
10134-007	City of Pearland	1102	City of Pearland	2
10134-008	City of Pearland	1102	City of Pearland	2
10134-010	City of Pearland	1102	City of Pearland	2.5
10134-007	City of Pearland	1102	City of Pearland	2.5
12849-001	CMH Parks Inc	1102	City of Pearland	0.075
13865-001	TIKI Leasing Co Ltd	1102	City of Pearland	0.049
12680-001	H & R Realty Investments	1102	City of Pearland	0.012
13864-001	Fresno Manufacturing LLC	1102	N/A Used Manufacturing % Increase For Fort Bend County	0.0084
10568-003	City of League City	1101	City of League City	0.66
10568-005	City of League City	1101	City of League City	7.5

Permit	Permittee	Segment	Use Population Projection For	Permitted Flow (MGD)
10495-002	City of Houston	1007	City of Houston	25
10495-003	City of Houston	1007	City of Houston	28
10495-009	City of Houston	1007	City of Houston	7
10495-010	City of Houston	1007	City of Houston	2
10495-016	City of Houston	1006	City of Houston	7
10495-030	City of Houston	1014	City of Houston	26.4
10495-037	City of Houston	1007	City of Houston	60
10495-050	City of Houston	1007	City of Houston	3.75
10495-053	City of Houston	1007	City of Houston	4
10495-065	City of Houston	1007	City of Houston	3
10495-075	City of Houston	1102	City of Houston	6.14
10495-076	City of Houston	1017	City of Houston	21
10495-077	City of Houston	1006	City of Houston	7.25
10495-078	City of Houston	1016	City of Houston	8
10495-079	City of Houston	1102	City of Houston	5.33
10495-090	City of Houston	1007	City of Houston	200
10495-095	City of Houston	1007	City of Houston	7.2
10495-099	City of Houston	1017	City of Houston	4
10495-100	City of Houston	1016	City of Houston	3.7
10495-101	City of Houston	1016	City of Houston	4
10495-109	City of Houston	1014	City of Houston	12
10495-111	City of Houston	1007	City of Houston	13.3
10495-112	City of Houston	902	City of Houston	0.82
10495-115	City of Houston	1016	City of Houston	3
10495-116	City of Houston	1007	City of Houston	18
10495-119	City of Houston	1007	City of Houston	23
10495-122	City of Houston	1016	City of Houston	5
10495-126	City of Houston	1016	City of Houston	2
10495-133	City of Houston	1016	City of Houston	3

Permit	Permittee	Segment	Use Population Projection For	Permitted Flow (MGD)
10495-135	City of Houston	1014	City of Houston	3.5
10495-136	City of Houston	1113	City of Houston	5
10495-139	City of Houston	1017	City of Houston	0.995
10495-146	City of Houston	1002	City of Houston	6.6
10495-148	City of Houston	1016	City of Houston	0.49
10495-149	City of Houston	1002	City of Houston	0.95
10495-150	City of Houston	1016	City of Houston	0.7
10495-151	City of Houston	1006	City of Houston	0.75
10526-001	City of Nassau Bay	1101	City of Nassau Bay	1.33
10520-001	City of Webster	1101	City of Webster	3.3
11571-001	Gulf Coast WDA & City of Friendswood	1101	City of Friendswood and % Increase Manufacturing for Harris County	9.25
12939-001	Harris County WCID #89	1102	Harris County WCID #84	0.95

Table C-3. GPCD by City

Municipality/County MUD	Total Permitted Flow (MGD)[A]	Population 2010[b]	GPCD Year 2010[c]
Brazoria County MUD 1	2.4	7,517	319
City of Alvin	5.381	23,231	232
City of Friendswood	9.25	24,553	377
City of Houston	532.026	2,199,988	242
City of League City	8.16	53,403	153
City of Nassau Bay	1.33	4,170	319
City of Pearland	13.636	63,685	214
City of Webster	3.3	13,076	252
Harris County WCID #84	0.95	2,475	384

[a] Sum of permitted flows in Table C-2 for each city

[b] From Table C-1

[c] Total permitted flow*10^6/Population 2010

Table C-4. Flow Projections

Permit Number	Facility Name	Permitted Flow (MGD)	Receiving Water	Use Pop Projection From	GPCD[a]	Pop 2050[b]	% Flow In City[c]	Flow 2050[d] (MGD)	Adj Flow 2050[e] (MGD)
10526-001	City of Nassau Bay	1.33	Clear Creek Tidal	City of Nassau Bay	319	4,170	100.0%	1.330	1.330
10568-005	City of League City	7.5	Clear Creek Tidal	City of League City	153	67,454	91.9%	9.473	9.473
11571-001	Gulf Coast Waste Disposal Authority	9.25	Clear Creek Tidal	City of Friendswood And % Increase Manufacturing	377	30,307	100.0%	11.418	13.546
10495-075	City of Houston	6.14	Turkey Creek	City of Houston	242	3,270,641	1.2%	9.128	9.128
10495-079	City of Houston	5.33	Mud Gully	City of Houston	242	3,270,641	1.0%	7.924	7.924
10134-002	City of Pearland	4.5	Clear Creek Above Tidal	City of Pearland	214	125,585	33.0%	8.874	8.874
10134-007	City of Pearland	4.0	Mary's Creek	City of Pearland	214	125,585	29.3%	7.888	7.888
10520-001	City of Webster	3.30	Clear Creek Tidal	City of Webster	252	28,334	100.0%	7.151	7.151
10134-010	City of Pearland	2.50	Clear Creek Above Tidal	City of Pearland	214	125,585	18.3%	4.930	4.930
12332-001	Brazoria County MUD No. 1	2.4	Mary's Creek	Brazoria County MUD 1	319	24,368	100.0%	7.780	7.780
10134-008	City of Pearland	2.00	Clear Creek Above Tidal	City of Pearland	214	125,585	14.7%	3.944	3.944
10134-010	City of Pearland	2.00	Clear Creek Above Tidal	City of Pearland	214	125,585	14.7%	3.944	3.944
12295-001	City of Pearland	0.95	Clear Creek Above Tidal	City of Pearland	214	125,585	7.0%	1.873	1.873
12939-001	Harris County WCID 89	0.95	Clear Creek Above Tidal	Harris County WCID #84	384	2648	100.0%	1.016	1.016
10568-003	City of League City	0.66	Clear Creek Tidal	City of League City	153	67454	8.1%	0.834	0.834
12849-001	CMH Parks Inc.	0.075	Hickory Slough	City of Pearland	214	125,585	0.6%	0.148	0.148
13865-001	Forestaire Estates	0.049	Cowart Creek	City of Pearland	214	125,585	0.4%	0.097	0.097
12822-001	Walker Water Works Inc.	0.035	Cowart Creek	City of Alvin	232	30,375	0.7%	0.046	0.046

Permit Number	Facility Name	Permitted Flow (MGD)	Receiving Water	Use Pop Projection From	GPCD[a]	Pop 2050[b]	% Flow In City[c]	Flow 2050[d] (MGD)	Adj Flow 2050[e] (MGD)
12680-001	H & R Realty Investments LLC	0.012	Mary's Creek	City of Pearland	214	125,585	0.1%	0.024	0.024
13864-001	Fresno Manufacturing LLC	0.0084	Clear Creek Above Tidal	Manufacturing % Increase	NA	NA	NA	0.0084	0.010

[a] From Table C-3

[b] From Table C-1

[c] Permitted flow for facility/total permitted flow for the city in which the facility is located

[d] GPCD*Population 2050*%flow in city

[e] Flow 2050+Permitted Flow*% increase of manufacturing industry water demand by county (Harris 23% and Fort Bend 14%)

Table C-5. Projected Flows by Watershed

Watershed	Segment	Projected Permitted Flow (MGD)
Clear Creek Tidal	1101	36.4
Chigger Creek	1101B	0.011[a]
Robinson Bayou	1101D	1.6[b]
Clear Creek Above Tidal	1102	24.6
Cowart Creek	1102A	0.1
Mary's Creek	1102B	15.7
Hickory Slough	1102C	0.1
Turkey Creek	1102D	9.1
Mud Gully	1102E	7.9

[a] There are currently no WWTFs discharging to Chigger Creek, so the projected increase in permitted flow for the closest WWTF (12822-001) was assigned to this watershed and subtracted for the total permitted flow projected to be discharged to segment 1102A.

[b] There are currently no WWTFs discharging to Robinson Bayou, so half of the projected increase in permitted flow for the closest WWTF (10568-005) was assigned to this watershed and subtracted for the total permitted flow projected to be discharged to segment 1101.