Adopted April 8, 2009
Approved by EPA June 2009

Eighteen Total Maximum Daily Loads for Bacteria in Buffalo and Whiteoak Bayous and Tributaries

Segments 1013, 1013A, 1013C, 1014, 1014A, 1014B, 1014E, 1014H, 1014K, 1014L, 1014M, 1014N, 1014O, 1017, 1017A, 1017B, 1017D, and 1017E

Water Quality Planning Division, Chief Engineer's Office

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Distributed by the
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
MC-203
P.O. Box 13087
Austin, Texas 78711-3087
E-mail: tmdl@tceq.state.tx.us

TMDL project reports are available on the TCEQ Web site at:
<www.tceq.state.tx.us/implementation/water/tmdl/>

The preparation of this report was financed in part through grants from
the U.S. Environmental Protection Agency.

This TMDL report is based in large part on the report titled
"Technical Support Document: Buffalo Bayou and Whiteoak Bayou TMDL, 2008"
prepared by the University of Houston and CDM.

Contents

Figures

Tables

Eighteen Total Maximum Daily Loads for Indicator Bacteria in Buffalo and Whiteoak Bayous and Tributaries

Executive Summary

This TMDL addresses 18 impairments to the contact recreation use due to exceedances of indicator bacteria criteria in Buffalo Bayou Tidal (1013), Buffalo Bayou Above Tidal (1014), Whiteoak Bayou Above Tidal (1017), and 15 of their tributaries (Table 1). The Texas Commission on Environmental Quality (TCEQ) first identified the impairments to the contact recreation use for the three main stem segments—Buffalo Bayou Tidal, Buffalo Bayou Above Tidal, and Whiteoak Bayou Above Tidal—in the *1996 Texas Water Quality Inventory and 303(d) List* (1996 Inventory and List). Eleven of their tributaries were first identified as impaired for the contact recreation use in the *2002 Texas Water Quality Inventory and 303(d) List* (2002 Inventory and List). Four more tributaries were first identified as having contact recreation impairments in the *2006 Texas Water Quality Inventory and 303(d) List* (2006 Inventory and List).

All of the water bodies included in this report are classified as freshwater except for Buffalo Bayou Tidal (1013). Although Segment 1013 is described as a tidal water body, the salinity and specific conductance show that it is freshwater. While there are tidal fluctuations at the United States Geological Survey (USGS) gauge at Shepherd, the salinity and specific conductance data do not support use of the criteria for a tidal water body. Therefore, *Escherichia coli* (*E. coli)* were used as the indicator bacteria for all of the segments. Throughout this document, the term “bacteria” is used to refer to the indicator bacteria used to assess the contact recreation use.

Bacteria concentrations are expressed as either colony forming units (cfu) or most probable number (MPN) per 100 milliliters (100 mL) depending on the type of test used to analyze the sample. The most probable number is a statistical estimate of the actual number of colony forming units in a water sample. These units are considered equivalent.

Using the *E. coli* criteria, 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 cfu or MPN per 100 mL; AND/OR
- individual samples exceed 394 cfu or MPN per 100 mL more than 25 percent of the time.

All of the water bodies covered by this report are within the Buffalo Bayou and Whiteoak Bayou watersheds. The bayous lie within the San Jacinto River Basin and eventually discharge to Galveston Bay. Buffalo Bayou Tidal has a drainage area of 29 square miles and is about 4 miles long. Buffalo Bayou Above Tidal is 24 miles long and has a watershed area of 358 square miles. The Whiteoak Bayou watershed has an area of 105 square miles and the stream segment is 23 miles long (H-GAC, 2001a).

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

Segment Number	Segment Name	First Year Listed	Assessment Units
1013	Buffalo Bayou Tidal	1996	1013_01
1013A	Little White Oak Bayou	2002	1013A_01
1013C	Unnamed Non-Tidal Tributary of Buffalo Bayou Tidal	2002	1013C_01
1014	Buffalo Bayou Above Tidal	2002	1014_01
1014A	Bear Creek	2006	1014A_01
1014B	Buffalo Bayou	2006	1014B_01
1014E	Langham Creek	2006	1014E_01
1014H	South Mayde Creek	2002	1014H_01, 1014H_02
1014K	Turkey Creek	2002	1014K_01, 1014K_02
1014L	Mason Creek	2006	1014L_01
1014M	Neimans Bayou (Newman Branch)	2002	1014M_01
1014N	Rummel Creek	2002	1014N_01
1014O	Spring Branch	2002	1014O_01
1017	Whiteoak Bayou Above Tidal	1996	1017_01, 1017_02, 1017_03, 1017_04
1017A	Brickhouse Gully/Bayou	2002	1017A_01
1017B	Cole Creek	2002	1017B_02
1017D	Unnamed Tributary of Whiteoak Bayou	2002	1017D_01
1017E	Unnamed Tributary of White Oak Bayou	2002	1017E_01

An important, unique feature of the Buffalo Bayou watershed is that two flood control reservoirs are located at the upstream end of Buffalo Bayou Above Tidal. The reservoirs are operated by the U. S. Army Corps of Engineers to minimize flooding downstream on Buffalo Bayou. The streams within the Reservoirs watershed are Bear Creek (1014A), Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), and Mason Creek (1014L). The Reservoirs watershed is analyzed separately from the other parts of the watersheds. Altogether, four watersheds were analyzed to develop TMDL allocations—Buffalo Bayou Tidal, Buffalo Bayou Above Tidal, Reservoirs, and Whiteoak Bayou watersheds.

Buffalo Bayou flows from the outlying, less-developed portions of Waller, Harris, and Fort Bend counties, joining Whiteoak Bayou Above Tidal in the highly urbanized central part of the Houston business district. The majority of the watershed area is situated in Harris County. The watersheds also include the City of Houston, along with several smaller cities including Hedwig Village, Spring Valley, Hillshire Village, Bunker Hill Village, Piney Point Village, Hunter's Creek Village, Jersey Village, and Katy (Figure 3).

Routine monitoring on Buffalo and Whiteoak Bayous is conducted by the TCEQ Region 12 Office and the City of Houston Health and Human Services Department. The 1,549 *E.*

coli samples that were used in this project were collected between 2001 and 2005, and represent both wet and dry conditions.

In all four watersheds, elevated levels of bacteria are widespread and persistent. Both the geometric-mean and single-sample criteria are exceeded at all sampling locations, often at high rates. In each watershed, sampling stations were dispersed throughout the watershed.

The most likely sources of bacteria in the 18 water bodies include non-compliant wastewater treatment facility discharges, storm water runoff (including discharges from municipal separate storm sewer systems, industrial facilities, and construction sites), sanitary sewer overflows, dry-weather discharges (illicit discharges) from storm sewers, failing on-site sewage facilities, and direct deposition from waterfowl and wildlife.

Three methods of analysis were used for analyzing existing bacteria loads, instream water quality, and percent load reductions—load duration curve (LDC) analyses, a mass balance analysis using the Bacteria Load Estimator Spreadsheet Tool (BLEST), and a Hydrological Simulation Program–FORTRAN (HSPF) analysis for simulation of watershed hydrology and water quality. These three methods were used because of the complex nature of the highly urbanized area, which includes high amounts of impervious cover, a complex and extensive storm water drainage system, and numerous wastewater discharges.

The results from the three analyses for all 18 segments are consistent. All the methods predict that a reduction of greater than 59 percent in loading is required for both permitted (WLA) and non-permitted (LA) sources in order to meet the water quality standard. For most segments and flow conditions, a reduction greater than a 95 percent in both WLA and LA is necessary to meet the water quality standard. This conclusion is consistent with the fact that ambient bacteria measurements vary between 3 and 103 times the water quality criteria.

In order to accommodate current discharge conditions, the waste load allocation for wastewater treatment facilities was established as the permitted flow for each facility times one-half the geometric mean criterion for bacteria. Future growth from existing or new permitted sources is not limited by these TMDLs as long as the sources do not exceed the limits of one-half the bacteria geometric mean criterion. The assimilative capacity of streams increases as the amount of flow increases—in other words, increases in flow allow for increased loadings if the discharge concentrations are at or below the limits. The TMDL calculations in this report will guide determination of the assimilative capacity of the streams under changing conditions, including future growth. Wastewater discharges from new or expanded 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 TCEQ is responsible for ensuring that TMDLs are developed for impaired surface waters in Texas.

A TMDL is like a budget—it determines the amount of a particular pollutant that a water body can receive and still meet its applicable water quality standards. In other words, 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 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 18 impairments to the contact recreation use due to exceedances of the bacteria criteria in Buffalo and Whiteoak Bayous and several of their tributaries (Table 2). Buffalo Bayou Tidal, Buffalo Bayou Above Tidal, and Whiteoak Bayou Above Tidal are the three classified water bodies; the remaining 15 water bodies are unclassified tributaries.

The TMDLs aggregate the loadings in the four main watersheds. The TMDL and load allocations were developed with the goal of attaining the water quality standards in each of the three main water bodies. These watersheds generally have consistent conditions and the governmental agencies responsible for maintaining their quality are the same in each watershed. The load allocations apply throughout each watershed, providing consistent requirements, with the result of attaining water quality standards in each listed water body.

The four subject watersheds of this report are the Buffalo Bayou Tidal (1013), the Buffalo Bayou Above Tidal (1014), the Whiteoak Bayou Above Tidal (1017), and the watershed that drains into the head of Buffalo Bayou Above Tidal (1014), referred to from this point on as the Reservoirs watershed (Figure 1). The Reservoirs watershed is controlled at its downstream end by two flood control dams (Addicks and Barker dams) that are used to manage high flow in the Buffalo Bayou system. The water bodies in each watershed are listed in Table 2.

As directed by the EPA, 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

Table 2. Water Bodies and Associated Watersheds

Segment Number	Segment Name	Watershed
1013	Buffalo Bayou Tidal	Buffalo Bayou Tidal
1013A	Little White Oak Bayou	
1013C	Unnamed Non-Tidal Tributary of Buffalo Bayou Tidal	
1014	Buffalo Bayou Above Tidal	Buffalo Bayou Above Tidal
1014A	Bear Creek	Reservoirs
1014B	Buffalo Bayou	
1014E	Langham Creek	
1014H	South Mayde Creek	
1014K	Turkey Creek	
1014L	Mason Creek	
1014M	Neimans Bayou (Newman Branch)	Buffalo Bayou Above Tidal
1014N	Rummel Creek	
1014O	Spring Branch	
1017	Whiteoak Bayou Above Tidal	Whiteoak Bayou
1017A	Brickhouse Gully/Bayou	
1017B	Cole Creek	
1017D	Unnamed Tributary of Whiteoak Bayou	
1017E	Unnamed Tributary of White Oak Bayou	

The commission adopted this document on April 8, 2009. Upon EPA approval, these TMDLs will become an update to the state's Water Quality Management Plan (WQMP). Updates to these TMDLs will be included in the state's WQMP, which is updated approximately quarterly and is subject to public notice.

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 report has been prepared in accordance with those regulations and guidelines.

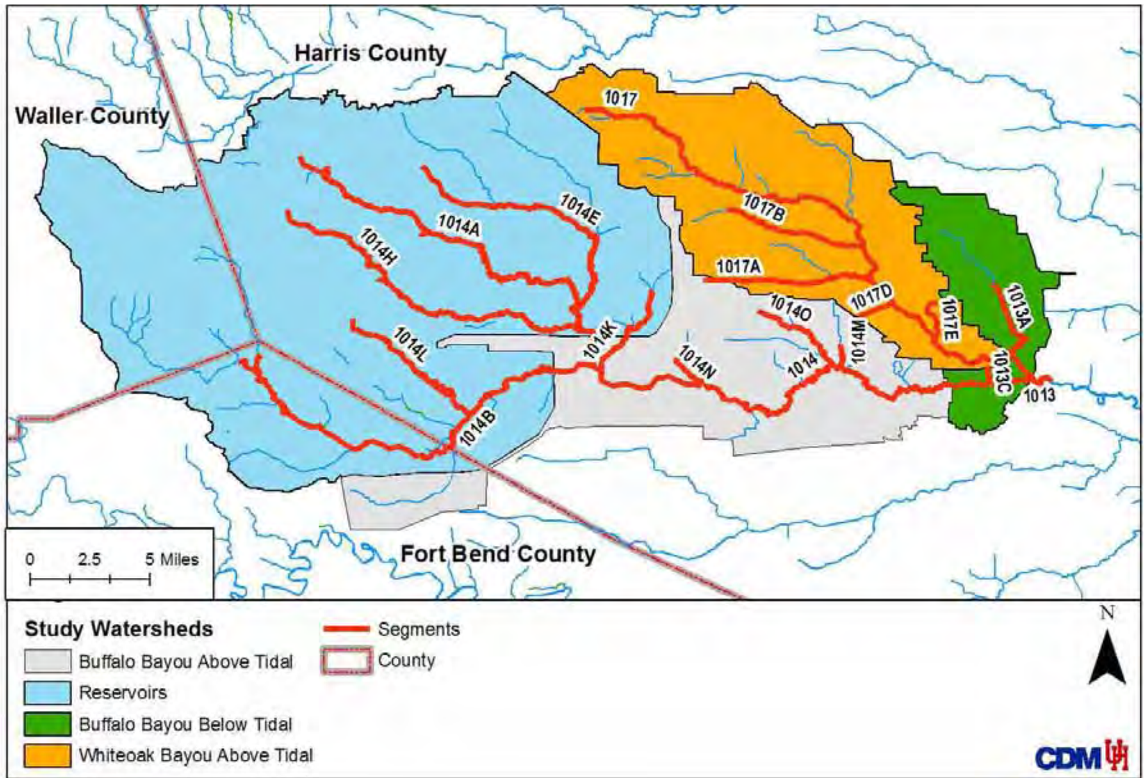


Figure 1. Segments and Watersheds

Problem Definition

The TCEQ first identified impairment of the contact recreation use for the three main-stem segments—Buffalo Bayou Tidal (1013), Buffalo Bayou Above Tidal (1014), and Whiteoak Bayou Above Tidal (1017)—in the 1996 Inventory and List. Eleven tributaries of the main-stem segments were first identified as impaired for contact recreation use in the 2002 Inventory and List. Four additional tributaries were identified as having contact recreation impairments in the 2006 Inventory and List (Table 1).

All of the water bodies included in this report are listed as freshwater except for Buffalo Bayou Tidal (1013). Although Buffalo Bayou Tidal (1013) is described as a tidal water body, the salinity and specific conductance show that this segment, too, is freshwater. The 2008 "Guidance for Assessing and Reporting Surface Water Quality in Texas" (TCEQ 2008) states that the specific conductance should exceed 3077 umhos per centimeter (umhos/cm) to be considered tidal or non-freshwater. While there are some tidal fluctuations at the USGS gauge at Shepherd, the salinity and specific conductivity data (Table 3) do not support an indicator standard for a tidal water body. Therefore, *E. coli* was used as the indicator bacteria for 1013.

The standards for water quality are defined for designated uses in the *Texas Surface Water Quality Standards* (TCEQ 2000). The designated uses assigned to the 18 water bodies included in this report are contact recreation, aquatic life, fish consumption, and general. As described in the TCEQ's "2008 Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data" (TCEQ 2008), the TCEQ requires a minimum of 10 samples in order to assess support of the contact recreation use. *E. coli* is the preferred indicator bacteria for assessing the contact recreation use in freshwater, but fecal coliform bacteria may also be used in the absence of enough *E. coli* data, since fecal coliform was the preferred indicator in the past. For this project, *E. coli* was used for data collection and analysis to support development of the TMDL.

Table 3. Salinity and Specific Conductance Data for Buffalo Bayou Tidal (1013)

Sampling Location	Constituent	Date Begin	Date End	Count	Average	Max	Meet Definition of High Conductivity Water?
11148	Sp. Conductance	3/8/99	2/16/05	90	529	854	N
	Salinity	9/3/03	2/16/05	14	1	1	
11149	None						
11345	Sp. Conductance	2/11/93	2/8/06	251	898	13,000	N*
	Salinity	2/11/93	2/8/06	185	1	7	
11347	Sp. Conductance	3/1/99	2/4/05	109	565	1,030	N
	Salinity	1/4/05	2/4/05	2	1	1	
11351	Sp. Conductance	3/1/99	2/4/05	113	530	958	N
	Salinity	1/4/05	2/4/05	2	1	1	
11384	Sp. Conductance	11/14/00	8/14/01	3	692	865	N
	Salinity	8/14/01	8/14/01	1	1	1	
15825	Sp. Conductance	6/28/00	2/16/05	55	680	2,798	N
	Salinity	11/6/01	2/16/05	19	1	1	
15843	Sp. Conductance	11/15/00	2/4/05	49	457	873	N
	Salinity	1/4/05	2/4/05	2	1	1	
16648	Sp. Conductance	3/1/99	2/16/05	99	485	789	N
	Salinity	9/3/03	2/16/05	14	1	1	
16675	Sp. Conductance	3/1/99	2/4/05	88	769	1,260	N
	Salinity	1/4/05	2/4/05	2	1	1	

N - maximum specific conductance < 3077 umhos/cm

N* - average specific conductance < 3077 umhos/cm; applies only to 11345. Ten samples out of 251 collected exceed 3077.

Using the *E. coli* criteria, 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 cfu or MPN per 100 mL; AND/OR
- individual samples exceed 394 cfu or MPN per 100 mL more than 25 percent of the time.

The most recently approved 303(d) list (2006) included all of the segments in this TMDL under category 5a, indicating a TMDL is underway or scheduled.

Ambient Indicator Bacteria Concentrations

The TCEQ Region 12 Office and the City of Houston Health and Human Services Department conducted routine monitoring on Buffalo and Whiteoak Bayous and the University of Houston obtained additional data for this project. For all of the watersheds, 1,549 *E. coli* samples were analyzed to develop the TMDL allocations.

Throughout the four watersheds of the project area, elevated levels of bacteria are widespread and persistent. Table 4 summarizes the number of sampling stations, samples, and criteria exceedances in the watersheds of the classified segments in the project area. Both the geometric-mean and single-sample criteria are exceeded at all sampling locations. The geometric means of the sampling data exceed the contact recreation criterion between 4 and 103 times at the individual sampling locations. In each watershed, sampling stations were located throughout the watershed; 1,549 *E. coli* samples were analyzed for 43 sampling locations. A summary of results from routine monitoring samples is presented in Table 5. These *E. coli* data were collected between 2001 and 2005 and represent both wet and dry conditions.

Routine monitoring data were examined for spatial and temporal trends as well as relationships with other water quality parameters. The spatial distribution of the monitoring data is shown in Figure 2. As seen in the figure, geometric means range from 324 MPN/100mL in upper Buffalo Bayou (station 17484) to over 12,900 MPN/100mL in Little Whiteoak Bayou (station 11148). Exceedances of the single-sample criterion are frequent in both bayous, with the majority of the sites experiencing exceedances of 86 percent or greater. For both bayous, the *E. coli* level appears to be lower at the upstream end and higher at the downstream end. Most of the tributaries seem to have about the same *E. coli* level as the bayou, but there are a few that have higher *E. coli* levels. The *E. coli* level in Whiteoak Bayou is generally higher than that in Buffalo Bayou.

Table 4. Summary of Exceedances in the Four Primary Watersheds

Watershed and Segments	Number of Stations	Number of *E. Coli* Samples	Range of Percent Exceedance of Single-Sample Criterion (MPN/100 mL)	Time Greater Than Geometric Mean Criterion (MPN/100 mL)
Buffalo Bayou Tidal 1013, 1013A, 1013C	8	299	84 to 100	14 to 103
Buffalo Bayou Above Tidal 1014M, 1014N, 1014O	14	494	49 to 89	3 to 27
Whiteoak Bayou 1017, 1017A, 1017B, 1017D, 1017E	14	465	44 to 100	4 to 94
Reservoirs 1014A, 1014B, 1014E, 1014H 1014K, 1014L	8	291	31 to 75	3 to 13

Table 5. Routine Monitoring Data for *E. coli* in the Project Area between 2001 and 2005

Station ID	Segment	Years Monitored	Geometric Mean** (MPN/100mL)	Number of Samples	Percent Greater than Single Sample Standard*
Buffalo Bayou Tidal Watershed					
11347	1013	2001-2004	3,248	36	94%
15843	1013	2001-2004	3,018	36	94%
11345	1013	2001-2004	2,105	37	97%
11148	1013A	2001-2005	12,983	38	100%
11351	1013	2001-2004	1,807	38	84%
15825	1013	2001-2005	6,839	38	100%
16648	1013A	2001-2005	6,330	38	97%
16675	1013C	2001-2005	5,024	38	89%
Watershed Range			**1,807 to 12,983**	**36 to 38**	**84% to 100%**
Buffalo Bayou Above Tidal Watershed					
11354	1014	2000-2006	1,376	20	65%
11353	1014	2001-2005	1,671	38	76%
11356	1014	2001-2005	1,392	38	84%
11360	1014	2001-2005	1,378	38	87%
11361	1014	2001-2005	802	38	71%
11363	1014	2001-2005	671	38	71%
15845	1014	2001-2005	1,721	38	82%
15846	1014	2001-2005	1,489	38	89%

Station ID	Segment	Years Monitored	Geometric Mean** (MPN/100mL)	Number of Samples	Percent Greater than Single Sample Standard*
Buffalo Bayou Above Tidal Watershed, continued					
11364	1014	2001-2005	412	39	49%
11362	1014	2000-2006	715	58	69%
11188	1014N	2001-2005	3,440	37	89%
16592	1014O	2001-2005	3,034	36	89%
16597	1014M	2001-2005	617	38	53%
Watershed Range			**412 to 3,440**	**20 to 58**	**49% to 89%**
Reservoirs Watersheds					
17484	1014A	2002-2005	324	36	42%
17492	1014B	2002-2005	570	36	44%
17482	1014E	2002-2005	1,122	36	61%
17493	1014H	2002-2005	417	35	31%
11163	1014H	2001-2005	455	38	50%
17483	1014K	2002-2005	1,597	36	75%
15847	1014K	2001-2005	844	38	68%
17494	1014L	2002-2005	1,149	36	67%
Watershed Range			**324 to 1,597**	**35 to 38**	**31% to 75%**
Whiteoak Bayou Watershed					
15828	1017	2000-2002	2,205	7	100%
11155	1017	2003-2005	531	16	44%
11396	1017	2003-2005	504	16	56%
16637	1017	2001-2006	4,584	34	97%
11390	1017	2001-2005	2,560	38	92%
15826	1017	2001-2005	6,461	38	100%
15827	1017	2001-2005	5,139	38	100%
15829	1017	2001-2005	1,556	38	84%
15831	1017	2001-2005	1,748	38	89%
16593	1017B	2001-2005	2,845	38	95%
16594	1017A	2001-2005	3,333	38	95%
16595	1017D	2001-2005	11,886	38	92%

Station ID	Segment	Years Monitored	Geometric Mean** (MPN/100mL)	Number of Samples	Percent Greater than Single Sample Standard*
Whiteoak Bayou Watershed, continued					
16596	1017E	2001-2005	3,234	38	92%
11387	1017	2000-2006	4,481	50	96%
Watershed Range			**504 to 11,886**	**7 to 50**	**44% to 100%**

mL – milliliter

MPN – most probable number

*assessment methodology allows up to 25 percent of the samples to exceed this value.

** the current contact recreation standard is a geometric mean of 126 MPN/100mL

Long-term trends, evaluated using fecal coliform data collected since the early 1970s in Buffalo and Whiteoak Bayous, are shown in Table 6. As shown in the table, elevated concentrations of fecal coliform bacteria were observed in the 1970s, with concentrations dropping dramatically in the 1980s.

Table 6. Historical Fecal Coliform Data

Bayou	Decade	Number of Samples	Geometric Mean (cfu/100mL)	Samples Exceeding Water Quality Standard (%)
Buffalo Bayou	1970	665	37,035	97.6
	1980	829	1,553	77.3
	1990	2,887	1,849	92.8
	2000	625	1,570	90.6
Whiteoak Bayou	1970	275	47,748	96.0
	1980	216	14,265	94.4
	1990	1,480	3,864	93.2
	2000	410	4,623	97.6

cfu – colony forming unit

mL - milliliter

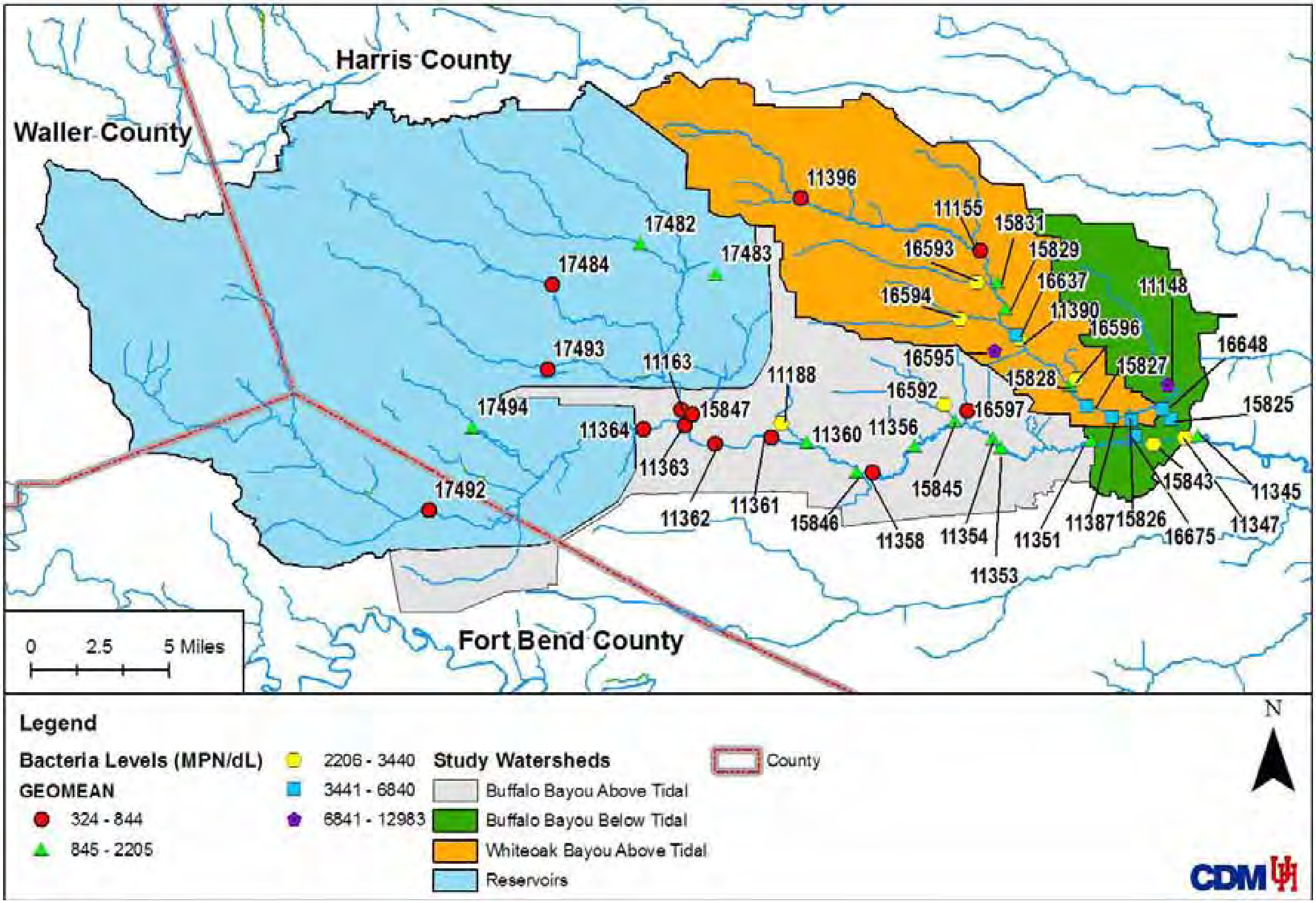


Figure 2. *E. coli* Geometric Mean Concentrations at Routine Monitoring Stations between 2001 and 2005

Watershed Overview

All of the water bodies covered by this report are within the Buffalo Bayou and Whiteoak Bayou watersheds. The watersheds lie within the San Jacinto River Basin and eventually discharge to Galveston Bay. Buffalo Bayou Tidal watershed has a drainage area of 29 square miles and is about 4 miles long. Buffalo Bayou Above Tidal is 24 mile long and has a watershed area of 358 square miles. The Whiteoak Bayou watershed has an area of 105 square miles and the stream segment is 23 miles long (H-GAC, 2001a).

Buffalo Bayou flows from the outlying, less-developed portions of Waller, Harris, and Fort Bend Counties, joining Whiteoak Bayou in the highly urbanized central part of the Houston business district. Buffalo and Whiteoak Bayou is located in three counties—Harris, Fort Bend, and Waller—with the majority of the watersheds situated in Harris County. The watersheds also includes the City of Houston along with several smaller cities, including Hedwig Village, Spring Valley, Hillshire Village, Bunker Hill Village, Piney Point Village, Hunter's Creek Village, Jersey Village, and Katy (Figure 3).

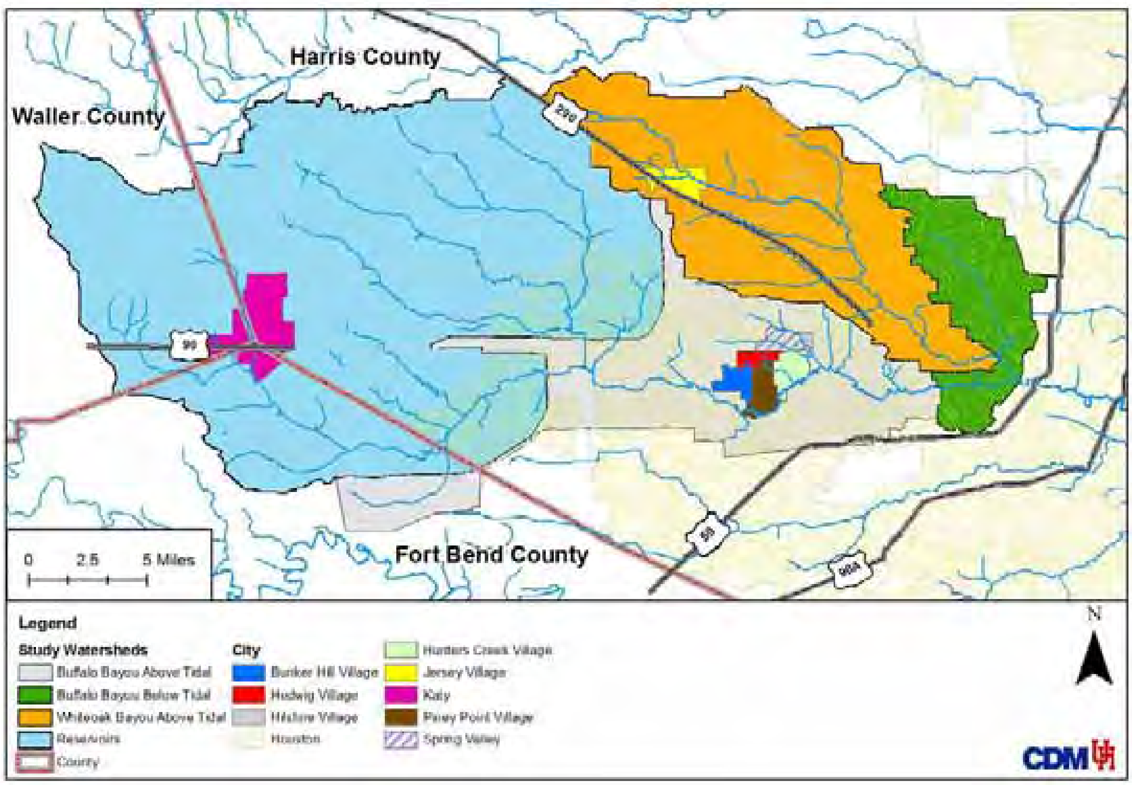


Figure 3. Municipalities in the TMDL Watersheds

An important, unique feature of the Buffalo Bayou watershed is that two flood control reservoirs are located at the upstream end of Buffalo Bayou Above Tidal. The U. S. Army Corps of Engineers operates the reservoirs to minimize flooding downstream on Buffalo Bayou, detaining floodwaters until the potential for flooding has dissipated. At that time, water is released downstream at a maximum flow of 2,000 cubic feet per second (cfs) based on the USGS gauge at Piney Point. The streams within the Reservoirs watershed are

Bear Creek (1014A), Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), and Mason Creek (1014L).

Climate

The climate in the Buffalo and Whiteoak Bayous watersheds is characterized by hot, humid summers and temperate winters. Prevailing winds are from the south and southwest most of the year, which brings moisture from the Gulf of Mexico that drives much of the precipitation in the area. The National Weather Service reports typical summer temperatures in the area range from a low of 70°F to highs between 90 and 94°F. Winter temperatures range from a low of around 40°F to a mild high around 63°F.

The Buffalo and Whiteoak Bayou watersheds experience frequent rainfall events, with annual precipitation totals of approximately 50 inches. Monthly rainfall totals are consistent throughout the year. High intensity rainfall often causes localized street flooding and occasional out-of-bank conditions. Because the study watersheds are located near the Gulf coast, they are subject to extreme weather between June 1 and November 30 every year, although the chance of tropical weather declines dramatically in October. As a result, an extensive storm water conveyance system has been developed throughout the area.

Land Use

Land use data for this study are based on classifications of land cover analyzed by the Houston-Galveston Area Council (H-GAC 2001b). The land cover data were derived from satellite image data and aerial photography from 2000, as well as Landsat 7 ETM multispectral satellite images from November 1999 and February 2000, appraisal data of third quarter 1999 from county appraisal districts, 2000 public utility connections data, and Census 2000 blocks and population. Land use in the TMDL watersheds is summarized in Table 7 and displayed in Figure 4.

Using typical conversion factors, the percent pervious and impervious land was calculated for each segment as shown in Table 8. Buffalo Bayou Tidal watershed (1013) is located in the center of Houston and has the highest percentage of impervious cover. Buffalo Bayou Above Tidal (1014) and Whiteoak Bayou watersheds (1017) are predominately developed with approximately 50 percent impervious cover. The Reservoirs watershed is currently only 14 percent impervious cover, but ongoing development will increase the impervious cover over time.

Soils

The State Soil Geographic Database (STATSGO) information was used to characterize the soils in the Buffalo and Whiteoak Bayou watersheds. This database is publicly available through the U.S. Department of Agriculture–Natural Resource Conservation Service (NRCS) and provides general soil data at a scale of 1:250,000 (NRCS 1994). The soil series types in the TMDL watersheds are listed in Table 9**.** Figure 5 presents the distribution of the seven types of surficial soils that are found in the TMDL watersheds.

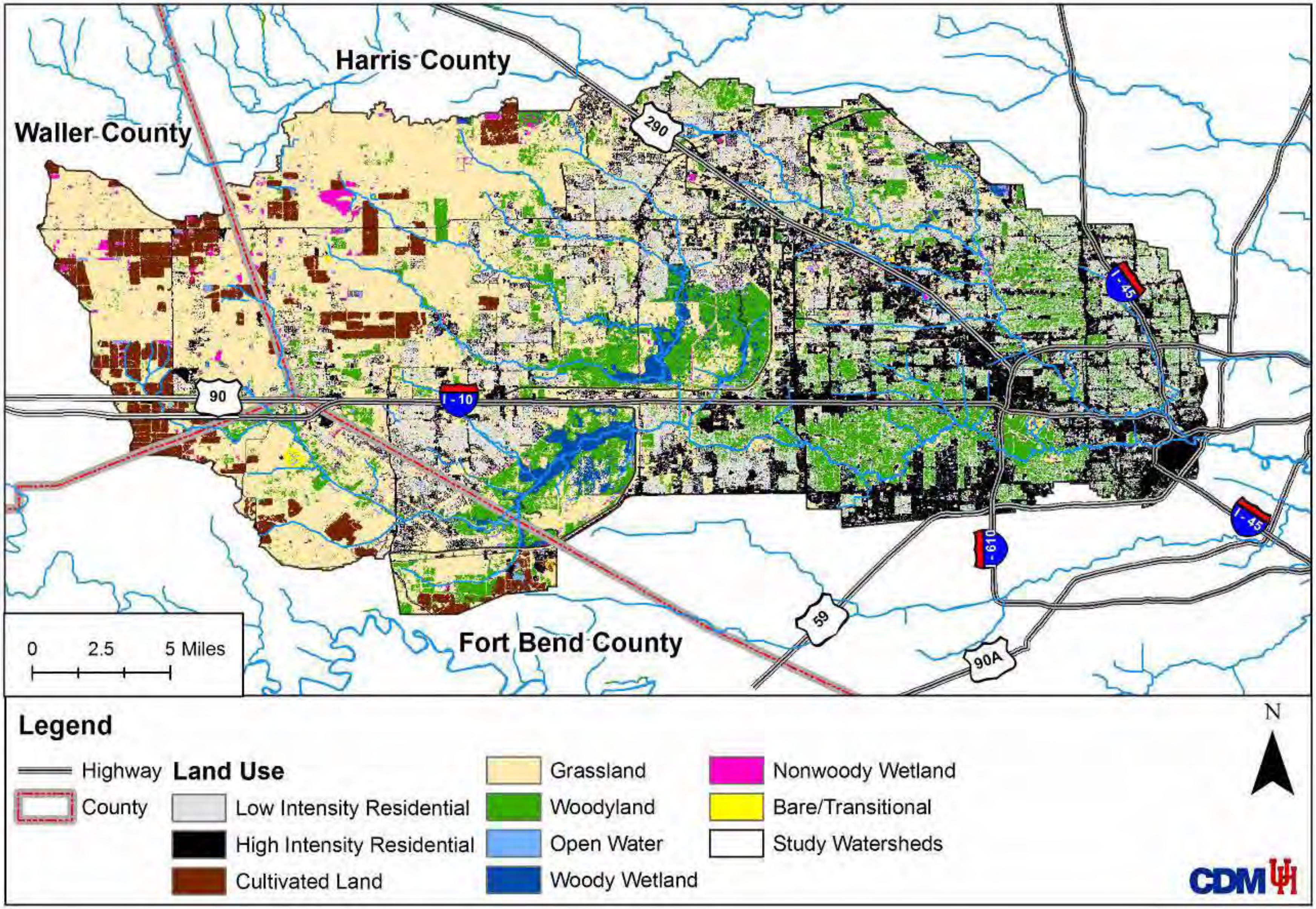


Figure 4. TMDL Watershed Land Use

Table 7. Summary of Land Use in TMDL Watersheds

	Watershed			
Land Use Category	**Buffalo Bayou Tidal**	**Buffalo Bayou Above Tidal**	**Reservoirs**	**Whiteoak Bayou**
Low Intensity Developed	38%	23%	9%	29%
High Intensity Developed	41%	33%	7%	30%
Cultivated Land	0%	2%	8%	0%
Grassland	8%	17%	57%	24%
Woody Land	12%	24%	12%	14%
Open Water	1%	1%	1%	1%
Woody Wetland	0%	0%	4%	1%
Non-Woody Wetland	0%	0%	2%	1%
Bare / Transitional Land	0%	0%	0%	0%

Table 8. Pervious and Impervious Cover in TMDL Watersheds

Watershed	Pervious (acres)	Impervious (acres)	Percent Impervious
Buffalo Bayou Tidal Watershed	7,146.04	11,582.01	62%
Buffalo Bayou Above Tidal Watershed	27,326.00	27,574.00	50%
Whiteoak Bayou Above Tidal Watershed	27,532.74	29,651.82	52%
Reservoirs Watershed	145,596.10	22,866.10	14%

Table 9. Soil Series in the TMDL Watersheds

Map Unit ID	Soil Series Name	Min Available Water Capacity (in/in)	Max Available Water Capacity (in/in)	Min Bulk Density (g/cm3)	Hydric Group
TX007	Aldine	0.11	0.15	1.3	D
TX048	Bernard	0.15	0.2	1.2	D
TX100	Clodine	0.15	0.2	1.35	D
TX163	Edna	0.10	0.15	1.4	D
TX231	Hockley	0.10	0.15	1.4	D
TX248	Katy	0.15	0.2	1.3	D
TX276	Lake Charles	0.15	0.2	1.2	D
TX618	Wockley	0.15	0.2	1.4	C

cm - centimeter

g – gram

in – inch

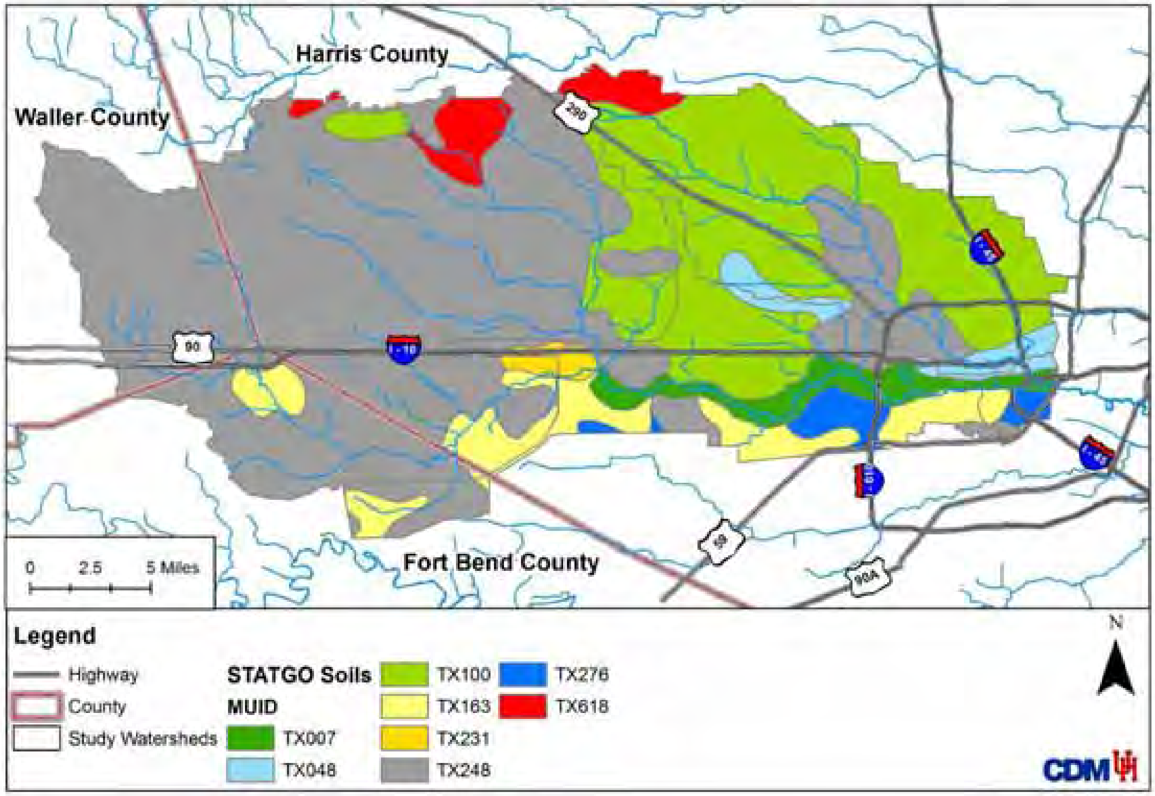


Figure 5. TMDL Watershed Soil Types

The soils in the upper watershed of Whiteoak Bayou are primarily in the Clodine soil series, as shown in the figure and table. The lower portions of the watershed are primarily from the Bernard and Katy soil series. In Buffalo Bayou, the majority of the soils are made up of the Aldine, Clodine, and Edna soil series. A small portion of the lower watershed in Buffalo Bayou is comprised of the Bernard series. The permeability of all soils in these watersheds is considered very slowly to moderately permeable. The NRCS groups the runoff potential into four hydrologic soil groups, with group A having the highest infiltration rate and group D having the lowest. The hydric group of the soils in the Buffalo and Whiteoak Bayou watersheds is mostly group D, which indicates that these soils have a low infiltration rate, and thus a high runoff potential when thoroughly wet. The infiltration rate of the Wockley soil series is considered low, since it is in hydric group C (Soil Survey Division, NRCS 1994).

Subwatersheds

Two of the analytical methods used in this report (BLEST and HSPF) analyze indicator bacteria loads on a subwatershed basis. The four TMDL watersheds were divided into 114 subwatersheds, nine in the Buffalo Bayou Tidal watershed, 16 in the Buffalo Bayou Above Tidal watershed, 16 in the Whiteoak Bayou watershed, and 73 in the Reservoirs watershed. The subwatersheds are listed in Table 10 and displayed in Figure 6.

Table 10. Subwatersheds in the TMDL Watersheds

Subwatershed	Segment	Watershed	Stream Name
1	1017A	Whiteoak Bayou	Brickhouse Gully
2	1017B		Cole Creek
3	1017		Whiteoak Bayou Above Tidal
4	1017		
5	1013A	Buffalo Bayou Tidal	Little White Oak Bayou
6	1013A		
7	1017	Whiteoak Bayou	Whiteoak Bayou Above Tidal
8	1017		
9	1017		
10	1017		
11	1017		
12	1017		
13	1017	Whiteoak Bayou	Whiteoak Bayou Above Tidal
17	1017		
26	1014O	Buffalo Bayou Above Tidal	Spring Branch
27	1014O		
28	1014H		South Mayde Creek
33	1014N		Rummel Creek
34	1014		Buffalo Bayou Above Tidal
35	1014B		Buffalo Bayou
36	1013	Buffalo Bayou Tidal	Buffalo Bayou Tidal
37	1013/ 1013C		Buffalo Bayou Tidal/ Unnamed Tributary
38	1013		Buffalo Bayou Tidal
39	1014	Buffalo Bayou Above Tidal	Buffalo Bayou Above Tidal
40	1017	Whiteoak Bayou	Whiteoak Bayou Above Tidal
41	1017		
42	1017/ 1017E		Whiteoak Bayou/ Unnamed Tributary
43	1017/ 1017D		Whiteoak Bayou/Unnamed Tributary
44	1014	Buffalo Bayou Above Tidal	Buffalo Bayou Above Tidal
45	1014		
46	1013	Buffalo Bayou Tidal	Buffalo Bayou Tidal
47	1013		
48	1013A		Little Whiteoak Bayou
49	1013A		
50	1014	Buffalo Bayou Above Tidal	Buffalo Bayou Above Tidal

Subwatershed	Segment	Watershed	Stream Name
51	1014M/ 1014	Buffalo Bayou Above Tidal (cont)	Neiman's Bayou/Buffalo Bayou Above Tidal
52	1014		Buffalo Bayou Above Tidal
53	1014		
54	1014		
55	1014		
56	1014K		Turkey Creek
101	1014K	Reservoirs	Turkey Creek
102	1014K		
103	1014K		
104	1014K		
105	1014K		
106	1014A		Bear Creek/Langham Creek
107	1014E		Langham Creek
108	1014E		
109	1014E		
110	1014E		
111	1014E		
112	1014E		
113	1014E		
114	1014E		
115	1014E		
116	1014E		
117	1014E		
118	1014A		Bear Creek
119	1014A		
120	1014A		
121	1014A		
122	1014A		
123	1014H		South Mayde Creek
124	1014H		
125	1014H		
126	1014H		
127	1014H		
128	1014H		
129	1014H		
130	1014H		

Subwatershed	Segment	Watershed	Stream Name
131	1014H	Reservoirs (cont)	South Mayde Creek (cont.)
132	1014B		Buffalo Bayou
133	1014B		
134	1014B		
135	1014B		
136	1014B		
137	1014B		
138	1014B		
139	1014B		
140	1014B		
141	1014B		
142	1014B		
143	1014B		
144	1014B		
145	1014B		
146	1014B		
147	1014L		Mason Creek
148	1014L		
149	1014L		
150	1014L		
151	1014L		
152	1014L		
153	1014L		
154	1014L		
155	1014B		Buffalo Bayou
156	1014B		
171	1014B		
172	1014B		
173	1014B		
174	1014B		
175	1014B		
176	1014B		
177	1014B		
178	1014B		
180	1014H		South Mayde Creek
181	1014H		

Subwatershed	Segment	Watershed	Stream Name
182	1014H	Reservoirs (cont)	
183	1014H		
184	1014H		
185	1014H		
186	1014H		
187	1014H		
188	1014H		

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 the 18 freshwater segments covered in this report is to achieve mean concentrations of *E. coli* below the geometric mean criterion of 126 MPN/100mL, while also being protective of the single sample criterion of 394 MPN/100 mL more than 75 percent of the time.

Critical Conditions

Sources of bacteria are varied and the transport of bacteria varies under different weather and flow conditions. These different sources can result in multiple critical conditions. Therefore, this TMDL will evaluate conditions under three different flow scenarios based on the flow duration curve: dry conditions (0 to 30th percentile), intermediate flow (30th to 70th percentiles) and wet conditions (70th percentile and above). In the context of the TMDL, the dry-weather condition is representative of stream conditions for the project watersheds that are not impacted by runoff and bayou flows are maintained primarily by wastewater treatment plant flows. The wet weather condition (critical condition) is representative of stream conditions for the project watersheds that are caused by rainfall events when instream flows are greater than the 70th percentile flow. Intermediate conditions include a mixed regime of wastewater discharge and rainfall runoff. These conditions are typically found several days after a rainfall event in the watershed and are typically defined as between the 30th and 70th percentile flows.

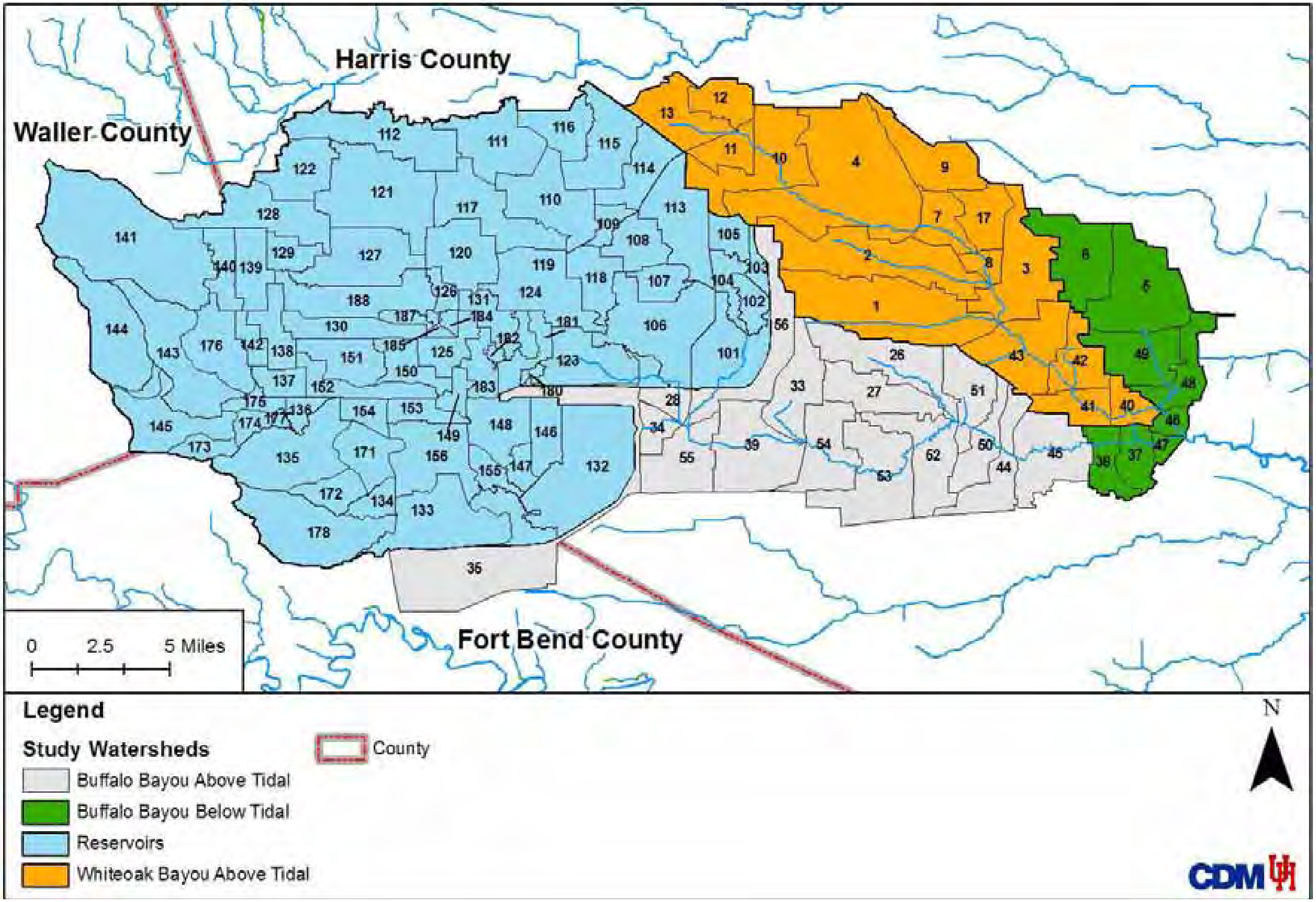


Figure 6. Subwatersheds in the TMDL Watersheds

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). Continuous discharges from Wastewater Treatment Facilities (WWTFs), and discontinuous storm water discharges from industries, construction, and the municipal separate storm sewer systems (MS4s) of cities are considered point sources of pollution. Nonpoint source pollution originates from sources that are not covered by a discharge permit. Nonpoint source pollution typically comes from multiple locations usually carried to surface waters by rainfall runoff.

Point Sources

Within the Reservoirs, Buffalo Bayou Above Tidal (1014) and Whiteoak Bayou (1017) watersheds there are numerous TPDES permitted continuous discharges. Also, these watersheds are regulated under the TPDES Phase 1 MS4 permit jointly held by Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation. Individual TPDES permits for industrial storm water permits and construction-site storm water also regulate discharges that have the potential to contribute indicator bacteria. All of the storm water discharges are included in the overall analysis of storm water loads; the separate contributions of the permits are not identified.

WWTFs

Discharges

The locations of the TPDES-permitted facilities that continuously discharge wastewater to water bodies addressed in the TMDLs covered by this report are listed in Table 11 and displayed in Figure 7. The data in Table 11 is current through 2006. This time period coincides with the period of the TMDL investigation. The instream water quality, sampling data, watershed characteristics, and modeling and analyses were conducted at this time and the analyses of pollutant reduction pertain to these analyses. Since 2006, dischargers have been added and removed from the watersheds. The future capacity allocation described below is available to accommodate additional dischargers in the future.

As of 2006, there were 126 permitted outfalls for WWTFs in all of the watersheds covered in this TMDL report. In the watershed of Buffalo Bayou Above Tidal, there were 14 dischargers with permitted flows ranging from 26.4 million gallons per day (MGD) to 0.001 MGD. In the Reservoirs watershed, there were 67 dischargers with permitted flows ranging from 6.7 MGD to 0.002 MGD. In the Whiteoak Bayou watershed, there were 45 dischargers with permitted flows ranging from 18 MGD to 0.002 MGD. There were no permitted discharges in the Buffalo Bayou Tidal watershed.

The majority of these facilities were small with less than 1 MGD permitted flow. In the highly urbanized watershed of Buffalo Bayou Above Tidal, there were 10 facilities with less than 1 MGD capacity and 4 large facilities serving large numbers of users with permitted flows from 3.05 MGD to 26.4 MGD. The Reservoirs watershed is the least developed and included 46 facilities with less than 1 MGD capacity and 21 larger facilities with permitted flows from 1.1 MGD to 6.7 MGD. The Whiteoak Bayou watershed, which is also highly urbanized, included 36 facilities with less than 1 MGD capacity and 9 larger facilities with permitted flows ranging from 1 MGD to 3.2 MGD.

Table 11. WWTF Dischargers in the TMDL Watersheds as of 2006

TPDES*	NPDES**	Facility Name	Segment	Assessment Unit	Flow (MGD)
Buffalo Bayou Watershed					
02731-000	0087416	DANIEL VALVE COMPANY	1014O	1014O_01	0.012
10495-030	0063002	HOUSTON, CITY OF	1014N	1014N_01	26.4
10495-109	0035017	HOUSTON, CITY OF	1014	1014_01	12
10495-135	0026395	HOUSTON, CITY OF	1014B	1014B_01	3.5
10584-001	0047457	MEMORIAL VILLAGE WAT	1014	1014_01	3.05
12346-001	0086185	WEST PARK MUD	1014B	1014B_01	0.5
12427-001	0088218	GEORGE AIVAZIAN	1014B	1014B_01	0.001
14070-001	0089940	WEATHERFORD PETCO	1014	1014_01	0.0108
14182-001	0122556	ANN ARUNDEL FARMS	1014B	1014B_01	0.992
13021-001	0095702	BIG OAKS MUD	1014B	1014B_01	0.7
13228-001	0098965	FORT BEND CO MUD 050	1014B	1014B_01	0.7
12830-001	0094056	ROBINSON, J.W.	1014K	1014K_01	0.006
14117-001	0119571	AQUASOURCE UTILITY	1014K	1014K_01	0.9
12355-001	0116505	ELEVEN TEN ROSALIE	1014K	1014N_01	0.005
Reservoir Watershed					
12233-001	0083933	UA HOLDINGS 1994-5	1014	1014_01	0.005
12682-001	0092584	HARRIS CO MUD 216	1014B	1014B_01	0.4
13172-002	0096911	CINCO MUD 001	1014B	1014B_01	0.91
13328-001	0100137	REMINGTON MUD 002	1014E	1014E_01	1.1
11290-001	0046621	JACKRABBIT ROAD PUD	1014A	1014A_01	5.1
11414-001	0104795	SASSON, ELI	1014A	1014A_01	0.06
11792-002	0070971	HARRIS CO MUD 105	1014A	1014A_01	2.5
12209-001	0083500	HARRIS CO MUD 127	1014A	1014A_01	1.15
12834-001	0094307	HARRIS CO MUD 167	1014A	1014A_01	0.294
12841-001	0094307	ROLLING CREEK UD	1014A	1014A_01	0.4
12858-001	0097373	HARRIS COUNTY, TEXAS	1014B	1014B_01	0.026

TPDES*	NPDES**	Facility Name	Segment	Assessment Unit	Flow (MGD)
Reservoir Watershed (cont.)					
13921-001	0117421	HARRIS COUNTY	1014A	1014A_01	0.02
02229-000	0079057	IGLOO PRODUCTS CORPORATION	1014B	1014B_01	0.05
10706-001	0025747	KATY, CITY OF	1014B	1014B_01	3.075
11893-001	0074004	MEMORIAL MUD	1014B	1014B_01	3
12298-001	0085448	FORT BEND CO MUD 034	1014B	1014B_01	1
12356-001	0086690	HARRIS CO MUD 345	1014B	1014B_01	0.71
12370-001	0087157	FORT BEND CO MUD 037	1014B	1014B_01	0.175
12927-001	0094579	HARRIS CO MUD 276	1014E	1014E_01	0.75
13245-001	0099856	GRAND LAKES MUD 004	1014B	1014B_01	0.9
13558-001	0098957	CINCO MUD 001	1014B	1014B_01	3.3
13674-001	0118541	NOTTINGHAM COUNTRY	1014B	1014B_01	0.051
13775-001	0115894	HARRIS FTB MUD 005	1014B	1014B_01	0.99
14011-001	0118109	FT BEND MUD 130	1014B	1014B_01	0.3
14134-001	0119873	FT BEND MUD 124	1014B	1014B_01	0.4
10932-001	0068047	HARRIS COUNTY, TEXAS	1014A	1014E_01	0.042
03153-000	0074292	TOSHIBA INTERNATIONAL CORPORATION	1014K	1014K_02	0.05
11472-001	0026263	SPENCER ROAD PUD	1014E	1014E_02	0.98
11486-001	0062031	HARRIS CO MUD 070	1014E	1014E_02	1.5
11523-001	0052906	HARRIS CO MUD 102	1014E	1014E_02	1.3
11682-001	0064734	LANGHAM CREEK UD	1014E	1014E_02	2
11836-001	0091626	HARRIS CO MUD 149	1014E	1014E_02	0.645
11906-001	0074896	HARRIS CO MUD 157	1014E	1014E_02	2.3
11935-001	0075981	NORTHWEST HC MUD 016	1014E	1014E_02	0.99
11947-001	0075884	HARRIS CO MUD 208	1014E	1014E_02	6.7
12124-001	0079707	HARRIS CO MUD 185	1014E	1014E_02	0.675
12128-001	0079537	HORSEPEN BAYOU MUD	1014E	1014E_02	0.95
12223-001	0083496	WEST HC MUD 015	1014E	1014E_02	0.6
12304-001	0085588	CHIMNEY HILL MUD	1014E	1014E_02	1.2
12310-001	0085871	R&K WEIMAN MHP	1014E	1014E_02	0.03

TPDES*	NPDES**	Facility Name	Segment	Assessment Unit	Flow (MGD)
Reservoir Watershed (cont.)					
12447-001	0088838	HARRIS CO MUD 196	1014E	1014E_02	1.4
12474-001	0089494	HARRIS CO MUD 166	1014E	1014E_02	0.625
12726-001	0100161	HARRIS CO MUD 155	1014E	1014E_02	1.55
12949-001	0095532	HARRIS CO MUD 284	1014A	1014A_02	0.6
13778-001	0097985	FRIEDMAN, STEPHEN	1014E	1014E_02	0.01
11284-001	0053091	WESTLAKE MUD 001	1014H	1014H_02	0.9
11696-002	0112585	ADDICKS UD	1014H	1014H_02	0.8
11917-001	0074403	HARRIS CO MUD 071	1014H	1014H_02	2.35
11969-001	0076660	MAYDE CREEK MUD	1014H	1014H_02	2
11989-001	0076775	FRY ROAD MUD	1014H	1014H_02	0.8
12110-001	0079201	KATY ISD	1014H	1014H_02	0.1
12140-001	0079618	WEST HC MUD 007	1014H	1014H_02	0.5
12189-001	0082830	TEX-SUN PARKS, LC	1014H	1014H_02	0.15
12247-001	0084468	WEST HC MUD 017	1014H	1014H_02	0.275
12516-001	0089907	WEST HOUSTON AIRPORT	1014H	1014H_02	0.015
12802-001	0093891	HARRIS CO MUD 238	1014H	1014H_02	0.825
14109-001	0119121	KATY-HOCKLEY	1014L	1014L_02	0.075
12466-001	0089061	OCEANEERING INTER.	1014K	1014K_02	0.012
13484-001	0104311	529 #35, LTD	1014K	1014K_02	0.2
11152-001	0021512	WEST MEMORIAL MUD	1014L	1014L_01	6.48
11883-001	0071625	CASTLEWOOD MUD	1014L	1014L_01	2
12289-001	0085332	GREEN TRAILS MUD	1014L	1014L_01	0.99
12479-001	0089346	NOTTINGHAM COUNTRY MUD	1014L	1014L_01	1.3
11598-001	0058408	WILLIAMSBURG REG SA	1014L	1014L_02	3
12132-001	0079634	WHITE OAK OWNERS	1017	1017_04	0.059
13764-001	0092932	ALLIANCE CH F3 GP	1017/1017E	1017_04	0.15
12685-001	0093581	MOODY CORP	1014E	1014E_01	0.1
Whiteoak Bayou Watershed					
13983-001	0095435	RESTAURANT SERVICE, L.L.C.	1017	1017_01	0.002
14070-001	0089940	WEATHERFORD U.S., L.P.	1017	1017_01	0.011

TPDES*	NPDES**	Facility Name	Segment	Assessment Unit	Flow (MGD)
Whiteoak Bayou Watershed (cont.)					
10495-099	0057347	HOUSTON, CITY OF	1017	1017_01	4
10876-001	0022853	HARRIS CO FWSD 061	1017	1017_01	1.6
10876-002	0091804	HARRIS CO FWSD 061	1017	1017_01	3
11188-001	0026697	ROLLING FORK PUD	1017	1017_01	0.49
11273-001	0026352	HARRIS CO MUD 006	1017	1017_01	0.75
11375-001	0026247	AQUASOURCE UTILITY	1017	1017_01	0.184
11389-001	0075736	CB&I CONSTRUCTORS	1017	1017_01	0.045
11485-001	0062235	HARRIS CO MUD 023	1017	1017_01	0.75
11538-001	0057029	GULF COAST WASTE DA	1017	1017_01	4.5
11563-001	0053325	REID ROAD MUD 001	1017	1017_01	1.75
11670-001	0063479	SUNBELT FWSD	1017	1017_01	0.99
11979-002	0076651	WHITE OAK BEND MUD	1017	1017_01	0.4
12121-001	0079146	HARRIS CO MUD 170	1017	1017_01	2.5
12139-001	0081256	FAIRBANKS PLAZA SHOP	1017	1017_01	0.04
12342-001	0085821	C & P UTILITIES	1017	1017_01	0.045
12397-001	0087416	DANIEL INDUSTRIES	1017	1017_01	0.012
12443-001	0088676	SUPERIOR DERRICK	1017	1017_01	0.0024
12465-001	0088927	TIFCO INDUSTRIES	1017	1017_01	0.035
12552-001	0090115	NCI BUILDING SYSTEMS	1017	1017_01	0.01
12552-002	0117064	NCI BUILDING SYSTEMS	1017	1017_01	0.01
12574-001	0091316	HARRIS CO MUD 130	1017	1017_01	0.95
12681-001	0092606	JERSEY VILLAGE	1017	1017_01	0.8
12795-001	0093726	NORTHWEST HC MUD 029	1017	1017_01	0.565
13433-001	0103705	AQUASOURCE DVLP. CO.	1017	1017_01	0.5
13509-001	0092746	TRINITY @ WINDFERN	1017	1017_01	0.04
13578-001	0118583	COOPER CAMERON CORP	1017	1017_01	0.008
13623-001	0109126	WEST HC MUD 021	1017	1017_01	0.5
13689-001	0111937	WEST HC MUD 11	1017	1017_01	1.5
13727-001	0113697	MOORPARK VILLAGE,INC	1017	1017_01	0.035
13807-001	0082597	MCDONALDS CORP.	1017	1017_01	0.003

TPDES*	NPDES**	Facility Name	Segment	Assessment Unit	Flow (MGD)
Whiteoak Bayou Watershed (cont.)					
13939-001	0082988	RIEDEL, ANTHONY	1017	1017_01	0.003
13983-001	0095435	RESTAURANT SERVICE	1017	1017_01	0.002
14072-001	0082317	WEST HC MUD 010	1017	1017_01	1.5
11051-001	0075841	VANCOUVER MANAGEMENT	1017	1017_02	0.03
10495-139	0026875	HOUSTON, CITY OF	1017A	1017A_01	0.995
11193-001	0075434	AQUASOURCE UTILITY	1017B	1017B_01	0.8
12222-001	0083950	AQUASOURCE UTILITY	1017B	1017B_01	0.25
13996-001	0117684	CROW FAMILY HOLDINGS	1017B	1017B_01	0.05
10495-076	0063011	HOUSTON, CITY OF	1017B	1017B_02	21
11005-001	0020095	CHAMP'S WATER CO	1017C	1017C_01	0.28
12714-001	0092908	HARRIS CO MUD 119	1017C	1017C_02	0.25
14359-001	0119431	HARRIS CO MUD 366	1017C	1017C_02	0.2
14506-001	0090735	SMITH, WILLIAM D.	1017	1017_01	0.012

* = Texas Pollution Discharge Elimination System

** = National Pollution Discharge Elimination System

Flows and loads associated with typical dry-weather WWTF discharges were estimated based on site-specific data available from sampling and supplied by WWTFs in the watershed. Self-reported flows from WWTF dischargers were obtained from TCEQ and U.S. EPA databases for the period from April 1999 through October 2003. Measured concentrations from sampling efforts in 2001 and 2006 ranged from less than the detection limit (< 1 Most Probable Number (MPN)/100mL) to over 200,000 MPN/100mL, with flow-weighted geometric means for the watersheds calculated to be between 4 MPN/100mL and 6 MPN/100mL. Loads for these WWTF dischargers using the most recent *E. coli* data from 2006 are shown in Table 12. Indicator bacteria levels in effluent from the individual WWTFs is typically low, with approximately 5 to 10 percent of the facilities exceeding the single-sample criterion for *E. coli* at any given time. This statistic is based on samples taken during un-announced visits during the summer of 2006.

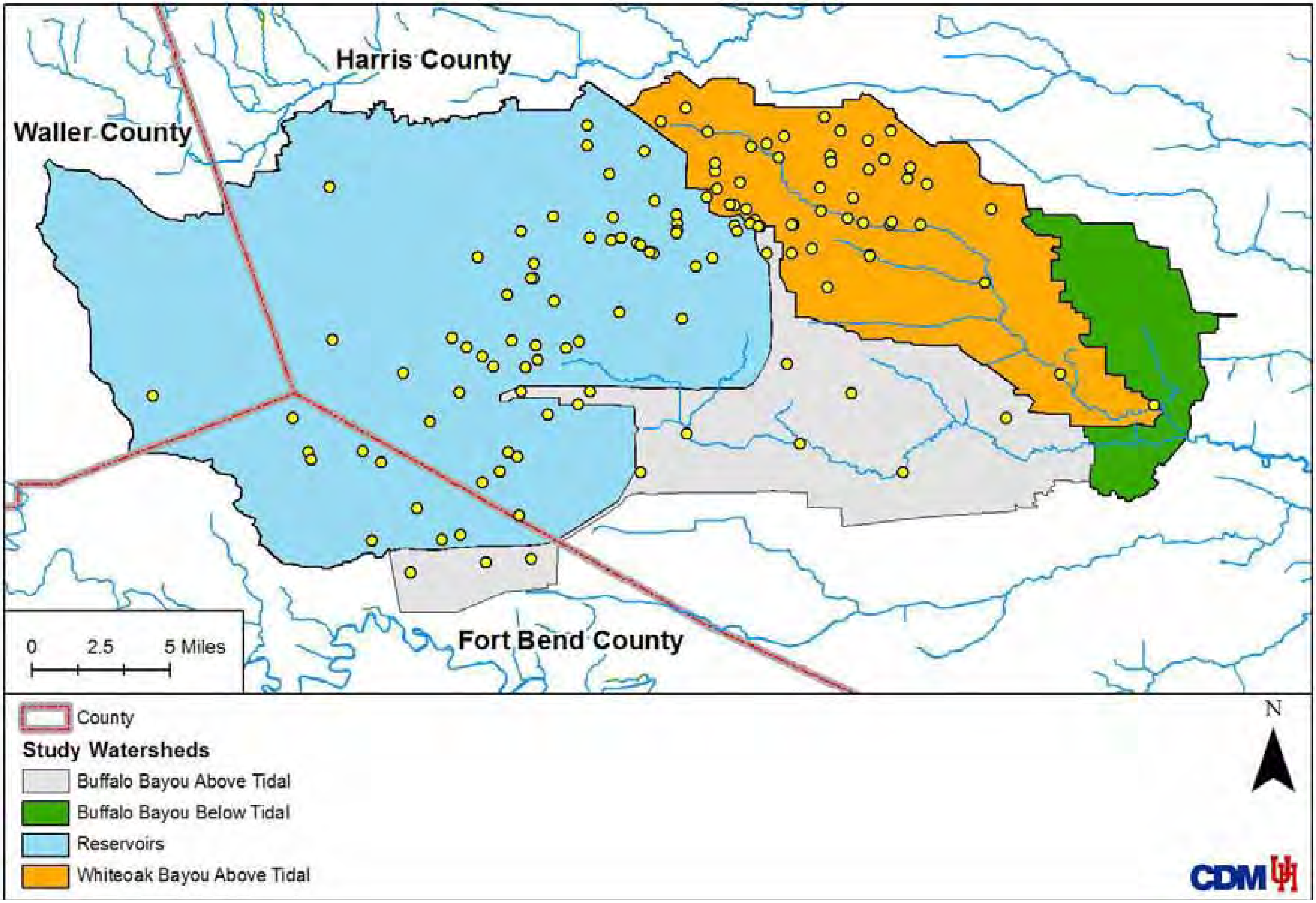


Figure 7. TPDES-Permitted Facilities in the TMDL Watersheds

To estimate intermediate flow conditions, effluent flow data from the City of Houston were used to develop a regression equation describing the relationship between WWTF flow and rainfall totals during the previous 12 hours. The WWTF data from four City of Houston plants (10495-030, 10495-076, 10495-099, and 10495-109) were used to develop the regression equation. Because the intermediate condition is transient in nature, it was necessary to determine an appropriate amount of rainfall to use in the regression to replicate intermediate conditions from the WWTFs. Based on an examination of observed flows from the City of Houston database, 0.25 in rainfall was found to be appropriate. Indicator bacteria concentrations associated with these flows were assumed to be the same as under dry-weather conditions. The calculated flow and loads from WWTFs under intermediate conditions are included in Table 12. The flow for intermediate conditions was calculated by determining the flow associated with intermediate conditions and adding that to the dry-weather flow. The load from intermediate conditions was determined by multiplying the WWTF intermediate flow times the dry-weather *E. coli* concentration in MPN/100mL, with the appropriate unit conversion factor, to give the total MPN per day.

Table 12. WWTF Flow, *E. coli* Concentration, and Load during Dry and Intermediate Conditions

TPDES Number	*E. coli* Value Used for Load Calculations	Avg. Self-Reported Flow (MGD)	Dry-Weather Load (Billion MPN/day)	Intermediate Conditions Flow (MGD)	Intermediate Conditions Load (Billion MPN/day)
02731-000	6.14	0.00170	0.00039	0.00180	0.00041
10495-030	6.14	9.50000	2.20000	10.00000	2.30000
10495-109	6.14	4.40000	1.00000	4.60000	1.10000
10495-135	2.00	0.54000	0.04100	0.57000	0.04300
10584-001	6.14	3.00000	0.69000	3.10000	0.73000
12233-001	26.00	0.00065	0.00064	0.00068	0.00067
12346-001	973.50	0.18000	6.60000	0.19000	7.00000
12355-001	6.14	0.00032	0.00007	0.00034	0.00008
12427-001	6.14	0.00005	0.00001	0.00005	0.00001
12682-001	6.14	0.04100	0.00950	0.04300	0.00990
12830-001	6.14	0.00220	0.00051	0.00230	0.00053
13021-001	6.14	0.14000	0.03300	0.15000	0.03500
13228-001	6.14	0.03900	0.00910	0.04100	0.00950
14070-001	6.14	0.00150	0.00034	0.00150	0.00036
14117-001	0.50	0.09800	0.00180	0.10000	0.00190
14182-001	6.14	0.02200	0.00500	0.02300	0.00530
02229-000	6.14	0.00770	0.00180	0.00810	0.00190
03153-000	6.14	0.01000	0.00240	0.01100	0.00250
10706-001	6.14	1.10000	0.26000	1.20000	0.28000
10932-001	1.00	0.01900	0.00072	0.02000	0.00076
11152-001	0.50	1.60000	0.03100	1.70000	0.03200

TPDES Number	*E. coli* Value Used for Load Calculations	Avg. Self-Reported Flow (MGD)	Dry-Weather Load (Billion MPN/day)	Intermediate Conditions Flow (MGD)	Intermediate Conditions Load (Billion MPN/day)
11284-001	32.00	0.57000	0.69000	0.60000	0.73000
11290-001	32550.00	2.50000	3100.00000	2.70000	3300.00000
11414-001	0.50	0.04100	0.00077	0.04300	0.00081
11472-001	0.50	0.38000	0.00720	0.40000	0.00760
11486-001	512.00	0.55000	11.00000	0.57000	11.00000
11523-001	1.75	0.78000	0.05200	0.83000	0.05500
11598-001	6.14	0.69000	0.16000	0.73000	0.17000
11682-001	2.00	0.44000	0.03400	0.47000	0.03500
11696-002	0.50	0.13000	0.00240	0.13000	0.00250
11792-002	24.00	0.22000	0.20000	0.24000	0.21000
11836-001	207500.00	0.29000	2300.00000	0.31000	2400.00000
11883-001	6.14	0.55000	0.13000	0.57000	0.13000
11893-001	84.00	1.30000	4.20000	1.40000	4.40000
11906-001	884.00	0.31000	10.00000	0.32000	11.00000
11917-001	6.14	0.31000	0.07300	0.33000	0.07600
11935-001	0.50	0.15000	0.00270	0.15000	0.00290
11947-001	18.00	1.80000	1.20000	1.90000	1.30000
11969-001	4.75	0.63000	0.11000	0.67000	0.12000
11989-001	6.14	0.29000	0.06700	0.30000	0.07100
12110-001	6.14	0.06700	0.01600	0.07000	0.01600
12124-001	0.50	0.25000	0.00470	0.26000	0.00500
12128-001	16.50	0.52000	0.32000	0.55000	0.34000
12140-001	6.14	0.14000	0.03200	0.15000	0.03400
12189-001	6.14	0.06200	0.01400	0.06500	0.01500
12209-001	0.50	0.24000	0.00450	0.25000	0.00470
12223-001	2.00	0.20000	0.01500	0.21000	0.01600
12247-001	6.14	0.19000	0.04300	0.20000	0.04500
12289-001	100.00	0.52000	2.00000	0.55000	2.10000
12298-001	6.14	0.08400	0.01900	0.08800	0.02000
12304-001	6.14	0.35000	0.08100	0.37000	0.08500
12310-001	0.50	0.02100	0.00039	0.02200	0.00041
12356-001	6.14	0.15000	0.03400	0.16000	0.03600
12370-001	6.14	0.11000	0.02600	0.12000	0.02700
12447-001	3.00	0.19000	0.02200	0.20000	0.02300
12466-001	6.14	0.00130	0.00030	0.00130	0.00031

TPDES Number	*E. coli* Value Used for Load Calculations	Avg. Self-Reported Flow (MGD)	Dry-Weather Load (Billion MPN/day)	Intermediate Conditions Flow (MGD)	Intermediate Conditions Load (Billion MPN/day)
12474-001	8.00	0.01500	0.00450	0.01600	0.00470
12479-001	6.14	0.43000	0.09900	0.45000	0.10000
12516-001	6.14	0.00094	0.00022	0.00099	0.00023
12685-001	0.50	0.07000	0.00130	0.07400	0.00140
12726-001	0.50	0.29000	0.00550	0.31000	0.00580
12802-001	1.00	0.15000	0.00580	0.16000	0.00610
12834-001	0.50	0.06400	0.00120	0.06700	0.00130
12841-001	0.50	0.04300	0.00081	0.04500	0.00086
12858-001	6.14	0.00610	0.00140	0.00640	0.00150
12927-001	2.00	0.00460	0.00035	0.00480	0.00037
12949-001	4.00	0.02300	0.00350	0.02400	0.00370
13172-002	6.14	0.32000	0.07300	0.33000	0.07700
13245-001	6.14	0.13000	0.03000	0.14000	0.03200
13328-001	56.00	0.02700	0.05600	0.02800	0.05900
13484-001	6.14	0.04200	0.00980	0.04400	0.01000
13558-001	6.14	0.94000	0.22000	0.98000	0.23000
13674-001	166.00	0.03300	0.21000	0.03500	0.22000
13775-001	6.14	0.09400	0.02200	0.09900	0.02300
13778-001	0.50	0.00100	0.00002	0.00110	0.00002
13921-001	0.75	0.00620	0.00018	0.00660	0.00019
14011-001	6.14	0.00830	0.00190	0.00870	0.00200
14109-001	6.14	0.00140	0.00032	0.00140	0.00033
14134-001	6.14	0.01300	0.00290	0.01300	0.00310
13983-001	4.35	0.00084	0.00014	0.00088	0.00015
14070-001	4.35	0.00150	0.00024	0.00150	0.00025
10495-076	2.00	8.70000	0.66000	9.10000	0.69000
10495-099	1.00	1.70000	0.06400	1.80000	0.06700
10495-139	4.35	0.48000	0.07900	0.51000	0.08400
10876-001	342.00	0.87000	11.00000	0.91000	12.00000
10876-002	794.00	0.88000	26.00000	0.93000	28.00000
11005-001	0.50	0.15000	0.00280	0.15000	0.00290
11051-001	5.50	0.03500	0.00720	0.03600	0.00760
11188-001	0.50	0.25000	0.00480	0.27000	0.00500
11193-001	0.50	0.51000	0.00960	0.53000	0.01000
11273-001	0.50	0.42000	0.00800	0.44000	0.00840

TPDES Number	*E. coli* Value Used for Load Calculations	Avg. Self-Reported Flow (MGD)	Dry-Weather Load (Billion MPN/day)	Intermediate Conditions Flow (MGD)	Intermediate Conditions Load (Billion MPN/day)
11375-001	0.50	0.09700	0.00180	0.10000	0.00190
11389-001	1.00	0.00930	0.00035	0.00980	0.00037
11485-001	0.50	0.41000	0.00770	0.43000	0.00810
11538-001	5.00	1.00000	0.20000	1.10000	0.21000
11563-001	11.00	0.67000	0.28000	0.70000	0.29000
11670-001	1.00	0.32000	0.01200	0.34000	0.01300
11979-002	1.00	0.19000	0.00710	0.20000	0.00750
12121-001	2.00	0.93000	0.07000	0.98000	0.07400
12132-001	16.50	0.03900	0.02400	0.04100	0.02600
12139-001	4.35	0.02400	0.00390	0.02500	0.00410
12222-001	0.50	0.06700	0.00130	0.07100	0.00130
12342-001	1.00	0.01900	0.00072	0.02000	0.00076
12397-001	179.00	0.00440	0.03000	0.00460	0.03100
12443-001	33.00	0.00130	0.00160	0.00140	0.00170
12465-001	1.00	0.00520	0.00020	0.00550	0.00021
12552-001	4.35	0.00580	0.00096	0.00610	0.00100
12552-002	4.35	0.00470	0.00078	0.00500	0.00082
14506-001	4.35	0.00970	0.00160	0.01000	0.00170
12574-001	0.50	0.12000	0.00230	0.13000	0.00240
12681-001	0.50	0.18000	0.00350	0.19000	0.00360
12714-001	6.00	0.14000	0.03300	0.15000	0.03400
12795-001	118.00	0.19000	0.85000	0.20000	0.89000
13433-001	0.50	0.01200	0.00022	0.01200	0.00023
13509-001	0.50	0.01300	0.00025	0.01400	0.00026
13578-001	4.35	0.00630	0.00100	0.00670	0.00110
13623-001	0.50	0.07200	0.00140	0.07600	0.00140
13689-001	105.00	0.34000	1.30000	0.35000	1.40000
13727-001	26.50	0.00700	0.00700	0.00740	0.00740
13764-001	9.00	0.05700	0.01900	0.05900	0.02000
13807-001	9.00	0.00075	0.00025	0.00079	0.00027
13939-001	11190.00	0.00120	0.49000	0.00120	0.51000
13983-001	0.50	0.00088	0.00002	0.00093	0.00002
13996-001	4.35	0.00160	0.00027	0.00170	0.00028
14072-001	0.50	1.00000	0.01900	1.10000	0.02000
14359-001	4.35	0.03100	0.00520	0.03300	0.00540

Biosolids

In addition to effluent discharges, WWTFs can contribute indicator bacteria loads from biosolids releases. Anecdotal evidence and observations at WWTFs have indicated that occasionally during large rainfall events, biosolids releases may occur from WWTF dischargers. The releases contribute to higher concentrations of indicator bacteria in the effluent because of the presence of biosolids from the WWTF being carried out in the discharge.

Assumptions regarding the occurrence of biosolids were made to match observations obtained from City of Houston WWTF flows. Based on these data, biosolids releases were assumed to occur when rainfall in the previous 12 hours was greater than 0.5 inches. Using the same approach as used for intermediate condition flows, flows associated with biosolids releases were calculated for a rainfall event equivalent to 0.5 inches.

Data collected from WWTF biosolids releases observed by TCEQ found that fecal coliform concentrations of stream samples near biosolids releases ranged from 90 to 153,000 cfu/100mL fecal coliform for a geometric mean of 4,146 cfu/100mL. This corresponds to an *E. coli* concentration of 2,612 MPN/100mL, using the ratio (0.63) of the criteria of the two indicator bacteria (126/200).

Because biosolids releases were assumed to occur only during wet weather, the daily load presented in Table 13 was adjusted to account for days with precipitation. Houston receives 74 days of precipitation out of the year according to National Oceanic and Atmospheric Administration (NOAA) statistics for the rain gauge located at Addicks Reservoir (NOAA 2001).

Table 13. WWTF Flow, *E. coli* Concentrations, and Load during Biosolid Releases

TCEQ Permit Number	Subwatershed	Biosolid Flow (MGD)	*E. coli* (MPN/100mL)	Biosolid Load (Billion MPN/day)
Whiteoak Bayou Watershed				
10495-139	1	0.03030	2,612	2.99000
10495-076	2	0.54600	2,612	53.90000
11193-001	2	0.03180	2,612	3.14000
12139-001	2	0.00149	2,612	0.14800
12222-001	2	0.00424	2,612	0.41800
13996-001	2	0.00010	2,612	0.01010
13983-001	4	0.00005	2,612	0.00519
14070-001	4	0.00009	2,612	0.00904
11051-001	4	0.00217	2,612	0.21400
11188-001	4	0.01590	2,612	1.57000
11273-001	4	0.02650	2,612	2.62000
11375-001	4	0.00608	2,612	0.60000

TCEQ Permit Number	Subwatershed	Biosolid Flow (MGD)	*E. coli* (MPN/100mL)	Biosolid Load (Billion MPN/day)
Whiteoak Bayou Watershed, cont.				
11389-001	4	0.00059	2,612	0.05790
11485-001	4	0.02560	2,612	2.52000
11538-001	4	0.06550	2,612	6.46000
11670-001	4	0.02040	2,612	2.01000
12342-001	4	0.00119	2,612	0.11800
12443-001	4	0.00008	2,612	0.00811
12552-001	4	0.00037	2,612	0.03600
12552-002	4	0.00030	2,612	0.02940
13433-001	4	0.00074	2,612	0.07250
13509-001	4	0.00084	2,612	0.08260
13578-001	4	0.00040	2,612	0.03920
13623-001	4	0.00454	2,612	0.44800
13689-001	4	0.02110	2,612	2.09000
13727-001	4	0.00044	2,612	0.04360
13807-001	4	0.00005	2,612	0.00463
13939-001	4	0.00007	2,612	0.00717
13983-001	4	0.00006	2,612	0.00548
10495-099	7	0.10700	2,612	10.50000
14506-001	9	0.00061	2,612	0.06030
12714-001	9	0.00902	2,612	0.89100
14359-001	9	0.00197	2,612	0.19400
11563-001	10	0.04190	2,612	4.14000
11979-002	10	0.01190	2,612	1.17000
12397-001	10	0.00028	2,612	0.02710
12574-001	10	0.00765	2,612	0.75500
Buffalo Bayou Above Tidal Watershed				
12681-001	10	0.01150	2,612	1.13000
14072-001	10	0.06330	2,612	6.25000
12121-001	11	0.05850	2,612	5.77000
12795-001	11	0.01200	2,612	1.18000
10876-001	13	0.05450	2,612	5.39000
10876-002	13	0.05530	2,612	5.46000
12465-001	13	0.00033	2,612	0.03210

TCEQ Permit Number	Subwatershed	Biosolid Flow (MGD)	*E. coli* (MPN/100mL)	Biosolid Load (Billion MPN/day)
Buffalo Bayou Above Tidal Watershed, cont.				
11005-001	17	0.00924	2,612	0.91200
12132-001	40	0.00246	2,612	0.24300
02731-000	27	0.00011	2,612	0.01030
10495-030	33	0.59800	2,612	59.00000
10495-135	35	0.03400	2,612	3.35000
12346-001	35	0.01130	2,612	1.12000
12427-001	35	0.00000	2,612	0.00032
12682-001	35	0.00256	2,612	0.25200
13021-001	35	0.00900	2,612	0.88900
13228-001	35	0.00245	2,612	0.24200
14182-001	35	0.00136	2,612	0.13400
13764-001	42	0.00355	2,612	0.35000
12233-001	44	0.00004	2,612	0.00401
10584-001	53	0.18700	2,612	18.50000
10495-109	55	0.27800	2,612	27.40000
12355-001	56	0.00002	2,612	0.00198
12830-001	56	0.00014	2,612	0.01350
14070-001	56	0.00009	2,612	0.00904
14117-001	56	0.00613	2,612	0.60600
Reservoirs Watershed				
03153-000	104	0.00064	2,612	0.06340
12466-001	105	0.00008	2,612	0.00790
13484-001	105	0.00264	2,612	0.26000
10932-001	106	0.00120	2,612	0.11800
11290-001	106	0.15900	2,612	15.70000
11523-001	108	0.04930	2,612	4.86000
12124-001	108	0.01580	2,612	1.56000
12474-001	108	0.00093	2,612	0.09170
12927-001	108	0.00029	2,612	0.02850
13778-001	108	0.00007	2,612	0.00650
11836-001	109	0.01830	2,612	1.80000
11935-001	109	0.00911	2,612	0.89900
11486-001	110	0.03420	2,612	3.38000

TCEQ Permit Number	Subwatershed	Biosolid Flow (MGD)	*E. coli* (MPN/100mL)	Biosolid Load (Billion MPN/day)
Buffalo Bayou Above Tidal Watershed, cont.				
11682-001	110	0.02780	2,612	2.75000
11414-001	113	0.00255	2,612	0.25200
11472-001	113	0.02400	2,612	2.37000
11947-001	113	0.11400	2,612	11.20000
12128-001	113	0.03260	2,612	3.22000
12304-001	113	0.02190	2,612	2.16000
12310-001	113	0.00130	2,612	0.12800
12685-001	113	0.00439	2,612	0.43400
12223-001	114	0.01230	2,612	1.22000
12726-001	115	0.01830	2,612	1.81000
12447-001	116	0.01220	2,612	1.20000
13328-001	116	0.00167	2,612	0.16500
11906-001	117	0.01930	2,612	1.90000
12209-001	119	0.01480	2,612	1.46000
12834-001	119	0.00400	2,612	0.39500
12841-001	119	0.00270	2,612	0.26700
12949-001	119	0.00145	2,612	0.14300
11792-002	120	0.01410	2,612	1.39000
13921-001	122	0.00039	2,612	0.03870
11696-002	123	0.00785	2,612	0.77500
12516-001	123	0.00006	2,612	0.00582
11284-001	124	0.03600	2,612	3.56000
12802-001	124	0.00960	2,612	0.94800
12140-001	125	0.00874	2,612	0.86300
11969-001	131	0.03980	2,612	3.93000
12858-001	133	0.00038	2,612	0.03760
13172-002	133	0.01980	2,612	1.96000
13245-001	133	0.00823	2,612	0.81300
13558-001	133	0.05870	2,612	5.80000
12370-001	135	0.00696	2,612	0.68700
14011-001	135	0.00052	2,612	0.05120
10706-001	136	0.07070	2,612	6.98000
02229-000	144	0.00048	2,612	0.04760

TCEQ Permit Number	Subwatershed	Biosolid Flow (MGD)	*E. coli* (MPN/100mL)	Biosolid Load (Billion MPN/day)
Reservoirs Watershed, cont.				
12356-001	146	0.00927	2,612	0.91500
12479-001	147	0.02690	2,612	2.66000
12289-001	148	0.03270	2,612	3.23000
11883-001	149	0.03420	2,612	3.38000
11598-001	150	0.04350	2,612	4.29000
14109-001	151	0.00009	2,612	0.00849
11152-001	153	0.10200	2,612	10.10000
11893-001	155	0.08240	2,612	8.14000
13674-001	155	0.00209	2,612	0.20600
13775-001	171	0.00591	2,612	0.58400
14134-001	171	0.00080	2,612	0.07850
12298-001	178	0.00525	2,612	0.51900
12110-001	181	0.00421	2,612	0.41500
11989-001	183	0.01810	2,612	1.79000
12189-001	183	0.00390	2,612	0.38500
12247-001	183	0.01170	2,612	1.15000
11917-001	185	0.01970	2,612	1.94000

mL – milliliter
MGD - million gallons per day
MPN – most probable number

Sanitary Sewer Overflows

Sanitary sewer overflows (SSOs) are releases of untreated wastewater, including domestic, commercial, and industrial wastewater. These releases usually occur as the result of a break, stoppage, or exceedance of capacity in the sanitary sewer conveyance system. Although SSOs are considered part of the WWTF discharge load for this TMDL, these overflows typically enter the storm water conveyance system, which then carries the overflows to the bayou.

SSOs occur under both wet and dry-weather conditions. SSO flow and indicator bacteria load estimates were developed in two separate ways:

1) using a City of Houston database for SSOs inside Houston city limits from March 2000 to December 2003 to calculate empirically the number of SSOs.
2) using a combination of SSO occurrence by age of pipe and housing age since SSO data were not available.

The locations of all reported SSOs are displayed in Figure 8 and the data are summarized in Table 14.

Because SSO flows reported in the City of Houston database may not reflect flow during an entire SSO event, SSO flows were estimated using volumes obtained from the U.S. EPA SSO Report to Congress (2004). The volume from each dry SSO was assumed to be 1,000 gallons; the SSO was assumed to occur for one day. This assumption is supported by the fact that over 85 percent of the SSOs recorded in the City of Houston database were resolved within 1 day. For wet weather, the U.S. EPA reported a median volume of 14,400 gallons per wet-weather SSO. Wet-weather SSOs were also assumed to occur over a one-day period.

SSOs are difficult to locate and sample so there is little data on *E. coli* concentrations in them. In place of SSO data, WWTF influent was sampled instead during both wet and dry conditions.

The *E. coli* concentration applied for dry-weather SSOs was 4.70×10^6 MPN/100mL, the geometric mean of all sampled dry-weather WWTF influent and SSOs. For wet-weather SSOs, the geometric mean of sampled wet-weather influent was reduced based on a U.S. EPA Report to Congress (2004), which states "… concentrations of fecal coliform found in combined sewer overflows and wet-weather SSOs are generally less than the concentrations found in untreated wastewater and dry-weather SSOs, and greater than the concentrations reported for urban storm water." Therefore, the value used for wet-weather SSOs was 3.50×10^5 MPN/100mL.

The concentration and flow for each type of SSO event were used in conjunction with the estimated number of SSO events to determine a daily load from these discharges into the bayous. These loads and flows were then reduced by a delivery factor, which is a measure of how many SSO releases actually reach a water body. Although the U.S. EPA SSO Report to Congress (2004) reports a delivery rate of 73 percent, analyses completed in previous project studies in these watersheds show that 43 percent and 39 percent of the volume released in an SSO would have the potential to reach Buffalo and Whiteoak Bayous, respectively.

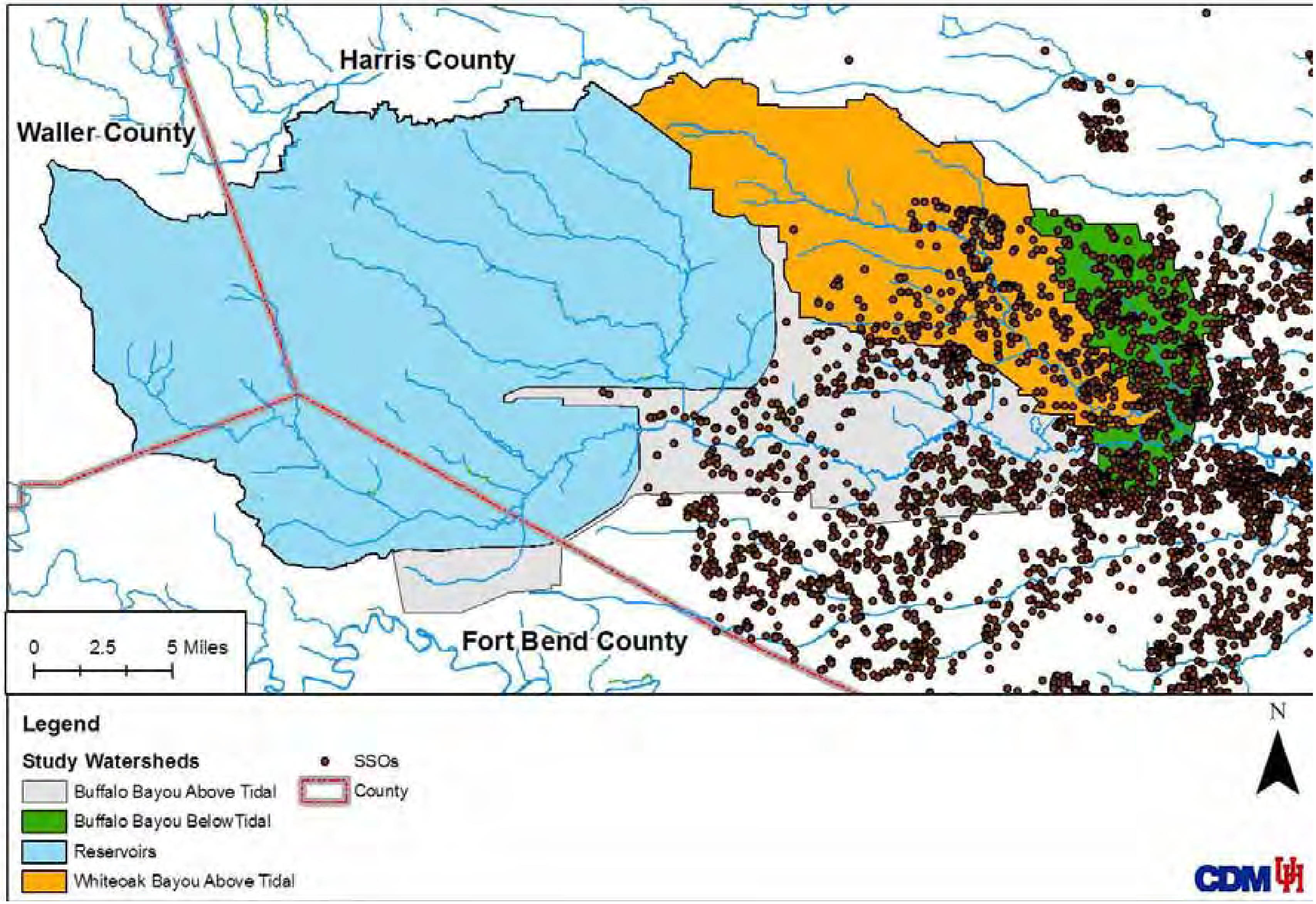


Figure 8. Sanitary Sewer Overflow Locations (March 2000 through December 2003)

Table 14. Sanitary Sewer Overflow Summary March 2000 to December 2003

Watershed	Number of SSOs in Database*			Volume (gallons)		
	Dry	Wet	Total	Dry	Wet	Total
Buffalo Bayou Tidal	349	115	464	682,092	325,195	1,007,287
Buffalo Bayou Above Tidal	281	115	396	535,476	226,699	762,175
Reservoirs	0	0	0	0	0	0
Whiteoak Bayou	261	93	354	332,009	127,601	459,610

*Excludes events between June 4, 2001 and June 14, 2001 since they reflect the influence of Tropical Storm Allison

SSO - Sanitary sewer overflow

Because SSO releases were assumed to occur during both wet and dry weather, the daily loads presented in Table 15 were adjusted to account for days with precipitation. Houston has 74 days of precipitation greater than 0.01 during the year according to NOAA statistics for the rain gauge located at Addicks Reservoir (NOAA 2001). Therefore, the dry-weather load for the year was divided by 291 days to adjust the loading for dry days only. The wet-weather load was treated in a similar manner, with the wet-weather load for the year divided by the days of dry weather. These adjustments were necessary to adequately represent average dry, intermediate, and wet-weather conditions on a daily basis.

Table 15. Estimates of SSO Flow and *E. coli* Loads

Subwatershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)
1	1.58E-05	2.81000	1.58E-05	2.81000	3.43E-04	4.55000
2	5.38E-06	0.95700	5.38E-06	0.95700	1.82E-04	2.41000
3	9.32E-06	1.66000	9.32E-06	1.66000	3.83E-04	5.08000
4	1.04E-05	1.86000	1.04E-05	1.86000	1.75E-04	2.32000
5	4.27E-05	7.60000	4.27E-05	7.60000	1.02E-03	13.60000
6	1.15E-05	2.04000	1.15E-05	2.04000	1.56E-04	2.06000
7	6.45E-06	1.15000	6.45E-06	1.15000	3.63E-04	4.81000
8	2.87E-06	0.51100	2.87E-06	0.51100	4.03E-05	0.53500
9	3.15E-06	0.56000	3.15E-06	0.56000	5.29E-05	0.70100
10	6.73E-06	1.20000	6.73E-06	1.20000	1.13E-04	1.50000
11	3.25E-06	0.57900	3.25E-06	0.57900	5.46E-05	0.72400
12	1.00E-06	0.17900	1.00E-06	0.17900	1.69E-05	0.22400
13	4.16E-06	0.74000	4.16E-06	0.74000	6.98E-05	0.92600
17	1.04E-05	1.85000	1.04E-05	1.85000	1.82E-04	2.41000
26	1.66E-05	2.96000	1.66E-05	2.96000	1.33E-04	1.77000

Subwatershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)
27	6.33E-06	1.13000	6.33E-06	1.13000	2.22E-05	0.29500
28	1.08E-06	0.19300	1.08E-06	0.19300	1.82E-05	0.24200
33	7.91E-06	1.41000	7.91E-06	1.41000	2.00E-04	2.65000
34	2.37E-06	0.42200	2.37E-06	0.42200	4.45E-05	0.59000
35	3.95E-07	0.07040	3.95E-07	0.07040	0.00E+00	0.00000
36	9.49E-06	1.69000	9.49E-06	1.69000	2.22E-04	2.95000
37	1.66E-05	2.96000	1.66E-05	2.96000	1.56E-04	2.06000
38	1.23E-05	2.18000	1.23E-05	2.18000	2.45E-04	3.24000
39	1.34E-05	2.39000	1.34E-05	2.39000	2.00E-04	2.65000
40	1.11E-05	1.98000	1.11E-05	1.98000	1.01E-04	1.34000
41	1.04E-05	1.85000	1.04E-05	1.85000	2.02E-05	0.26700
42	1.51E-05	2.68000	1.51E-05	2.68000	2.02E-05	0.26700
43	6.81E-06	1.21000	6.81E-06	1.21000	2.42E-04	3.21000
44	7.51E-06	1.34000	7.51E-06	1.34000	1.33E-04	1.77000
45	1.11E-05	1.97000	1.11E-05	1.97000	4.89E-04	6.49000
46	3.95E-07	0.07040	3.95E-07	0.07040	2.00E-04	2.65000
47	1.58E-06	0.28100	1.58E-06	0.28100	4.45E-05	0.59000
48	2.37E-05	4.22000	2.37E-05	4.22000	2.67E-04	3.54000
49	1.98E-05	3.52000	1.98E-05	3.52000	2.45E-04	3.24000
50	7.51E-06	1.34000	7.51E-06	1.34000	1.11E-04	1.47000
51	1.62E-05	2.89000	1.62E-05	2.89000	6.00E-04	7.96000
52	9.88E-06	1.76000	9.88E-06	1.76000	3.56E-04	4.72000
53	4.74E-06	0.84400	4.74E-06	0.84400	1.11E-04	1.47000
54	4.35E-06	0.77400	4.35E-06	0.77400	1.33E-04	1.77000
55	1.98E-06	0.35200	1.98E-06	0.35200	0.00E+00	0.00000
56	7.91E-07	0.14100	7.91E-07	0.14100	2.22E-05	0.29500
101	1.12E-09	0.00020	1.12E-09	0.00020	1.89E-08	0.00025
102	2.65E-07	0.04720	2.65E-07	0.04720	4.45E-06	0.05900
103	6.62E-08	0.01180	6.62E-08	0.01180	1.11E-06	0.01480
104	4.28E-07	0.07620	4.28E-07	0.07620	7.19E-06	0.09530
105	3.04E-07	0.05410	3.04E-07	0.05410	5.11E-06	0.06770
106	5.50E-07	0.09790	5.50E-07	0.09790	9.24E-06	0.12200
107	2.14E-06	0.38100	2.14E-06	0.38100	3.59E-05	0.47600
108	2.63E-06	0.46900	2.63E-06	0.46900	4.42E-05	0.58600
109	2.31E-06	0.41100	2.31E-06	0.41100	3.88E-05	0.51400
110	5.13E-06	0.91300	5.13E-06	0.91300	8.62E-05	1.14000
111	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000

Subwatershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)
112	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
113	8.06E-06	1.44000	8.06E-06	1.44000	1.36E-04	1.80000
114	4.77E-06	0.84900	4.77E-06	0.84900	8.01E-05	1.06000
115	4.65E-06	0.82700	4.65E-06	0.82700	7.81E-05	1.04000
116	6.06E-07	0.10800	6.06E-07	0.10800	1.02E-05	0.13500
117	2.87E-06	0.51100	2.87E-06	0.51100	4.82E-05	0.63900
118	3.43E-06	0.61000	3.43E-06	0.61000	5.76E-05	0.76300
119	7.00E-06	1.25000	7.00E-06	1.25000	1.18E-04	1.56000
120	4.88E-06	0.86900	4.88E-06	0.86900	8.20E-05	1.09000
121	8.70E-07	0.15500	8.70E-07	0.15500	1.46E-05	0.19400
122	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
123	2.04E-06	0.36300	2.04E-06	0.36300	3.43E-05	0.45500
124	5.01E-07	0.08930	5.01E-07	0.08930	8.43E-06	0.11200
125	1.35E-06	0.24100	1.35E-06	0.24100	2.27E-05	0.30100
126	1.03E-07	0.01830	1.03E-07	0.01830	1.73E-06	0.02290
127	2.04E-10	0.00004	2.04E-10	0.00004	3.42E-09	0.00005
128	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
129	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
130	5.45E-08	0.00970	5.45E-08	0.00970	9.15E-07	0.01210
131	2.11E-06	0.37500	2.11E-06	0.37500	3.54E-05	0.46900
132	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
133	3.73E-06	0.66400	3.73E-06	0.66400	6.26E-05	0.83000
134	1.30E-06	0.23100	1.30E-06	0.23100	2.18E-05	0.28900
135	8.03E-07	0.14300	8.03E-07	0.14300	1.35E-05	0.17900
136	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
137	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
138	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
139	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
140	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
141	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
142	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
143	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
144	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
145	8.48E-08	0.01510	8.48E-08	0.01510	1.43E-06	0.01890
146	6.01E-07	0.10700	6.01E-07	0.10700	1.01E-05	0.13400
147	3.12E-08	0.00555	3.12E-08	0.00555	5.24E-07	0.00695
148	4.89E-06	0.87000	4.89E-06	0.87000	8.21E-05	1.09000

Subwatershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)	Flow to stream (MGD)	Load to stream (Billion MPN/day)
149	1.66E-06	0.29600	1.66E-06	0.29600	2.79E-05	0.37000
150	3.75E-06	0.66700	3.75E-06	0.66700	6.30E-05	0.83500
151	2.23E-06	0.39800	2.23E-06	0.39800	3.75E-05	0.49800
152	1.07E-06	0.19000	1.07E-06	0.19000	1.79E-05	0.23800
153	1.80E-06	0.32000	1.80E-06	0.32000	3.02E-05	0.40100
154	1.86E-08	0.00330	1.86E-08	0.00330	3.12E-07	0.00413
155	6.17E-07	0.11000	6.17E-07	0.11000	1.04E-05	0.13700
156	3.09E-06	0.55000	3.09E-06	0.55000	5.19E-05	0.68800
171	2.37E-06	0.42200	2.37E-06	0.42200	3.99E-05	0.52800
172	3.72E-07	0.06620	3.72E-07	0.06620	6.25E-06	0.08280
173	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
174	2.72E-09	0.00048	2.72E-09	0.00048	4.57E-08	0.00061
175	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
176	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
177	1.24E-07	0.02200	1.24E-07	0.02200	2.08E-06	0.02750
178	0.00E+00	0.00000	0.00E+00	0.00000	0.00E+00	0.00000
180	3.75E-07	0.06680	3.75E-07	0.06680	6.31E-06	0.08360
181	2.77E-06	0.49200	2.77E-06	0.49200	4.65E-05	0.61600
182	4.98E-07	0.08860	4.98E-07	0.08860	8.36E-06	0.11100
183	2.95E-06	0.52400	2.95E-06	0.52400	4.95E-05	0.65600
184	7.45E-07	0.13300	7.45E-07	0.13300	1.25E-05	0.16600
185	5.96E-07	0.10600	5.96E-07	0.10600	1.00E-05	0.13300
186	3.18E-07	0.05660	3.18E-07	0.05660	5.34E-06	0.07080
187	1.24E-07	0.02210	1.24E-07	0.02210	2.08E-06	0.02760
188	6.68E-09	0.00119	6.68E-09	0.00119	1.12E-07	0.00149

mL – milliliter
MGD – million gallons per day
MPN - most probable number
SSO - sanitary sewer overflow

TPDES Regulated Storm Water

The four TMDL watersheds are covered under the City of Houston/Harris County storm water discharge permit (TPDES MS4 Permit No. WQ0004685000). Under this storm water discharge permit, Harris County, Harris County Flood Control District, City of Houston, and Texas Department of Transportation are designated as co-permittees. Sampling conducted by the co-permittees under provisions of the MS4 permit and sampling conducted for this project demonstrate that storm water is a significant source of indicator bacteria. The storm water runoff includes not only MS4 permitted discharges, but also permitted discharges from industrial facilities and construction sites. The loads from these sources are combined in the analysis of the wet-weather storm water discharges.

Dry-Weather Discharges/Illicit Discharges

Discharges from storm water conveyances that do not originate from storm water runoff can contribute indicator bacteria loads to the receiving waters in the four TMDL watersheds. These discharges, which are termed dry-weather discharges or illicit discharges, are unauthorized if the discharges contribute pollutants to an impaired water body that is listed for that pollutant. Indicator bacteria loads from non-permitted storm water can enter the streams from permitted outfalls and illicit discharges under both dry and wet-weather conditions. Dry-weather and illicit discharges are regulated under WWTF permits, and where applicable, under the provisions of an MS4.

Dry-weather discharges through pipes were sampled during 2001 to estimate *E. coli* loads. The sampling was conducted along the entire length of the main stem of Buffalo and Whiteoak Bayous (Figure 9). Sampling was conducted only downstream of the reservoirs (i.e., at the mouth of the Reservoirs watershed) in Buffalo Bayou. Samples were collected only during dry conditions, which were roughly defined as a period of at least three or more days with less than 0.1 inches of rainfall in the immediate sampling area. Samples were collected on foot in Whiteoak Bayou, while a canoe was used to maneuver down Buffalo Bayou. Samples from submerged outfalls were not collected since it would be impossible to determine if dry-weather flows were occurring.

The loads were calculated using measured flow and concentration from the sampling effort. For the purpose of determining loads, the discharges were assumed to occur only on dry-weather days. Although the flows may be present during wet-weather conditions, they cannot be explicitly separated from wet conditions because of the method used to calculate indicator bacteria loading for these conditions.

Using data reported at the Addicks Reservoir rain gauge maintained by NOAA (National Climatic Data Center 2003), 74 days of the year on average experience rainfall greater than 0.01 inches, and thus dry-weather discharges were assumed to occur during the remaining 291 days. Therefore, the dry-weather load for the year was divided by 291 days to adjust the loading for dry days only.

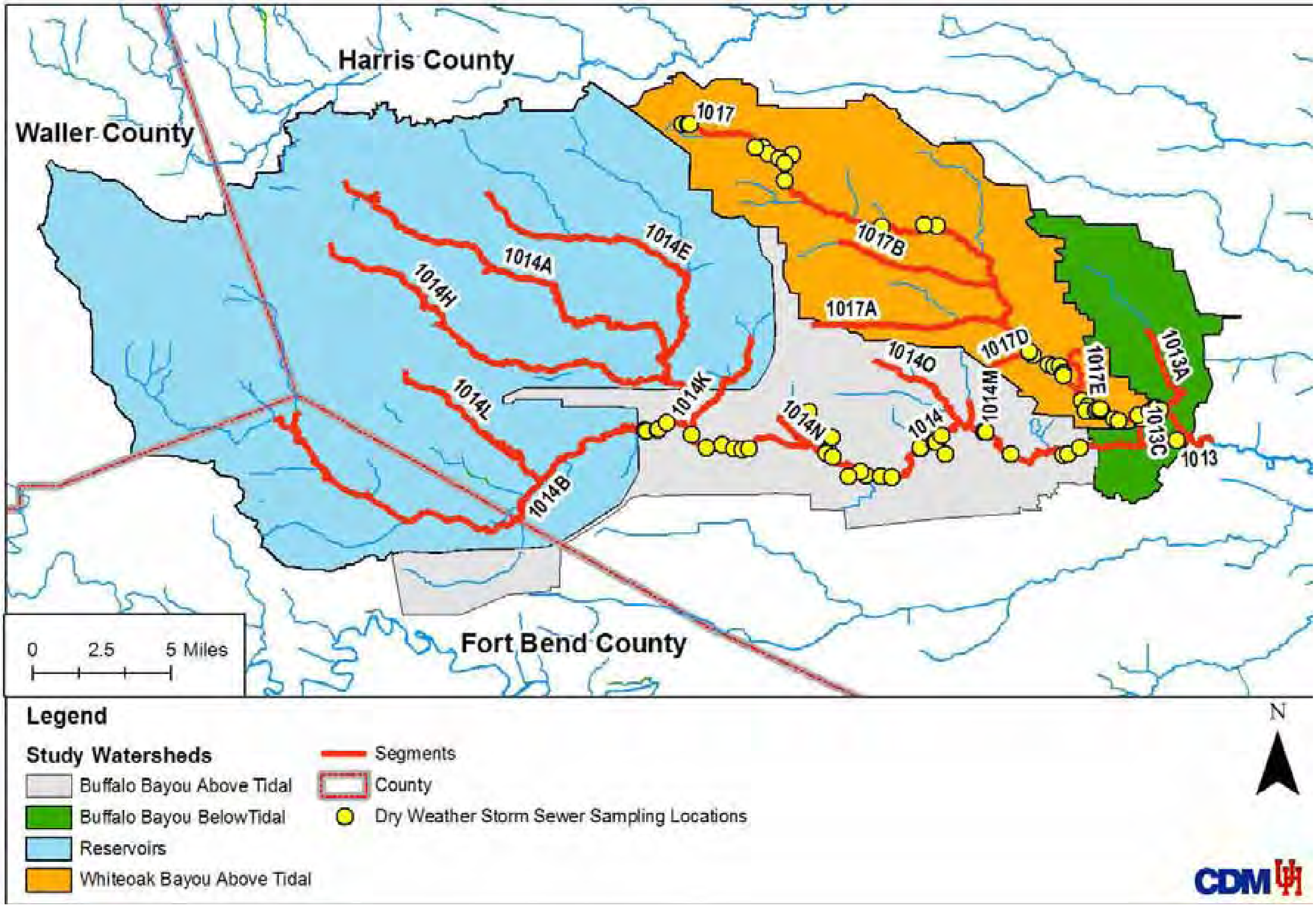


Figure 9. Locations of Dry-Weather Samples

A summary of loads on a subwatershed basis are presented in Table 16. The flows shown in the table were calculated by summing all dry-weather discharge flows in each subwatershed. These total flows per subwatershed in MGD were multiplied by 365 to get a yearly flow, and then divided by 291, the number of dry days per year. This was done to ensure dry-weather discharges were only counted on dry-weather days in MGD. The indicator bacteria loading from dry-weather discharges was calculated as the multiplication of the measured flow, the measured *E. coli* concentration, and the number of days in a year (365). This value was divided by 291 to give the total load on a dry-weather day in MPN/day. The largest *E. coli* load was in Subwatershed 43 (Whiteoak Bayou watershed), at 2.21 x 10^{11} MPN/day. The smallest non-zero load was 7.43x10^5 MPN/day in Subwatershed 44 Buffalo Bayou Tidal watershed.

Wet-Weather Storm Water Discharges

Indicator bacteria loading from watershed sources during wet weather can be simulated using a water quality model or a simple approach using the curve number method (NRCS 1986) and measured *E. coli* event mean concentrations (EMCs) from local sampling. This indicator bacteria load accounts for any loading deposited on the watershed by animals, but does not account for direct deposition into the stream.

The wet-weather condition refers to the conditions in the stream based on the flow duration curve. In the context of the TMDL, the wet-weather condition is associated with high flow conditions in the stream, defined as the 70th percentile or greater. The intermediate condition is also partially influenced by wet-weather discharges since it is a mixed flow regime of wastewater discharge and rainfall runoff, and is defined on the flow duration curve as the region between the 30th and 70th percentile flows.

Simple flow calculations were based on the curve number method, land use data, and STATSGO soils data presented in Table 8. Soil cover was generally assumed to be in good condition, with soil hydrologic group D used to guide curve number selection. In addition, a typical rainfall condition with 0.59 inches of rain, based on the average between 1943 and 1990 at the NOAA Addicks gauge (National Climatic Data Center 2003), was used to estimate runoff for wet-weather conditions. In the context of these calculations, the rainfall value does not represent a single, specific storm event but rather the average daily rainfall that would be expected on rainy days during a given year. This is an important consideration because the TMDL must be calculated on a daily basis.

Table 16. Summary of Observed Dry-Weather Regulated Storm Water Discharges

Subwatershed	Flow on Dry Day (MGD)	Load on Dry Day (Billion MPN/day)
Whiteoak Bayou Watershed		
4	0.00371	0.01110
7	0.01340	0.03790
10	0.02460	1.28000
11	0.01270	0.01790

Subwatershed	Flow on Dry Day (MGD)	Load on Dry Day (Billion MPN/day)
Whiteoak Bayou Watershed (cont'd)		
13	0.01060	0.00862
34	0.04100	2.57000
35	0.03720	0.03140
40	0.14100	0.48800
41	0.05710	3.16000
43	0.31600	221.00000
47	0.00054	0.01470
Buffalo Bayou Above Tidal Watershed		
44	0.00030	0.00074
45	0.04080	15.50000
39	0.21300	0.25300
42	0.10000	22.40000
50	0.00474	0.14900
52	0.08080	54.80000
53	0.00635	0.13200
54	0.14000	179.00000
55	0.05160	20.60000

MGD – million gallons per day

MPN – most probable number

Loading was estimated for *E. coli* using EMCs presented in the Storm Water Joint Task Force Annual Report (2002), a study with local data from the Houston area between 1992-1993 and 1998-2002. The land use for the EMCs employed in this analysis did not always match the types of land cover described by H-GAC; thus, assumptions were made to determine the appropriate EMC for each land cover type. Because the collected data were fecal coliform rather than *E. coli*, the fecal coliform data were converted to *E. coli* values using a ratio of the standards. A summary of the data used to calculate a simple flow and load estimate for wet-weather storm-sewer discharges is presented in Table 17. Wet-weather loads were assumed to occur only on wet days; thus, the loads were corrected to account only for the 74 days of rainfall that typically occur in Houston.

Because the instream intermediate condition is a mixed flow regime comprised of WWTF effluent as well as runoff, wet-weather storm sewer loads were also estimated. The intermediate condition was intended to represent median flow conditions across the watersheds. Because this flow condition contains some runoff, it was necessary to account for this residual loading as well. The residual loading was determined by finding the percentage of wet-weather storm sewer flows needed to reach median flow instream and applying that same percentage to the wet-weather storm sewer loads. The following presents the calculation: wet-weather storm-sewer discharge load times (median flow in the bayou - dry-weather flow in bayou) divided by the total wet-weather storm-sewer discharge flow.

Loads calculated using the simple approach described in this section are presented in Table 18 for the intermediate and wet-weather scenarios. The largest *E. coli* load from wet-weather storm-water discharges occurred in Subwatershed 1 (Whiteoak Bayou watershed), which has one of the largest drainage areas with a high percentage of low and high-intensity land uses, with 5.99 x 10^{13} MPN/day. The smallest load was in Subwatershed 142 (Reservoirs watershed) with a load of 1.29 x 10^{11} MPN/day.

Table 17. Summary of Assumptions used for Wet Weather Calculations

Land Use	Curve Number	Fecal coliform EMC (cfu/100mL)	*E. coli* EMC (MPN/100mL)
Low Intensity Developed	92	63,357	39,915
High Intensity Developed	96	73,836	46,517
Cultivated	84	43,632	28,118
Grassland	80	43,632	28,118
Woody Land	77	43,632	28,118
Woody Wetlands	0	N/A	N/A
Nonwoody wetland	0	N/A	N/A
Transitional	94	44,632	28,118

cfu - colony forming units

mL – milliliter

EMC - event mean concentration

MPN – most probable number

Table 18. Summary of Wet-Weather Regulated Storm Water Discharges

Subwatershed	Intermediate Condition		Wet-Weather Condition	
	Flow (MGD)	*E. coli* Load (Billion MPN/day)	Flow (MGD)	*E. coli* Load (Billion MPN/day)
1	2.42	4,090	35.44	60,000
2	1.92	3,290	28.18	48,200
3	0.84	1,370	12.36	20,000
4	1.84	3,040	26.92	44,500
5	0.42	694	23.95	39,600
6	0.27	446	15.39	25,500
7	0.42	682	6.14	10,000
8	0.19	310	2.79	4540
9	0.66	1,090	9.63	16,000
10	1.03	1,690	15.11	24,800
11	0.38	620	5.56	9100
12	0.17	267	2.42	3910
13	0.50	809	7.32	11,900
17	0.46	757	6.77	11100
26	5.30	8,840	16.02	26,700
27	3.77	6,410	11.39	19,400
28	0.65	1,060	1.97	3,200
33	4.30	7,360	12.99	22,300
34	0.92	1,430	2.78	4,310
35	4.04	6,700	12.20	20,300
36	0.20	350	11.45	20,000
37	0.17	287	9.52	16,400
38	0.16	277	9.24	15,800
39	5.99	9,910	18.11	30,000
40	0.40	673	5.88	9,870
41	0.66	1,120	9.64	16,500
42	0.67	1,110	9.76	16,300
43	1.43	2,440	20.94	35,800
44	4.66	8,110	14.10	24,500
45	3.77	6,360	11.40	19,200
46	0.08	130	4.30	7,420
47	0.06	108	3.49	6,150
48	0.19	315	10.80	18,000
49	0.25	413	14.22	23,600

Subwatershed	Intermediate Condition		Wet-Weather Condition	
	Flow (MGD)	*E. coli* Load (Billion MPN/day)	Flow (MGD)	*E. coli* Load (Billion MPN/day)
50	3.40	5,890	10.30	17,800
51	3.23	5,500	9.77	16,600
52	4.71	8,130	14.24	24,600
53	6.09	10,400	18.42	31,500
54	3.11	5,270	9.40	15,900
55	4.42	7,500	13.38	22,700
56	4.70	8,020	14.21	24,300
101	0.04	48	0.17	188
102	0.13	215	0.52	851
103	0.70	1,220	2.77	4,820
104	0.67	1,090	2.64	4,310
105	0.90	1,550	3.56	6,130
106	0.70	1,070	2.78	4,250
107	0.66	1,030	2.60	4,070
108	1.05	1,710	4.15	6,760
109	0.56	892	2.21	3,530
110	1.53	2,460	6.05	9,720
111	0.31	328	1.22	1,300
112	0.13	141	0.52	556
113	2.97	4,830	11.74	19,100
114	1.65	2,630	6.52	10,400
115	1.86	3,120	7.34	12,300
116	0.59	931	2.32	3,680
117	0.66	1,040	2.60	4,120
118	0.93	1,480	3.68	5,860
119	1.09	1,700	4.30	6,720
120	0.50	786	1.98	3,100
121	0.98	1,100	3.86	4,350
122	0.12	131	0.49	518
123	0.40	627	1.56	2,480
124	1.20	1,930	4.72	7620
125	1.50	2,480	5.93	9,800
126	0.90	1,370	3.56	5,420
127	0.33	407	1.32	1,610
128	0.55	747	2.18	2,950

Subwatershed	Intermediate Condition		Wet-Weather Condition	
	Flow (MGD)	*E. coli* Load (Billion MPN/day)	Flow (MGD)	*E. coli* Load (Billion MPN/day)
129	0.14	207	0.56	816
130	0.44	631	1.72	2,490
131	0.56	894	2.20	3,530
132	0.10	110	0.41	435
133	2.80	4,670	11.08	18,400
134	0.56	768	2.20	3,040
135	1.60	2,570	6.32	10,100
136	0.28	482	1.12	1,900
137	0.29	467	1.16	1,850
138	0.41	641	1.61	2,530
139	0.38	496	1.50	1,960
140	0.22	301	0.85	1,190
141	1.49	1,920	5.87	7,600
142	0.03	33	0.12	129
143	1.64	2,570	6.48	10,100
144	0.40	439	1.59	1,730
145	1.18	1,730	4.65	6,850
146	0.44	733	1.75	2,890
147	0.03	36	0.11	141
148	2.15	3,400	8.51	13,400
149	0.34	582	1.36	2,300
150	0.56	864	2.20	3,420
151	0.67	1,070	2.64	4,250
152	0.99	1,680	3.92	6,630
153	0.87	1,410	3.45	5,560
154	0.15	252	0.60	996
155	0.45	734	1.78	2,900
156	3.11	4,970	12.29	19,700
171	1.24	1,940	4.89	7,680
172	0.39	584	1.55	2,310
173	0.06	62	0.23	243
174	0.10	164	0.39	649
175	0.18	311	0.72	1,230
176	0.38	593	1.49	2,340
177	0.09	148	0.36	584

Subwatershed	Intermediate Condition		Wet-Weather Condition	
	Flow (MGD)	*E. coli* Load (Billion MPN/day)	Flow (MGD)	*E. coli* Load (Billion MPN/day)
178	1.07	1,550	4.24	6,130
180	0.10	170	0.39	673
181	0.88	1,420	3.46	5,600
182	0.19	313	0.74	1,240
183	1.01	1,670	4.00	6,610
184	0.23	405	0.92	1,600
185	0.16	261	0.61	1,030
186	0.09	157	0.36	621
187	0.09	114	0.35	449
188	0.24	326	0.95	1,290

Nonpoint Sources

Sources of indicator bacteria loads that are not regulated are called nonpoint sources. Because all of the watersheds are covered under an MS4 permit, nonpoint source pollutants are those that enter the impaired stream directly. There are two nonpoint sources in the TMDL watersheds—onsite sewage facilities and direct deposition. In addition to these nonpoint sources, sediment resuspension of indicator bacteria contributes a load to the bayous. Although sediment resuspension loads are not external loads, they are included in the load allocation because all of the identified sources contribute loads to the sediment. By decreasing all of these loads, the indicator bacteria load for the sediments will also decrease.

Onsite Sewage Facilities

Onsite sewage facilities (OSSFs) can be a source of indicator bacteria loading to streams and rivers. Indicator bacteria loading from failing OSSFs can be transported to streams in a variety of ways, including runoff from surface discharge to the receiving waters or from transport by storm water runoff.

Over time, most OSSFs operating at full capacity will fail. OSSF failures are proportional to the adequacy of a state's minimum design criteria (Hall 2002). The 1995 American Housing Survey conducted by the U.S. Census Bureau estimates that nationwide, 10 percent of occupied homes with OSSFs experience malfunctions during the year (U.S. Census Bureau 1995). A study conducted by Reed, Stowe, & Yanke, LLC (2001) reported that approximately 13 percent of the OSSFs in Texas were chronically malfunctioning. Most studies estimate that the minimum lot size necessary to ensure against contamination is roughly one-half to one acre (Hall 2002). Some studies, however, found that lot sizes in this range or even larger could still cause contamination of ground or surface water (University of Florida 1987). It is estimated that areas with more than 40 OSSFs per square mile (6.25 septic systems per 100 acres) can be considered to have potential contamination problems (Canter and Knox 1985).

Harris County provided a database from an inventory of open discharge of sewage effluent into roadside ditches. These data were evaluated only to determine if failing septic systems were identified in subwatersheds entirely covered by municipal utility districts (MUDs). Failing septic systems located in subwatersheds that are more than 99 percent covered by MUDs were excluded from the analysis. These systems were assumed to have been addressed by connecting to the MUD sanitary system (Figure 10).

The number of septic systems for regions outside of Harris County was calculated using the average failing septic system density, calculated as the total number of failing septic systems in the project area divided by the area of the project watershed. The calculated septic density was 7.34×10^{-5} septic systems/acre. The new failing septic system inputs are provided in Table 19. The Reservoirs watershed has the largest number of failing septic systems, as would be expected since it is more rural.

The flow and indicator bacteria loads associated with failing septic systems are presented in Table 20. The flow from OSSFs per subwatershed were calculated by multiplying the number of failing septic systems, number of individuals per household, delivery rate, and wastewater production per person per day in MGD to yield the flow in MGD. The OSSF *E. coli* load per subwatershed was determined by multiplying the OSSF flow per subwatershed and the *E. coli* concentration assumed for wastewater to yield the indicator bacteria load in MPN/day.

The highest OSSF loads occur in Subwatershed 1 located in the Whiteoak Bayou watershed and in the Reservoirs watershed in Subwatershed 105, both with a loading of 7.06×10^{10} MPN/day.

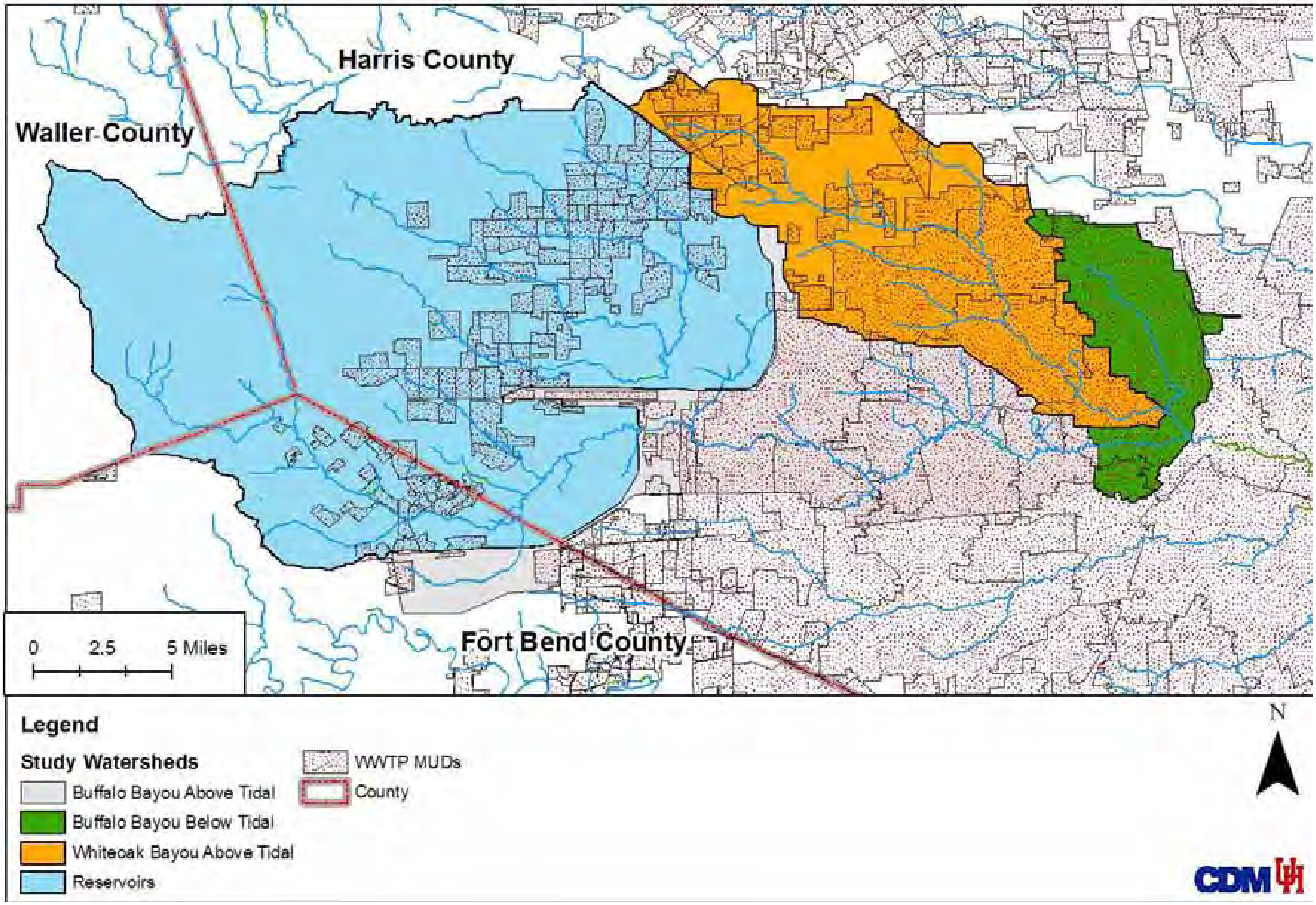


Figure 10. MUD Coverage Map

Table 19. Estimated Failing Septic Systems Loads in the TMDL Watersheds

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Buffalo Bayou Above Tidal Watershed		
26	0	0
27	0	0
28	0	0
33	0	0
34	0	0
35	3.07	0.000017
39	0	0
44	0	0
45	0	0
50	0	0
51	0	0
52	0	0
53	0	0
54	0	0
55	0	0
56	0	0
Buffalo Bayou Tidal Watershed		
5	0	0
6	0	0
36	0	0
37	0	0
38	0	0
46	0	0
47	0	0
48	0	0
49	0	0
Whiteoak Bayou Watershed		
1	70.6	0.000391
2	0	0
3	0	0
4	34	0.000188
7	0	0
8	0	0
9	0	0
10	0	0

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Reservoirs Watershed, cont.		
116	0	0
117	0	0
118	22.1	0.000122
119	0	0
120	0	0
121	0	0
122	0	0
123	0	0
124	0	0
125	0	0
126	0	0
127	0	0
128	0	0
129	0	0
130	0	0
131	0	0
132	0	0
133	0.218	0.000001
134	0	0
135	0.807	0.000004
136	12.3	0.000068
137	0.258	0.000001
138	5.84	0.000032
139	6.21	0.000034
140	0	0
141	0	0
142	0	0
143	0	0
144	0	0
145	0	0
146	0.00419	0
147	0	0
148	0	0
149	1.15	0.000006
150	0.233	0.000001

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Whiteoak Bayou Watershed , cont.		
11	0	0
12	0	0
13	0	0
17	0	0
40	0	0
41	0	0
42	0	0
43	0	0
Reservoirs Watershed		
101	0	0
102	0	0
103	0	0
104	0	0
105	70.6	0.000391
106	0	0
107	0	0
108	17.7	0.000098
109	0	0
110	0	0
111	0	0
112	0	0
113	0	0
114	0	0
115	0	0

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Reservoirs Watershed, cont.		
151	0.935	0.000005
152	0	0
153	0	0
154	0	0
155	0	0
156	0	0
171	0	0
172	0	0
173	0	0
174	0	0
175	0	0
176	0	0
177	0	0
178	0	0
180	0.199	0.000001
181	1.03	0.000006
182	0	0
183	1.87	0.00001
184	0	0
185	0	0
186	0	0
187	0.0659	0
188	3.56	0.00002

Table 20. Septic System Flow and Loading

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Buffalo Bayou Above Tidal Watershed		
26	0	0
27	0	0
28	0	0
33	0	0
34	0	0
35	3.07	0.000017
39	0	0
44	0	0
45	0	0
50	0	0
51	0	0
52	0	0
53	0	0
54	0	0
55	0	0
56	0	0
Buffalo Bayou Tidal Watershed		
5	0	0
6	0	0
36	0	0
37	0	0
38	0	0
46	0	0
47	0	0
48	0	0
49	0	0
Whiteoak Bayou Watershed		
1	70.6	0.000391
2	0	0
3	0	0
4	34	0.000188
7	0	0
8	0	0

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Reservoirs Watershed, cont.		
116	0	0
117	0	0
118	22.1	0.000122
119	0	0
120	0	0
121	0	0
122	0	0
123	0	0
124	0	0
125	0	0
126	0	0
127	0	0
128	0	0
129	0	0
130	0	0
131	0	0
132	0	0
133	0.218	0.000001
134	0	0
135	0.807	0.000004
136	12.3	0.000068
137	0.258	0.000001
138	5.84	0.000032
139	6.21	0.000034
140	0	0
141	0	0
142	0	0
143	0	0
144	0	0
145	0	0
146	0.00419	0
147	0	0
148	0	0

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Whiteoak Bayou Watershed, cont.		
9	0	0
10	0	0
11	0	0
12	0	0
13	0	0
17	0	0
40	0	0
41	0	0
42	0	0
43	0	0
Reservoirs Watershed		
101	0	0
102	0	0
103	0	0
104	0	0
105	70.6	0.000391
106	0	0
107	0	0
108	17.7	0.000098
109	0	0
110	0	0
111	0	0
112	0	0
113	0	0
114	0	0
115	0	0

Subwatershed	*E. coli* (Billion MPN/day)	Flow (MGD)
Reservoirs Watershed, cont.		
149	1.15	0.000006
150	0.233	0.000001
151	0.935	0.000005
152	0	0
153	0	0
154	0	0
155	0	0
156	0	0
171	0	0
172	0	0
173	0	0
174	0	0
175	0	0
176	0	0
177	0	0
178	0	0
180	0.199	0.000001
181	1.03	0.000006
182	0	0
183	1.87	0.00001
184	0	0
185	0	0
186	0	0
187	0.0659	0
188	3.56	0.00002

MGD - million gallons per day
MPN - most probable number

Direct Deposition

The bayou and its surrounding area provide a good habitat for many types of wildlife, such as waterfowl, raccoon, and other mammals, whose protection and management are under the jurisdiction of the Texas Parks and Wildlife Department. Other unmanaged mammals not under the jurisdiction of the Texas Parks and Wildlife Department can be sources of indicator bacteria. Direct deposition does not include loading deposited on the watershed that is carried via runoff to the bayous during rainfall events. These loads are accounted for in the regulated storm water discharge portion of the load.

Densities for several bird species likely to inhabit the watersheds were estimated using the reference *Birds of North America*. Reported estimates are provided in Table 21, along with estimated population densities of other species of waterfowl known to inhabit the watershed. For species without population densities, population density was estimated as the average of the known population densities. The percentage contribution from the waterfowl was assumed to be 50 percent, based on the assumption that the birds nest and sleep away from the stream 50 percent of the time.

Bridge crossings over major tributaries that provide roosting places where feral rock pigeons nest are also included as a source of direct deposition. Observations suggested that the birds roosted only on bridge supports that run parallel to the bayous. Therefore, bridge locations were determined using data exported from the Tropical Storm Allison Recovery Project (TSARP) Hydrologic Engineering Center – River Analysis System (HEC-RAS) models. Bridges included in this analysis were limited to those 50 feet in width or greater, because smaller bridges typically have support systems that appear to prevent roosting directly over the bayou. Therefore, for narrow sections of the bayou (i.e., Whiteoak Bayou and the Reservoirs watershed in Upper Buffalo Bayou) it was assumed that two supports might be located close enough to the bayou for the birds to contribute to direct deposition loading. For the wider sections (i.e., segments 1013 and 1014 in lower Buffalo Bayou), a total of three supports was conservatively assumed to be within the buffer zone that could contribute direct deposition loading. The feral rock pigeons were assumed to roost with one foot of spacing between the birds.

Calculation of the number of birds per bridge was determined as the number of bridge supports over the water multiplied by the width in feet, divided by the number of birds per foot. Bacteria loading from feral rock doves was estimated using the same *E. coli* production value as for waterfowl. The loading was calculated by multiplying the number of bridges in a subwatershed, the number of feral rock doves on the bridge, and the fecal production rate to yield the bridge-crossing direct deposition loading in MPN/day.

In addition to birds and waterfowl direct deposition in the bayou, an estimate of mammals that might be found near the water was included in the direct deposition estimate. This estimate included deer, opossum, raccoon, and rodents. The density of animals was assumed to be 3.5 animals per stream buffer acre, based on estimates reported from the Orange County Bacteria TMDL (TCEQ 2007) for wetland land uses. Dogs were also included in the direct deposition calculations. The American Veterinary Medicine Association estimates approximately 0.58 dogs per household in the U.S. Using these data coupled with watershed-specific population, housing size, and area gives an overall dog density of 0.53 dogs per acre. This density was adjusted to reflect the amount of watershed that is covered by areas not suitable for recreation with dogs, such as wetlands and cultivated land uses, to a final density of 0.41 dogs per acre of watershed.

Loading for these mammals was estimated using fecal bacteria deposition rates reported in the literature. The value used for calculations was 2.03×10^9 MPN/day per animal. The mammal direct deposition load was calculated as the multiplication of stream length, stream width, mammal density, and fecal production rate to yield the mammalian direct deposition loading in MPN/day. It was assumed that these animals would spend only 5 percent of their time in or near to the bayou.

The indicator bacteria loads associated with direct deposition are presented in Table 22**.** The loads presented in the table are the sum of direct deposition from waterfowl, feral rock pigeons, and mammals. The watershed with the highest overall direct deposition load is in Subwatershed 26 with a load of 2.47 X 10^{10} MPN/day, reflecting the large number of bridges in the watershed. The watershed with the least amount of direct deposition loading from indicator bacteria is Subwatershed 105, located in the Reservoirs watersheds.

Table 21. Bird Species and Estimated Densities

Species of Birds	Population Density (pairs/acre)	Percent Contribution
American Pigeon	0.000294	50%
Barn Swallow	0.000294	50%
Black Bellied Whistling Duck	0.000294	50%
Black-crowned Night Heron	0.000294	50%
Blue Winged Teal	0.000294	50%
Blue-gray Gnatcatcher	0.000294	50%
Cackling Goose	0.000294	50%
Canada Goose	0.000294	50%
Canvasback	0.000294	50%
Cinnamon Teal	0.000294	50%
Double-crested Cormorant	0.000294	50%
Duck	0.000294	50%
Fulvours Whistling Duck	0.000294	50%
Gadwall	0.000294	50%
Golden-crowned Kinglet	0.000294	50%
Great Blue Heron	0.000827	50%
Great Egret	0.000608	50%
Green Heron	0.000294	50%
Green-winged Teal	0.000294	50%
Hooded Merganser	0.000294	50%
Lesser Grebe	0.000294	50%
Lesser Scaup	0.000294	50%
Little Blue Heron	0.000294	50%
Mallard	0.000294	50%
Mottled Duck	0.000294	50%

Species of Birds	Population Density (pairs/acre)	Percent Contribution
Neotropic Cormorant	0.000057	50%
Northern Pintail	0.000294	50%
Northern shoveler	0.000294	50%
Pled-billed Grebe	0.000294	50%
Redhead Duck	0.000294	50%
Ring-necked Duck	0.000294	50%
Roseate Spoonbill	0.000033	50%
Ross's Goose	0.000294	50%
Ruby-crowned Kinglet	0.000294	50%
Snow Goose	0.000294	50%
Tricolored Heron	0.000294	50%
White Ibis	0.000028	50%
White-faced Ibis	0.000215	50%
Wood Duck	0.000294	50%
Yellow Crowned Night Heron	0.000294	50%

Table 22. Calculated Loads from Direct Deposition

Sub-watershed	*E. coli* (Billion MPN/day)
Buffalo Bayou Above Tidal Watershed	
26	24.7
27	12.9
28	3.29
33	20.9
34	3.79
35	4.37
39	16.9
44	1.63
45	13.3
50	8.56
51	2.06
52	22.1
53	12.7
54	11.3
55	6.05

Sub-watershed	*E. coli* (Billion MPN/day)
Reservoirs Watershed, cont.	
116	0.534
117	7.64
118	8.07
119	11.6
120	6.65
121	7
122	1.05
123	1.89
124	2.63
125	3.77
126	1.07
127	15.2
128	5.3
129	3.79
130	7.9

Sub-watershed	*E. coli* (Billion MPN/day)
Buffalo Bayou Tidal Watershed	
56	6.62
5	6.02
6	5.2
36	6.72
37	10.7
38	4.36
46	5.67
47	12.5
48	8.75
49	5.5
Whiteoak Bayou Watershed	
1	18.7
2	17.2
3	5.53
4	16.8
7	8.89
8	3.2
9	9.32
10	6.36
11	2.9
12	3.08
13	6.57
17	7.4
40	6.65
41	7.84
42	3.89
43	7.29
Reservoirs Watershed	
101	6.23
102	2.25
103	2.59
104	7.37
105	0.375
106	9.33

Sub-watershed	*E. coli* (Billion MPN/day)
Reservoirs Watershed, cont.	
131	4.96
132	7.25
133	2.56
134	3.72
135	7.71
136	2.67
137	3.07
138	5.71
139	2.55
140	1.25
141	7.25
142	5.75
143	14.3
144	11.8
145	7.23
146	2.49
147	1.46
148	4.52
149	5.75
150	5.34
151	1.3
152	7.7
153	4.82
154	9.03
155	2.94
156	2.38
171	6.76
172	4.15
173	4.27
174	3.48
175	2.89
176	6.88
177	2.04
178	10.6

Sub-watershed	*E. coli* (Billion MPN/day)	Sub-watershed	*E. coli* (Billion MPN/day)
Reservoirs Watershed, cont.		Reservoirs Watershed, cont.	
107	7.35	180	0.672
108	7.52	181	4.29
109	1.34	182	1.73
110	8.64	183	1.53
111	5.81	184	0.731
112	4.27	185	3.37
113	9.84	186	0.494
114	2.58	187	0.395
115	3.65	188	12.5

MPN – most probable number

Sediment Resuspension

Sampling conducted in 2001 and 2002 showed that sediments on the beds of the bayous exhibit high concentrations of *E. coli* (Table 23). These sediments can be resuspended when shear stress exerted on the stream bed exceeds the critical shear stress for incipient motion. This scouring results in stream sediment with associated indicator bacteria being resuspended, and thus contributing to the overlying water concentrations of *E. coli*. Although these indicator bacteria loads are not external loads, they are included in the load allocation because all of the identified sources contribute loads to the sediment. By decreasing all of these loads, the indicator bacteria load for the sediments may also decrease.

Factors influencing the bed shear stress include the density of sediment particles, the diameter of sediment particles, and the consolidation of the streambed. Based on work conducted by Hjulstrom in 1935, typical velocities that cause streambed erosion exceed 2.95 ft/s for clay-sized ($d < 0.004$ mm) particles.

Table 23. Summary of Sediment Sampling

Buffalo Bayou Above Tidal (1014)	
Intersection*	***E. coli* Geomean (MPN/100mL sediment)**
Fry	585
Westheimer	33,334
Highway 6	12,253
Eldridge	78,267
Kirkwood	115,044
Wilcrest	201,101
Beltway 8	48,961
Piney Point	107,100
Voss	78,076
IH610	41,163
Westcott	25,042
Shephard	76,035

Whiteoak Bayou (1017)	
Intersection*	***E. coli* Geomean (MPN/100mL sediment)**
Deihl	69,426
Beltway 8	21,405
W Little York	41,478
Tidwell	31,137
Houston	232,179

* - name of intersecting highway or street
MPN – most probable number

Although sediment studies have been conducted, site-specific scour rates are not available for the Houston area. Therefore, *E. coli* resuspension rates measured in Jamieson et. al., 2005) were used. This study noted scour rates of indicator bacteria between 8,200 and 15,000 cfu/m^2/s, with the average resuspension rate of 11,400 cfu/m^2/s.

By multiplying the occurrence of resuspension flows, sediment scour rates, and estimates of bayou width and stream lengths, the resuspension *E. coli* load was calculated as shown in Table 24. Because loading is a function of stream width and length, the streams with the largest stream surface area exposed to bed sediment will consequently have the largest bed sediment contribution. The subwatershed with the largest contribution is Subwatershed 127, with a contribution of 4.96 x 10^{12} MPN/day. The subwatershed with the smallest non-zero contribution is Subwatershed 35, with a loading of 1.74 x 10^{10} MPN/day.

Table 24. Calculated *E. coli* Loads from Resuspension

Subwatershed	Resuspension Loads (Billion MPN/day)
Buffalo Bayou Above Tidal Watershed	
26	477
27	392
28	145
33	393
34	167
35	17.4
39	394
44	71.9
45	499
50	202
51	90.5
52	360
53	473
54	322
55	179
56	29
Buffalo Bayou Tidal Watershed	
5	484
6	544
36	121
37	121
38	104
46	162
47	115
48	210
49	242
Whiteoak Bayou Watershed	
1	1370
2	1590
3	0
4	1220
7	589
8	384

Subwatershed	Resuspension Loads (Billion MPN/day)
Reservoirs Watershed, cont.	
116	174
117	2270
118	2420
119	3130
120	1950
121	2280
122	342
123	400
124	857
125	1230
126	348
127	4960
128	1730
129	1240
130	2580
131	1620
132	2370
133	187
134	780
135	2080
136	870
137	786
138	1860
139	831
140	406
141	2370
142	1880
143	4680
144	3860
145	2360
146	812
147	477
148	1260

Subwatershed	Resuspension Loads (Billion MPN/day)
Whiteoak Bayou Watershed, cont.	
9	958
10	523
11	268
12	369
13	470
17	570
40	0
41	0
42	0
43	0
Reservoirs Watershed	
101	2030
102	735
103	844
104	1970
105	122
106	3040
107	2400
108	2240
109	438
110	2380
111	1890
112	1390
113	2780
114	625
115	973

Subwatershed	Resuspension Loads (Billion MPN/day)
Reservoirs Watershed, cont.	
149	1010
150	1310
151	425
152	1860
153	1570
154	2950
155	960
156	561
171	2200
172	922
173	1390
174	1130
175	941
176	2240
177	664
178	3450
180	219
181	1400
182	348
183	284
184	238
185	883
186	161
187	129
188	4060

MPN – most probable number

Linkage Analysis

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

Generally, if high indicator bacteria concentrations are measured in a water body at low to median flow in the absence of runoff events, the main contributing source is probably 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.

Indicator bacteria contributions from nonpoint sources are greatest during runoff events. Rainfall runoff, depending on 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 indicator bacteria concentrations in the water body as the first flush of storm runoff enters the receiving stream, and then a gradual decrease as the runoff continues. Over time, two factors reduce the concentration in storm water runoff. First, the sources of indicator bacteria are attenuated as runoff washes them from the land surface. Secondly, the increasing volume of water in the receiving stream has a diluting effect on instream indicator bacteria concentrations.

Three methods of analysis were used for analyzing indicator bacteria loads, instream water quality, and load reductions—Load Duration Curve (LDC) analyses, a mass balance analysis using Bacteria Load Estimation Spreadsheet Tool (BLEST), and an Hydrologic Simulation Program Fortran (HSPF) analysis for simulation of watershed hydrology and water quality.

Load Duration Curve Analysis

Load duration curves are similar in appearance to flow duration curves; however, the y-axis is expressed in terms of an indicator bacteria load in MPN/day. The curve represents the single-sample water quality criterion for *E. coli* (394 MPN/100 mL), expressed in terms of a load through multiplication by the flows historically observed at this site. The basic steps to generate an LDC involve:

- preparing flow duration curves (FDC) for gauged sampling locations;
- estimating existing indicator bacteria loading in the receiving water using ambient water quality data; and
- interpreting LDCs to derive TMDL elements—Waster Load Allocation (WLA), Load Allocation (LA), Margin of Safety (MOS), and percent reduction goals.

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. Historical observations of indicator bacteria concentration are paired with flow data and are plotted on the LDC. The indicator bacteria load (y-value of each point) is calculated by multiplying the indicator bacteria concentration (MPN/100mL) by the instantaneous flow (cubic feet per second) at the same site and time, with appropriate volumetric and time unit conversions. Indicator bacteria loads that exceed water quality criteria fall above the 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 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.

The flow data and indicator bacteria data used to develop LDCs were from the USGS flow gauges in the TMDL watersheds and the closest TCEQ indicator bacteria sampling locations (Figure 11). Data collected by the TCEQ during routine monitoring from January 1, 2001 through September 30, 2003, were used to develop the LDCs. Only one data point was collected for station 11155, so this station was excluded from LDC development.

Load Duration Curve Analysis Results

Three flow regimes were classified on the load duration curve, with dry condition flows defined as between the 0 and 30th percentiles, intermediate conditions between the 30th and 70th percentiles, and the wet condition as the 70th percentile or higher. The medians of the observed loads were calculated for each of the three flow regimes and plotted on Figures 12 through 17 as a red line.

The observed data are typically above the load duration curve under wet, intermediate, and dry conditions. For locations above the Addicks and Barker Reservoirs (i.e., TCEQ monitoring locations 17484, 17482, and 17492), exceedances of the TMDL were observed less often than exceedances of the TMDL below the reservoirs (11362 and 11360). Exceedances of the TMDL in Whiteoak Bayou (11387) are similar in magnitude to Buffalo Bayou.

Mass Balance Analysis

A mass balance analysis was conducted using the Bacteria Load Estimator Spreadsheet Tool (BLEST), which was developed to determine indicator bacteria loads on segment-by-segment for the four TMDL watersheds. BLEST is designed to calculate or estimate the indicator bacteria loads and load reductions for each segment needed to attain the water quality standard for the segment. BLEST estimates load reductions for a fixed time interval and a given segment and does not incorporate the temporal variations associated with pathogen loads. It does, however, allow an evaluation of loads by subwatershed (Figure 6).

The indicator bacteria sources included in BLEST are divided into the waste load allocation (permitted sources), the load allocations (non-permitted sources), and the margin of safety. The waste load allocation sources include:

- wastewater treatment plant discharges
- storm water discharges (including discharges from MS4, industrial, and construction storm water permits).

Sources included in the load allocation include:

- septic system discharges;
- sediment resuspension from the stream bed

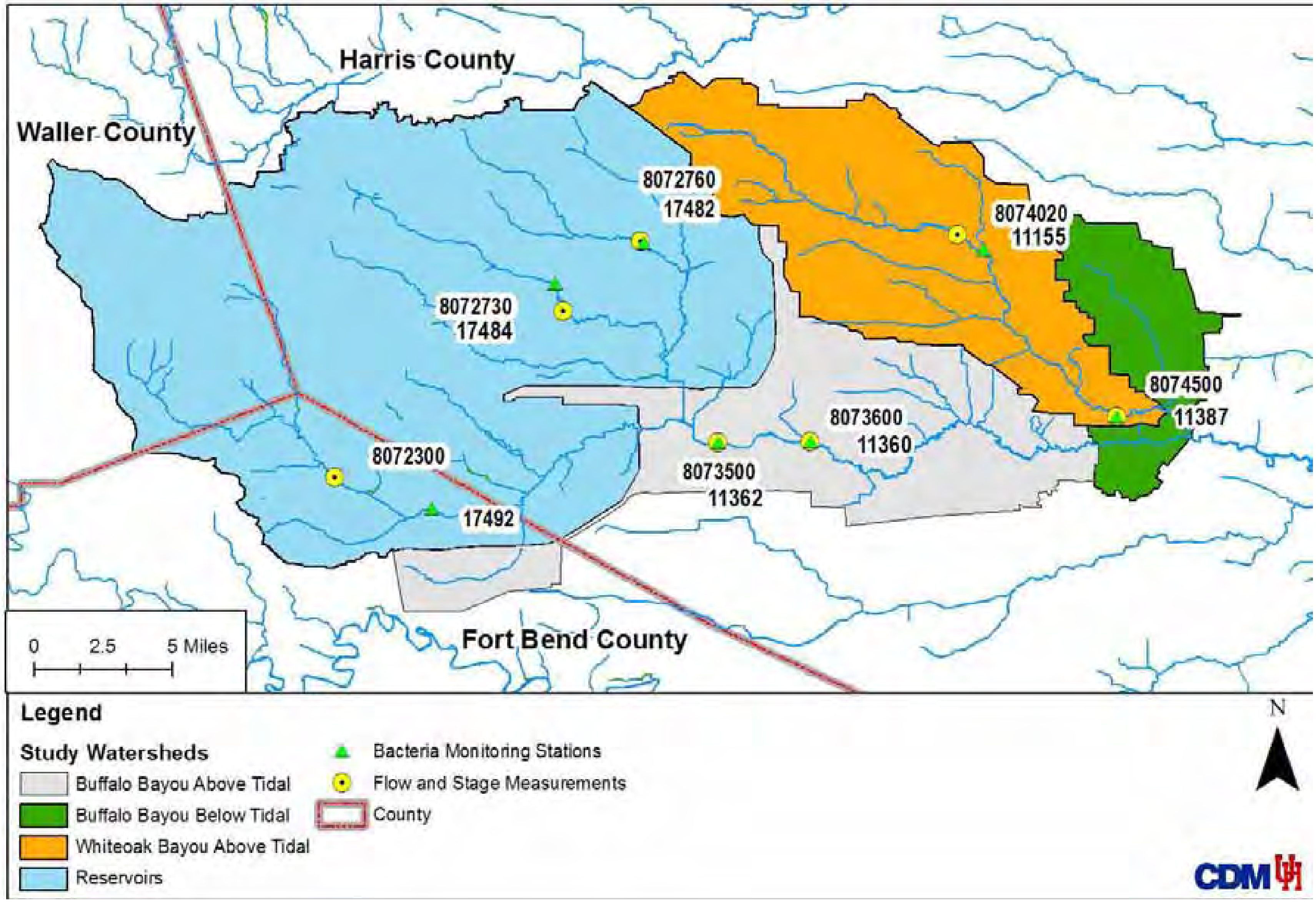


Figure 11. Location of Indicator Bacteria and USGS Stations Used for LDC Development

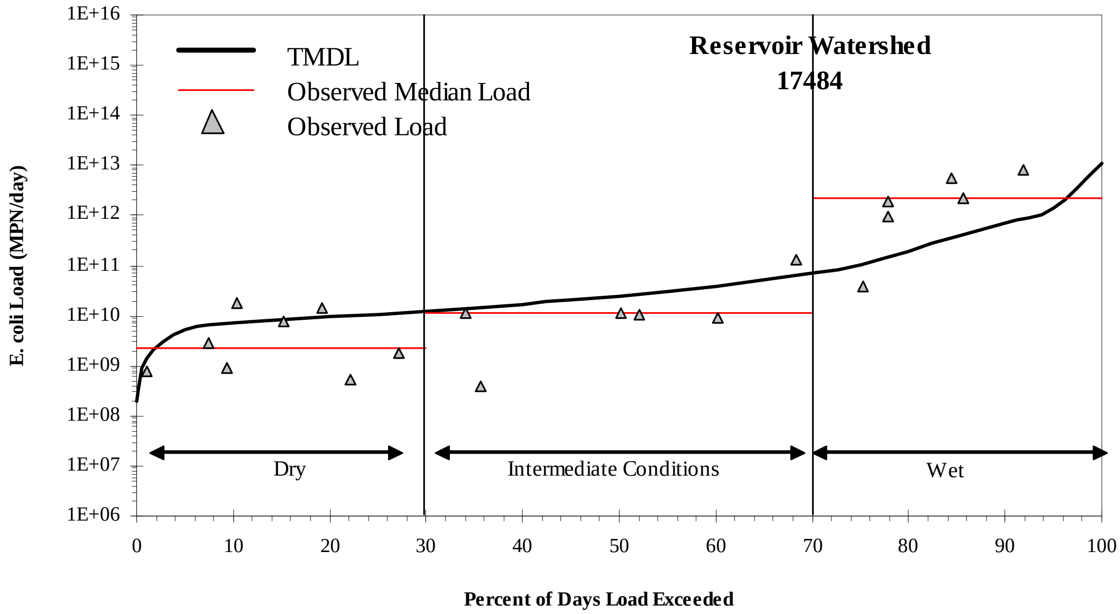


Figure 12. LDC for Sampling Location 17484 in Reservoirs watershed

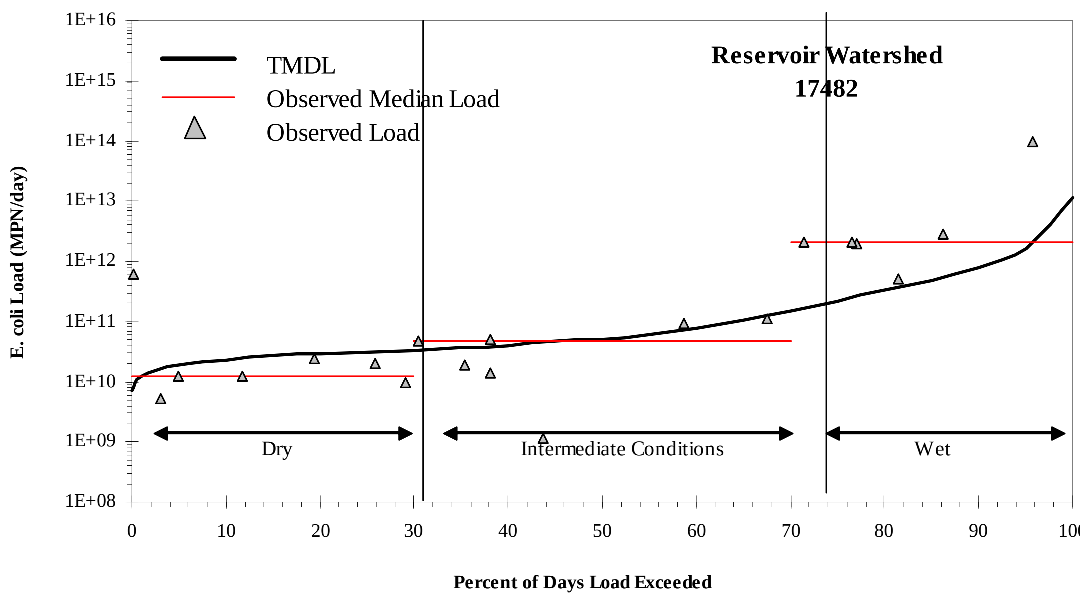


Figure 13. LDC for Sampling Location 17482 in Reservoirs watershed

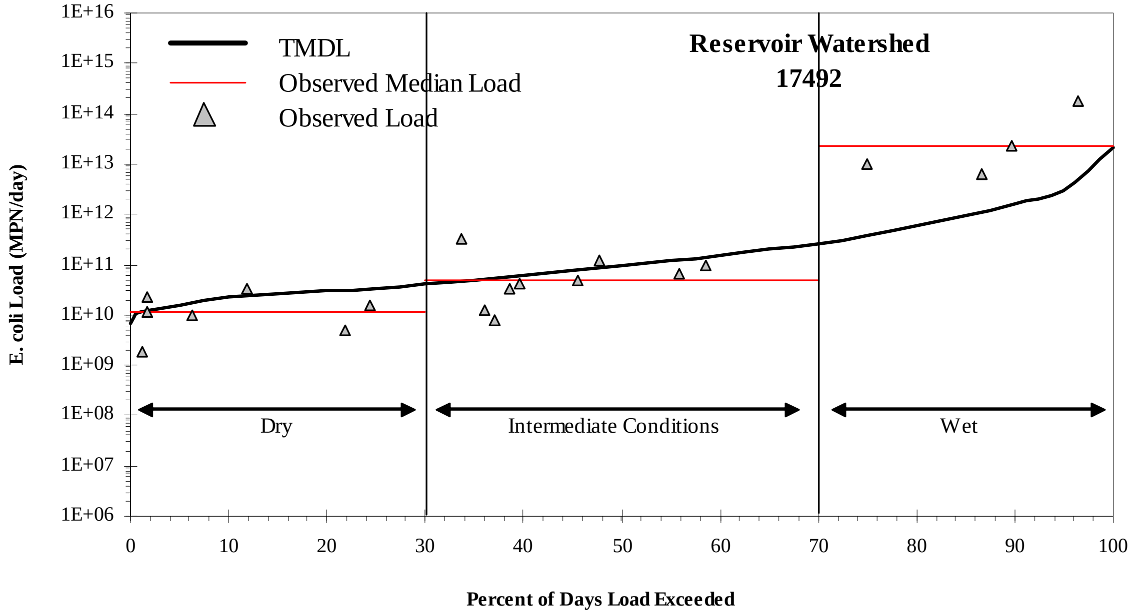


Figure 14. LDC for Sampling Location 17492 in Reservoirs watershed

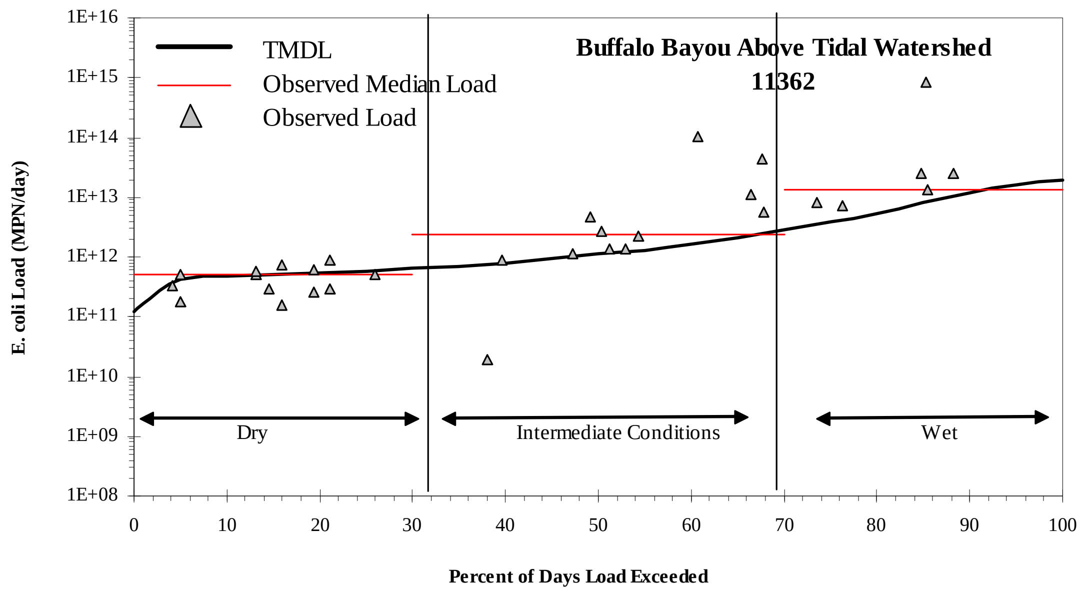


Figure 15. LDC for Sampling Location 11362 in Buffalo Bayou Above Tidal Watershed

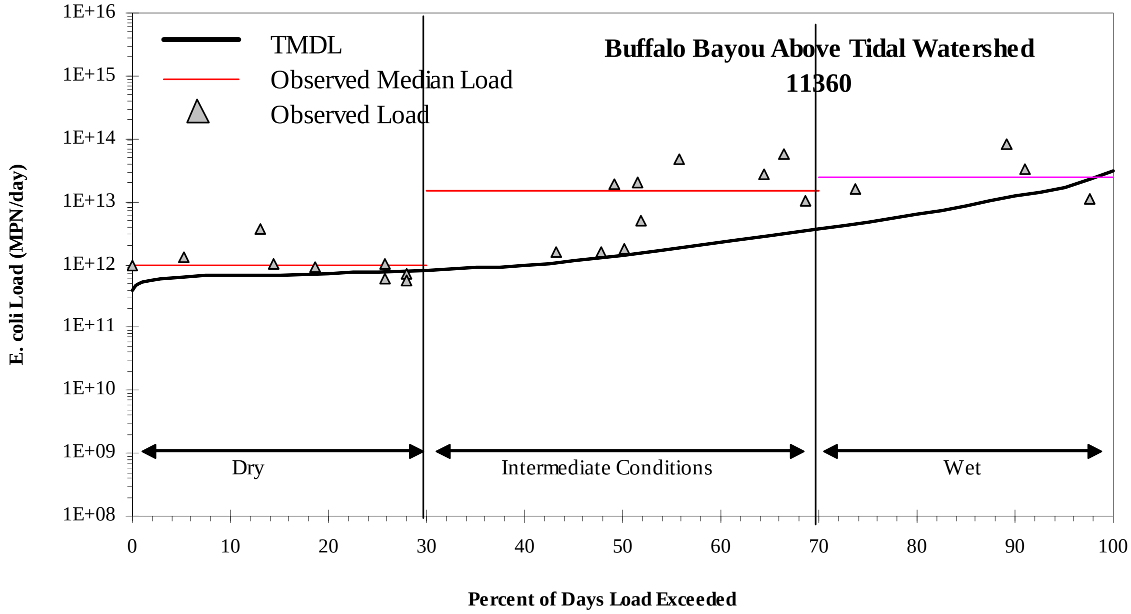


Figure 16. LDC for Sampling Location 11360 in Buffalo Bayou Above Tidal Watershed

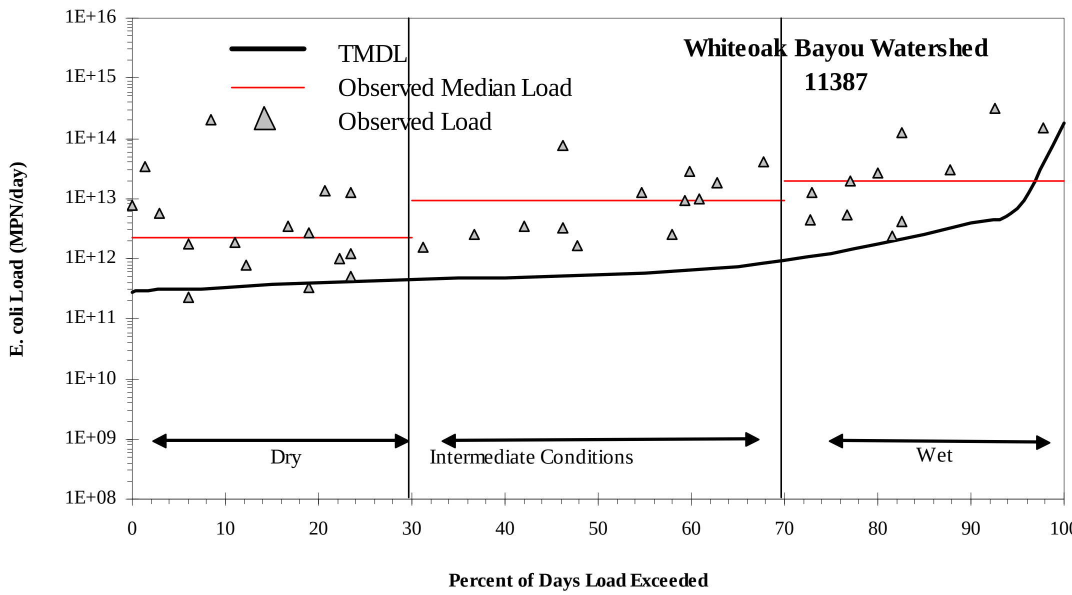


Figure 17. LDC for Sampling Location 11387 in Whiteoak Bayou Watershed

- nonpoint source direct input to the bayou via birds, wildlife, and other non-managed animals
- net die-off, settling, and other unaccounted-for processes.

For each source, a load associated with dry, intermediate, and wet weather was calculated. Dry-weather loads are defined as those present in the bayou when the bayou flow is close to that maintained solely by WWTF effluent. This represents a dry-weather condition with no influent or runoff from the watersheds. Typical travel times in the bayou are on the order of 5-7 days, but it may take considerably longer for all traces of runoff pollutants to exit the bayous.

The intermediate condition was assumed to be representative of median flow. The median flow in the bayou is 10-20 MGD higher than the dry condition described above. The difference between the two can be ascribed to small rain events and residual runoff from recent rain events. Therefore, the intermediate condition incorporates some effects of runoff into load calculations.

The wet-weather condition reflects flows received at the peak of a typical Houston rainfall event. Therefore, the wet-weather condition implemented in BLEST incorporates indicator bacteria sources that may be acting only under high-flow conditions, such as bed sediment resuspension.

The loads for the three different conditions are determined using data collected for this project. When actual data were not available, literature values were used to calculate indicator bacteria loading.

Some indicator bacteria sources are associated with specific flow conditions. For example, dry-weather storm-sewer discharge loads or dry-weather SSO discharge loads are specifically defined as loads that are outside the influence of runoff conditions. Direct deposition loads would generally be expected under dry or intermediate conditions as well, since animals typically take shelter in inclement conditions. Sediment resuspension, wet-weather SSOs, or wet-weather storm water discharge loads, on the other hand, are expected during periods of high flow that might follow a large runoff event. Finally, WWTF loads are constantly discharging into the bayou during both wet and dry conditions, although loading from the plants is assumed to be related to flow condition.

BLEST was compared to available water quality data between 2001 and 2003 using box plots. The BLEST flows and loads generally were consistent with the observations, but there were occasions when the BLEST flows and loads were at the extreme low or high end of the observations.

Load allocation values are negative because they include the capacity gained from die-off, settling, and other processes. The load from these processes is much greater than that from the other LA sources and thus it is negative.

Mass Balance Analysis Results

Reservoirs Watershed

In the reservoirs segments, the total instream load estimated from sources acting under dry weather was 1,331.22 billion MPN/day, as shown in Table 25. The TMDL target, also the same as the contact recreational target, is calculated as the estimated flow multiplied by the water quality standard. The target is 98.16 billion MPN/day, about one order of magnitude less than the load estimated in the stream. The dry-weather total load reflects the sum of dry-weather WWTF discharges, SSOs, dry-weather storm sewer flows, OSSFs, and direct deposition, as well as losses associated with die-off, settling, and other processes. The majority of the *E. coli* loading in this segment under dry-weather conditions stems from WWTF discharges. Because the Reservoirs watershed is the headwaters of Buffalo Bayou, there are no upstream sources of indicator bacteria loading.

Under intermediate conditions, the calculated load was determined to be 19,676.24 billion MPN/day, while the TMDL target was 353.08 billion MPN/day. The intermediate conditions reflect the sum of wastewater (which has been simulated with increased flow because of inflow and infiltration in the collection system), SSO, dry and wet-weather storm sewer discharge, OSSF, and direct deposition loads, as well as losses associated with die-off, settling, and other processes. During intermediate conditions, residual loading from wet-weather storm-sewer discharges is the largest contributor to *E. coli* loads.

Finally, during wet-weather conditions that represent a typical rainy day in Houston, based on the flow duration curve, the total estimated indicator bacteria load was 98,255.36 billion MPN/day. The TMDL target was calculated to be 1,096.73 billion MPN/day. The sources acting under wet weather include WWTFs (which are assumed to have increased flows from infiltration and inflow as well as biosolid releases), wet-weather discharges from storm sewers, septic systems, bed sediment resuspension, and losses associated with die-off, settling, and other unaccounted processes. Wet-weather loads, followed by bed sediment resuspension, are the largest contributor to indicator bacteria loading in the Reservoirs watershed.

Buffalo Bayou Above Tidal Watershed

The BLEST output for Segment 1014, shown here in Table 26, is calculated similarly to the output presented for the Reservoirs watershed segments. The one primary difference between the two segments is that Segment 1014 reflects the influence of upstream inputs from the Reservoirs watershed, included in the Upstream Sources block of the BLEST output.

Under dry-weather conditions, indicator bacteria loading for Segment 1014 was estimated to be 1,437.82 billion MPN/day. The TMDL target is calculated to be 186.94 billion MPN/day. The TMDL target is an increase of 88.78 billion MPN/day from the Reservoirs watershed to the Buffalo Bayou Above Tidal watershed. Estimated *E. coli* loads under intermediate conditions were calculated to be 43,634.34 billion MPN/day, with a target load of 747.05 billion MPN/day. Finally, wet-weather flow conditions were calculated to have an *E. coli* load of 171,349.99 billion MPN/day. The TMDL target load was calculated to be 2,101.84 billion MPN/day.

Buffalo Bayou Tidal Watershed

Output for the Buffalo Bayou Tidal watershed for BLEST is presented in Table 27. Under dry-weather conditions, indicator bacteria loading for Segment 1013 was estimated to be 1,457.91 billion MPN/day, just slightly higher than the dry-weather load for Segment 1014. This is because there are no WWTF discharges in this segment. The TMDL target was calculated to be 186.94 billion MPN/day.

Under intermediate conditions, instream indicator bacteria loads were calculated to be 44,328.07 billion MPN/day, with the primary source of loading being residual wet-weather loads. The TMDL target was calculated to be 755.60 billion MPN/day, almost two orders of magnitude less than the calculated instream load.

Finally, under wet-weather conditions, the instream load for Segment 1013 was determined to be 210,317.91 billion MPN/day, while the contact recreation target was 2,590.16 billion MPN/day. The majority of the instream loading was derived from wet-weather storm-sewer discharges associated with regulated storm water discharges.

Whiteoak Bayou Watershed

The BLEST output for the Whiteoak Bayou watershed is presented in Table 28. As shown in the table, dry-weather instream *E. coli* loads were calculated as 122.49 billion MPN/day, with the largest source of indicator bacteria loading associated with dry-weather storm-sewer discharges. The TMDL target load was determined to be 98.79 billion MPN/day. WWTF loads in the Whiteoak Bayou watershed are lower than those observed in the Reservoirs watershed segments, but greater than those observed in Segments 1013 and 1014.

Under intermediate conditions, instream indicator bacteria loads were calculated to be 5,334.25 billion MPN/day. The TMDL target was determined to be 170.34 billion MPN/day, more than one order of magnitude less than the instream load. The largest source of loading in intermediate stream flow conditions is residual loading from wet-weather sources, similar to Buffalo Bayou Above Tidal.

Finally, for wet-weather conditions, the largest source of indicator bacteria loading is storm sewer discharges, which contribute the majority of the instream load of 78,351.69 billion MPN/day. The TMDL target for wet-weather conditions is several orders of magnitude lower, at 1,083.66 billion MPN/day.

Table 25. BLEST Output for Reservoirs watershed

E. coli Sources	Instream Flow Condition Based on Flow Duration Curve					
	Dry (< 30th percentile)		Intermediate (30th - 70th percentile)		Wet (> 70th percentile)	
	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)
Waste Load Allocation		88.34		317.77		987.06
WWTFs						
WWTF Discharges	20.58	5,438.79	21.64	5,719.04	21.64	5,719.04
WWTF Biosolid Releases	-	-	-	-	1.29	127.55
SSO						
SSO - All Conditions	9.40E-05	16.74	9.40E-05	16.74	1.58E-03	20.94
Regulated Storm Water Discharges						
Dry-Weather Storm-Sewer Discharges	0.00	0.00	0.00	0.00	-	-
Wet-Weather Storm Water Discharges	-	-	52.39	81,936.42	207.01	323,778.18
Load Allocation		9.82		35.31		109.67
OSSF	8.02E-04	145.05	8.02E-04	145.05	8.02E-04	145.05
Bed Sediment	-	-	-	-	-	110,559.23
Direct Deposition	-	365.55	-	365.55	-	0.00
Net Die-off/Settling/Unaccounted Processes		-4,634.90		-68,506.55		-342,094.62
Upstream Input		0.00		0.00		0.00
Upstream Input from Reservoirs	0.00	0.00	0.00	0.00	0.00	0.00
Final Load Calculation						
Calculated Load	20.58	1,331.22	74.03	19,676.24	229.94	98,255.36
Contact Recreation Target (126 MPN/100mL)	20.58	98.16	74.03	353.08	229.94	1,096.73
TMDL Target	-	**98.16**	-	**353.08**	-	**1,096.73**

MGD = million gallons per day, MPN = most probable number, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTF = wastewater treatment plant

Table 26. BLEST Output for Buffalo Bayou Above Tidal Watershed

E. coli Sources	Instream Flow Condition Based on Flow Duration Curve					
	Dry (< 30th percentile)		Intermediate (30th - 70th percentile)		Wet (> 70th percentile)	
	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)
Waste Load Allocation		124.07		401.02		953.81
WWTFs						
WWTF Discharges	18.00	10.66	18.93	11.21	18.93	11.21
WWTF Biosolid Releases	-	-	-	-	1.13	111.55
SSO						
SSO - All Conditions	1.12E-04	19.97	1.12E-04	19.97	2.58E-03	34.14
Regulated Storm Water Discharges						
Dry-Weather Storm-Sewer Discharges	0.62	272.84	0.62	272.84	-	-
Wet-Weather Storm Water Discharges	-	-	63.06	106,894.47	190.67	323,215.52
Load Allocation		13.79		44.56		105.98
OSSF	1.70E-05	3.07	1.70E-05	3.07	1.70E-05	3.07
Bed Sediment	-	-	-	-	-	4,211.90
Direct Deposition	-	171.21	-	171.21	-	0.00
Net Die-off/Settling/Unaccounted Processes	-	-371.14	-	-83,414.66	-	-254,492.77
Upstream Input		49.08		301.47		1042.05
Upstream Input from Reservoirs	20.58	1,331.22	74.03	19,676.24	229.94	98,255.36
Final Load Calculation						
Calculated Load	39.19	1,437.82	156.63	43,634.34	440.67	171,349.99
Contact Recreation Target (126 MPN/100mL)	39.19	186.94	156.63	747.05	440.67	2,101.84
TMDL Target		**186.94**		**747.05**		**2,101.84**

MGD = million gallons per day, MPN = most probable number, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTF = wastewater treatment plant

Table 27. BLEST Output for Buffalo Bayou Tidal Watershed

E. coli Sources	Instream Flow Condition Based on Flow Duration Curve					
	Dry (< 30th percentile)		Intermediate (30th - 70th percentile)		Wet (> 70th percentile)	
	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)
Waste Load Allocation		82.80		94.76		531.76
WWTFs	0.00	0.00	0.00	0.00	0.00	0.00
WWTF Discharges	-	-	-	-	0.00	0.00
WWTF Biosolid Releases						
SSO						
SSO - All Conditions	1.38E-04	24.56	1.38E-04	24.56	2.56E-03	33.90
Regulated Storm Water Discharges						
Dry-Weather Storm-Sewer Discharges	5.36E-04	0.01	5.36E-04	0.01	-	-
Wet-Weather Storm Water Discharges			1.79	3,019.07	102.38	172,505.86
Load Allocation		9.20		10.53		59.08
OSSF	0.00E+00	0.00	0.00E+00	0.00	0.00E+00	0.00
Bed Sediment	-	-	-	-	-	2,102.32
Direct Deposition	-	65.46	-	65.46	-	0.00
Net Die-off/Settling/Unaccounted Processes	-	-69.94	-	-2,415.36	-	-135,674.17
Upstream Input		94.94		650.31		1,996.32
Upstream Input from Segment 1014	39.19	1,437.82	156.63	43,634.34	440.67	171,349.99
Final Load Calculation						
Calculated Load	39.19	1,457.91	158.42	44,328.07	543.05	210,317.91
Contact Recreation Target (126 MPN/100mL)	39.19	186.94	158.42	755.60	543.05	2,590.16
TMDL Target	**-**	**186.94**	**-**	**755.60**	**-**	**2,590.16**

MGD = million gallons per day, MPN = most probable number, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTF = wastewater treatment plant

Table 28. BLEST Output for Whiteoak Bayou Watershed

E. coli Sources	Instream Flow Condition Based on Flow Duration Curve					
	Dry (< 30th percentile)		Intermediate (30th - 70th percentile)		Wet (> 70th percentile)	
	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)	Flow (MGD)	Load (billion MPN/day)
Waste Load Allocation		88.91		153.31		975.30
WWTFs						
WWTF Discharges	20.03	41.94	21.06	44.10	21.06	44.10
WWTF Biosolid Releases	-	-	-	-	1.26	124.16
SSO						
SSO - All Conditions	1.22E-04	21.77	1.22E-04	21.77	2.36E-03	31.26
Regulated Storm Water Discharges						
Dry-Weather Storm-Sewer Discharges	0.68	248.95	0.68	248.95	-	-
Wet-Weather Storm Water Discharges	-	-	13.97	23,355.31	204.88	342,538.83
Load Allocation		9.88		17.03		108.36
OSSF	5.79E-04	104.66	5.79E-04	104.66	5.79E-04	104.66
Bed Sediment	-	-	-	-	-	8,304.91
Direct Deposition	-	131.65	-	131.65	-	0.00
Net Die-off/Settling/Unaccounted Processes		-426.47		-18,572.19		-272,796.22
Upstream Input		0.00		0.00		0.00
Upstream Input from Segment 1014	0.00	0.00	0.00	0.00	0.00	0.00
Final Load Calculation						
Calculated Load	20.71	122.49	35.71	5,334.25	227.20	78,351.69
Contact Recreation Target (126 MPN/100mL)	20.71	98.79	35.71	170.34	227.20	1,083.66
TMDL Target	-	**98.79**	-	**170.34**	-	**1,083.66**

MGD = million gallons per day, MPN = most probable number, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTF = wastewater treatment plant

Hydrologic Simulation Program FORTRAN Analysis

Hydrologic Simulation Program FORTRAN (HSPF) models for the simulation of *E. coli* were developed for Buffalo and Whiteoak Bayous. The models include indicator bacteria associated with the water column, suspended sediments, and sediments on the streambed. Sediment transport as well as scour and deposition were simulated. Indicator bacteria build-up and wash-off in the watersheds were also included in the simulations.

Model set-up included developing the datasets for the following:

- Physical Input
  - Delineation of Subwatersheds
  - Meteorological Data
  - Land Use Discretization
  - Soil Characteristics
  - Hydrologic Data
- Model input and parameters associated with flow
  - Constant inputs
  - Time-varying inputs
- Model input and parameters associated with indicator bacteria sources
  - Constant inputs
  - Time-varying inputs
- Fate and transport
  - Die-off

There are several sources of indicator bacteria that have associated flows. These sources include WWTFs, SSOs, dry-weather storm-sewer discharges, wet-weather storm-sewer discharges, and OSSFs. Of these sources, only wet-weather storm-sewer flows are simulated in HSPF, and are adjusted through the calibration process. Direct deposition was also adjusted slightly across the watershed to improve calibration. The remaining sources were input into HSPF as a point source in each subwatershed.

The watersheds included in this report are dominated by WWTF flows under dry-weather conditions; thus, these discharges are critical to any simulation. An algorithm was developed to disaggregate self-reported monthly flows into hourly values that represent dry, intermediate, and wet-weather flows from the plants. The time-varying flow associated with each plant was processed and input as a point source into their respective subwatersheds. The remaining source flows, including SSOs, dry-weather storm-sewer discharges, and OSSFs, were input into the model as a constant flow.

Inputs to simulate the fate and transport of *E. coli* in HSPF include WWTFs, SSOs, dry-weather storm-sewer discharges, wet-weather storm-sewer discharges, OSSFs, direct deposition, and sediment resuspension. In addition, the HSPF model simulates losses of indicator bacteria through die-off and settling. SSOs, dry-weather storm-sewer discharges, OSSFs, and direct deposition are all input directly into HSPF as point sources for each subwatershed. The remaining sources, WWTFs, wet-weather storm-sewer discharges, sediment resuspension, and indicator bacteria losses are simulated in HSPF as dynamic processes. The WWTF input is determined by taking the time-varying flow calculated for the hydrology calibration and multiplying it by measured and estimated concentrations. The remaining sources are simulated explicitly in HSPF.

The development of indicator bacteria parameters for calibration of the HSPF model focused on matching the distribution of indicator bacteria concentrations in the bayous so that all modeled values were within the 95 percent confidence interval of the observed data. In addition, the model parameters were maintained within a pre-determined range of values that were specified based on watershed-specific data and literature values.

The statistical comparison of the final calibration to observed values is presented in Table 29 for the Whiteoak Bayou watershed. The percent error for each station was calculated as the difference between observed and modeled geometric mean, divided by the observed value. The majority of the overall errors in the statistical model comparison were less than 30 percent, with high and low flow comparisons exhibiting a wider range of errors because of the smaller data set, and increased variability at those flow regimes.

Longitudinal plots of paired observed and modeled values for Whiteoak Bayou watershed are shown in Figure 18. Samples taken from locations in Whiteoak Bayou—Heights, Ella, and West 43rd—were used to assess the reliability of the model. Shown on the figures are the confidence interval about each geometric mean for the overall conditions (A) as well as geometric means calculated using paired data under flow less than the median (B) and flows greater than the median (C). As shown in the figures, the confidence intervals about the observed data points sometimes range several orders of magnitude, indicating that the data used to calculate the geometric means are variable. Regardless, the confidence intervals routinely overlap for the model and observed points, suggesting that the concentrations are not that different from a statistical perspective.

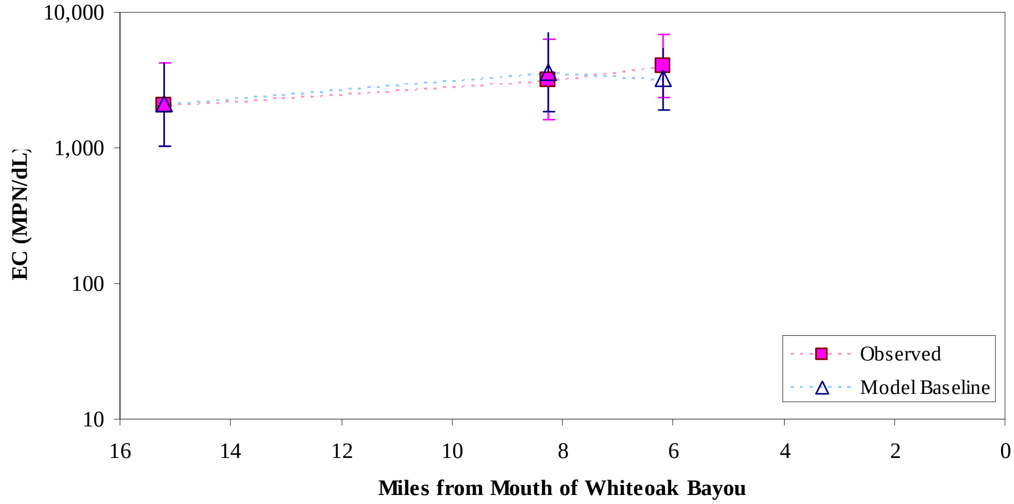
The Buffalo Bayou model results are presented in Table 30. The majority of the model result errors are 30 percent or less during the overall flow condition. Low and high-flow conditions exhibit higher degrees of error, with some errors exceeding 100 percent. The low flow error generally exhibits the highest percent errors of all flow conditions.

The Langham Creek and Eldridge calibration locations exhibit high percent errors. These errors were investigated to determine if they could be reduced by adjusting the model calibration. Based on this evaluation, it was determined that several WWTFs in the Langham Creek watershed had high concentrations of indicator bacteria measured in their discharge during the 2006 sampling conducted by the TCEQ. The effect of these WWTFs is projected downstream of the creek, causing over-prediction of indicator bacteria concentrations at Addicks, Eldridge, and Dairy Ashford. Although the high bacteria concentrations in these plants appear to be abnormally high, the WWTF concentrations were measured, and therefore were not adjusted to improve the model calibration.

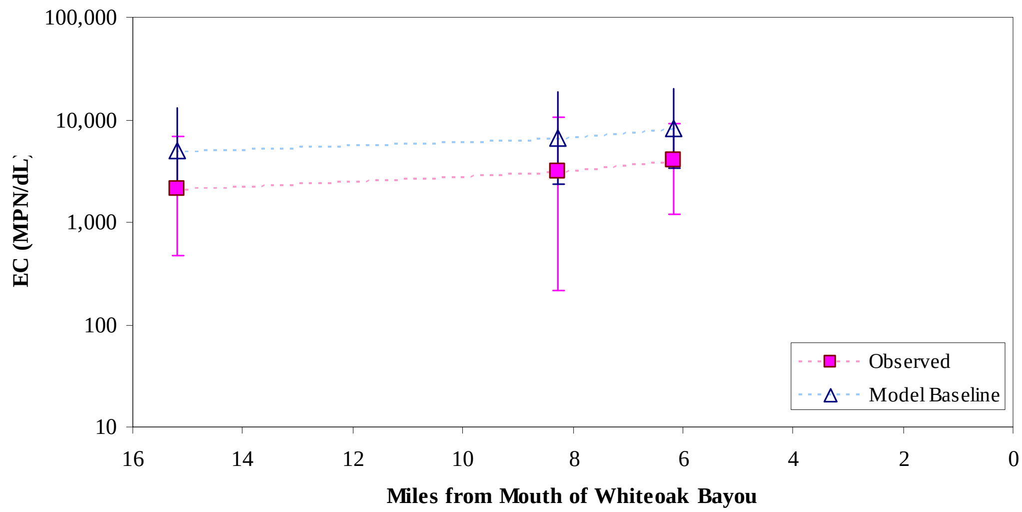
Finally, a comparison of paired model and observed geometric means are shown in Figure 19. The sampling locations in Buffalo Bayou Above Tidal—Highway 6, Eldridge, Dairy Ashford, West Belt, Briar Forest, Voss, Chimney Rock, and Shepherd—were used to assess the reliability of the model. The variability in observed values is generally quite large; thus, the error bars span several orders of magnitude. Even though the variability associated with these points is quite high, the model is able to reproduce the geometric mean concentrations acceptably, as demonstrated by the close nature of the observed and modeled geometric mean concentrations.

Table 29. Whiteoak Bayou Calibration for *E. coli* Geometric Means (MPN/100mL)

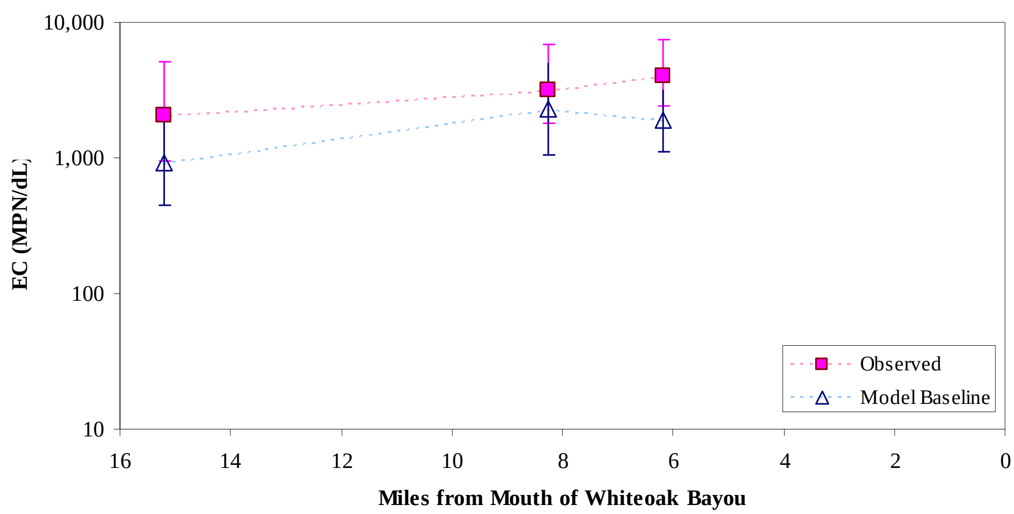
	Heights Blvd (11387)			Little Whiteoak Bayou (16648)		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	4,062.9	2,879.0	-29%	10,767.9	12,181.1	13%
High Flow	7,341.0	5,615.4	-24%	14,764.1	23,217.7	57%
Low Flow	2,108.9	1,600.3	-24%	12,485.4	12,251.8	-2%
Flow < median	6,646.3	6,170.0	-7%	9,193.5	17,662.5	92%
Flow > median	3,084.2	1,878.7	-39%	13,224.4	7,122.1	-46%
	Cole Creek @ Bolivia (16593)			**West 43rd (15829)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	2,639.1	1,747.7	-34%	2,086.1	2,552.4	22%
High Flow	3,723.9	3,629.5	-3%	4,798.2	5,148.9	7%
Low Flow	1,182.3	698.2	-41%	1,396.2	1,034.9	-26%
Flow < median	5,143.7	4,745.0	-8%	2,433.1	5,277.3	117%
Flow > median	1,431.5	699.6	-51%	1,811.7	1,311.5	-28%
	Ella (11391)			**Brickhouse Gully (16594)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	3,185.9	3,274.4	3%	3,860.5	6,007.9	56%
High Flow	6,639.8	6,387.7	-4%	14,872.5	5,160.8	-65%
Low Flow	1,391.7	1,929.0	39%	1,600.8	5,901.5	269%
Flow < median	4,962.0	5,830.5	18%	5,420.9	5,576.9	3%
Flow > median	2,265.7	2,100.8	-7%	2,665.7	6,516.2	144%



(A) Paired Geometric Means Under All Flow Conditions



(B) Paired Geometric Means When Flows are Less than Median



(C) Paired Geometric Means When Flows are Greater than Median

Figure 18. Longitudinal Plots for Whiteoak Bayou

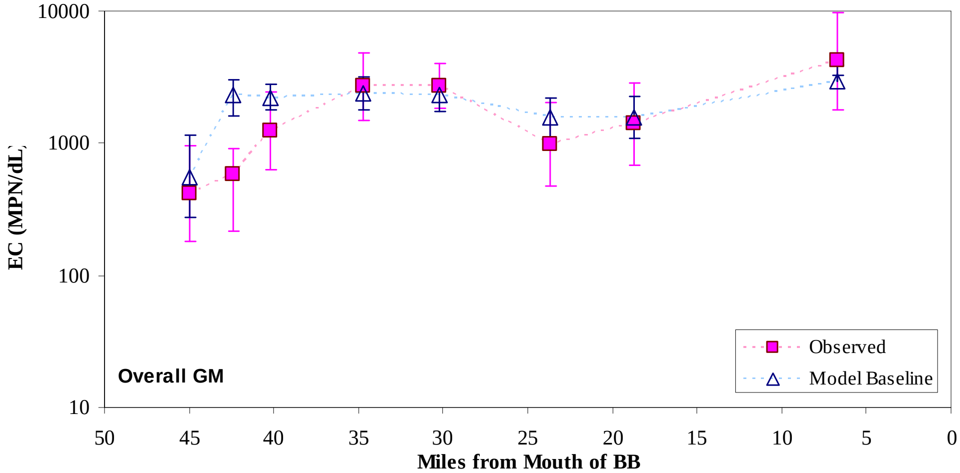
Table 30. Buffalo Bayou Calibration for *E. coli* Geometric Means (MPN/100mL)

	Langham Creek at SH 6 (17842)			Bear Creek @ Old Greenhouse (17484)		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	545.0	5,731.5	952%	372.4	372.6	0%
High Flow	2,949.0	3,789.6	29%	4,759.3	257.9	-95%
Low Flow	179.6	8,945.7	4881%	97.6	639.8	555%
Flow < median	206.4	7,565.0	3564%	131.8	507.4	285%
Flow > median	1,785.3	4,082.6	129%	1,052.3	273.7	-74%
	S. Mayde Creek at Groeschek Rd. (17493)			**Mason Creek at Park Pine Rd. (17494)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	414.7	384.4	-7%	1147.1	818.8	-29%
High Flow [2]	4,731.4	425.4	-91%	6,119.9	1,616.3	-74%
Low Flow [3]	122.2	445.0	264%	1,076.6	319.6	-70%
Flow < median	95.2	503.8	429%	464.7	412.6	-11%
Flow > median	1,807.0	293.3	-84%	2,402.4	1,434.3	-40%
	Highway 6 (11364)			**Eldridge (11363)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	414.3	548.1	32%	579.2	2,328.2	302%
High Flow	734.7	1,590.3	116%	746.8	2,038.8	173%
Low Flow	169.3	434.3	157%	302.8	3,194.1	955%
Flow < median	263.3	407.4	55%	905.6	1,867.7	106%
Flow > median	772.9	824.3	7%	338.8	3,033.0	795%
	West Belt (11360)			**Briar Forest (15846)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	2,695.8	2,387.8	-11%	2,707.2	2,303.6	-15%
High Flow	5,797.7	3,255.3	-44%	10,157.9	3,369.5	-67%
Low Flow	611.3	1,998.0	227%	442.2	1,728.5	291%
Flow < median	5,120.0	2,819.3	-45%	752.9	1,730.0	130%
Flow > median	1,004.8	1,849.4	84%	6,822.1	2,832.9	-58%

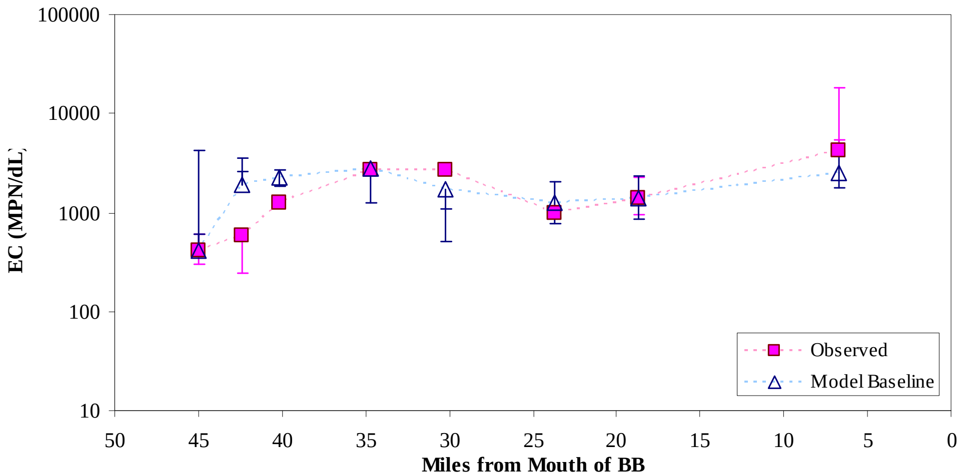
	Chimney Rock (15845)			Shepherd (11351)		
	Observed	Modeled	Error	Observed	Modeled	Error
Overall	1,402.7	1565.8	12%	4,192.8	2,948.7	-30%
High Flow	2,561.7	2046.4	-20%	7,469.4	3,582.5	-52%
Low Flow	512.2	1473.7	188%	1,088.2	2,431.8	123%
Flow < median	932.5	1398.1	50%	1,695.8	2,520.6	49%
Flow > median	2,459.1	1829.7	-26%	6,723.7	3,200.1	-52%

	Buffalo Bayou at Peek Rd. (17492)			Addicks (11163)		
	Observed	Modeled	Error	Observed	Modeled	Error
Overall	567.7	690.1	22%	495	2,956	497%
High Flow	6,244.7	615.3	-90%	436	1,582	263%
Low Flow	204.2	852.0	317%	382	4,408	1055%
Flow < median	209.6	862.9	312%	446	2,093	369%
Flow > median	1,282.7	574.8	-55%	570	3,799	566%

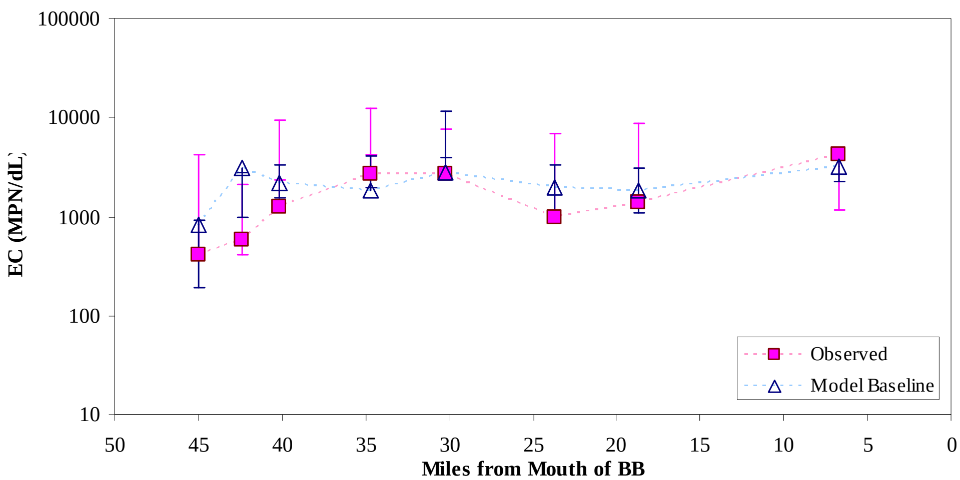
	Dairy Ashford (11362)			Voss (11356)		
	Observed	Modeled	Error[1]	Observed	Modeled	Error[1]
Overall	1,244.0	2,230.8	79%	993.3	1,551.8	56%
High Flow	4,137.7	3,051.9	-26%	1,810.6	1,997.1	10%
Low Flow	351.6	2,376.2	576%	408.1	1,477.9	262%
Flow < median	3,508.0	2,261.9	-36%	489.2	1,256.4	157%
Flow > median	354.6	2,193.7	519%	2,181.8	1,962.0	-10%



(A) Paired Geometric Means under All Conditions



(B) Paired Geometric Means When Flows are Less than Median



(C) Paired Geometric Means When Flows are Greater than Median

Figure 19. Longitudinal Plots for Buffalo Bayou

Margin of Safety

The margin of safety (MOS) should account for uncertainty in the analysis used to develop the TMDL and thereby 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 method assumptions to develop allocations; and
- 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 control strategies for the complex environmental processes that affect water quality. Quantification of this uncertainty, to the extent possible, is the basis for assigning a margin of safety.

The TMDLs covered by this report use an implicit margin of safety for a number of reasons. By using three methods to analyze indicator bacteria loads, the uncertainty in establishing the allocations is reduced. The method used to establish WWTF loads requires a reduction in loads below current requirements. Where possible, the values and assumptions used in the three methods were chosen to be a protective as possible. In addition, the water quality standards for contact recreation have many assumptions built in that are protective of human health, so that by using the standard as the TMDL target, an additional margin of safety is added.

Pollutant Load Reductions

The estimates of pollutant load reductions was based on the best available data and analyzed using three methods. The pollutant load reduction analyses show which sources are significant contributors of indicator bacteria to the water bodies. This helps the stakeholders prioritize their efforts during the development of the implementation plan.

Load Duration Curves (LDCs)

Although LDCs can be developed for all flow gauges in Buffalo Bayou, load reductions for segments 1013 and 1014 could not be determined because the Addicks and Barker reservoirs exert influence on the flow regime. Additional LDC curves for 17482, 17484, and 17492 were generated, but they have limited data (56 points per flow condition). Thus, these allocations may be unreliable. Therefore, load reductions based upon the LDCs were developed only for the Whiteoak Bayou watershed and are shown in Table 31.

The U.S. EPA (2006) specifies a methodology in their document *An Approach for Using Load Duration Curves in the Development of TMDLS* for calculating the WLA for continuous discharges. According to this document, the load should be calculated as the permitted flow from all WWTFs discharging to the segment multiplied by the single-sample criterion (394MPN/100mL). For the TMDLs in this report, one-half of the single-sample criterion (197MPN/100mL) was used because of instream and downstream capacity considerations.

Table 31. Load Duration Curve Allocations for Whiteoak Bayou Watershed (1017)

(Loads presented in Billion MPN/day)

Condition		Flow condition			
		All	Dry	Intermediate	Wet
Existing Loads[1]		5,432	2,246	9,540	19,418
Allocated Loads	WLA_{WWTF}	336	336	336	336
	$WLA_{Storm\ Water}$	162	0	196	2,561
	LA	18	16	22	284
TMDL [2]		516	352	554	3,181
Percent Reduction		91%	84%	94%	84%

[1] calculated as the median of the observed loads for the flow condition of interest

[2] calculated as the median of the TMDL loads for the flow condition of interest

WLA_{WWTF} – waste load allocation for WWTF discharges

$WLA_{Storm\ Water}$ – waste load allocation for storm water discharges

The large numbers of WWTF discharges are widely distributed throughout the Buffalo Bayou Above Tidal, Reservoirs, and Whiteoak watersheds. These discharges compose all of the low, non-storm water flow. If WWTFs were to discharge at the water quality criteria, there would be no capacity to accommodate other loads and downstream discharges. This problem is especially significant for the Buffalo Bayou Tidal watershed, which currently has no WWTF discharges. Buffalo Bayou Above Tidal (1014) and Whiteoak Bayou (1017) provide the low flow base for Buffalo Bayou Tidal (1013) because there are no dischargers within the Buffalo Bayou Tidal watershed.

If the discharges in both of these upstream segments are at the water quality criteria, there is no capacity for the Buffalo Bayou Tidal watershed. For the Whiteoak Bayou watershed, the load for WWTFs used a value of 336 billion MPN per day that was calculated using a permitted flow of 45.1 MGD and *E. coli* concentration of 197 MPN/100 mL.

Load duration curves are based on the entire flow regime, but the analysis of them focused on three flow regimes:

- dry or low flow (less than 30th percentile), where WWTF discharges dominate;
- intermediate conditions (between the 30th and 70th percentiles), where contributions are from low flow and high flow sources; and
- wet or high flow conditions (flows greater than the 70th percentile), where storm water discharges dominate.

The existing load was calculated as the median value of the observed loads plotted on the LDC for each flow regime of interest. The TMDL was the median of the single-sample criterion for each flow condition. Load reductions range from 84 percent under dry-weather conditions to 94 percent under intermediate weather conditions.

The load remaining after the WWTF loading is subtracted from the TMDL was divided between the WLA for storm water discharges and the LA. Under dry-flow conditions, the entire remaining load was assigned to the LA because storm water discharges do not contribute to low flow conditions. For wet and intermediate flow conditions, 90 percent of the remaining load was assigned to the storm water discharges and 10 percent was assigned to the LA. The LA determined using the BLEST tables was assigned to the LA and the remaining load was assigned to the storm water discharges.

Mass Balance

The Bacteria Load Estimation Spreadsheet Toll (BLEST) is a spreadsheet approach that accounts for all the potential sources of indicator bacteria loading in the watershed, based on measured data or literature values. Using the loads predicted by BLEST, waste load and load allocations were determined for the four watersheds. A summary of estimated loads along with the allocated loads and required percent reductions is presented in Table 32.

The indicator bacteria load was distributed between the WLA and LA, with the WLA receiving 90 percent of the TMDL and the LA receiving 10 percent of the TMDL. The WLA was then calculated as the TMDL minus any upstream inputs from other segments multiplied by 90 percent.

The TMDL target was calculated using the geometric mean concentration of 126 MPN/dL, as representative of long-term conditions. The margin of safety was included implicitly. Upstream loading was calculated by assigning flows associated with WWTFs an *E. coli* concentration of one-half of the geometric mean criterion (63 MPN/dL), while the remaining upstream flows from other sources were assigned the *E. coli* geometric mean criterion (126 MPN/dL).

The final percentage reductions in waste load range from a 59 percent reduction in dry-weather condition loads in the Whiteoak Bayou watershed to almost a 100 percent load reduction in many of the intermediate and wet-weather flow-condition loading scenarios.

Table 32. Allocated Loads (Billion MPN/day) and Percent Reductions using BLEST

Description		Buffalo Bayou Above Tidal Watershed			Buffalo Bayou Tidal Watershed		
		Dry	Intermediate	Wet	Dry	Intermediate	Wet
Existing	WLA	303	107,198	323,372	25	3,044	172,540
	LA	-197	-83,240	-250,278	-4	-2,350	-133,572
Allocated	WLA	124	401	954	83	95	532
	LA	14	45	106	9	11	59
	Upstream Input	49	301	1,042	95	650	1,996
TMDL		187	747	2,102	187	756	2,590
Percent Reduction	WLA	59%	99.6%	99.7%	0%	96.8%	99.7%
	LA	0%	0%	0%	0%	0%	0%

Description		Whiteoak Bayou Watershed			Reservoirs Watershed		
		Dry	Intermediate	Wet	Dry	Intermediate	Wet
Existing	WLA	313	23,670	342,738	5,456	87,672	329,646
	LA	-190	-18,336	-264,387	-4,124	-67,996	-231,390
Allocated	WLA	89	153	975	88	318	987
	LA	10	17	108	10	35	110
	Upstream Input	0	0	0	0	0	0
TMDL		99	170	1,083	98	353	1,097
Percent Reduction	WLA	72%	99.4%	99.7%	98.4%	99.6%	99.7%
	LA	0%	0%	0%	0%	0%	0%

Hydrologic Simulation Program FORTRAN (HSPF)

The third method used to evaluate load reductions was the HSPF model. The HSPF model was evaluated for three load reductions scenarios—75 percent, 85 percent, and 95 percent reductions of the permitted and non-permitted a loads. The 75 percent reduction was selected as the minimum reduction for evaluation because it was consistent with the low-end of reductions determined using BLEST and LDCs. Each of the reduction scenarios was evaluated for four flow conditions—all flow conditions, dry-weather conditions (flows less than the 30th percentile), intermediate conditions (flows between the 30th and 70th percentiles), and wet weather (flows greater than the 70th percentile).

The Buffalo and Whiteoak Bayou HSPF output for each segment was evaluated to determine the percentage of single sample exceedances as well as their geometric means over the entire simulation period. The daily time period, the daily average flow, and bacteria concentration were calculated for each day. These values were then used to develop all calculations, including the percent exceedance, geometric mean, and evaluation of monthly geometric means. Simulations were run to evaluate the effects of the individual reductions in the WLA and LA loads. The WLA was held static while the LA was reduced. Alternatively, the LA was held static while the WLA was reduced. This provides an assessment of relative magnitudes of the two loads and it identifies where reductions will have the greatest effect. In order for the stream to meet the water quality standard, the geometric mean of model output must be less than 126 MPN/100mL and the single-sample criterion exceedances must be less than 25 percent.

The results of the percent exceedances analysis are presented in Tables 33 through 36. As shown in the tables, the LA reductions had little impact on the percent exceedances, with only the dry-weather reservoir evaluation demonstrating any reduction in exceedances at all. The WLA reductions, however, had more impact. In Segment 1013, the 75 percent reduction scenario decreased the percent exceedances from nearly 100 percent to between 85 percent and 89 percent for the various flow conditions. The 95 percent reduction decreased the percent exceedances to 29 percent in wet weather, thus meeting the single-sample criterion. For the other segments, a similar pattern is observed, with the 95 percent reductions resulting in some flow conditions meeting the single-sample criterion.

In Tables 37 through 40, the results of the reductions on the geometric mean of the entire simulation period are presented. Unlike the percent exceedances analyses, the model results generally come close to the geometric mean criterion but never below it.

Table 33. Percent Exceedance of Single-Sample Criterion for HSPF Model Runs for Buffalo Bayou Tidal Watershed

Buffalo Bayou Tidal Watershed						
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		100	100	100	100
WLA	75%	87	85	89	87
	85%	73	69	79	69
	95%	40	29	48	39
LA	75%	100	100	100	100
	85%	100	100	100	100
	95%	100	100	100	100

Table 34. Percent Exceedance of Single-Sample Criterion for HSPF Model Runs for Buffalo Bayou Above Tidal Watershed

Buffalo Bayou Above Tidal Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		100	100	100	100
WLA	75%	85	90	85	80
	85%	66	68	72	57
	95%	29	20	42	22
LA	75%	100	100	100	100
	85%	100	100	100	100
	95%	100	100	100	100

Table 35. Percent Exceedance of Single-Sample Criterion for HSPF Model Runs for Whiteoak Bayou Watershed

Whiteoak Bayou Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		99	100	100	98
WLA	75%	79	59	84	93
	85%	72	50	75	90
	95%	47	22	43	77
LA	75%	94	86	97	98
	85%	94	86	97	98
	95%	94	86	97	98

Table 36. Percent Exceedance of Single-Sample Criterion for HSPF Model Runs for Reservoirs Watershed

Reservoirs Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		99	97	100	100
WLA	75%	89	97	96	73
	85%	76	96	83	46
	95%	46	91	38	12
LA	75%	99	97	100	100
	85%	99	96	100	100
	95%	99	96	100	100

Table 37. Geometric Mean of Entire HSPF Simulation Period for Buffalo Bayou Tidal Watershed

Buffalo Bayou Tidal Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		3,241	2,292	3,820	3,685
WLA	75%	1,091	843	1,301	1,119
	85%	736	595	873	725
	95%	321	293	370	291
LA	75%	3,188	2,212	3,776	3,670
	85%	3,181	2,201	3,770	3,669
	95%	3,174	2,190	3,765	3,667

Table 38. Geometric Mean of Entire HSPF Simulation Period for Buffalo Bayou Above Tidal Watershed

Buffalo Bayou Above Tidal Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		2,236	1,894	2,476	2,305
WLA	75%	858	748	1,031	771
	85%	595	541	720	509
	95%	270	281	320	207
LA	75%	2,189	1,814	2,435	2,294
	85%	2,183	1,803	2,429	2,292
	95%	2,176	1,792	2,424	2,291

Table 39. Geometric Mean of Entire HSPF Simulation Period for Whiteoak Bayou Watershed

Whiteoak Bayou Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		4,700	2,580	4,307	9,615
WLA	75%	1,203	621	1,199	2,340
	85%	780	425	768	1,461
	95%	342	216	327	573
LA	75%	4,181	1,902	4,301	8,851
	85%	4,165	1,885	4,290	8,845
	95%	4,148	1,868	4,278	8,838

Table 40. Geometric Mean of Entire HSPF Simulation Period for Reservoirs Watershed

Reservoirs Watershed					
Source Reduced	**% Reduction**	**All**	**Dry**	**Intermediate**	**Wet**
Baseline		2,612	3,248	2,879	1,846
WLA	75%	933	1,214	1,050	613
	85%	649	884	728	409
	95%	313	496	345	174
LA	75%	2,514	3,007	2,795	1,827
	85%	2,499	2,967	2,783	1,824
	95%	2,482	2,923	2,771	1,821

Although the model has the ability to simulate an indicator bacteria concentration every hour to obtain an average daily *E. coli* concentration, samples cannot be collected with such frequency. Instead, the TCEQ collects routine monitoring samples at most monitoring stations approximately once per month. Therefore, the geometric means of the minimum and maximum daily values for each month were tabulated as shown in Tables 41 through 44. These values give upper and lower bounds on the potential range of geometric means that might be observed in any given month. As these values show, the *E. coli* concentrations fall below the water quality standard for all segments except Buffalo Bayou Tidal (1013) when the WLA is reduced by 95 percent.

These findings suggest that a combination of WLA and LA reductions will be required across the watershed, and that reductions greater than 95 percent will be necessary to achieve water quality standards under all three flow conditions.

Table 41. Monthly Geometric Mean over HSPF Simulation Period for Buffalo Bayou Tidal Watershed

Buffalo Bayou Tidal Watershed			
Source Reduced	**% Reduction**	**Minimum**	**Maximum**
Baseline		1,067	12,955
WLA	75%	373	4,390
	85%	261	2,999
	95%	133	1,264
LA	75%	1,017	12,935
	85%	1,010	12,932
	95%	1,004	12,930

Table 42. Monthly Geometric Mean over HSPF Simulation Period for Buffalo Bayou Above Tidal Watershed

Buffalo Bayou Above Tidal Watershed			
Source Reduced	**% Reduction**	**Minimum**	**Maximum**
Baseline		1,651	3,968
WLA	75%	358	3,616
	85%	247	2,759
	95%	120	1,274
LA	75%	1,009	6,702
	85%	1,003	6,699
	95%	997	6,697

Table 43. Monthly Geometric Mean over HSPF Simulation Period for Reservoirs Watershed

Reservoirs Watershed			
Source Reduced	**% Reduction**	**Minimum**	**Maximum**
Baseline		824	5,968
WLA	75%	303	3,005
	85%	211	2,278
	95%	100	1,164
LA	75%	753	5,869
	85%	734	5,855
	95%	710	5,843

Table 44. Monthly Geometric Mean over HSPF Simulation Period for Whiteoak Bayou Watershed

Whiteoak Bayou Watershed			
Source Reduced	**% Reduction**	**Minimum**	**Maximum**
Baseline		824	5,968
WLA	75%	303	3,005
	85%	211	2,278
	95%	100	1,164
LA	75%	753	5,869
	85%	734	5,855
	95%	710	5,843

Summary of Load Reduction Methods

As shown in the previous section, three different methods were used to evaluate indicator bacteria loading and the required reductions to meet the TMDL for each segment. Findings from the three methods are fairly consistent. They all predict greater than a 59 percent reduction in loading for either WLA or LA in order to meet the water quality standard. In fact, most segments and flow conditions require greater than a 95 percent reduction in WLA and LA to meet the water quality standard. All three methods show that large reductions in loading under all three flow conditions will be required to meet the TMDL target loads.

Uncertainty and Conservative Assumptions

Although there is a large degree of uncertainty in many method parameters used for this project, observed data have been used when available; and when not available, conservative assumptions have been implemented. The fact that three separate methodologies arrived at similar conclusions to derive the load reductions suggests that the uncertainties, while present, do not affect the ultimate conclusion that large load reductions across the watersheds are required to achieve water quality standards.

The strength of this TMDL is the use of the LDC method, the BLEST mass balance method, and the HSPF watershed model to analyze sources and determine the TMDL allocations. LDCs are a simple statistical method. Tidal Prism is a simple mass balance method. The HSPF model is a complex watershed and water quality model. The LDC and BLEST methods provide first steps in describing the water quality problem. These tools:

- are easily developed and explained to stakeholders; and
- use the available water quality and flow data.

The LDC method does not require any assumptions regarding loading rates, stream hydrology, land use conditions, and other conditions in the watershed. The BLEST method is based on subwatersheds so that local details on indicator bacteria loads can be analyzed. Weaknesses of these methods include the limited information they provide regarding the magnitude or specific origin of the various sources. Only limited information is available regarding point and nonpoint sources in the watershed.

The HSPF model provides a much more complex analytical tool that enables the detailed analysis of bacteria loads. This model also can be a valuable tool in analyzing the results of implementation measures during the development of the implementation plan.

The U.S. EPA supports the use of these approaches to characterize pollutant sources. The Texas Bacteria TMDL Task Force also identifies these methods as tools for TMDL development. Many other states are using these methods to develop TMDLs.

A weakness of all three methods is the general difficulty in analyzing and characterizing *E. coli* in the environment.

TMDL Calculations

The TMDL represents the maximum amount of a pollutant that the stream can receive in a single day without exceeding the water quality standard (load capacity). The load allocations for the three flow conditions were based on the flows used in the three different analyses. The three analyses presented previously were conducted to characterize the major sources of bacteria and to provide guidance for load reductions and implementation. The HSPF model was calibrated to USGS gauge information. The BLEST method and the LDC methods were based on the same information. The TMDL allocations are based on the three flow values in the BLEST tables.

WWTF Waste Load Allocation

The 2006 TPDES-permitted WWTFs listed in Table 11 are allocated a daily waste load calculated as their permitted discharge flow rate multiplied by one-half of the instream geometric-mean criterion. One-half of the water quality criterion (63 MPN/100mL) is used as the target to provide instream and downstream load capacity. The large numbers of WWTF discharges are widely distributed throughout the Buffalo Bayou Above Tidal, Reservoirs, and Whiteoak watersheds, and these discharges provide all of the low, non-storm water flow. All future TPDES-permitted WWTF dischargers added in the Buffalo and Whiteoak watersheds will be assigned from the future capacity allocation. Any additional flow for these facilities is accounted for in the development of the future capacity allocation.

If WWTFs were to discharge at the water quality criterion (126 MPN/100mL), there would be no capacity to accommodate other loads and existing downstream discharges. This problem is significant for the Buffalo Bayou Tidal watershed, which currently has no WWTF discharges. Buffalo Bayou Above Tidal (1014) and Whiteoak Bayou (1017) provide the low-flow base for Buffalo Bayou Tidal (1013) because there are no dischargers within the Buffalo Bayou Tidal watershed. If the discharges in both of these upstream segments are at the water quality criteria, there is no capacity for the Buffalo Bayou Tidal watershed.

Waste load allocations are developed for all TPDES-permitted WWTFs in the project area as of December 2006. These are the dischargers contributing to the flow during the time that the sampling and analysis of sources loads was conducted. The flows used in calculating the TMDL allocations are based on the flows measured through 2006. All TPDES-permitted dischargers added in the four TMDL watersheds after 2006 will be assigned from the future capacity allocation based on the discharge concentration of 63 MPN/100mL.

The WLA for all waste water treatment facilities (WLA_{WWTF}) is derived from the following equation.

Equation 1

$$WLA_{WWTF} = swqs/2 * flow * unit\ conversion\ factor$$

Where:

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

Table 45 summarizes the WLA for the 2006 TPDES-permitted facilities within the watersheds covered by this report.

Table 45. Waste Load Allocations for TPDES-Permitted Facilities

TPDES	NPDES	Facility Name	Segment	Assessment Unit	Flow (MGD)	Allocation (Billion MPN/day)
Buffalo Bayou Watershed						
10495-109	0035017	HOUSTON, CITY OF	1014	1014_01	12	28.6147
10584-001	0047457	MEMORIAL VILLAGE WAT	1014	1014_01	3.05	7.2729
14070-001	0089940	WEATHERFORD PETCO	1014	1014_01	0.0108	0.0258
10495-135	0026395	HOUSTON, CITY OF	1014B	1014B_01	3.5	8.346
12346-001	0086185	WEST PARK MUD	1014B	1014B_01	0.5	1.1923
12427-001	0088218	GEORGE AIVAZIAN	1014B	1014B_01	0.001	0.0024
14182-001	0122556	ANN ARUNDEL FARMS	1014B	1014B_01	0.992	2.3655
13021-001	0095702	BIG OAKS MUD	1014B	1014B_01	0.7	1.6692
13228-001	0098965	FORT BEND CO MUD 050	1014B	1014B_01	0.7	1.6692
12830-001	0094056	ROBINSON, J.W.	1014K	1014K_01	0.006	0.0143
14117-001	0119571	AQUASOURCE UTILITY	1014K	1014K_01	0.9	2.1461
12355-001	0116505	ELEVEN TEN ROSALIE	1014K	1014K_01	0.005	0.0119
10495-030	0063002	HOUSTON, CITY OF	1014N	1014N_01	26.4	62.9523
02731-000	0087416	DANIEL VALVE COMPANY	1014O	1014O_01	0.012	0.0286
Reservoir Watershed						
12233-001	0083933	UA HOLDINGS 1994-5	1014	1014_01	0.005	0.0119
12132-001	0079634	WHITE OAK OWNERS	1017	1017_04	0.059	0.1407
11290-001	0046621	JACKRABBIT ROAD PUD	1014A	1014A_01	5.1	12.1612
11414-001	0104795	SASSON, ELI	1014A	1014A_01	0.06	0.1431
11792-002	0070971	HARRIS CO MUD 105	1014A	1014A_01	2.5	5.9614

TPDES	NPDES	Facility Name	Segment	Assessment Unit	Flow (MGD)	Allocation (Billion MPN/day)
Reservoir Watershed, cont.						
12209-001	0083500	HARRIS CO MUD 127	1014A	1014A_01	1.15	2.7422
12834-001	0094307	HARRIS CO MUD 167	1014A	1014A_01	0.294	0.7011
12841-001	0094307	ROLLING CREEK UD	1014A	1014A_01	0.4	0.9538
13921-001	0117421	HARRIS COUNTY	1014A	1014A_01	0.02	0.0477
12949-001	0095532	HARRIS CO MUD 284	1014A	1014A_02	0.6	1.4307
10932-001	0068047	HARRIS COUNTY, TEXAS	1014A	1014E_01	0.042	0.1002
12682-001	0092584	HARRIS CO MUD 216	1014B	1014B_01	0.4	0.9538
13172-002	0096911	CINCO MUD 001	1014B	1014B_01	0.91	2.1699
12858-001	0097373	HARRIS COUNTY, TEXAS	1014B	1014B_01	0.026	0.062
02229-000	0079057	IGLOO PRODUCTS CORPORATION	1014B	1014B_01	0.05	0.1192
10706-001	0025747	KATY, CITY OF	1014B	1014B_01	3.075	7.3325
11893-001	0074004	MEMORIAL MUD	1014B	1014B_01	3	7.1537
12298-001	0085448	FORT BEND CO MUD 034	1014B	1014B_01	1	2.3846
12356-001	0086690	HARRIS CO MUD 345	1014B	1014B_01	0.71	1.693
12370-001	0087157	FORT BEND CO MUD 037	1014B	1014B_01	0.175	0.4173
13245-001	0099856	GRAND LAKES MUD 004	1014B	1014B_01	0.9	2.1461
13558-001	0098957	CINCO MUD 001	1014B	1014B_01	3.3	7.869
13674-001	0118541	NOTTINGHAM COUNTRY	1014B	1014B_01	0.051	0.1216
13775-001	0115894	HARRIS FTB MUD 005	1014B	1014B_01	0.99	2.3607
14011-001	0118109	FT BEND MUD 130	1014B	1014B_01	0.3	0.7154
14134-001	0119873	FT BEND MUD 124	1014B	1014B_01	0.4	0.9538
13328-001	0100137	REMINGTON MUD 002	1014E	1014E_01	1.1	2.623
12927-001	0094579	HARRIS CO MUD 276	1014E	1014E_01	0.75	1.7884
12685-001	0093581	MOODY CORP	1014E	1014E_01	0.1	0.2385
11472-001	0026263	SPENCER ROAD PUD	1014E	1014E_02	0.98	2.3369
11486-001	0062031	HARRIS CO MUD 070	1014E	1014E_02	1.5	3.5768
11523-001	0052906	HARRIS CO MUD 102	1014E	1014E_02	1.3	3.0999
11682-001	0064734	LANGHAM CREEK UD	1014E	1014E_02	2	4.7691
11836-001	0091626	HARRIS CO MUD 149	1014E	1014E_02	0.645	1.538

TPDES	NPDES	Facility Name	Segment	Assessment Unit	Flow (MGD)	Allocation (Billion MPN/day)
Reservoir Watershed, cont.						
11906-001	0074896	HARRIS CO MUD 157	1014E	1014E_02	2.3	5.4845
11935-001	0075981	NORTHWEST HC MUD 016	1014E	1014E_02	0.99	2.3607
11947-001	0075884	HARRIS CO MUD 208	1014E	1014E_02	6.7	15.9765
12124-001	0079707	HARRIS CO MUD 185	1014E	1014E_02	0.675	1.6096
12128-001	0079537	HORSEPEN BAYOU MUD	1014E	1014E_02	0.95	2.2653
12223-001	0083496	WEST HC MUD 015	1014E	1014E_02	0.6	1.4307
12304-001	0085588	CHIMNEY HILL MUD	1014E	1014E_02	1.2	2.8615
12310-001	0085871	R&K WEIMAN MHP	1014E	1014E_02	0.03	0.0715
12447-001	0088838	HARRIS CO MUD 196	1014E	1014E_02	1.4	3.3384
12474-001	0089494	HARRIS CO MUD 166	1014E	1014E_02	0.625	1.4903
12726-001	0100161	HARRIS CO MUD 155	1014E	1014E_02	1.55	3.6961
13778-001	0097985	FRIEDMAN, STEPHEN	1014E	1014E_02	0.01	0.0238
11284-001	0053091	WESTLAKE MUD 001	1014H	1014H_02	0.9	2.1461
11696-002	0112585	ADDICKS UD	1014H	1014H_02	0.8	1.9076
11917-001	0074403	HARRIS CO MUD 071	1014H	1014H_02	2.35	5.6037
11969-001	0076660	MAYDE CREEK MUD	1014H	1014H_02	2	4.7691
11989-001	0076775	FRY ROAD MUD	1014H	1014H_02	0.8	1.9076
12110-001	0079201	KATY ISD	1014H	1014H_02	0.1	0.2385
12140-001	0079618	WEST HC MUD 007	1014H	1014H_02	0.5	1.1923
12189-001	0082830	TEX-SUN PARKS, LC	1014H	1014H_02	0.15	0.3577
12247-001	0084468	WEST HC MUD 017	1014H	1014H_02	0.275	0.6558
12516-001	0089907	WEST HOUSTON AIRPORT	1014H	1014H_02	0.015	0.0358
12802-001	0093891	HARRIS CO MUD 238	1014H	1014H_02	0.825	1.9673
03153-000	0074292	TOSHIBA INTERNATIONAL CORPORATION	1014K	1014K_02	0.05	0.1192
12466-001	0089061	OCEANEERING INTER.	1014K	1014K_02	0.012	0.0286
13484-001	0104311	529 #35, LTD	1014K	1014K_02	0.2	0.4769
11152-001	0021512	WEST MEMORIAL MUD	1014L	1014L_01	6.48	15.4519
11883-001	0071625	CASTLEWOOD MUD	1014L	1014L_01	2	4.7691
12289-001	0085332	GREEN TRAILS MUD	1014L	1014L_01	0.99	2.3607

TPDES	NPDES	Facility Name	Segment	Assessment Unit	Flow (MGD)	Allocation (Billion MPN/day)
Reservoir Watershed, cont.						
12479-001	0089346	NOTTINGHAM COUNTRY MUD	1014L	1014L_01	1.3	3.0999
14109-001	0119121	KATY-HOCKLEY	1014L	1014L_02	0.075	0.1788
11598-001	0058408	WILLIAMSBURG REG SA	1014L	1014L_02	3	7.1537
13764-001	0092932	ALLIANCE CH F3 GP	1017/1017E	1017_04	0.15	0.3577
Whiteoak Bayou Watershed						
13983-001	0095435	RESTAURANT SERVICE, L.L.C.	1017	1017_01	0.002	0.0048
14070-001	0089940	WEATHERFORD U.S., L.P.	1017	1017_01	0.011	0.0262
10495-099	0057347	HOUSTON, CITY OF	1017	1017_01	4	9.5382
10876-001	0022853	HARRIS CO FWSD 061	1017	1017_01	1.6	3.8153
10876-002	0091804	HARRIS CO FWSD 061	1017	1017_01	3	7.1537
11188-001	0026697	ROLLING FORK PUD	1017	1017_01	0.49	1.1684
11273-001	0026352	HARRIS CO MUD 006	1017	1017_01	0.75	1.7884
11375-001	0026247	AQUASOURCE UTILITY	1017	1017_01	0.184	0.4388
11389-001	0075736	CB&I CONSTRUCTORS	1017	1017_01	0.045	0.1073
11485-001	0062235	HARRIS CO MUD 023	1017	1017_01	0.75	1.7884
11538-001	0057029	GULF COAST WASTE DA	1017	1017_01	4.5	10.7305
11563-001	0053325	REID ROAD MUD 001	1017	1017_01	1.75	4.173
11670-001	0063479	SUNBELT FWSD	1017	1017_01	0.99	2.3607
11979-002	0076651	WHITE OAK BEND MUD	1017	1017_01	0.4	0.9538
12121-001	0079146	HARRIS CO MUD 170	1017	1017_01	2.5	5.9614
12139-001	0081256	FAIRBANKS PLAZA SHOP	1017	1017_01	0.04	0.0954
12342-001	0085821	C & P UTILITIES	1017	1017_01	0.045	0.1073
12397-001	0087416	DANIEL INDUSTRIES	1017	1017_01	0.012	0.0286
12443-001	0088676	SUPERIOR DERRICK	1017	1017_01	0.0024	0.0057
12465-001	0088927	TIFCO INDUSTRIES	1017	1017_01	0.035	0.0835
12552-001	0090115	NCI BUILDING SYSTEMS	1017	1017_01	0.01	0.0238
12552-002	0117064	NCI BUILDING SYSTEMS	1017	1017_01	0.01	0.0238
12574-001	0091316	HARRIS CO MUD 130	1017	1017_01	0.95	2.2653
12681-001	0092606	JERSEY VILLAGE	1017	1017_01	0.8	1.9076

TPDES	NPDES	Facility Name	Segment	Assessment Unit	Flow (MGD)	Allocation (Billion MPN/day)
Whiteoak Bayou Watershed, cont.						
12795-001	0093726	NORTHWEST HC MUD 029	1017	1017_01	0.565	1.3473
13433-001	0103705	AQUASOURCE DVLP. CO.	1017	1017_01	0.5	1.1923
13509-001	0092746	TRINITY @ WINDFERN	1017	1017_01	0.04	0.0954
13578-001	0118583	COOPER CAMERON CORP	1017	1017_01	0.008	0.0191
13623-001	0109126	WEST HC MUD 021	1017	1017_01	0.5	1.1923
13689-001	0111937	WEST HC MUD 11	1017	1017_01	1.5	3.5768
13727-001	0113697	MOORPARK VILLAGE,INC	1017	1017_01	0.035	0.0835
13807-001	0082597	MCDONALDS CORP.	1017	1017_01	0.003	0.0072
13939-001	0082988	RIEDEL, ANTHONY	1017	1017_01	0.003	0.0072
13983-001	0095435	RESTAURANT SERVICE	1017	1017_01	0.002	0.0048
14072-001	0082317	WEST HC MUD 010	1017	1017_01	1.5	3.5768
14506-001	0090735	SMITH, WILLIAM D.	1017	1017_01	0.012	0.0286
11051-001	0075841	VANCOUVER MANAGEMENT	1017	1017_02	0.03	0.0715
10495-139	0026875	HOUSTON, CITY OF	1017A	1017A_01	0.995	2.3726
11193-001	0075434	AQUASOURCE UTILITY	1017B	1017B_01	0.8	1.9076
12222-001	0083950	AQUASOURCE UTILITY	1017B	1017B_01	0.25	0.5961
13996-001	0117684	CROW FAMILY HOLDINGS	1017B	1017B_01	0.05	0.1192
10495-076	0063011	HOUSTON, CITY OF	1017B	1017B_02	21	50.0757
11005-001	0020095	CHAMP'S WATER CO	1017C	1017C_01	0.28	0.6677
12714-001	0092908	HARRIS CO MUD 119	1017C	1017C_02	0.25	0.5961
14359-001	0119431	HARRIS CO MUD 366	1017C	1017C_02	0.2	0.4769

The TCEQ intends to implement these individual WLAs through the permitting process. However, there may be more economical or technically feasible means of achieving the goal of improved water quality, and circumstances may warrant changes in individual WLAs. Therefore, these individual WLAs, as well as the WLAs for storm water, are non-binding until implemented via a separate TPDES permitting action, which may involve preparation of an update to the state’s Water Quality Management Plan Update. Regardless, all permitting actions will demonstrate compliance with the TMDL.

Compliance with the WLA_{WWTF} will be achieved by adhering to the indicator bacteria discharge limits and disinfection requirements of TPDES permits as well as changes to domestic TPDES WWTF permits to include water quality-based effluent limitations, representative monitoring requirements for bacteria, or other requirements established in the Implementation Plan.

Upon permit amendment or permit renewal, the executive director or commission may establish interim effluent limits and/or monitoring-only requirements to allow a permittee time to modify effluent quality in order to attain the final effluent limits necessary to meet the TCEQ and EPA approved TMDL allocations. The duration of any interim effluent limits may not be any longer than three years from the date of permit re-issuance. New permits are not subject to interim effluent limits because compliance schedules are not allowed for a new permit.

Where a TMDL has been approved, domestic WWTF TPDES permits will require conditions consistent with the requirements and assumptions of the waste load allocations. For NPDES/ TPDES-regulated municipal and small-construction storm water discharges, water quality-based effluent limits that implement the WLA for storm water may be expressed as best management practices (BMPs) or other similar requirements, rather than as numeric effluent limits (November 22, 2002, memorandum from EPA relating to establishing WLAs for storm water sources). The EPA memo also states that:

> "...the Interim Permitting Approach Policy recognizes the need for an iterative approach to control pollutants in storm water discharges...[s]pecifically, the policy anticipates that a suite of BMPs will be used in the initial rounds of permits and that these BMPS will be tailored in subsequent rounds."

Using an iterative, adaptive BMP approach to the maximum extent practicable is appropriate to address the storm water component of this TMDL. The iterative, adaptive approach is reflected in the TPDES Permit Number WQ0004685000 and applicable Storm Water Management Plans (SWMPs).

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 TMDL document; 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.

The strength of this TMDL is the use of the HSPF, load duration curve, and BLEST mass balance methods to determine the TMDL allocations. All of these methods have been used in TMDLs across the country and they have proven to be reliable. By using all three methods, the reliability of the conclusions in enhanced. The weakness of this TMDL is the general difficulty in analyzing and characterizing *E. coli* in the environment.

TMDL Load Allocations

Throughout the source analyses above, the conditions during 2001 through 2006 were used to determine current loads and current percent reduction goals that are needed to achieve the water quality standard. However, the TMDL load allocations (Equation 2) must be written to be applicable for the full permitted loads listed in Table 45 and the allocations must be able to accommodate future increases in permitted sources. The future capacity allowance is important in the Houston area because a population increase greater than 50 percent in the Houston/Harris County area is expected by 2035 (H-GAC 2007). The population increases in each of the four TMDL watersheds were calculated based on the data from the H-GAC report (Table 46). The population increases range from 15 percent to 44 percent.

Equation 2

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

Where:

TMDL = total maximum daily load (load capacity)
WLA = waste load allocation (permitted source contributions)
LA = load allocation (non-permitted source contributions)
MOS = margin of safety

Table 46. Population Increases

Watershed	2005	2035	Increase
Buffalo Bayou Tidal	165350	206056	19.75%
Buffalo Bayou Above Tidal	368919	434246	15.04%
Reservoirs	275357	489540	43.75%
Whiteoak Bayou	325330	409226	20.50%

The permitted flow is nearly three times greater than the average reported flow for the WWTF discharges (Table 47). The flow difference between the average reported flow and the permitted flow is not included in the observed flows presented in the BLEST tables. The volume of this additional flow represents additional load capacity based on the geometric mean criterion of 126 MPN/100mL and additional WLA_{WWTF} load capacity based on half of the geometric mean criterion (63 MPN/100mL).

The additional flow for the future capacity is calculated by multiplying the average reported flow from the current WWTF discharges in the watershed times the predicted population increases.

Additional load is determined using Equation 1 (page 98) and the additional capacity is determined by using Equation 3.

Equation 3

$$WLA_{\text{Additional Capacity}} = \text{swqs} * \text{flow} * \text{unit conversion factor}$$

Where:

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

This additional capacity is added to the load capacity calculated in the BLEST tables that represent the conditions during the 2001 to 2006 study (Tables 25 through 28) to determine the TMDL for each watershed (Table 47). The Buffalo Bayou Tidal watershed, which currently has no WWTF discharges, was allocated a two MGD capacity for future growth to accommodate a greater than 19 percent population increase. Additional capacity and load due to the difference between permitted flow and reported flow, and future capacity for assessment units, are presented in Table 47.

Watershed TMDL Allocations

The allocations for the four TMDL watersheds are calculated directly. The TMDL (load capacity) is calculated by multiplying the flow times the contact recreation geometric mean criterion of 126 MPN/100mL for *E. coli*. This is the indicator bacteria capacity of the water body. The additional flow from using the permitted flow and the additional flow from the future capacity in each watershed are added to the flows for each of the three flow categories to determine the final TMDL for each watershed and flow category. The upstream loads from the BLEST tables also have the additional flow added to represent the additional capacity and additional load added from the additional upstream flow calculated using Equation 1 (page 98).

The TMDL equation, modified to accommodate the additional factors, is expressed as:

Equation 4

$$TMDL = \Sigma WLA_{WWTF} + \Sigma WLA_{\text{Storm Water}} + \Sigma LA + MOS + \Sigma USL + FC$$

Where:

ΣWLA_{WWTF} = waste load allocation (permitted WWTF)
$\Sigma WLA_{\text{Storm Water}}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
MOS = margin of safety
USL = Upstream Load
FC = Future Capacity

The TMDL, $\Sigma WLA_{WWTF,}$ MOS, ΣUSL, and FC allocations are set by flow and the contact recreation criterion. The load that remains after subtracting $\Sigma WLA_{WWTF,}$ MOS, ΣUSL, and FC is allocated to the $\Sigma WLA_{\text{Storm Water}}$ and ΣLA. Permitted storm water sources are allocated 90 percent of the remaining load and the remaining 10 percent is allocated to non-permitted sources (non-point).

The TMDL allocations for the four watersheds are presented in Tables 49, 50, and 51 for wet, intermediate, and dry flow conditions, respectively. For the Buffalo Bayou Above Tidal and Buffalo Bayou Tidal watersheds, upstream loads are conveyed by the other TMDL watersheds. Buffalo Bayou Above Tidal receives a load from the Reservoirs watershed and Buffalo Bayou Tidal receives loads from the Buffalo Bayou Above Tidal and Whiteoak Bayou watersheds. These loads are a part of the TMDL for the receiving watershed.

The TMDL load allocations were developed for all three flow conditions. Table 49 presents the load allocations for wet conditions. These values are considered the critical conditions for the Buffalo Bayou Tidal, Buffalo Bayou Above Tidal, Reservoirs, and Whiteoak Bayou watersheds. The wet-flow condition has been chosen because it represents maximum daily load.

Assessment Unit TMDL Allocations

Allocations are also developed for each impaired assessment unit in the four watersheds for the critical high flow (wet) conditions. These allocations are developed to match the 2006 303(d) list of impaired water bodies in Texas. The TMDL regulations (40 CFR 130.7) require that loads be assigned to all the entries on the 303(d) list. The 2006 303(d) list has been approved by EPA and which identifies impairments by individual assessment units. In its approval of the list, EPA has determined that each assessment unit is a segment per 40 CFR 130.7 and that a TMDL must be written for each identified assessment unit.

The allocations for the critical conditions of the assessment units are determined from the watershed ratio of the area of assessment unit watershed to the overall area of the watershed. The percentages in Table 52 are multiplied times the components of the allocations, except for the WLA_{WWTF} and Future Capacity components, which are calculated based on the WWTF discharges in the assessment unit watershed (Table 48) and the population increases for the watershed (Table 46).

A summary of all allocation components for the impaired assessment units is presented in Table 53. The final TMDL allocations needed to comply with the requirements of 40 CFR 130.7 for the impaired assessment units are presented in Table 54. In this table, the upstream loads are combined with the load allocation (LA) and the future capacity is included in the TMDL.

The final TMDL allocations in Table 54 are based on the current contact recreation criteria of 126 MPN/100mL. Should the contact recreation criteria change in the future or if the contact recreation use changes, Appendix A presents a method that can be used to calculate revised TMDL allocations for Table 54. Appendix A includes graphs showing the relationship between the changed criteria and the TMDL allocations and the equations that can be used to calculate the revised TMDL allocations.

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 permitted sources is provided for in the TMDL allocations. This growth 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 increased loadings. The equations and tables in this TMDL will guide determination of the assimilative capacity of the stream under changing conditions, including future growth.

The three-tiered antidegradation policy in the water quality standards prohibits an increase in loading that would cause or contribute to degradation of an existing use. The antidegradation policy applies to both point and nonpoint source pollutant discharges. In general, antidegradation procedures establish a process for reviewing individual proposed actions to determine if the activity will degrade water quality. The TMDLs in this document will result in protection of existing beneficial uses, and conform to the Texas antidegradation policy.

Additional dischargers represent additional flow that is not accounted for in the current allocations. Changes in MS4 jurisdiction or additional development associated with population increases in the watershed can be accommodated by shifting allotments between the waste load allocation and the load allocation. This can be done without the need to reserve future capacity waste load allocations for storm water. In un-urbanized areas, growth can be accommodated by shifting loads between the load allocation and the waste load allocation (for storm water). In urbanized areas currently regulated covered by an MS4 permit, development and/or re-development of land in urbanized areas must implement the control measures/programs outlined in an approved Storm Water Pollution Prevention Plan (SWPPP).

Although additional flow may occur from development or re-development, loading of the pollutant of concern should be controlled and/or reduced through the implementation of best management practices (BMPs) as specified in both the NPDES permit and the SWPPP. Currently, it is envisioned that an iterative, adaptive management BMP approach be used to address storm water discharges. This approach encourages the implementation of controls (i.e. structural or non-structural), implementation of mechanisms to evaluate the performance of the controls, and finally, allowance to make adjustments (i.e., more stringent controls or specific BMPs) as necessary to protect water quality.

Table 47. Watershed Flow and Load Changes Using Full Permitted Flow

Watershed	Average Reported Flow (MGD)	Permitted Flow (MGD)	Difference (MGD)	Additional Load Capacity (Billion MPN/Day)	Additional Load (Billion MPN/Day)	Future WWTF Capacity (Billion MPN/Day)	Population Increase
Buffalo Bayou Above Tidal	17.92477	48.7768	30.85203	147.15	73.58	6.42917	15.04%
Buffalo Bayou Tidal	0	0	0	0.00	0.00	4.76962*	19.75%
Reservoirs	20.51719	73.685	53.16781	253.59	126.80	21.4067	43.75%
Whiteoak Bayou	19.97647	51.6084	31.63193	150.87	75.44	9.76622	20.50%
Total	**58.41843**	**174.0702**					

MPN – most probable number

MGD = million gallons per day

* Buffalo Bayou Tidal currently has no WWTF discharges, so a future capacity for 2.0 MGD flow is allocated.

Table 48. Assessment Unit Flow and Load Changes Using Full Permitted Flow

Assessment Unit	Average Reported Flow (MGD)	Permitted Flow (MGD)	Difference (MGD)	Additional Load Capacity (Billion MPN/Day)	Additional Load (Billion MPN/Day)	Future WWTF Capacity (Billion MPN/Day)	Population Increase
1013_01	0	0	0	0	0	1.19240*	19.75%
1013A_01	0	0	0	0	0	1.19240*	19.75%
1013A_02	0	0	0	0	0	1.19240*	19.75%
1013C_01	0	0	0	0	0	1.19240*	19.75%
1014_01	7.40215	15.0658	7.66365	36.55	18.28	18.27634	15.04%
1014A_01	3.1332	9.566	6.4328	30.68	15.34	15.34100	43.75%
1014A_02	0.023	0.6	0.577	2.75	1.38	1.37604	43.75%
1014B_01	5.25815	21.68	16.42185	78.33	39.16	39.16298	43.75%
1014E_01	0.1016	1.95	1.8484	8.82	4.41	4.40808	43.75%
1014E_02	6.537	23.455	16.918	80.69	40.35	40.34621	43.75%
1014H_01	0	0	0	0	0	2.38481**	43.75%
1014H_02	2.53994	8.715	6.17506	29.45	14.73	14.72634	43.75%
1014K_01	0.10052	0.911	0.81048	3.87	1.93	1.93284	43.75%
1014K_02	0.0533	0.262	0.2087	1.00	0.50	0.49771	43.75%
1014L_01	3.1	10.77	7.67	36.58	18.29	18.29149	43.75%
1014L_02	0.6914	3.075	2.3836	11.37	5.68	5.68443	43.75%
1014M_01	0	0	0	0	0	2.38481**	43.75%
1014N_01	9.5	26.4	16.9	80.61	40.30	40.30328	15.04%
1014O_01	0.0017	0.012	0.0103	0.05	0.02	0.02456	15.04%

Assessment Unit	Average Reported Flow (MGD)	Permitted Flow (MGD)	Difference (MGD)	Additional Load Capacity (Billion MPN/Day)	Additional Load (Billion MPN/Day)	Future WWTF Capacity (Billion MPN/Day)	Population Increase
1017_01	9.76587	27.5444	17.77853	84.80	42.40	42.39841	20.50%
1017_02	0.03	0.035	0.005	0.02	0.01	0.01192	20.50%
1017_03	0	0	0	0	0	2.38481**	20.50%
1017_04	0.096	0.209	0.113	0.54	0.27	0.26948	20.50%
1017A_01	0.48	0.995	0.515	2.46	1.23	1.22818	20.50%
1017B_01	0.5786	1.1	0.5214	2.49	1.24	1.24344	20.50%
1017B_02	8.7	21	12.3	58.67	29.33	29.33316	20.50%
1017C_01	0.15	0.28	0.13	0.62	0.31	0.31003	20.50%
1017C_02	0.171	0.45	0.279	1.33	0.67	0.66536	20.50%
1017D_01	0	0	0	0	0	2.38481**	20.50%
1017E_01	0	0	0	0	0	2.38481**	20.50%
Total	**58.41343**	**174.0752**					

MPN = most probable number

MGD = million gallons per day

* Assessment Unit currently has no WWTF discharges, so a future capacity for 0.5 MGD flow is allocated.

** Assessment Unit currently has no WWTF discharges, so a future capacity for 1.0 MGD flow is allocated.

Table 49. Watershed TMDL Summary for All Segments at Wet-Flow Conditions

Watershed	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)	Upstream Load (Billion MPN/day)	Future WWTF Capacity (Billion MPN/day)
Buffalo Bayou Above Tidal	2,558.25	116.32	1120.73	124.53	0.00	1190.25	6.43
Buffalo Bayou Above Tidal(1014), Neimans Bayou (Newman Branch) (1014M), Rummel Creek (1014N), Spring Branch (1014O)							
Buffalo Bayou Tidal	3,048.46	0.00	737.25	81.92	0.00	2224.53	4.77
Buffalo Bayou Tidal (1013), Little White Oak Bayou (1013A), Unnamed Non-Tidal Tributary of Buffalo Bayou Tidal (1013C)							
Reservoirs	1,393.13	175.72	1076.40	119.60	0.00	0.00	21.41
Bear Creek (1014A), Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), Mason Creek (1014L)							
Whiteoak Bayou	1,254.06	123.08	1009.10	112.12	0.00	0.00	9.77
Whiteoak Bayou (1017), Brickhouse Gully (1017A), Cole Creek (1017B), Unnamed Tributary of Whiteoak Bayou (1017D), Unnamed Tributary of White Oak Bayou (1017E)							

WLA_{WWTF} – waste load allocation for WWTF discharges

$WLA_{Storm\ Water}$ – waste load allocation for all storm water permitted discharges

MPN – most probable number

Table 50. Watershed TMDL Summary for All Segments at Intermediate-Flow Conditions

Watershed	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)	Upstream Load (Billion MPN/day)	Future WWTF Capacity (Billion MPN/day)
Buffalo Bayou Above Tidal	1,203.46	116.32	567.94	63.10	0	449.67	6.43
Buffalo Bayou Above Tidal(1014), Neimans Bayou (Newman Branch) (1014M), Rummel Creek (1014N), Spring Branch (1014O)							
Buffalo Bayou Tidal	1,207.47	0.00	197.00	21.89	0	983.81	4.77
Buffalo Bayou Tidal (1013), Little White Oak Bayou (1013A), Unnamed Non-Tidal Tributary of Buffalo Bayou Tidal (1013C)							
Reservoirs	649.48	175.72	407.12	45.24	0	0	21.41
Bear Creek (1014A), Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), Mason Creek (1014L)							
Whiteoak Bayou	340.74	123.08	187.11	20.79	0	0	9.77
Whiteoak Bayou (1017), Brickhouse Gully (1017A), Cole Creek (1017B), Unnamed Tributary of Whiteoak Bayou (1017D), Unnamed Tributary of White Oak Bayou (1017E)							

WLA_{WWTF} – waste load allocation for WWTF discharges

$WLA_{Storm\ Water}$ – waste load allocation for all storm water permitted discharges

MPN – most probable number

Table 51. Watershed TMDL Summary for All Segments at Dry-Flow Conditions

Watershed	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)	Upstream Load (Billion MPN/day)	Future WWTF Capacity (Billion MPN/day)
Buffalo Bayou Above Tidal	556.49	116.32	0.00	221.31	0.00	212.43	6.43
Buffalo Bayou Above Tidal(1014), Neimans Bayou (Newman Branch) (1014M), Rummel Creek (1014N), Spring Branch (1014O)							
Buffalo Bayou Tidal	655.83	0.00	0.00	332.40	0.00	318.66	4.77
Buffalo Bayou Tidal (1013), Little White Oak Bayou (1013A), Unnamed Non-Tidal Tributary of Buffalo Bayou Tidal (1013C)							
Reservoirs	336.14	175.72	0.00	139.01	0.00	0.00	21.41
Bear Creek (1014A), Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), Mason Creek (1014L)							
Whiteoak Bayou	267.16	123.08	0.00	134.31	0.00	0.00	9.77
Whiteoak Bayou (1017), Brickhouse Gully (1017A), Cole Creek (1017B), Unnamed Tributary of Whiteoak Bayou (1017D), Unnamed Tributary of White Oak Bayou (1017E)							

WLA_{WWTF} – waste load allocation for WWTF discharges

$WLA_{Storm\ Water}$ – waste load allocation for all storm water permitted discharges

MPN – most probable number

Table 52. Assessment Unit Watershed Areas

Assessment Unit	Main Watershed	Total Area (acres)	Percentage
1013_01	1013	2611.30	17%
1013A_01	1013	2288.23	15%
1013C_01	1013	169.27	1%
	1013 Total	**5068.80**	
1014_01	1014	29799.64	72%
1014M_01	1014	1278.76	3%
1014N_01	1014	3127.89	8%
1014O_01	1014	7158.06	17%
	1014 Total	**41364.35**	
1017_01	1017	7602.92	14%
1017_02	1017	2280.57	4%
1017_03	1017	6547.41	12%
1017_04	1017	23526.19	43%
1017A_01	1017	7624.29	14%
1017B_02	1017	5874.38	11%
1017D_01	1017	695.77	1%
1017E_01	1017	780.13	1%
	1017 Total	**54931.66**	
1014A_01	Reservoir	24084.18	14%
1014B_01	Reservoir	80155.46	45%
1014E_01	Reservoir	29812.76	17%
1014H_01	Reservoir	5014.50	3%
1014H_02	Reservoir	22451.96	13%
1014K_01	Reservoir	4487.43	3%
1014K_02	Reservoir	1931.86	1%
1014L_01	Reservoir	10356.67	5%
	Reservoir Total	**178294.82**	
	GRAND TOTAL	**289758.77**	

Table 53. Assessment Unit TMDL Summary for All Impaired Segments at Wet-Flow (Critical) Conditions

Assessment Unit	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)	Upstream Load (Billion MPN/day)	Future WWTF Capacity (Billion MPN/day)
1013_01	1,574.77	0.00	267.95	29.77	0.00	1,275.86	1.19
1013A_01	1,379.94	0.00	234.66	26.07	0.00	1,118.01	1.19
1013C_01	102.08	0.00	16.37	1.02	0.00	82.70	1.19
1014_01	1841.94	35.93	837.68	93.08	0.00	856.98	18.28
1014A_01	195.04	22.81	141.20	15.69	0.00	0.00	15.34
1014B-01	626.91	51.70	482.44	53.60	0.00	0.00	39.16
1014E_01	236.83	4.65	205.00	22.78	0.00	0.00	4.41
1014H_01	39.18	0.00	33.12	3.68	0.00	0.00	2.38
1014H_02	175.43	20.78	125.93	13.99	0.00	0.00	14.73
1014K_01	35.06	2.17	27.86	3.10	0.00	0.00	1.93
1014K_02	15.09	0.62	12.58	1.40	0.00	0.00	0.50
1014L_01	69.66	25.68	23.11	2.57	0.00	0.00	18.29
1014M_01	76.75	0.00	34.79	3.87	0.00	35.71	2.38
1014N_01	204.66	62.96	5.56	0.62	0.00	95.22	40.30
1014O_01	434.90	0.03	209.26	23.25	0.00	202.34	0.02
1017_01	173.57	65.69	58.94	6.55	0.00	0.00	42.40
1017_02	52.06	0.08	46.77	5.20	0.00	0.00	0.01
1017_03	149.47	0.00	132.38	14.71	0.00	0.00	2.38

Assessment Unit	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)	Upstream Load (Billion MPN/day)	Future WWTF Capacity (Billion MPN/day)
1017_04	537.09	0.50	482.69	53.63	0.00	0.00	0.27
1017A_01	175.57	2.37	154.77	17.20	0.00	0.00	1.23
1017B_02	137.95	50.08	52.68	5.85	0.00	0.00	29.33
1017D_01	12.54	0.00	9.14	1.02	0.00	0.00	2.38
1017E_01	12.54	0.00000	9.14	1.02	0	0.00	2.38481

WLA_{WWTF} – waste load allocation for WWTF discharges

$WLA_{Storm\ Water}$ – waste load allocation for all storm water permitted discharges

MPN – most probable number

MGD = million gallons per day

Table 54. Final TMDL Allocations for All Impaired Assessment Units at Wet-Flow (Critical) Conditions

Assessment Unit	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)
1013_01	1,574.77	1.19	267.95	1,305.63	0
1013A_01	1,379.94	1.19	234.66	1,144.09	0
1013C_01	102.08	1.19	16.37	84.52	0
1014_01	1,841.94	54.21	837.68	950.06	0
1014A_01	195.04	38.15	141.2	15.69	0
1014B_01	626.91	90.87	482.44	53.6	0
1014E_01	236.83	9.06	205	22.78	0
1014H_01	39.18	2.38	33.12	3.68	0
1014H_02	175.43	35.51	125.93	13.99	0
1014K_01	35.06	4.11	27.86	3.1	0
1014K_02	15.09	1.12	12.58	1.4	0
1014L_01	69.66	43.98	23.11	2.57	0
1014M_01	76.75	2.38	34.79	39.58	0
1014N_01	204.66	103.26	5.56	95.84	0
1014O_01	434.9	0.05	209.26	225.59	0
1017_01	173.57	108.09	58.94	6.55	0
1017_02	52.06	0.10	46.77	5.2	0
1017_03	149.47	2.38	132.38	14.71	0
1017_04	537.09	0.77	482.69	53.63	0

Assessment Unit	TMDL (Billion MPN/day)	WLA_{WWTF} (Billion MPN/day)	$WLA_{Storm\ Water}$ (Billion MPN/day)	LA (Billion MPN/day)	MOS (Billion MPN/day)
1017A_01	175.57	3.60	154.77	17.2	0
1017B_02	137.95	79.41	52.68	5.85	0
1017D_01	12.54	2.38	9.14	1.02	0
1017E_01	12.54	2.38	9.14	1.02	0

WLA_{WWTF} – waste load allocation for WWTF discharges

$WLA_{Storm\ Water}$ – waste load allocation for all storm water permitted discharges

MPN – most probable number

MGD = million gallons per day

Seasonal Variation

Federal regulations in 40 CFR 130.7(c)(1) require that TMDLs account for seasonal variation in watershed conditions and pollutant loading. An analysis of all *E. coli* data showed no seasonal variations. 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.

Public Participation

In accordance with requirements of law promulgated in 2001 under Texas House Bill 2912, a stakeholder group was formed, public meetings were conducted, and notices of meetings were posted on the TMDL program's Web calendar. Two weeks prior to scheduled meetings, 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 page was established to provide meeting summaries, ground rules, and a list of steering committee members at the TCEQ Web site <www.tceq.state.tx.us/implementation/water/tmdl/22-buffalobayou.html> and the Houston-Galveston Area Council Web site <www.h-gac.com/community/water/tmdl/default.aspx>

From the inception of this TMDL, 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.

Over the course of the Buffalo and Whiteoak Bayou TMDLs project, public participation has played a large role. Members of the stakeholder group include government, permitted facilities, agriculture, business, environmental and community interests in the Buffalo and Whiteoak Bayou watersheds.

Eighteen meetings were held between May 2000 and July 2007 to present both project status reports from the TCEQ and updates on the technical aspects of the project. The meetings were held at project milestones and were used to solicit input and feedback from the stakeholders. Stakeholder input provided valuable local insight to the project staff.

Implementation and Reasonable Assurances

The TMDL development process involves the preparation of two documents:

3) **a TMDL**, which determines the maximum amount of pollutant a water body can receive within one 24-hour period and still meet applicable water quality standards; and
4) **an Implementation Plan (or I-Plan)**, which is a detailed description and schedule of the measures necessary to achieve the pollutant reductions identified in the TMDL.

The TCEQ is committed to developing 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. The effort, known as the Bacteria Implementation Group (BIG), is being lead by the Houston-Galveston Area Council with funding from the TCEQ. 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 55). The area-wide I-Plan, which will include the watersheds in this report, is expected to be completed in June 2010.

Table 55. Watersheds Included in Houston/Harris County Implementation Plan.

Watershed	Number of Segments	Counties
Clear Creek	9	Harris, Fort Bend, Galveston, Brazoria
Buffalo Bayou Above Tidal, Buffalo Bayou Tidal, Reservoirs & Whiteoak Bayous	18	Harris, Waller, 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. Additionally, if further research results in revisions to the surface water quality standards, an adaptive management approach affords the TCEQ and stakeholders the opportunity to adjust the implementation in a corresponding manner.

The stakeholder led Bacteria Implementation Group will develop the I-Plan for *Eighteen Total Maximum Daily Loads for Bacteria in Buffalo and Whiteoak Bayous and Tributaries*, along with all other TMDLs for bacteria in the Houston area. Through the Bacteria Implementation Group, the excellent resources and expertise of the organizations and individuals involved in the group are available to develop the plan. An adaptive management strategy will be used to develop a plan to set priorities, provide flexibility, and will be appropriate for all stakeholders. Social and economic factors may be considered by the stakeholders during the development of the I-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, a TMDL and I-Plan direct the correction of unacceptable water quality conditions that exist in an impaired surface water in the state. A TMDL broadly identifies the pollutant load goal after assessment of existing conditions and the impact on those conditions from probable or known sources. A TMDL identifies a total loading from the combination of point sources and nonpoint sources that would allow attainment of the established water quality standard.

An I-Plan specifically identifies the actions that will be taken to achieve the pollutant loading goals of the TMDL.

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.

The TMDL report and the underlying assumptions, model scenarios, and assessment results are not, and should not be, interpreted as required effluent limitations, pollutant load reductions that will be applied to specific permits, or any other regulatory action necessary to achieve attainment of the water quality standard. The I-Plan developed by stakeholders and approved by the state will direct implementation efforts to certain sources contributing to the impaired water quality.

In determining source reductions, the I-Plan may consider factors such as:

- cost and/or feasibility:
- current availability or likelihood of funding;
- existing or planned pollutant reduction initiatives such as watershed-based protection plans;
- whether a source is subject to an existing regulation;
- the willingness and commitment of a regulated or unregulated source; and
- a host of additional factors.

Ultimately, the I-Plan will identify the commitments and requirements to be implemented through specific permit actions and other means. For these reasons, the I-Plan that is adopted may not approximate the predicted loadings identified category by category in the TMDL and its underlying assessment, but with certain exceptions, the I-Plan must nonetheless meet the overall loading goal established by the EPA-approved TMDL.

An exception would include an I-Plan that identifies a phased implementation that takes advantage of an adaptive management approach. It is not practical or feasible to approach all TMDL implementation as a one-time, short-term restoration effort. This is particularly true when a challenging wasteload reduction or load reduction is required by the TMDL, high uncertainty with the TMDL analysis exists, there is a need to reconsider or revise the established water quality standard, or the pollutant load reduction would require costly infrastructure and capital improvements.

Instead, activities contained in the first phase of implementation may be the full scope of the initial I-Plan and include strategies to make substantial progress towards source reduction and elimination, refine the TMDL analysis, conduct site-specific analyses of the appropriateness of an existing use, and monitor in stream water quality to gauge the results of the first phase. Ultimately, the accomplishments of the first phase would lead to development of a phase two or final I-Plan, or revision of TMDL. This adaptive management approach is consistent with established guidance from EPA (see August 2, 2006, memorandum from EPA relating to clarifications on TMDL revisions).

The TCEQ’s Water Quality Management Plan (WQMP) directs the state’s efforts to address water quality problems and restore water quality uses throughout Texas. The WQMP is continually updated with new, more specifically focused WQMPs, or “water quality management plan elements” as identified in federal regulations (40 Code of Federal Regulations (CFR) Sec. 130.6(c)). Consistent with federal requirements, each TMDL is a plan element of a WQMP and commission adoption of a TMDL is state certification of the WQMP update.

Because the TMDL does not reflect or direct specific implementation by any one pollutant discharger, the TCEQ certifies additional water quality management plan elements to the WQMP after the I-Plan is adopted by the commission. Based on the TMDL and I-Plan, the TCEQ will propose and certify WQMP updates to establish required water-quality-based effluent limitations necessary for specific TPDES wastewater discharge permits. The TCEQ would normally establish best management practices, which are a substitute for effluent limitations in TPDES MS4 permits, as allowed by the federal rules where numeric effluent limitations are infeasible (see November 22, 2002, memorandum from EPA relating to establishing TMDL WLAs for storm water sources). Thus, the TCEQ would not identify specific implementation requirements applicable to a specific TPDES storm water permit through an effluent limitation update. However, the TCEQ would revise a storm water permit, require a revised Storm Water Management Program or Pollution Prevention Plan, or implement other specific revisions affecting storm water dischargers in accordance with an adopted I-Plan.

References

Canter, L.W. and R.C. Knox, 1985. Septic Tank System Effects on Ground Water Quality. Lewis Publishers, Boca Raton, FL.

EPA (Environmental Protection Agency) 1991. Guidance for Water Quality-Based Decisions: The TMDL Process. <www.epa.gov/OWOW/tmdl/decisions/>.

EPA 2004. Impacts and Control of CSOs and SSOs. EPA 833-R-04-001. Washington, D.C.

EPA 2006. An Approach for Using Load Duration Curves in the Development of TMDLS. EPA 841-B07-006.

Hall, S. 2002. Washington State Department of Health, Wastewater Management Program Rule Development Committee, Issue Research Report – Failing Systems. June 2002.

H-GAC (Houston-Galveston Area Council) 2001a. Draft Basin Summary Report. Houston, Texas.

H-GAC 2002. Land Cover Classification. Houston, Texas.

H-GAC 2007. 2035 Regional Growth Forecast. Houston, Texas. <www.h-gac.com/community/forecasting/documents/2035RGF.pdf>.

Jamieson, R. C., Joy, D. M., Lee, H., Kostacschuk, R., and Gordon, R. J., 2005. Resuspension of Sediment-Associated *Escherichia coli* in a Natural Stream. Journal of Environmental Quality, 34(2), 581-859.

National Climatic Data Center 2003. Hourly Precipitation Data Rainfall Event Statistics for Addicks-Houston (1943-1999). NOAA.

NRCS (Natural Resource Conservation Service) 1986. Urban Hydrology for Small Watersheds. TR-55. Washington, D.C.

NRCS 1994. "STATSGO Soils." Downloaded from Texas Natural Resources Information Service, <www.tnris.state.tx.us>. July 2002.

NOAA (National Oceanic and Atmospheric Administration) 2001. Divisional Normals and Standard Deviations of Temperature, Precipitation, and Heating and Cooling Degree Days: 1971-2000 (and previous normal periods). Section 1: Temperature. Climatograph of the United States 85, National Oceanic and Atmospheric Administration. Asheville, NC.

Reed, Stowe, & Yanke, LLC., 2001. Study to Determine the Magnitude of, and Reasons for, Chronically Malfunctioning On-Site Sewage Facility Systems in Texas. September 2001.

Soil Survey Division, NRCS 1994. Official Soil Series Descriptions. United States Department of Agriculture. <www.statlab.iastate.edu/ soils>. Accessed August 8, 2002.

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

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

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

TCEQ 2006. Texas Water Quality Inventory and 303(d) List. <www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/305_303.html>.

TCEQ 2007. Seventeen Total Maximum Daily Loads for Bacteria, Dissolved Oxygen, and pH in Adams Bayou, Cow Bayou, and Their Tributaries, Segments 0508, 0508A, 0508B, 0508C, 0511, 0511A, 0511B, 0511C, and 0511E. Adopted by the commission on June 13, 2007 and by U.S. EPA on August 28, 2007.

TCEQ 2008. Guidance for Assessing Texas Surface and Finished Drinking Water Quality Data. <http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/mtr/swqm_resources.html>.

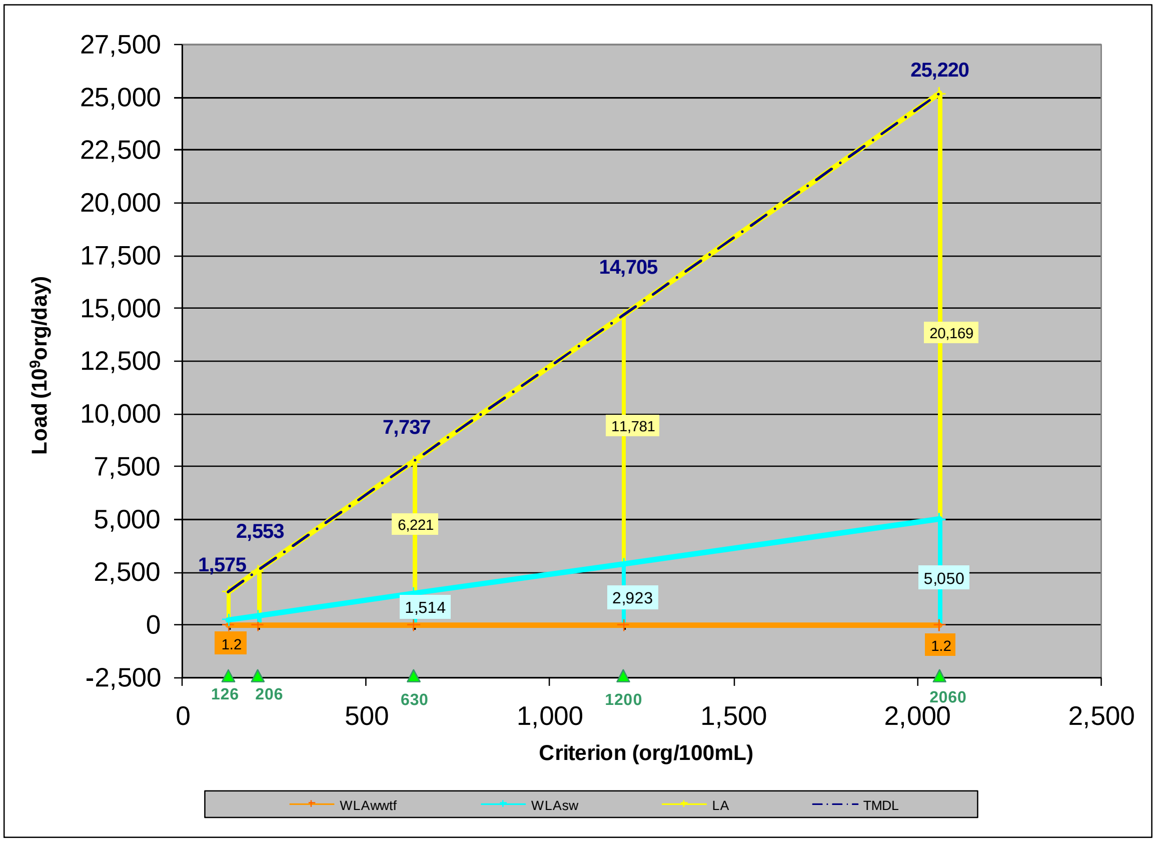
University of Florida 1987. Institute of Food and Agricultural Sciences, University Of Florida, Florida Cooperative Extension Service. No. 31, December, 1987.

University of Houston and CDM 2008. Technical Support Document for Buffalo and Whiteoak Bayou TMDL. < www.tceq.state.tx.us/assets/public/implementation/water/tmdl/ 22buffalobayou/22-techsupportdoc.pdf>.

U.S. Census Bureau 1995. <www.census.gov/>.

Appendix A.
Equations for Calculating TMDL Allocations for Changed Contact Recreation Standards

Assessment Unit 1013_01



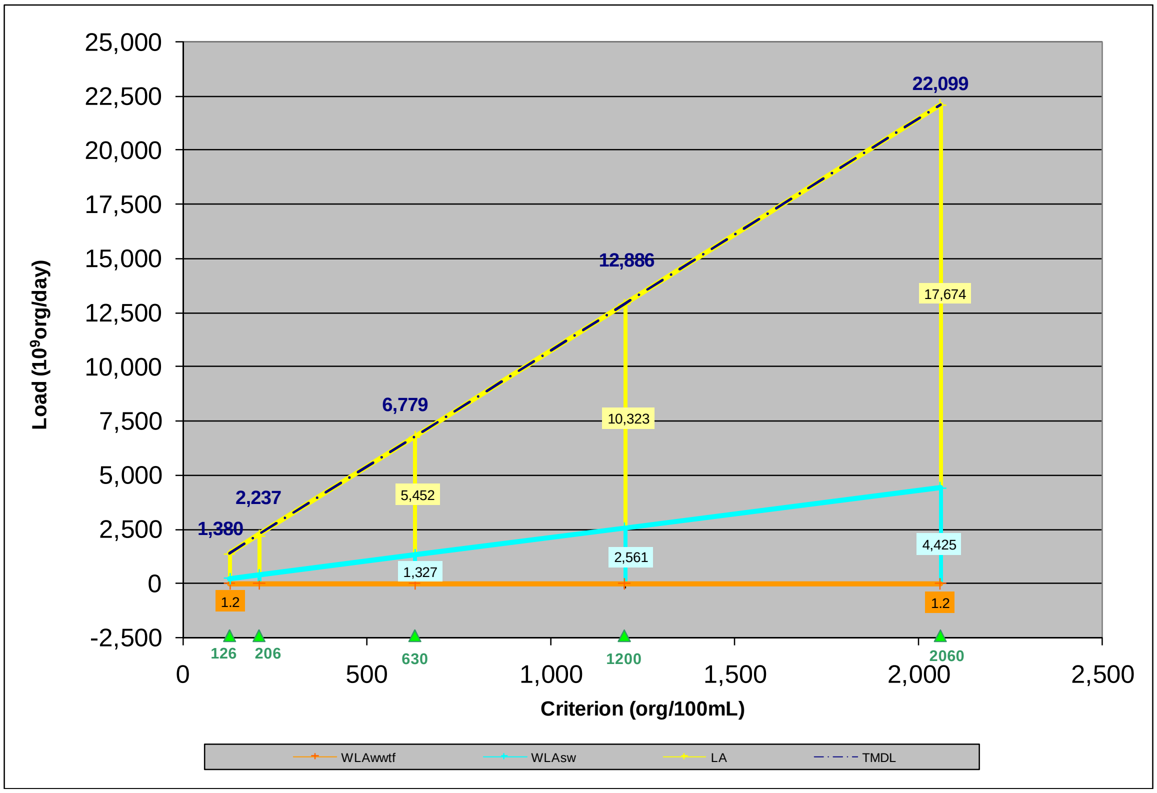
Equations for Calculating New TMDL and Allocations

$$TMDL = 12.2258*Std + 34.31$$
$$LA = 9.7535*Std$$
$$WLA_{Storm\ Water} = 2.4724*Std$$
$$WLA_{WWTF} = 1.19$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1013A_01



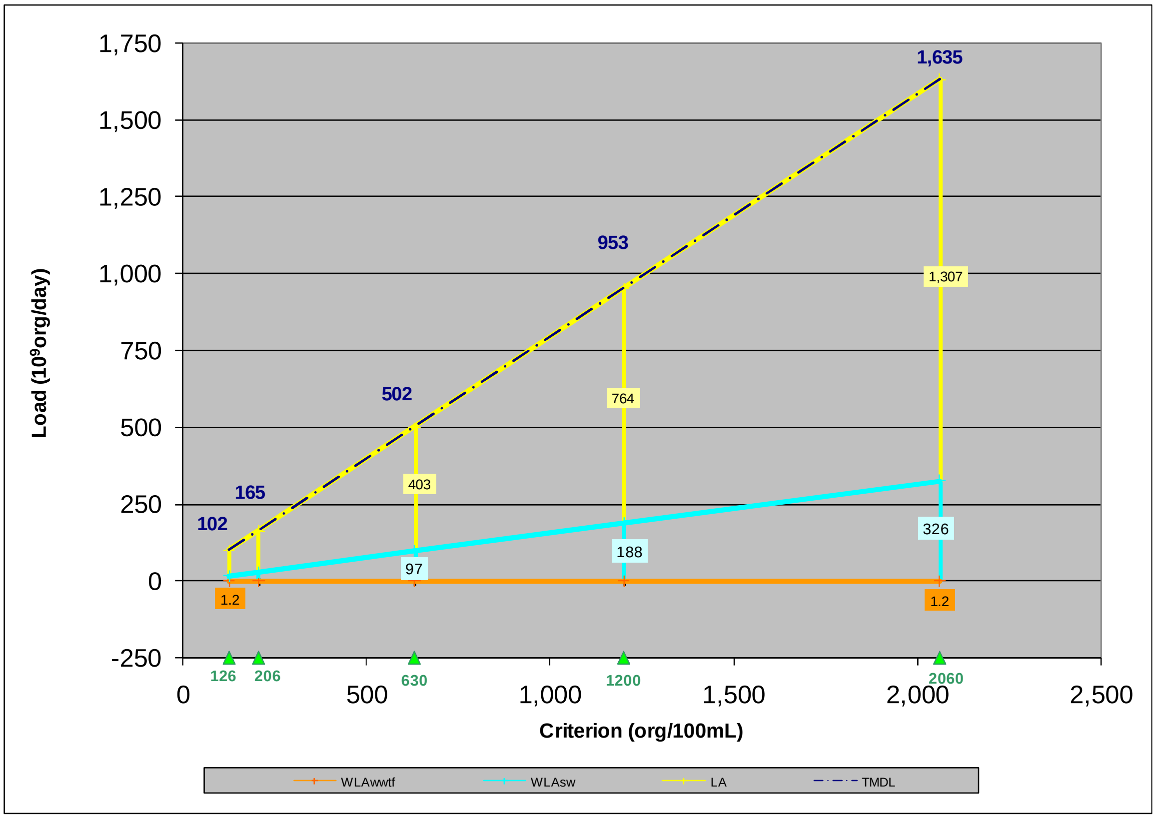
Equations for Calculating New TMDL and Allocations

$$TMDL = 10.7133*Std + 30.07$$
$$LA = 8.5468*Std$$
$$WLA_{Storm\ Water} = 2.1665*Std$$
$$WLA_{WWTF} = 1.19$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1013C_01



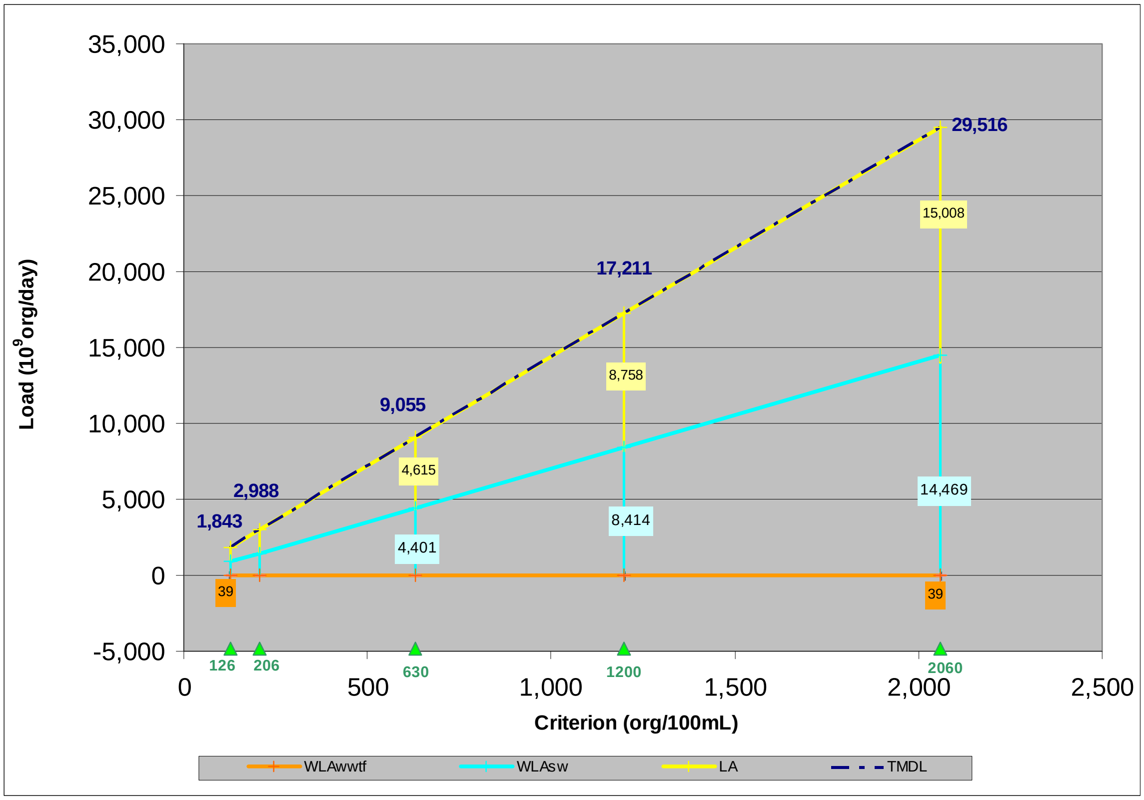
Equations for Calculating New TMDL and Allocations

$$\text{TMDL} = 0.7925*\text{Std} + 2.22$$
$$\text{LA} = 0.6322*\text{Std}$$
$$\text{WLA}_{\text{Storm Water}} = 0.1603*\text{Std}$$
$$\text{WLA}_{\text{WWTF}} = 1.19$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$\text{WLA}_{\text{Storm Water}}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014_01



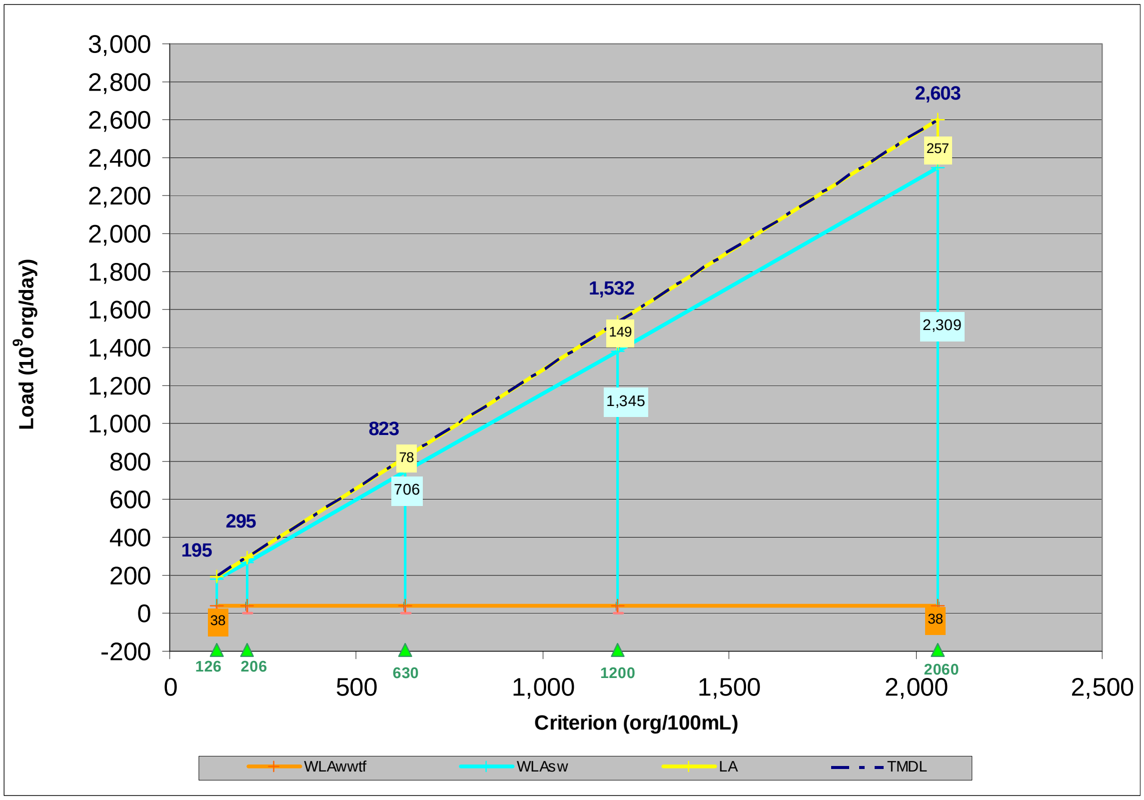
Equations for Calculating New TMDL and Allocations

$$TMDL = 1.2452*Std + 38.15$$
$$LA = 0.1245*Std$$
$$WLA_{Storm\ Water} = 1.1206*Std$$
$$WLA_{WWTF} = 38.15$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014A_01



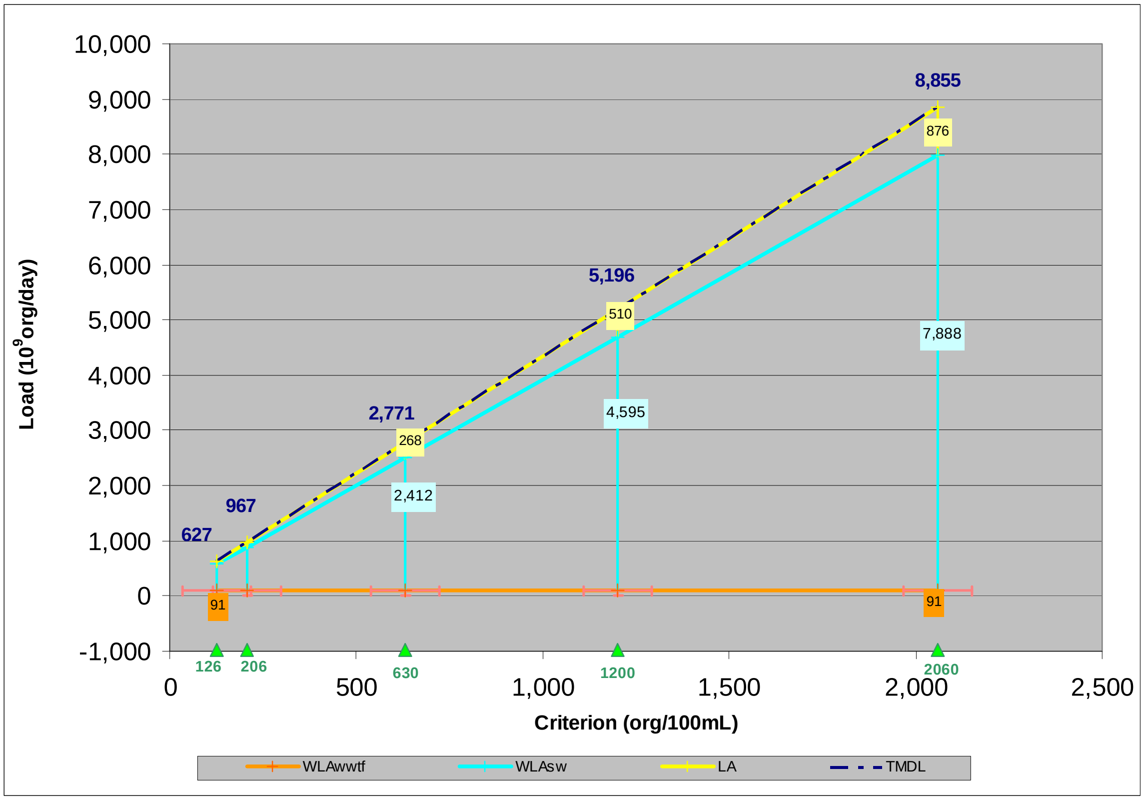
Equations for Calculating New TMDL and Allocations

$$TMDL = 1.2452*Std + 38.15$$
$$LA = 0.1245*Std$$
$$WLA_{Storm\ Water} = 1.1206*Std$$
$$WLA_{WWTF} = 38.15$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014B_01



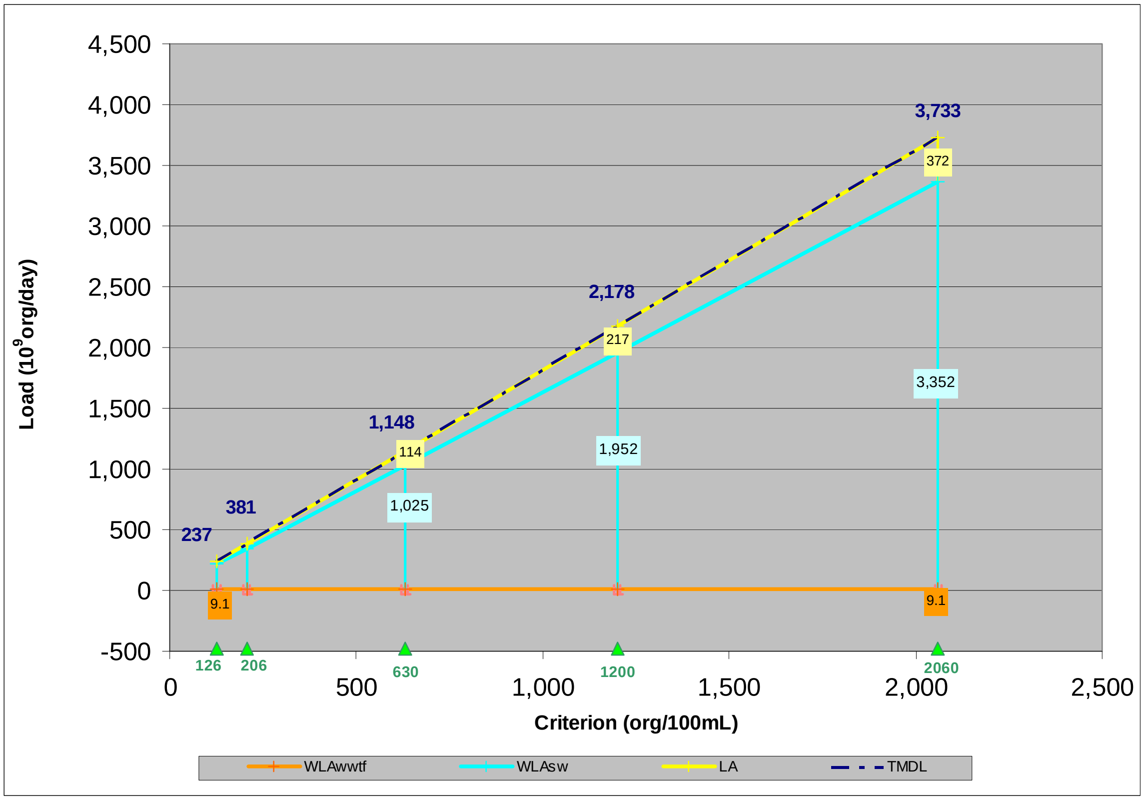
Equations for Calculating New TMDL and Allocations

$$TMDL = 4.2543*Std + 90.87$$
$$LA = 0.4254*Std$$
$$WLA_{Storm\ Water} = 3.8289*Std$$
$$WLA_{WWTF} = 90.87$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014E_01



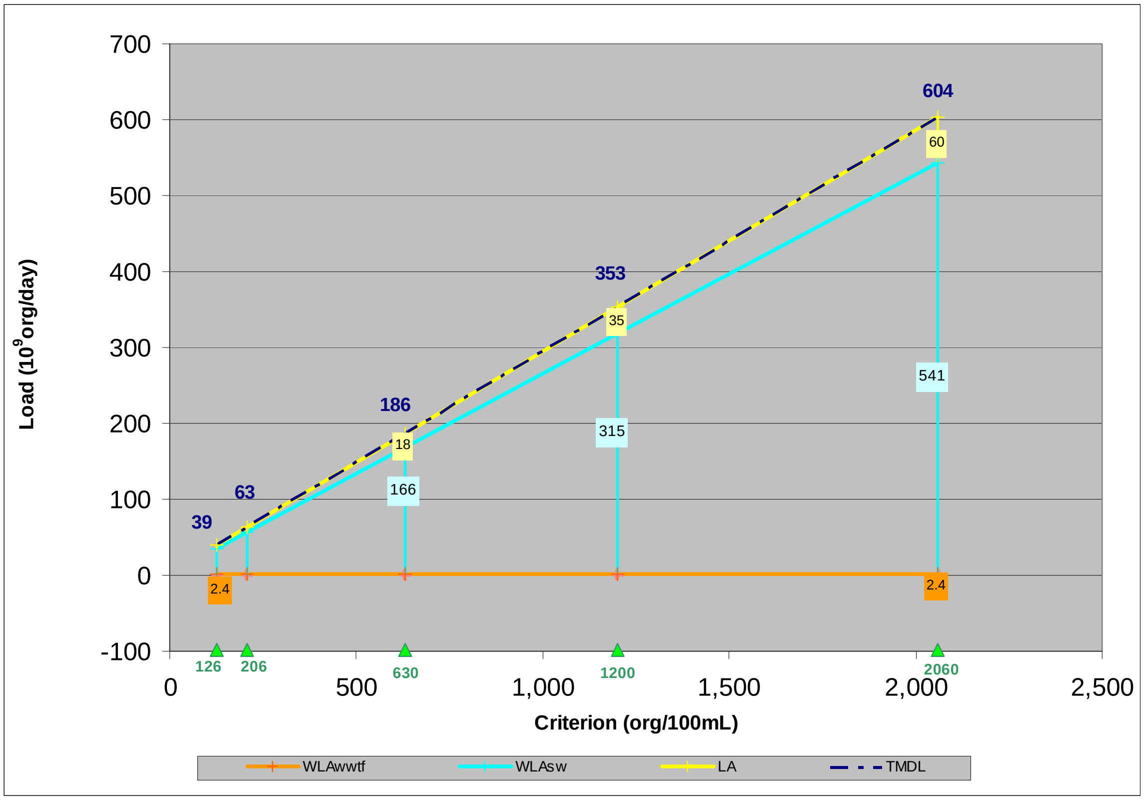
Equations for Calculating New TMDL and Allocations

$$\text{TMDL} = 1.8078 \times \text{Std} + 9.06$$
$$\text{LA} = 0.1808 \times \text{Std}$$
$$\text{WLA}_{\text{Storm Water}} = 1.6270 \times \text{Std}$$
$$\text{WLA}_{\text{WWTF}} = 9.06$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$\text{WLA}_{\text{Storm Water}}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014H_01



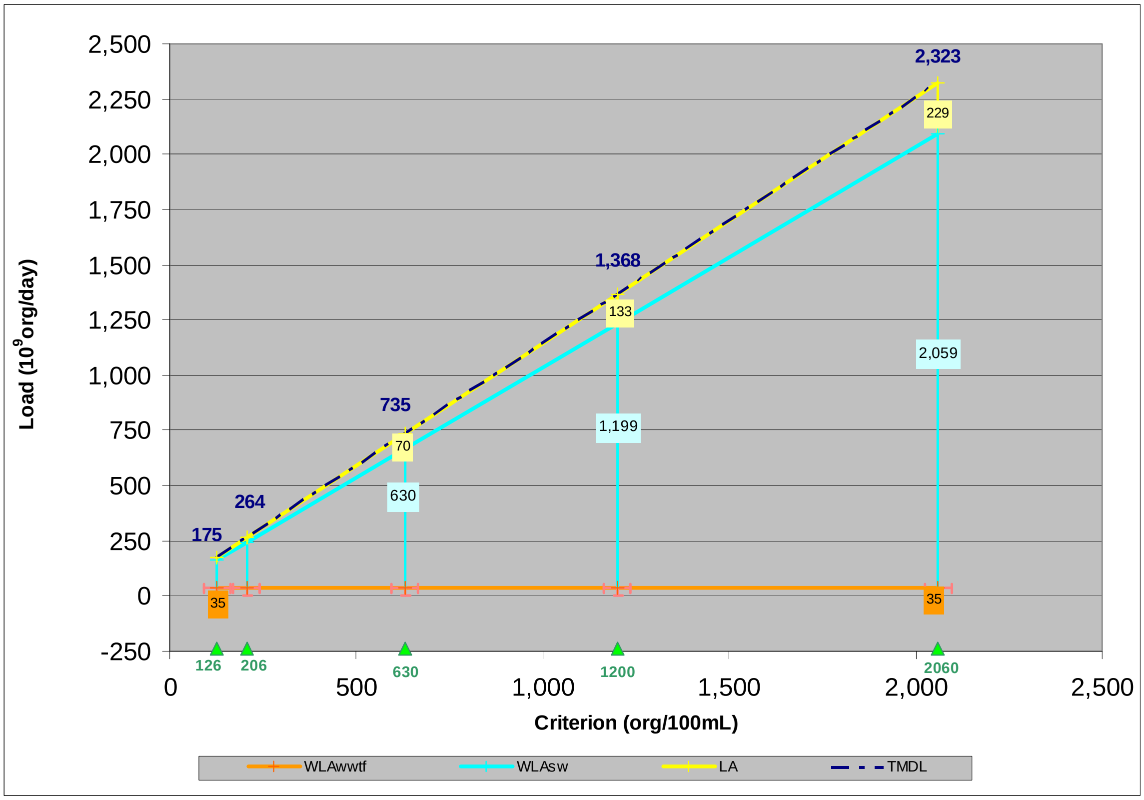
Equations for Calculating New TMDL and Allocations

$$TMDL = 0.2921*Std + 2.38$$
$$LA = 0.0292*Std$$
$$WLA_{Storm\ Water} = 0.2629*Std$$
$$WLA_{WWTF} = 2.38$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014H_02



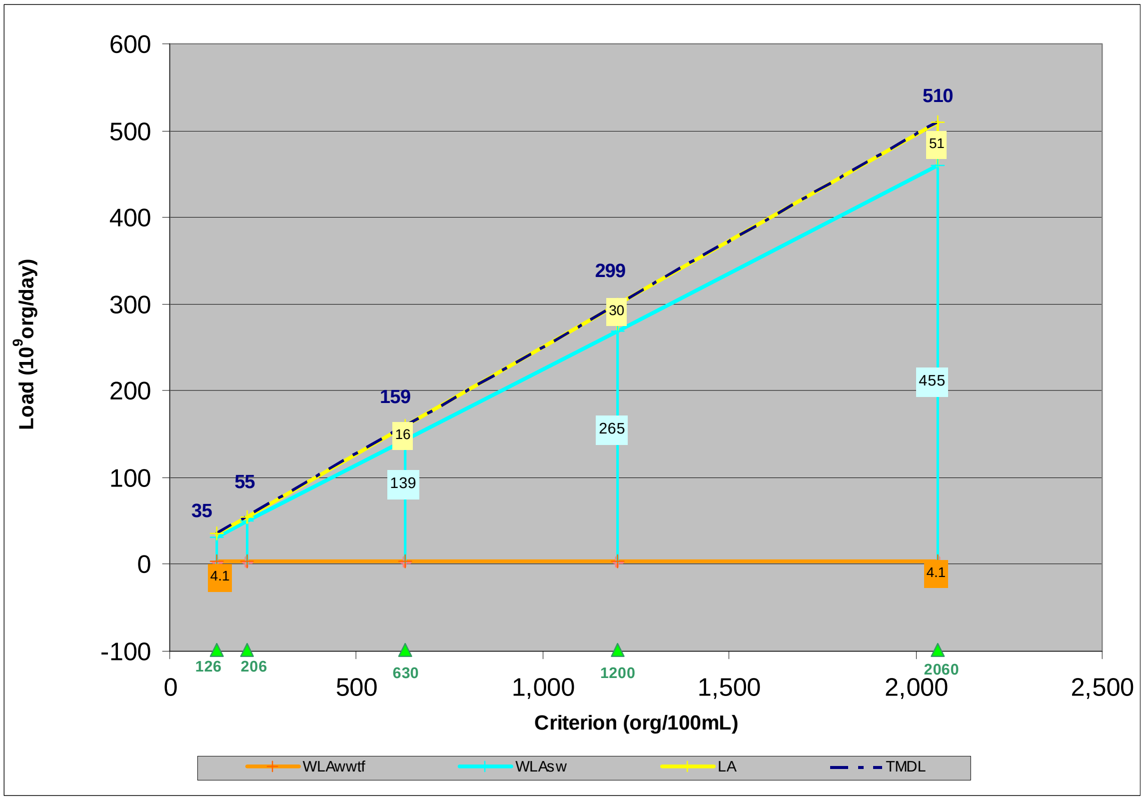
Equations for Calculating New TMDL and Allocations

$$TMDL = 1.1105*Std + 35.31$$
$$LA = 0.1110*Std$$
$$WLA_{Storm\ Water} = 0.9994*Std$$
$$WLA_{WWTF} = 35.31$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014K_01



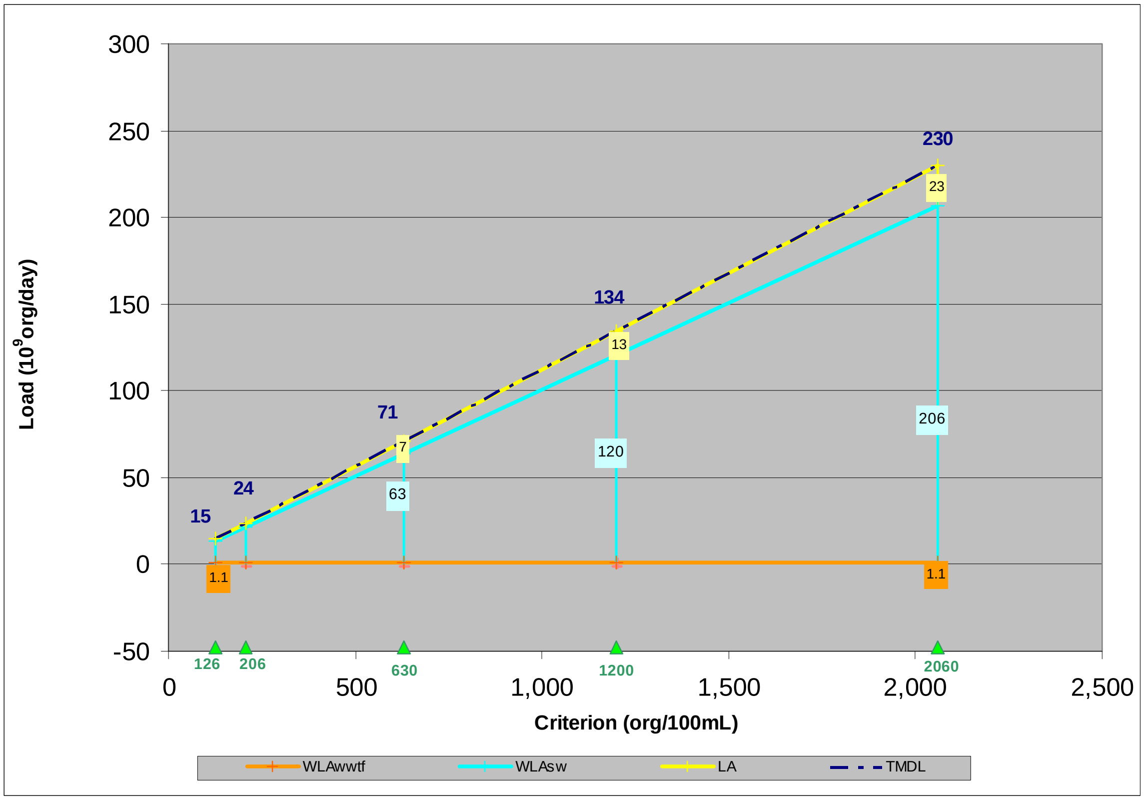
Equations for Calculating New TMDL and Allocations

$$TMDL = 0.2457*Std + 4.11$$
$$LA = 0.246*Std$$
$$WLA_{Storm\ Water} = 0.2211*Std$$
$$WLA_{WWTF} = 4.11$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014K_02



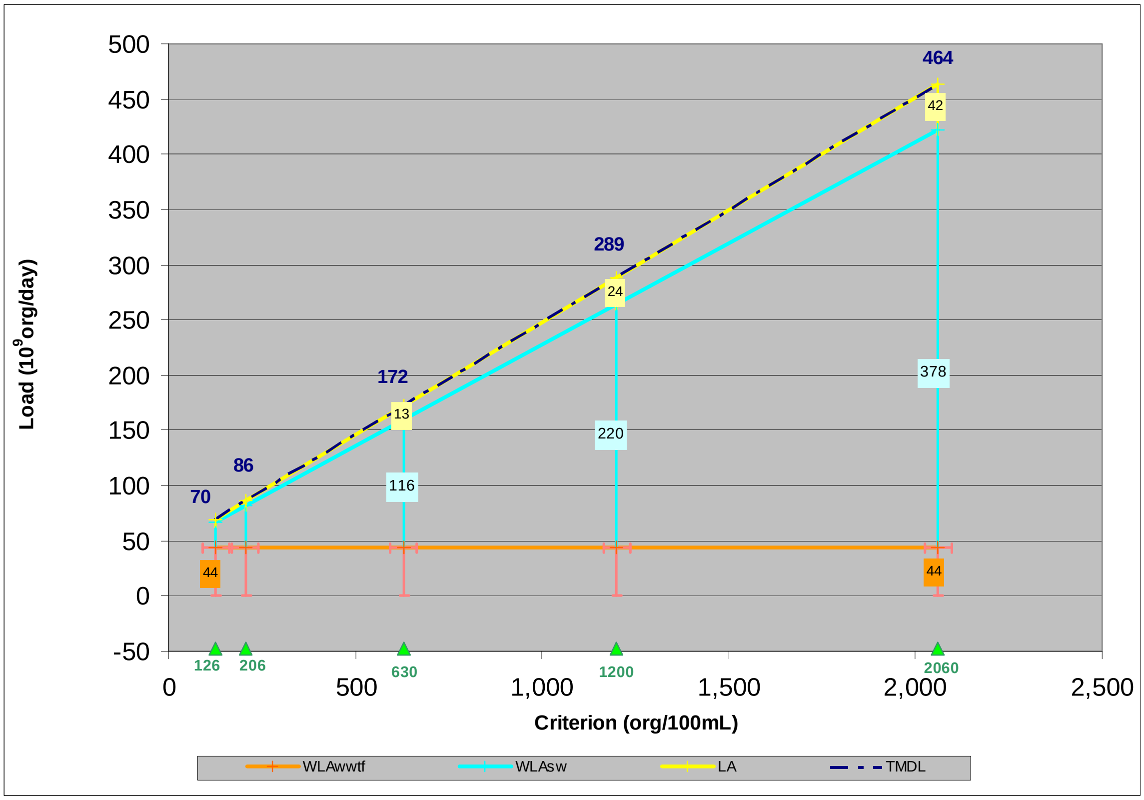
Equations for Calculating New TMDL and Allocations

$$TMDL = 0.1110*Std + 1.12$$
$$LA = 0.0111*Std$$
$$WLA_{Storm\ Water} = 0.0998*Std$$
$$WLA_{WWTF} = 1.12$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014L_01



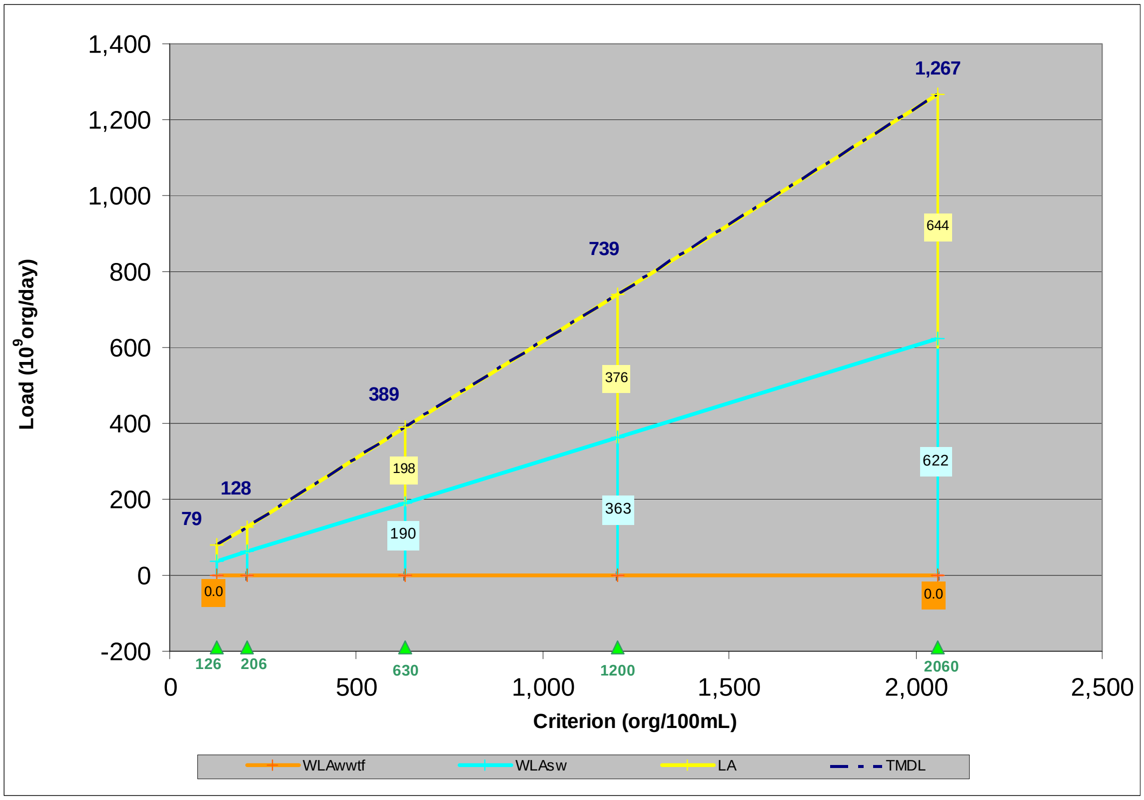
Equations for Calculating New TMDL and Allocations

$TMDL = 0.2038*Std + 43.98$
$LA = 0.0204*Std$
$WLA_{Storm\ Water} = 0.1834*Std$
$WLA_{WWTF} = 43.98$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014M_01



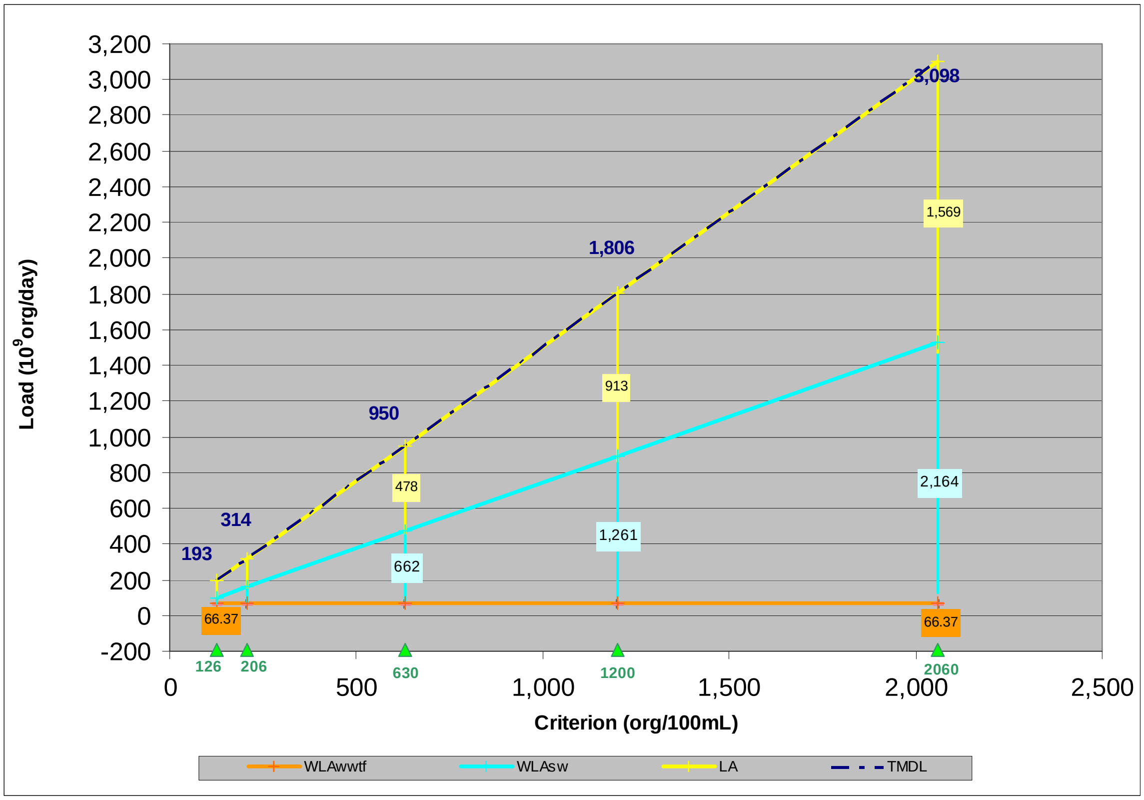
Equations for Calculating New TMDL and Allocations

$$TMDL = 0.6140*Std + 1.72$$
$$LA = 0.3119*Std + 1.69$$
$$WLA_{Storm\ Water} = 0.3021*Std + 0.03$$
$$WLA_{WWTF} = 0.00$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014N_01



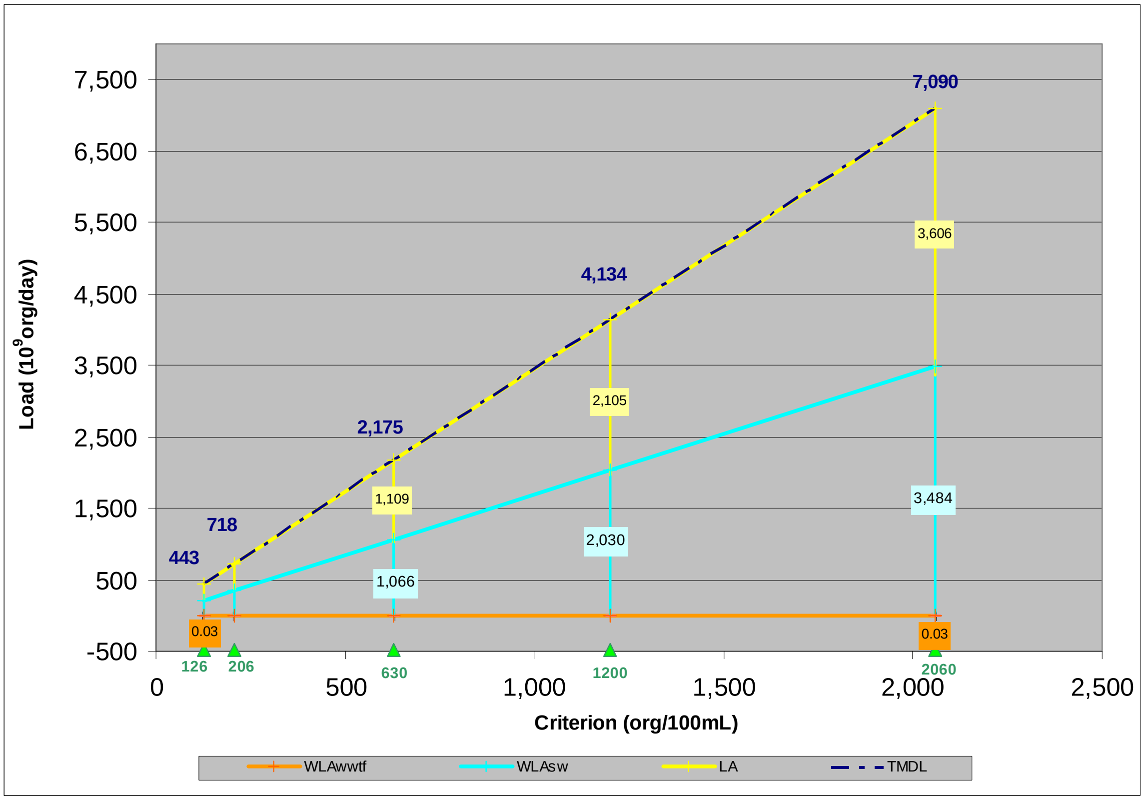
Equations for Calculating New TMDL and Allocations

$$TMDL = 1.5019*Std + 4.21$$
$$LA = 0.7629*Std - 2.49$$
$$WLA_{Storm\ Water} = 0.7390*Std - 59.66$$
$$WLA_{WWTF} = 66.37$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1014O_01



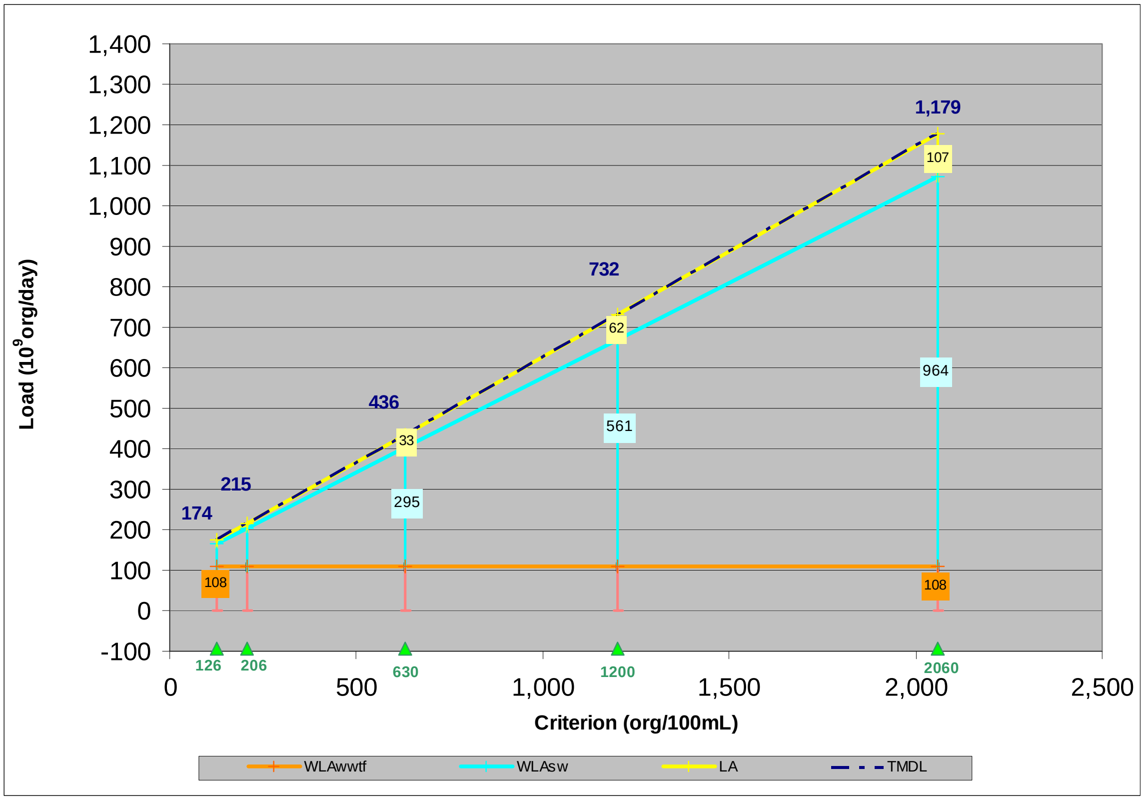
Equations for Calculating New TMDL and Allocations

TMDL = 3.4371*Std + 9.63
LA = 1.7459*Std + 9.48
$WLA_{Storm\ Water}$ = 1.6911*Std + 0.13
WLA_{WWTF} = 0.03

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017_01



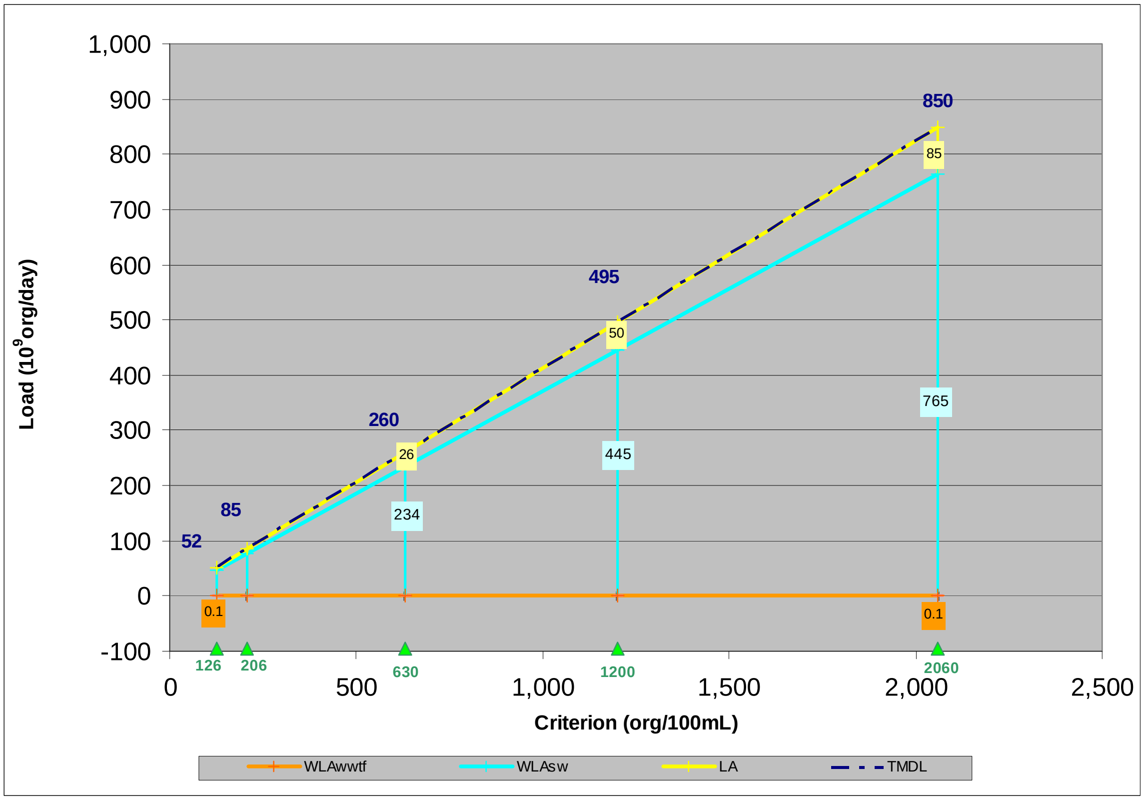
Equations for Calculating New TMDL and Allocations

$$\mathrm{TMDL} = 0.5198 * \mathrm{Std} + 108.09$$
$$\mathrm{LA} = 0.0520 * \mathrm{Std}$$
$$\mathrm{WLA}_{\mathrm{Storm\ Water}} = 0.4678 * \mathrm{Std}$$
$$\mathrm{WLA}_{\mathrm{WWTF}} = 108.09$$

Where:

$\mathrm{WLA}_{\mathrm{WWTF}}$ = waste load allocation (permitted WWTF)
$\mathrm{WLA}_{\mathrm{Storm\ Water}}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017_02



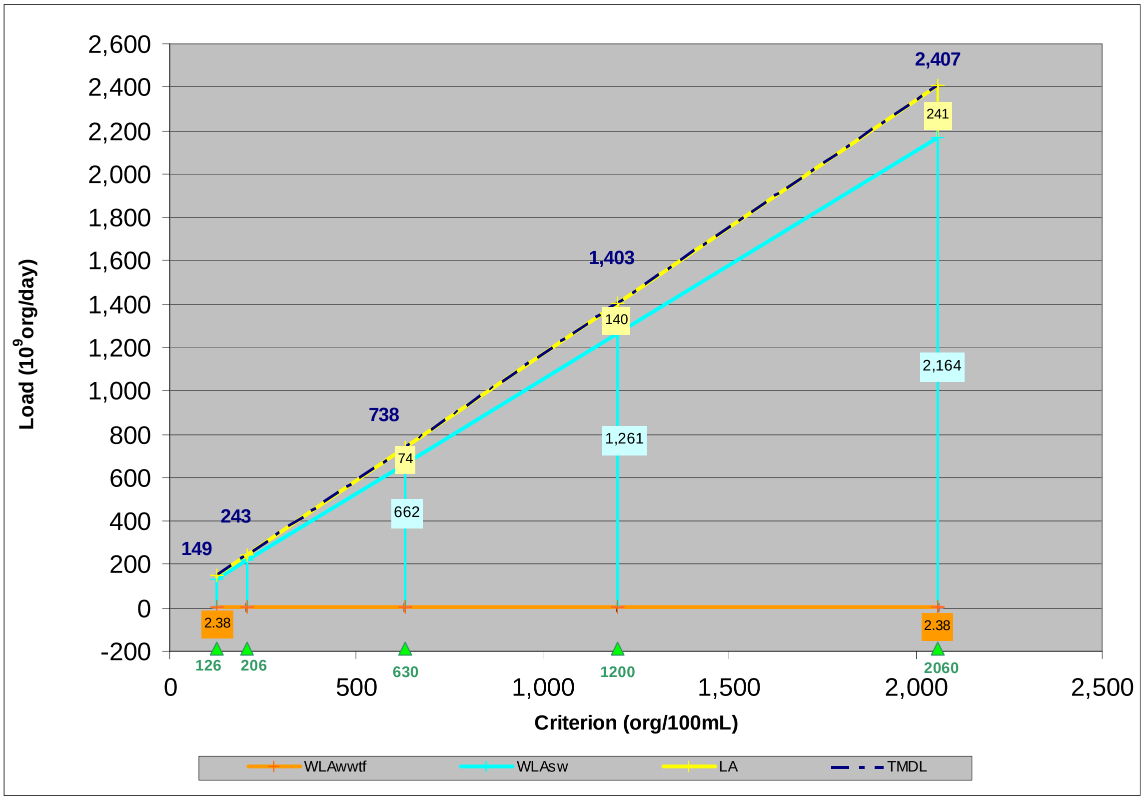
Equations for Calculating New TMDL and Allocations

$$TMDL = 0.4125*Std + 0.10$$
$$LA = 0.0413*Std$$
$$WLA_{Storm\ Water} = 0.3712*Std$$
$$WLA_{WWTF} = 0.10$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017_03



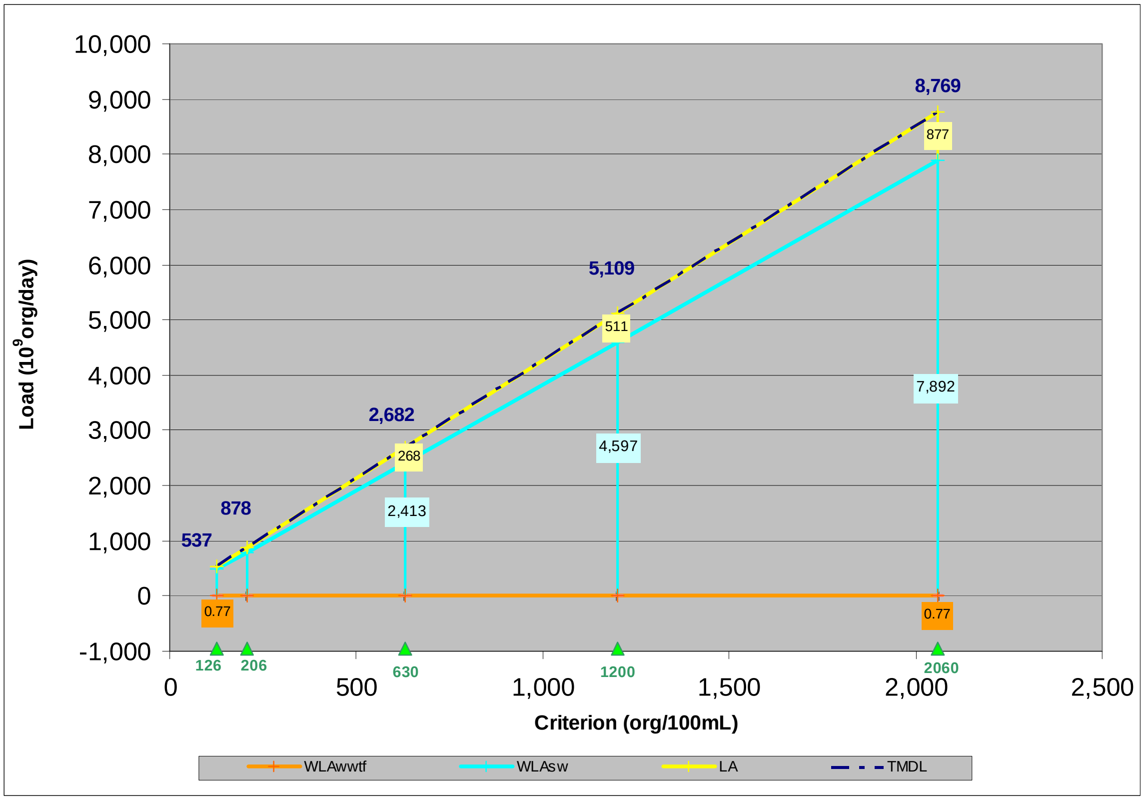
Equations for Calculating New TMDL and Allocations

$$TMDL = 1.1674*Std + 2.38$$
$$LA = 0.1167*Std$$
$$WLA_{Storm\ Water} = 1.0506*Std$$
$$WLA_{WWTF} = 2.38$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017_04



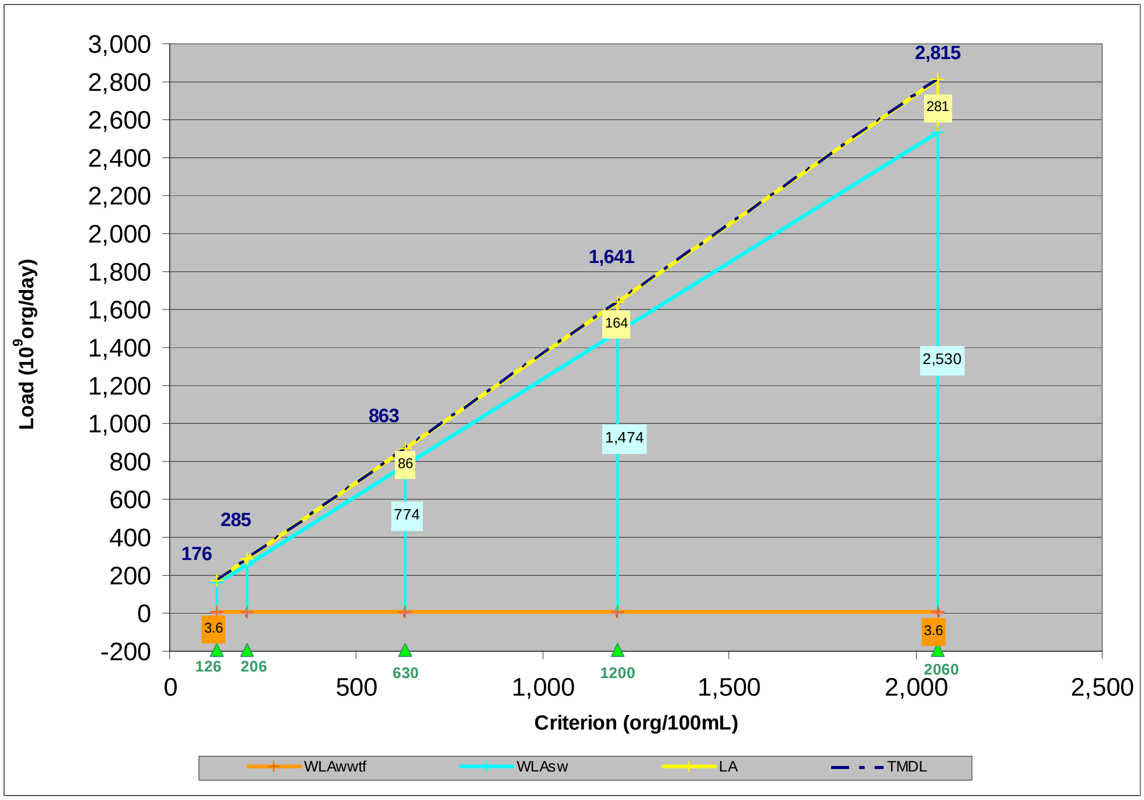
Equations for Calculating New TMDL and Allocations

$$TMDL = 4.2565 * Std + 0.77$$
$$LA = 0.4256 * Std$$
$$WLA_{Storm\ Water} = 3.8309 * Std$$
$$WLA_{WWTF} = 0.77$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017A_01



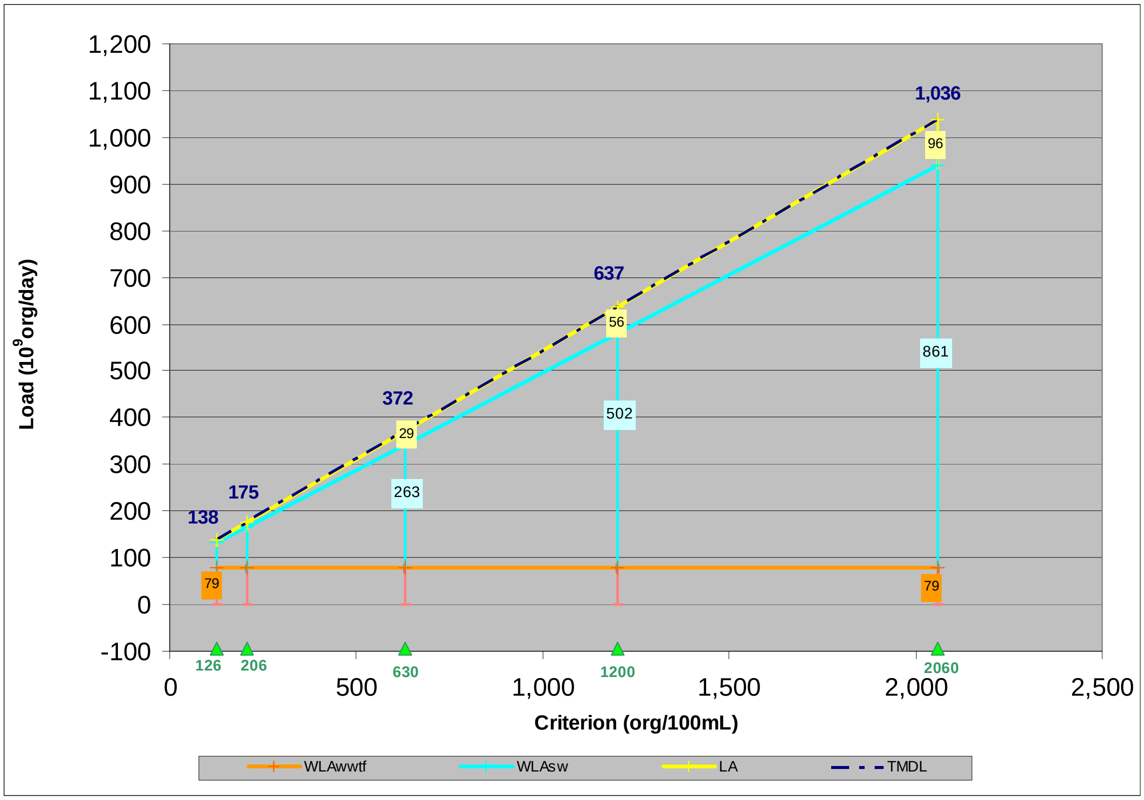
Equations for Calculating New TMDL and Allocations

TMDL = 1.3648*Std + 3.60
LA = 0.1365*Std
$WLA_{Storm\ Water}$ = 1.2283*Std
WLA_{WWTF} = 3.60

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017B_02



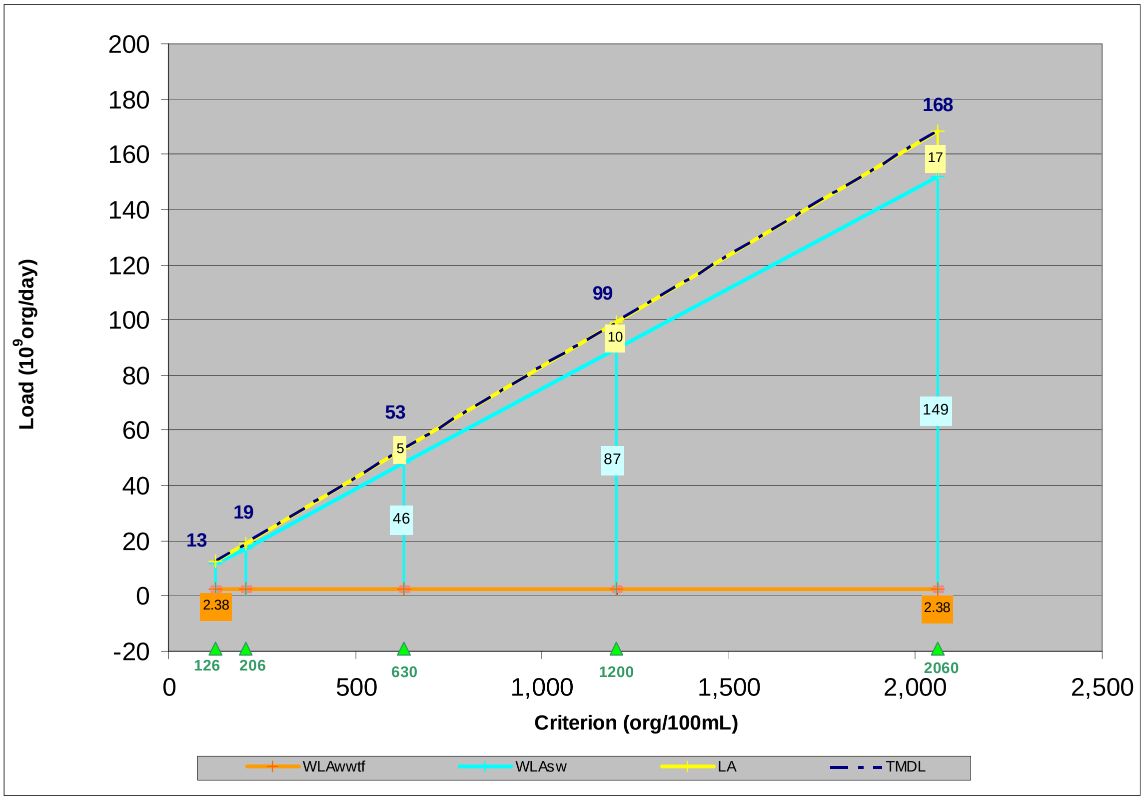
Equations for Calculating New TMDL and Allocations

$$\text{TMDL} = 0.4645*\text{Std} + 79.41$$
$$\text{LA} = 0.0464*\text{Std}$$
$$\text{WLA}_{\text{Storm Water}} = 0.4181*\text{Std}$$
$$\text{WLA}_{\text{WWTF}} = 79.41$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$\text{WLA}_{\text{Storm Water}}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017D_01



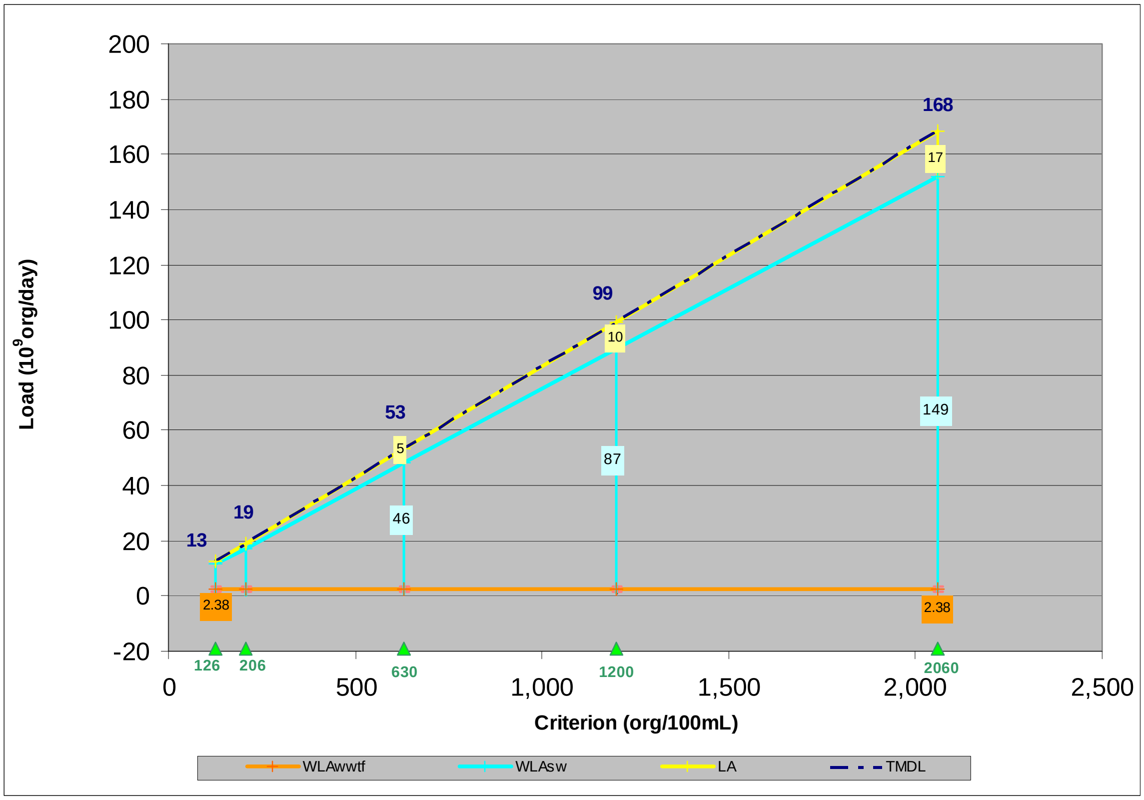
Equations for Calculating New TMDL and Allocations

$$TMDL = 0.0806*Std + 2.38$$
$$LA = 0.0081*Std$$
$$WLA_{Storm\ Water} = 0.0725*Std$$
$$WLA_{WWTF} = 2.38$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard

Assessment Unit 1017E_01



Equations for Calculating New TMDL and Allocations

$$TMDL = 0.0806*Std + 2.38$$
$$LA = 0.0081*Std$$
$$WLA_{Storm\ Water} = 0.0725*Std$$
$$WLA_{WWTF} = 2.38$$

Where:

WLA_{WWTF} = waste load allocation (permitted WWTF)
$WLA_{Storm\ Water}$ = waste load allocation (permitted storm water)
LA = load allocation (non-permitted source contributions)
Std = Revised Contact Recreation Standard