Total Maximum Daily Loads for Fecal Pathogens in Buffalo Bayou and Whiteoak Bayou

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TECHNICAL SUPPORT DOCUMENT FOR BUFFALO AND WHITEOAK BAYOU TMDL

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CHAPTER 1 : PROBLEM DEFINITION

States are required to develop a total maximum daily load (TMDL) for all water bodies identified as not meeting their designated per the Clean Water Act Section 303(d). TMDLs are estimates of pollutant loads that a stream can sustain and still meet the water quality standard. In their simplest form, TMDLs are the allowable loading determined from the water quality standard and stream flow.

The TMDL described in this document is being developed for impairments to contact recreational use for indicator bacteria in Buffalo and Whiteoak Bayou watersheds, which include Segments 1013, 1014 and 1017. These segments have been defined by the Texas Commission on Environmental Quality (TCEQ) as portions of Buffalo and Whiteoak Bayou that have similar characteristics.

1.1 WATERSHED DESCRIPTION

Buffalo Bayou and Whiteoak Bayous, the impaired streams addressed in this study, are located in and around the greater Houston area. Buffalo Bayou meanders 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 span across three counties, Harris, Fort Bend and Waller, with the majority of the watershed situated in Harris County. The watersheds also encompass the City of Houston along with several, smaller cities, including Hedwig Village, Spring Valley, Hilshire Village, Bunker Hill Village, Piney Point Village, Hunter's Creek Village, Jersey Village and Katy. A map of the overall
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watershed area is illustrated in **Figure 1.1**.

Buffalo and Whiteoak Bayous lie within the San Jacinto River Basin and eventually discharge to Galveston Bay. Segment 1013, Buffalo Bayou tidal watershed, has a drainage area of 7 square miles and is about 4 miles long. Buffalo Bayou above tidal, segment 1014, 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).

Segments 1014 and 1017 were placed on the Texas Clean Water Action 303(d) List in 1992, while Segment 1013 was placed on the list in 1994. In 2002, eleven (11) tributaries of these bayous were placed on the 303(d) list for not meeting pathogen water quality standards. These tributaries, shown in **Figure 1.2,** include Bear Creek (1014A), Upper Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), Mason Creek (1014L), Neimans Bayou (1014M), Rummel Creek (1014N), Spring Branch (1014O) and one unnamed tributary (1013C). In Whiteoak Bayou, the tributaries include Brickhouse Gully (1017A), Cole Creek (1017B), Little Whiteoak Bayou (1013A), and two unnamed tributaries (1017D and 1017E). Those tributaries discharging to Segment 1014 (i.e., 1014A, 1014B, 1014E, 1014H, 1014K, and 1014L) are denoted as “Reservoir Watersheds” or “Reservoir” for the purposes of this report, as will be subsequently described. A list of these segments and associated water bodies is presented in **Table 1.1**.

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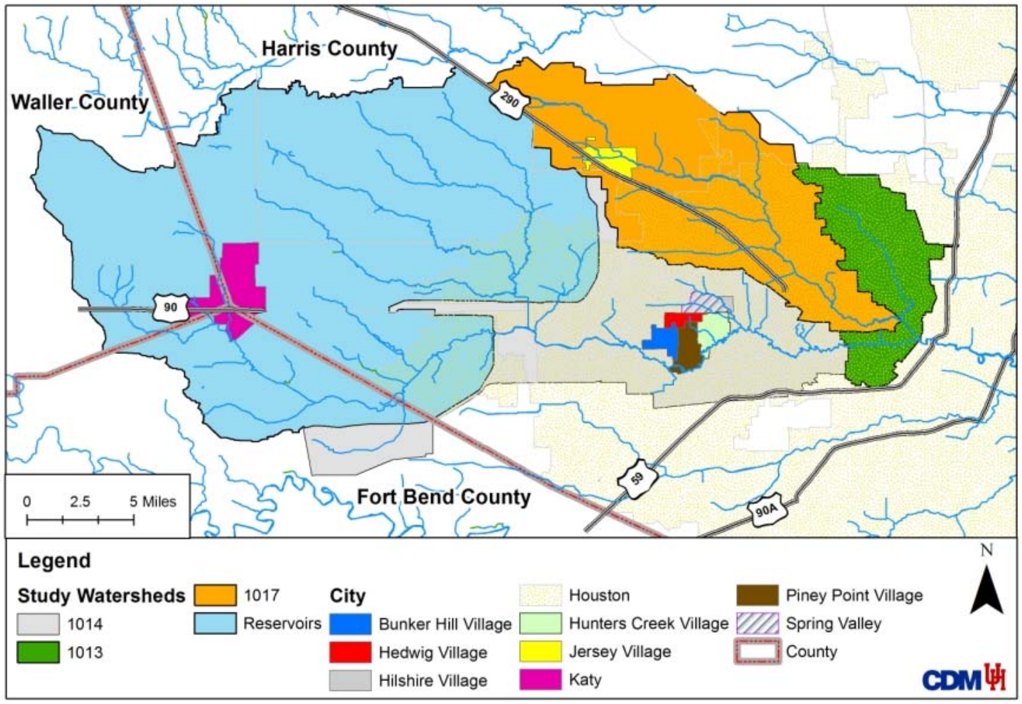

Figure 1.1 Buffalo and Whiteoak Bayou watersheds

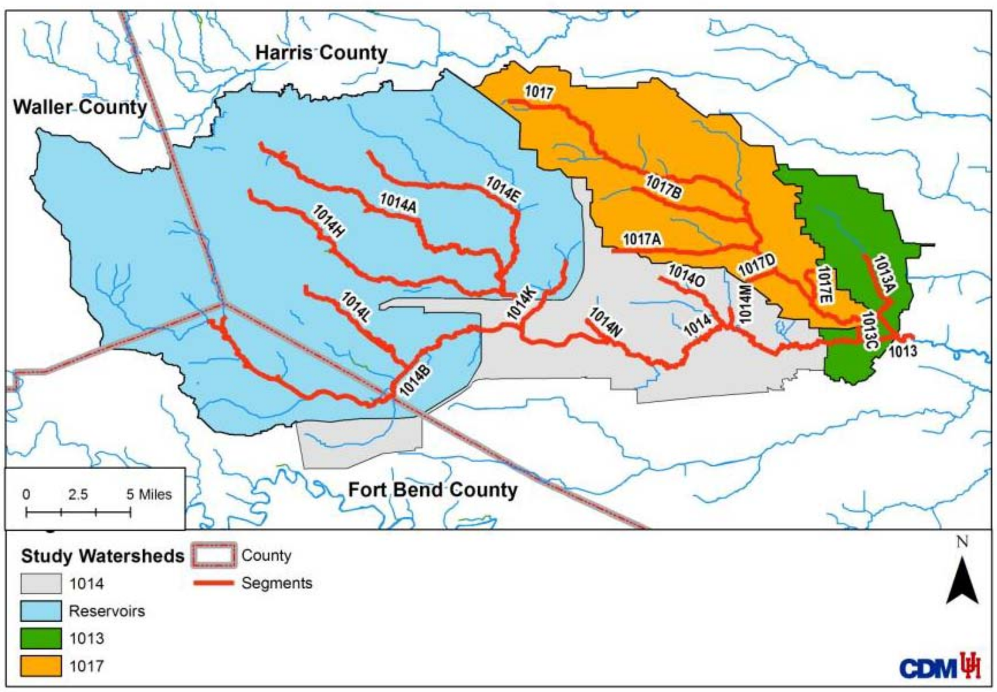

Figure 1.2 Buffalo and Whiteoak Bayou Segments

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Table 1.1 Water Bodies and Associated Watersheds

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

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A unique feature of the Buffalo Bayou watershed is that two flood control reservoirs are located along its main stem. The reservoirs are operated by the U. S. Army Corps of Engineers to minimize flooding downstream on Buffalo Bayou. The reservoirs detain flood waters until the potential for flooding has dissipated. At that point, water is released downstream at a maximum flow of 2,000 cfs (based upon United States Geological Survey (USGS) gage at Piney Point). The streams draining the reservoir watershed, which encompasses segments Bear Creek (1014A), Upper Buffalo Bayou (1014B), Langham Creek (1014E), South Mayde Creek (1014H), Turkey Creek (1014K), Mason Creek (1014L), were grouped and termed for this document as the "reservoir watershed segments."

1.2 ENDPOINT DESIGNATION

All TMDLs must identify a water quality target that indicates a measurable goal for the TMDL. Endpoints must be consistent with existing water quality standards. This endpoint provides a measurable goal for the TMDL. The endpoint for this project will be attaining the single sample standard for *E. coli* of 394 MPN/dL 75% of the time or greater while still being protective of the geometric mean standard.

Segments 1014 and 1017 are non-tidal segments while Segment 1013 is a tidal segment. Tidal segments are often characterized using the bacteria group enterococci rather than *E. coli*. However, in the case of this TMDL, *E. coli* was used instead of enterococci for several reasons, including salinity conditions, the availability of *E. coli* data and the lack of enterococci data. As shown in **Table 1.1**, only one station (station 11382) in Segment 1013 meets the definition of a high conductivity water indicating that it is brackish or salt water. In addition, the majority of the data used to develop the TMDL were collected and evaluated between 2001 and 2003. During this period, only *E. coli* data and a small amount of fecal coliform data were collected in Segment 1013 as shown in **Table 1.2**. The majority of enterococci data was collected starting in 2004.

Table 1.1 Routine Monitoring Data for Salinity and Specific in Segment 1013

Station ID	Seg-ment	Constituent	Date		Number of Samples	Specific Conductance or Salinity (μmho/cm or ppt, respectively)		
			Minimum	Maximum		Aver-age	Max-imum	High Conductivity Water?[1]
11148	1013A	Sp. Condu.	3/8/1999	2/8/2007	125	542	861	N
	1013A	Salinity	9/3/2003	2/8/2007	36	1	1	
11345	1013	Sp. Condu.	2/10/1999	11/7/2007	226	917	13,000	N*
	1013	Salinity	2/10/1999	11/7/2007	168	1	7	
11347	1013	Sp. Condu.	3/1/1999	2/5/2007	143	581	2,520	N
	1013	Salinity	8/12/2002	2/5/2007	35	1	1	
11351	1013	Sp. Condu.	3/1/1999	2/5/2007	136	528	958	N
	1013	Salinity	12/3/2004	2/5/2007	24	1	1	
11382	1013	Sp. Condu.	8/12/2002	4/23/2004	6	4,250	11,200	Y
	1013	Salinity	8/12/2002	4/23/2004	3	4	6	
11384	1013	Sp. Condu.	11/14/2000	8/14/2001	3	692	865	N
	1013	Salinity	8/14/2001	8/14/2001	1	1	1	
15825	1013	Sp. Condu.	6/28/2000	10/20/2005	60	688	2,798	N
	1013	Salinity	11/6/2001	10/20/2005	24	1	1	
15843	1013	Sp. Condu.	11/15/2000	2/5/2007	72	471	873	N
	1013	Salinity	12/3/2004	2/5/2007	24	1	1	
16648	1013A	Sp. Condu.	3/1/1999	2/8/2007	121	496	857	N
	1013A	Salinity	9/3/2003	2/8/2007	36	1	1	
16675	1013C	Sp. Condu.	3/1/1999	2/5/2007	111	775	1,320	N
	1013C	Salinity	12/3/2004	2/5/2007	24	1	1	

[1]N - maximum specific conductance < 3077 mmhos/cm
N* - 241 samples out of 251 collected are below 3077

Abbreviation:
ppt - parts per thousand

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Table 1.2 Summary of Bacteria Routine Monitoring Data for Segment 1013

Station ID	Segment	Constituent	Date		Number of Samples	Average	Maxi-mum
			Minimum	Maximum			
11148	1013A	Fecal, MF	08-Mar-99	23-May-01	70	67,868	200,000
	1013A	*E. coli*	10-Dec-01	08-Feb-07	61	28,669	240,000
11149	1013A	Fecal, MF	26-May-99	26-May-99	1	460	460
11345	1013	Fecal, MF Agar	10-Feb-99	30-Jan-03	25	4,248	21,000
	1013	Fecal, MF	08-Feb-99	16-May-01	37	13,984	200,000
	1013	*E. coli*	06-Dec-01	15-Nov-04	38	6,486	69,000
	1013	Entero	14-Nov-00	07-Nov-07	56	1,504	22,000
11347	1013	Fecal, MF	01-Mar-99	16-May-01	85	8,572	200,000
	1013	*E. coli*	06-Dec-01	29-Sep-05	38	16,032	170,000
	1013	Entero	03-Dec-04	05-Feb-07	22	1,348	20,000
11351	1013	Fecal, MF Agar	13-Jun-01	18-Jun-01	2	2,400	2,800
	1013	Fecal, MF	28-Jan-99	16-May-01	115	11,088	200,000
	1013	*E. coli*	13-Jun-01	15-Nov-04	39	10,369	140,000
	1013	Entero	03-Dec-04	05-Feb-07	23	2,602	28,000
11384	1013	Fecal, MF Agar	14-Aug-01	14-Aug-01	1	454	454
	1013	*E. coli*	14-Nov-00	23-May-01	2	2,751	3,609
	1013	Entero	13-Feb-01	14-Aug-01	2	60	110
15825	1013	Fecal, MF Agar	14-Nov-00	30-Jan-03	8	7,486	28,000
	1013	Fecal, MF	09-Apr-99	23-May-01	34	14,346	100,000
	1013	*E. coli*	10-Dec-01	20-Oct-05	44	15,739	240000
	1013	Entero	06-Nov-01	31-Jul-03	7	1,841	6,488
15843	1013	Fecal, MF	08-Feb-99	16-May-01	38	11,494	200,000
	1013	*E. coli*	06-Dec-01	24-Jul-06	38	16,341	200,000
	1013	Entero	03-Dec-04	05-Feb-07	22	2,353	20,000
16647	1013	Fecal, MF	09-Apr-99	15-Sep-99	6	5,548	15,000
16648	1013A	Fecal, MF	01-Mar-99	23-May-01	86	21,689	200,000
	1013A	*E. coli*	10-Dec-01	08-Feb-07	61	17,176	190,000
16675	1013C	Fecal, MF	01-Mar-99	16-May-01	66	31,716	440,000
	1013C	*E. coli*	06-Dec-01	05-Feb-07	61	25,220	240,000

Abbreviations:
MF – membrane filtration

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1.3 CRITICAL CONDITION

All TMDLs must identify a critical condition, at which point the pollutant source is expected to have the potential to affect water quality the most. Sources of bacteria are varied and can act 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 upon the flow duration curve: Low Flow (0-30 percentile), Intermediate flow (30 to 70th percentiles) and High flow (70th and above). In the context of the TMDL, the dry weather condition is representative of stream conditions for the study watersheds that are not impacted by runoff and bayou flows are maintained primarily by wastewater treatment plant flows; this is typically defined as less than the 30^{th} percentile flow. The wet weather condition is representative of stream conditions for the study watersheds that are caused by rainfall events. Bayou flows are mostly runoff when in-stream flows are greater than the 70^{th} percentile flow, based upon an examination of the stream flow-duration curve. Intermediate conditions includes 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 30^{th} and 70^{th} percentile flows.

1.4 MARGIN OF SAFETY

Conservative assumptions have been made throughout this TMDL report and thus constitute an implicit margin of safety. No explicit margin of safety was applied.

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CHAPTER 2 : SUMMARY OF EXISTING DATA

Buffalo and Whiteoak Bayous are very well monitored streams, with water quality data as far as the early 1970's. These watersheds also have extensive data on their physical properties that are summarized in the following sections.

2.1 WATERSHED CHARACTERISTICS

The following sections describe the watershed characteristics for the Buffalo and Whiteoak Bayou watersheds. Included is a explanation of the land use of the watersheds, climate, economy and soils.

2.1.1 LAND USE

Land use data for this study are based upon classifications of land cover analyzed by the Houston-Galveston Area Council (Houston-Galveston Area Council 2001; 2002). Land cover data were derived from several sources, including year 2000 satellite image data and aerial photography as well as Landsat 7 ETM multi-spectral satellite images from November 1999 and February 2000, county appraisal data from the third quarter of 1999, year 2000 public utility connections data, and Census 2000 blocks and population.

As shown in **Figure 2.1** and summarized in **Table 2.1**, the H-GAC land use data include estimates for the following categories of land use/land cover: residential (predominantly single family subdivisions, single family residence, and mobile homes), commercial (all developed non-residential uses, some apartment complexes), open land

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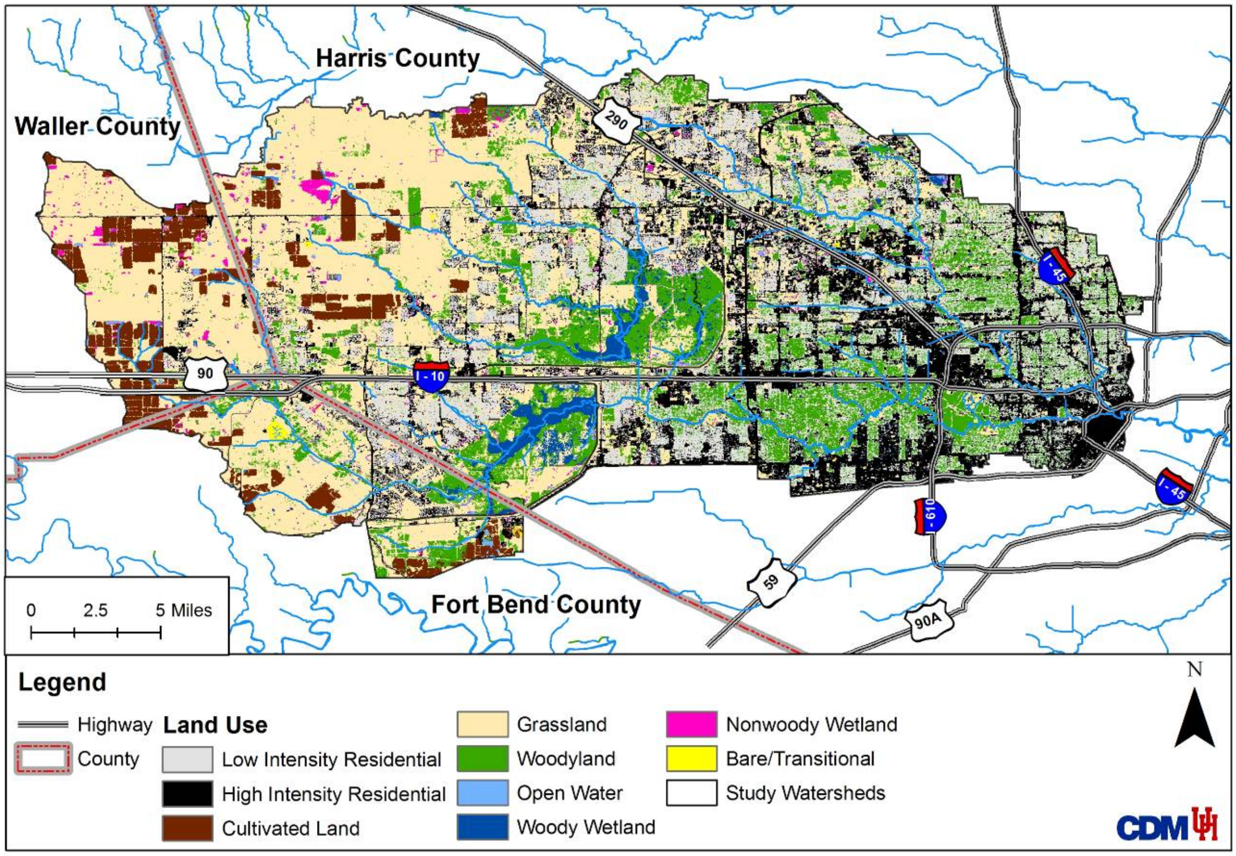

Figure 2.1 Land use/Land Cover

Table 2.1 Summary of Land Use in Buffalo and Whiteoak Bayous

Segment	Low Intensity Developed	High Intensity Developed	Cultivated Land	Grass-land	Woody Land	Open Water	Woody Wetland	Non-Woody Wetland	Bare / Transitional Land
Reservoirs	9%	7%	8%	57%	12%	1%	4%	2%	0%
1013	38%	41%	0%	8%	12%	1%	0%	0%	0%
1014	22%	33%	2%	17%	24%	1%	0%	0%	0%
1017	29%	30%	0%	24%	14%	1%	1%	1%	0%

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(undeveloped land, including parks and rights of way), water and other (indeterminate land classifications that are primarily open land and/or water). Land use in Segments 1013, 1014, and 1017 is dominated by high and low intensity developed land, while the Reservoir watershed is primarily grassland.

2.1.2 CLIMATE

The climate in the Buffalo and Whiteoak Bayou watersheds is distinguished 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˚F and 94˚F. Winter temperatures range from a low of around 40˚F to a mild high around 63˚F.

The study area experiences frequent rainfall events with annual precipitation totals around 50 inches. Monthly rainfall totals are fairly consistent throughout the year, with the slightly more rainfall falling in May and June (approximately 5 inches) compared to the remainder of the year (3 to 4 inches). High intensity rainfall often causes localized street flooding and occasional out of bank conditions. As the study watersheds are located near the Gulf Coast, they are potentially subject to hurricanes between June 1 and November 30 every year, although the chance of tropical weather declines dramatically in October.

2.1.3 ECONOMY

The Greater Houston Metropolitan region, partially covered by the Buffalo and Whiteoak Bayou watersheds, is home to more than three million people. These individuals work in a variety of industry and commercial ventures. Some of the major contributors to the economy in the region are the petroleum, energy and medical sectors. The study area includes the central business district of Houston, home to many multi-national corporations.

Buffalo Bayou, in particular, is especially important to the region's economy. Just outside the central business district of Houston, outside the study area, Buffalo Bayou becomes the Houston Ship Channel, the second busiest port in the United States. The Houston Ship Channel serves as a port of entry to the large petroleum refining industries located along its margins and affords options for shipping supplies across the world.

2.1.4 SOIL CLASSIFICATION

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 (Natural Resource Conservation Service 1994).

The distribution of the soil series types is shown in **Table 2.2**. **Figure 2.2** presents the eight types of surficial soils that are found in the Buffalo and Whiteoak Bayou watersheds. 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.

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Table 2.2 Soil Series in Buffalo and Whiteoak Bayou 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

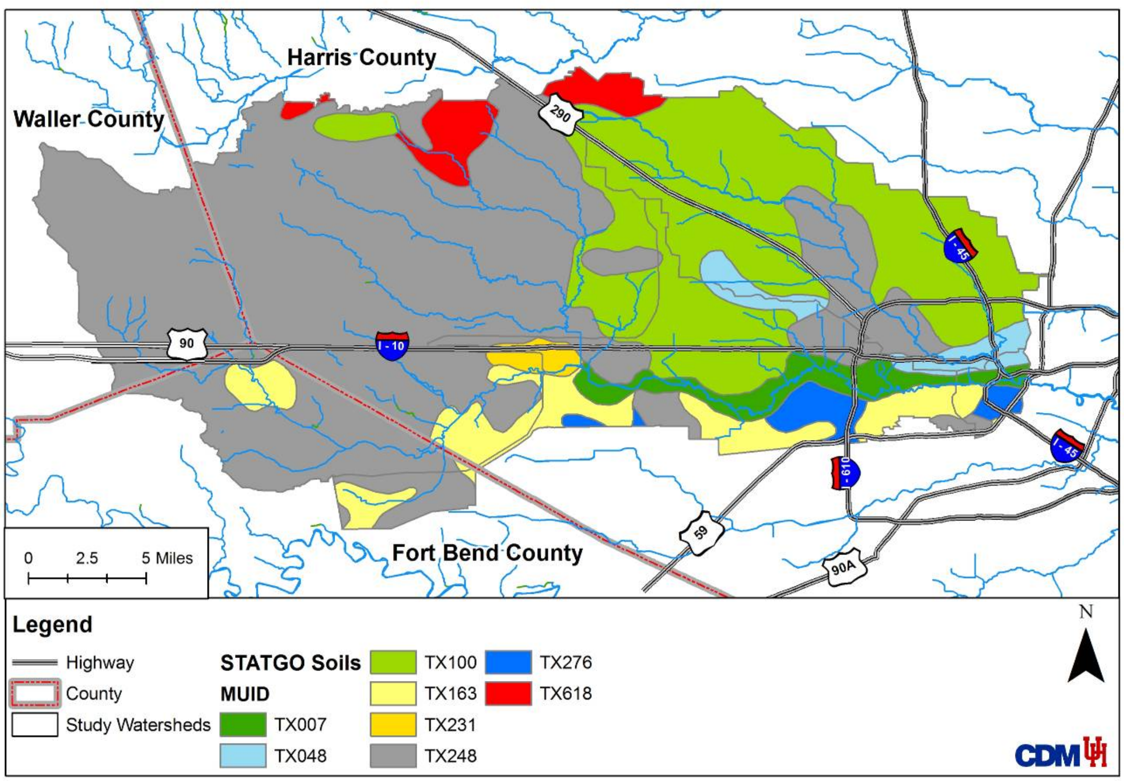

Figure 2.2 Soils in the Buffalo and Whiteoak Bayou Watersheds

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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 being the highest infiltration rate and group D being the slowest. 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, as it is in hydric group C (Soil Survey Division Natural Resources Conservation Service United States Department of Agriculture 1994).

2.2 ROUTINE WATER QUALITY DATA

Routine monitoring on Buffalo and Whiteoak Bayous is conducted primarily by the Region 12 TCEQ Field Office and the City of Houston Health and Human Services Department. A summary of results from routine monitoring samples is presented in **Table 2.3**. These data were collected between 2001 and 2006 and represent both wet and dry conditions. These data demonstrate that exceedances of the single sample standard are quite frequent in both bayous, with the majority of the sites experiencing exceedances of 86% or greater.

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 2.3**. As seen in the figure, geometric means range from lower concentrations in upper Buffalo Bayou (station 17494) to over 12,900 MPN/dL in Little Whiteoak Bayou (station 11148). For both bayous, the bacteria 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 bacteria level

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Table 2.3 Routine Monitoring Data for *E. coli* in the Study Area (between 2001 and 2005)

Station ID	Segment	Years Monitored	Geometric Mean (MPN/dL)	Number of Samples	% 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%
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%
Addicks and Barker Reservoir 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 Above Tidal 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%

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Table 2.3 Routine Monitoring Data for *E. coli* in the Study Area (between 2001 and 2005)

Station ID	Segment	Years Monitored	Geometric Mean (MPN/dL)	Number of Samples	% Greater than Single Sample Standard
16593	1017B	2001-2005	2,845	38	95%
16594	1017A	2001-2005	3,333	38	95%
16595	1017D	2001-2005	11,886	38	92%
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%

Abbreviation: dL – deciliter, MPN – most probable number

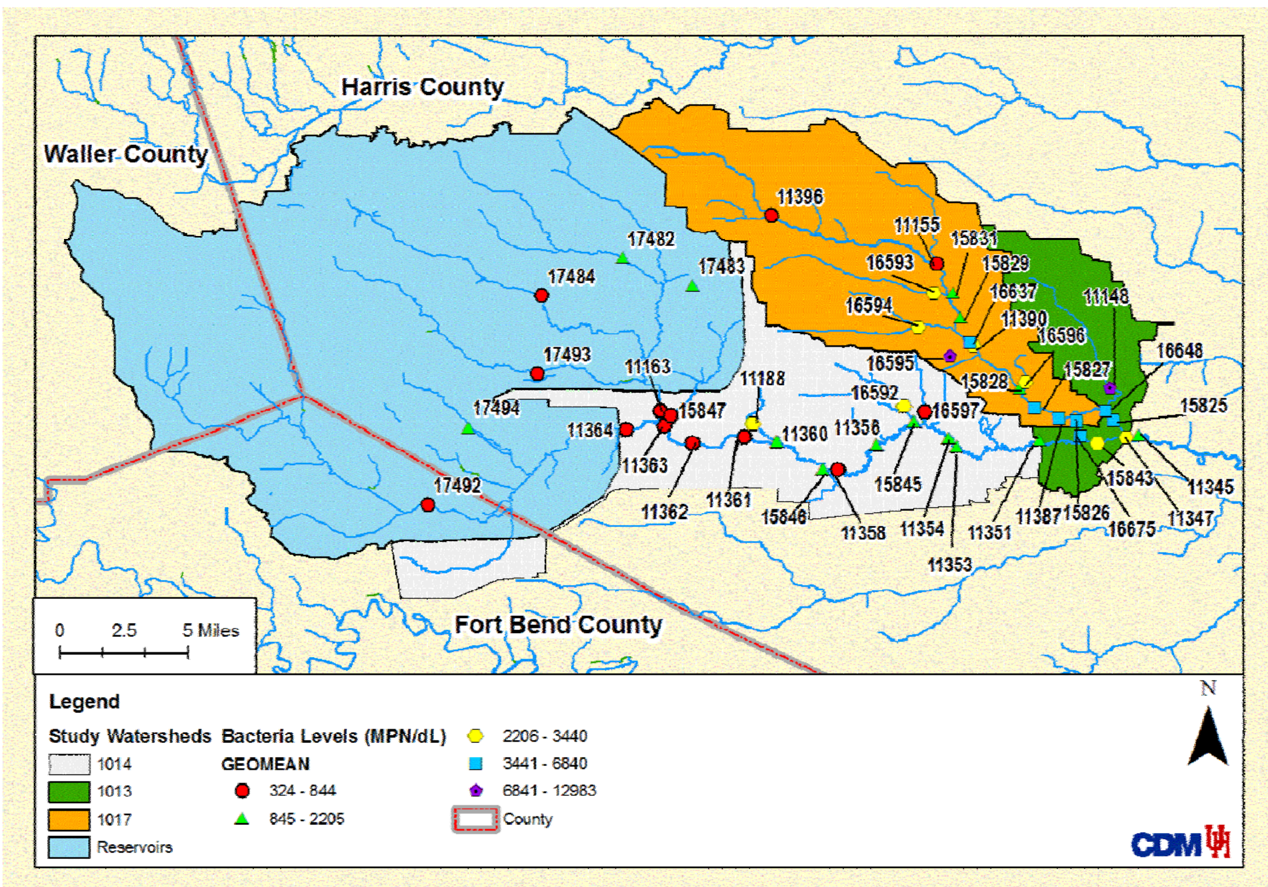

Figure 2.3 Bacteria Geometric Mean concentrations at Routine Monitoring Stations Between 2001 and 2005

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as the bayou, but there are a few that have higher bacteria levels. The bacteria level in Whiteoak Bayou is generally higher than that in Buffalo Bayou.

Long term trends were evaluated using fecal coliform data collected in Buffalo and Whiteoak Bayous since the early 1970's, as shown in **Table 2.4**. Fecal coliform data were used as they were the only bacteria collected consistently over the past three decades. As shown in the table, elevated concentrations of fecal coliform bacteria were observed in the 1970's, with concentrations dropping in the 1980's. The decline in the 1980's is believed to be related to the installation of major wastewater treatment plants in the watershed which were not required to dechlorinate their effluent. The excess chlorine in the bayou may have played a role in lower fecal coliform concentrations. No long-term trends were apparent in the 1990's and 2000.

Seasonal differences and relationships with other water quality parameters were examined, but in general no trends were found. One of the more important predictors of bacteria levels is precipitation. This relationship was examined in special studies conducted for the project, as will be discussed in a subsequent section.

Table 2.4 Historical Fecal Coliform Data

Bayou	Year	Number of Samples	Geometric Mean (cfu/dL)	Samples Exceeding Water Quality Standard (%)
Buffalo Bayou	1970	665	37,035	97.6
	1980	829	1553	77.3
	1990	2,887	1849	92.8
	2000	625	1570	90.6
Whiteoak Bayou	1970	275	47,748	96.0
	1980	216	14,265	94.4
	1990	1480	3,864	93.2
	2000	410	4,623	97.6

Abbreviations:
cfu – colony forming unit; dL - deciliter

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2.3 FLOW MEASUREMENTS

Flow measurements are collected at a total of 13 USGS gauges throughout both watersheds. Of the 13 gages, nine record flow and stage while the remaining four record only stage as shown in **Figure 2.4**. Flows in the bayou, as would be expected, were found to be much lower in the upper watershed and increase toward the terminus (**Figure 2.5**). The gauge at Shepherd Dr at Buffalo Bayou, 08074000, is a partial record station and only records storm flows, thus its record is biased toward high flows, generally above 2000 cfs. Median flows at other gauges in Buffalo Bayou ranged from 2.8 cfs at 08072730 to 158 cfs at 08073700, while in Whiteoak Bayou median flows ranged from 5.9 cfs at 08074250 to 54 cfs at 08074500.

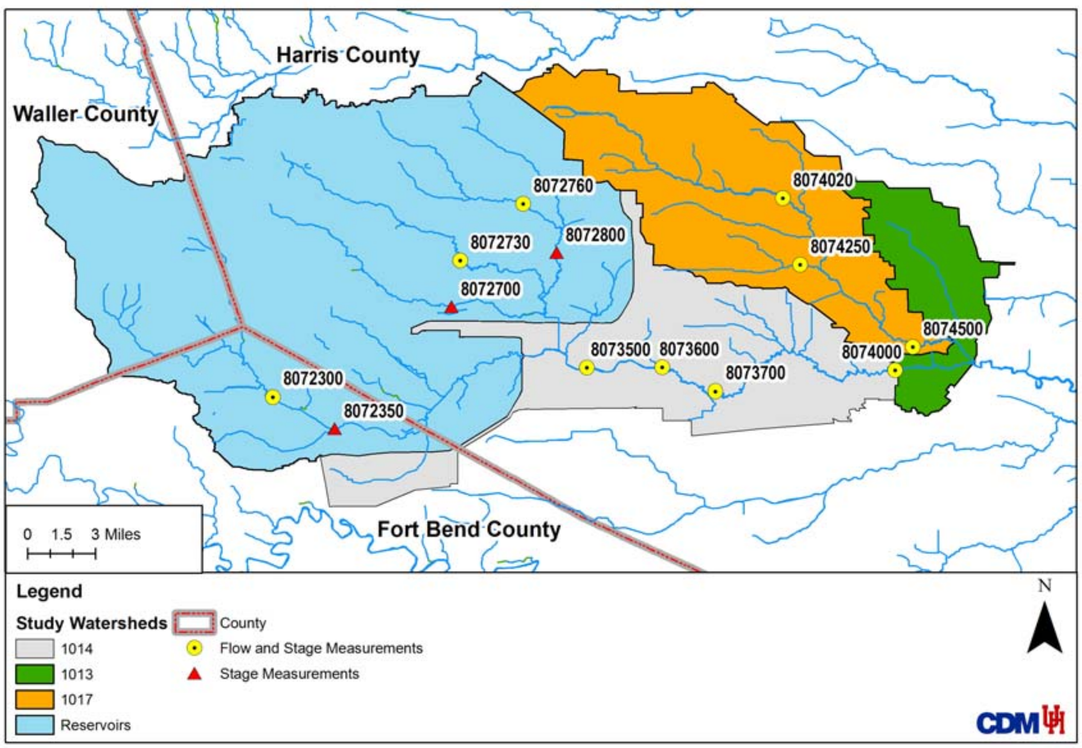

Figure 2.4 USGS Gauge Locations in Buffalo and Whiteoak Bayous

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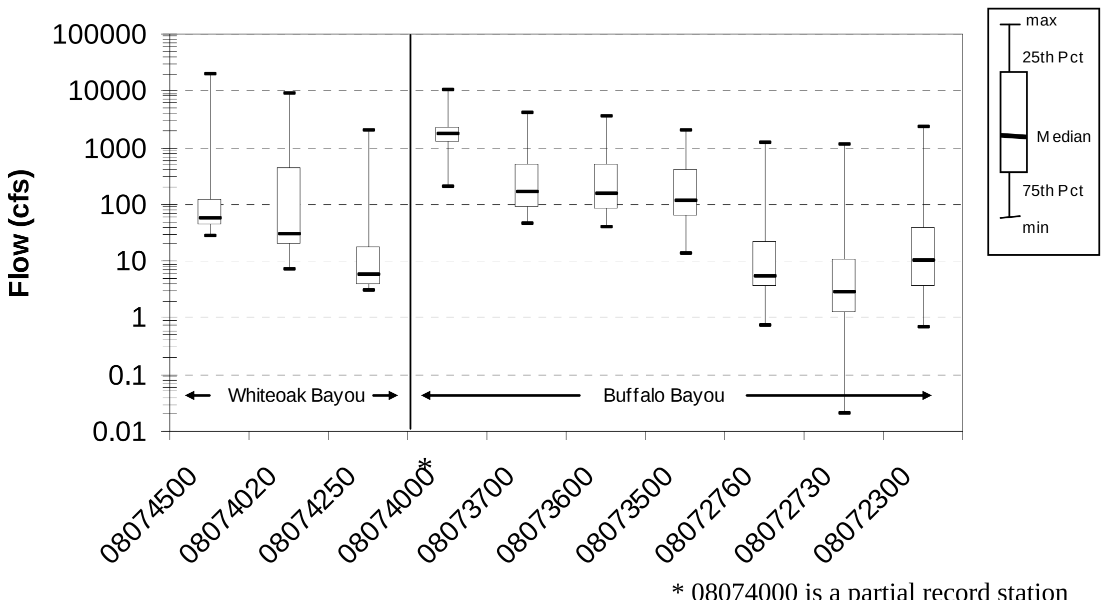

Figure 2.5 Range of Measured Flows between 2001 and 2003

2.4 SPECIAL STUDIES

Supplemental studies have been undertaken by H-GAC, the City of Houston and Harris County to evaluate in-stream dynamics, wastewater effluent and sediment influence on bacteria levels. The TMDL team has also undertaken special studies including targeted sampling of wastewater treatment plants, bacteria source tracking, sampling of dry weather storm sewers, measuring bacteria concentrations in sediment, evaluating bacteria dynamics in the bayou and monitoring runoff levels. This section will briefly review findings from these special studies that are related to sediment, runoff and reservoir discharges. Additional details of work conducted for this project can be found in the project document.

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2.4.1 SEDIMENT ANALYSIS

Sediment sampling was conducted in the bayou. Results of the sediment bacteria analysis show that *E. coli* concentrations ranged from less than detection limit (< 1 MPN/dL) to over 230,000 MPN/dL. Sampling around WWTPs also showed similar levels of bacteria. Additional discussion of sediment is presented in **Section 3.2.3.**

2.4.2 RUNOFF ANALYSIS

Locations on both Buffalo and Whiteoak Bayou were monitored during storm events, along the main stem as well as tributaries and reservoir discharges. Higher bacteria levels were observed during storm events based upon main-stem monitoring of both bayous. At most locations, there appeared to be some correlation between bayou flow and *E. coli* levels as shown in **Figure 2.6** for Buffalo Bayou at Dairy Ashford and Cole Creek at Diehl, a tributary of Whiteoak Bayou.

Additional runoff monitoring was conducted for the project at the Barker and Addicks Reservoirs and their immediate tributaries. Findings for the reservoir sampling were similar to those noted previously in the project, namely that *E. coli* concentrations appear to reflect trends in flow conditions as shown in shown in **Figure 2.7**. Dry weather sampling efforts confirmed that wet weather bacteria levels were several orders of magnitude greater than those typically found in dry conditions.

Additional discussion of runoff is presented in **Section 3.1.5.**

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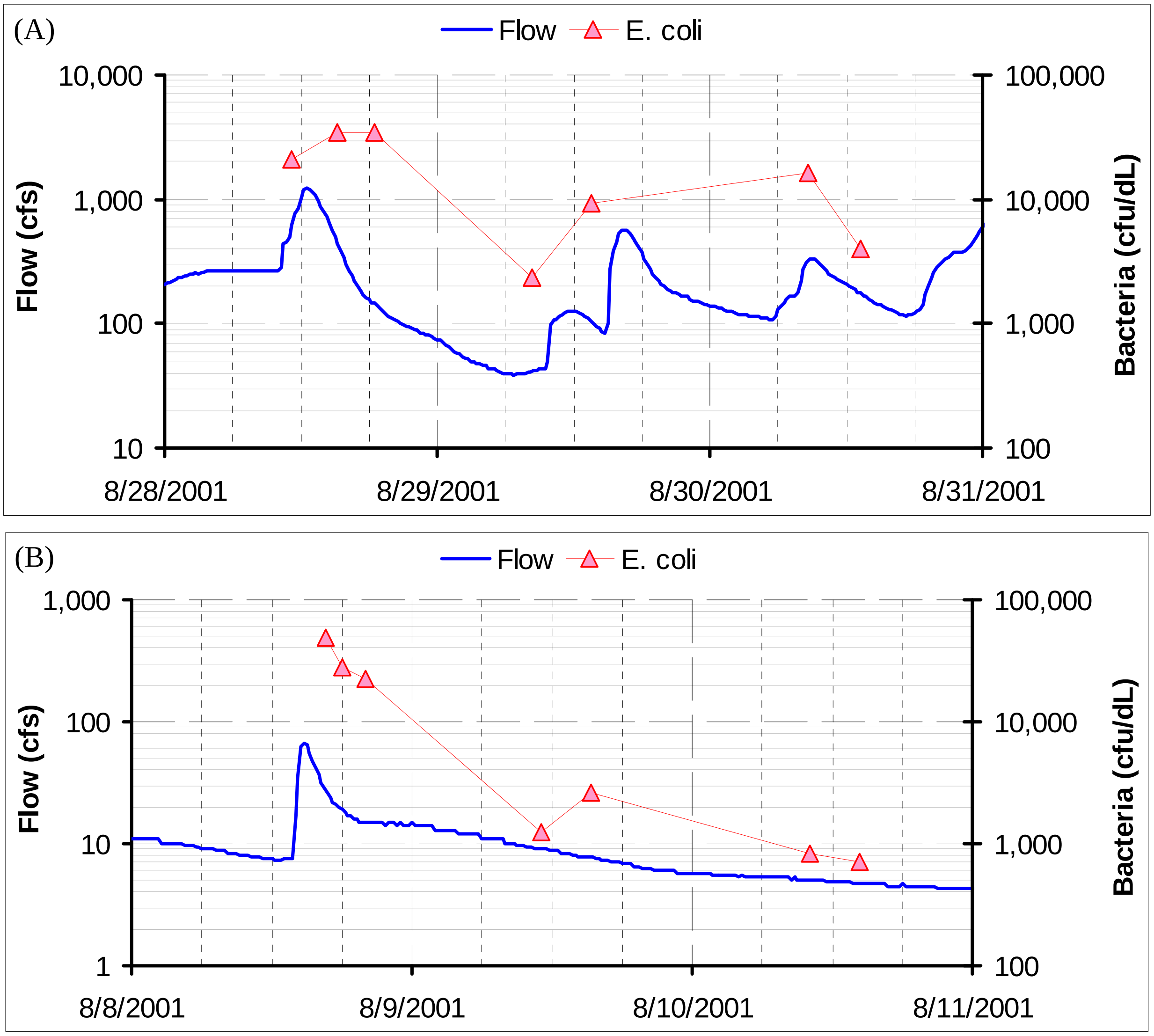

Figure 2.6 Bacteria Levels during Storm Monitoring in 2001 at (A) Buffalo Bayou at Dairy Ashford and (B) Cole Creek at Diehl

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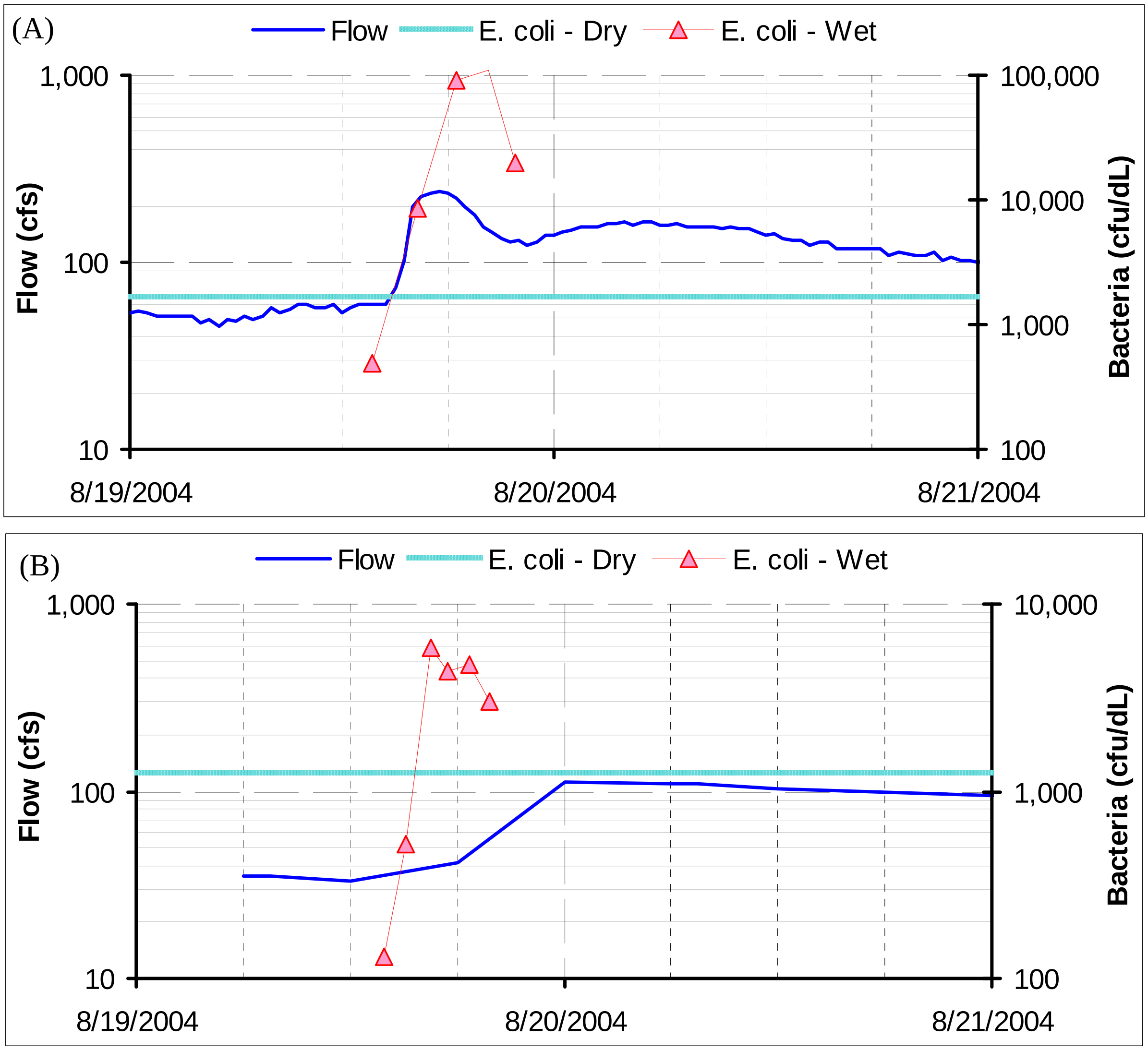

Figure 2.7 Bacteria Levels during Storm Monitoring at the Reservoirs in 2004 at (A) Buffalo Bayou at Dairy Ashford and (B) Addicks Reservoir Discharge

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2.4.3 RESERVOIR DISCHARGE ANALYSIS

In addition to sediment and wet weather sampling, an extended reservoir detention period was sampled in 2004. During that time, Houston experienced one of it's wettest summers and the reservoirs detained water for an almost two month period. The reservoirs began detaining water around June 10, 2004. Samples were collected beginning in July 1, 2004 and continued until the pools were empty on July 24, 2004. As shown in **Figure 2.8**, bacteria concentrations were very low in the reservoir pools after being detained for more three weeks. Once the reservoir pools were emptied and the streams that feed the reservoirs were able to flow through the reservoir basin again, the bacteria levels began to increase.

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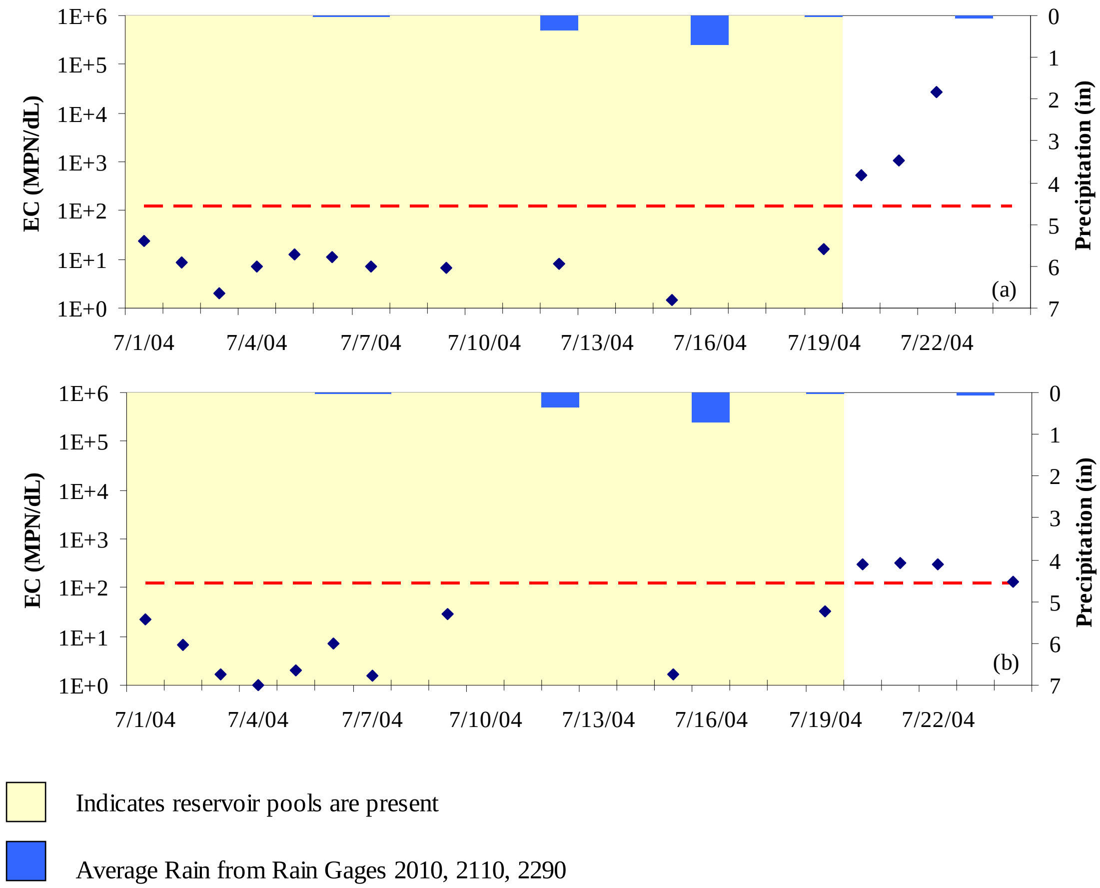

Figure 2.8 Bacteria Levels at (a) Barker Reservoir Pool, (b) Addicks Reservoir Pool, and (c) Dairy Ashford

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CHAPTER 3 : SOURCE ANALYSIS

Bacteria can have many sources in a watershed, from both point and nonpoint. Point sources are typically discharges that are piped directly to the stream and are regulated under the Texas Pollutant Discharge Elimination System (TPDES). In addition, storm water discharges from urban areas covered under municipal separate storm sewer system (MS4) permits are also considered point sources. Nonpoint sources are diffuse in nature, not having a single point of discharge to the stream and are usually, although not always, associated with runoff conditions. The possible sources of bacteria in Buffalo and Whiteoak Bayous are discussed in this section.

As previously described, the two study watersheds, Buffalo and Whiteoak Bayous, are made up of three water quality segments, segments 1013, 1014, 1017 as well as the "Reservoir Watersheds." The individual segments were also divided into smaller units called subwatersheds, which are regions that all drain to a common point and have similar hydrologic and physical characteristics. These subwatersheds are described in more detail in **Section 4** and are presented in **Figure 3.1**. The subwatersheds are identified with their respective segment IDs in **Table 3.1**.

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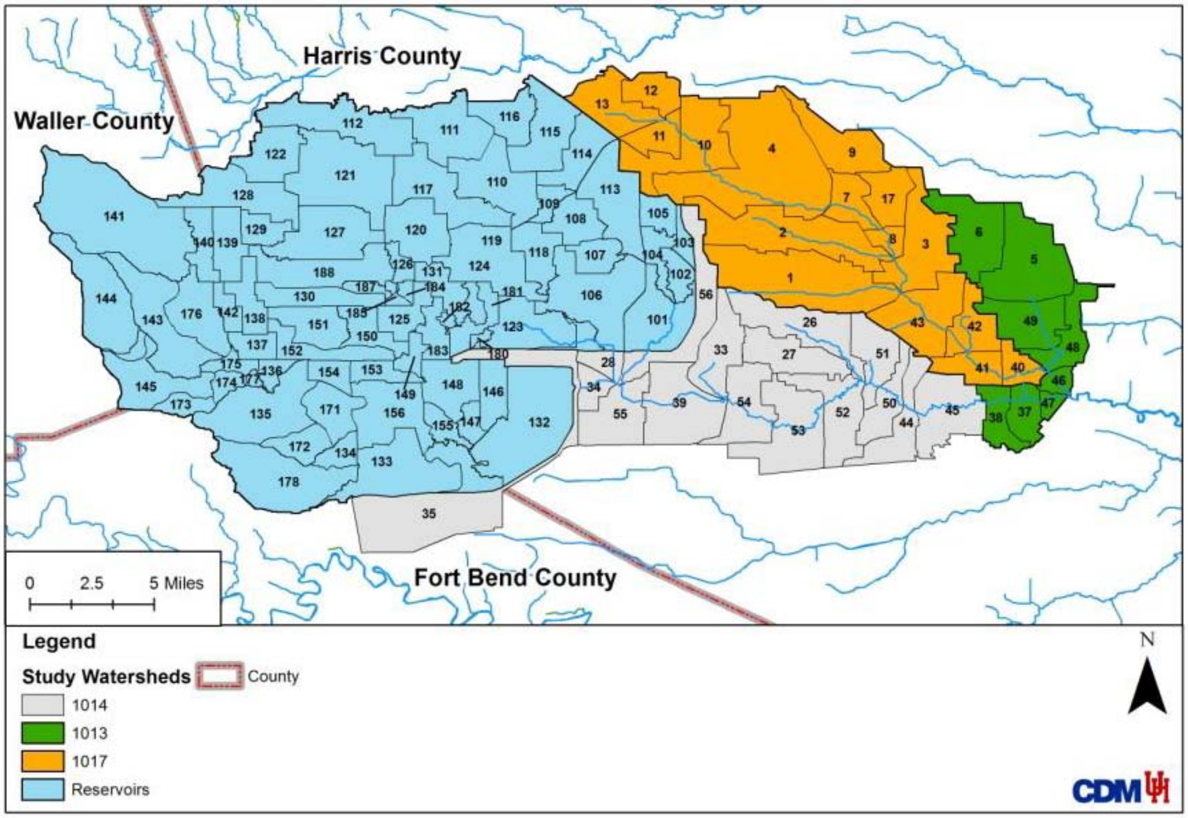

Figure 3.1 Subwatershed Identification Numbers

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Table 3.1 Subwatershed and Segment Identification

Sub-watershed	Segment	Watershed Name
1	1017A	Whiteaok Bayou
2	1017B	Whiteaok Bayou
3	1017	Whiteaok Bayou
4	1017	Whiteaok Bayou
5	1013A	Buffalo Bayou
6	1013A	Buffalo Bayou
7	1017	Whiteaok Bayou
8	1017	Whiteaok Bayou
9	1017	Whiteaok Bayou
10	1017	Whiteaok Bayou
11	1017	Whiteaok Bayou
12	1017	Whiteaok Bayou
13	1017	Whiteaok Bayou
17	1017	Whiteaok Bayou
26	1014O	Buffalo Bayou
27	1014O	Buffalo Bayou
28	1014H	Buffalo Bayou
33	1014N	Buffalo Bayou
34	1014	Buffalo Bayou
35	1014B	Buffalo Bayou
36	1013	Buffalo Bayou
37	1013/1013C	Buffalo Bayou
38	1013	Buffalo Bayou
39	1014	Buffalo Bayou
40	1017	Whiteaok Bayou
41	1017	Whiteaok Bayou
42	1017/1017E	Whiteaok Bayou
43	1017/1017D	Whiteaok Bayou
44	1014	Buffalo Bayou
45	1014	Buffalo Bayou
46	1013	Buffalo Bayou
47	1013	Buffalo Bayou
48	1013A	Buffalo Bayou
49	1013A	Buffalo Bayou
50	1014	Buffalo Bayou
51	1014M/1014	Buffalo Bayou
52	1014	Buffalo Bayou
53	1014	Buffalo Bayou
54	1014	Buffalo Bayou
55	1014	Buffalo Bayou

Sub-watershed	Segment	Watershed Name
117	1014E	Reservoir
118	1014A	Reservoir
119	1014A	Reservoir
120	1014A	Reservoir
121	1014A	Reservoir
122	1014A	Reservoir
123	1014H	Reservoir
124	1014H	Reservoir
125	1014H	Reservoir
126	1014H	Reservoir
127	1014H	Reservoir
128	1014H	Reservoir
129	1014H	Reservoir
130	1014H	Reservoir
131	1014H	Reservoir
132	1014B	Reservoir
133	1014B	Reservoir
134	1014B	Reservoir
135	1014B	Reservoir
136	1014B	Reservoir
137	1014B	Reservoir
138	1014B	Reservoir
139	1014B	Reservoir
140	1014B	Reservoir
141	1014B	Reservoir
142	1014B	Reservoir
143	1014B	Reservoir
144	1014B	Reservoir
145	1014B	Reservoir
146	1014B	Reservoir
147	1014L	Reservoir
148	1014L	Reservoir
149	1014L	Reservoir
150	1014L	Reservoir
151	1014L	Reservoir
152	1014L	Reservoir
153	1014L	Reservoir
154	1014L	Reservoir
155	1014B	Reservoir
156	1014B	Reservoir

`

Table 3.1 Subwatershed and Segment Identification

Sub-watershed	Segment	Watershed Name	Sub-watershed	Segment	Watershed Name
56	1014K	Buffalo Bayou	171	1014B	Reservoir
101	1014K	Reservoir	172	1014B	Reservoir
102	1014K	Reservoir	173	1014B	Reservoir
103	1014K	Reservoir	174	1014B	Reservoir
104	1014K	Reservoir	175	1014B	Reservoir
105	1014K	Reservoir	176	1014B	Reservoir
106	1014A	Reservoir	177	1014B	Reservoir
107	1014E	Reservoir	178	1014B	Reservoir
108	1014E	Reservoir	180	1014H	Reservoir
109	1014E	Reservoir	181	1014H	Reservoir
110	1014E	Reservoir	182	1014H	Reservoir
111	1014E	Reservoir	183	1014H	Reservoir
112	1014E	Reservoir	184	1014H	Reservoir
113	1014E	Reservoir	185	1014H	Reservoir
114	1014E	Reservoir	186	1014H	Reservoir
115	1014E	Reservoir	187	1014H	Reservoir
116	1014E	Reservoir	188	1014H	Reservoir

3.1 REGULATED SOURCES

In Buffalo and Whiteoak Bayous, there are several types of permitted dischargers, including domestic and industrial wastewater treatment plants and various types of permitted stormwater discharges. This section will discuss the regulated sources evaluated in the Buffalo and Whiteoak Bayou watersheds, including WWTPs, SSOs, and regulated stormwater discharges.

3.1.1 WWTPS

A total of 126 domestic WWTPs were permitted by TCEQ in Segments 1013, 1014 and 1017 at the end of 2003. Their location is presented in **Figure 3.2**. For the purposes of this

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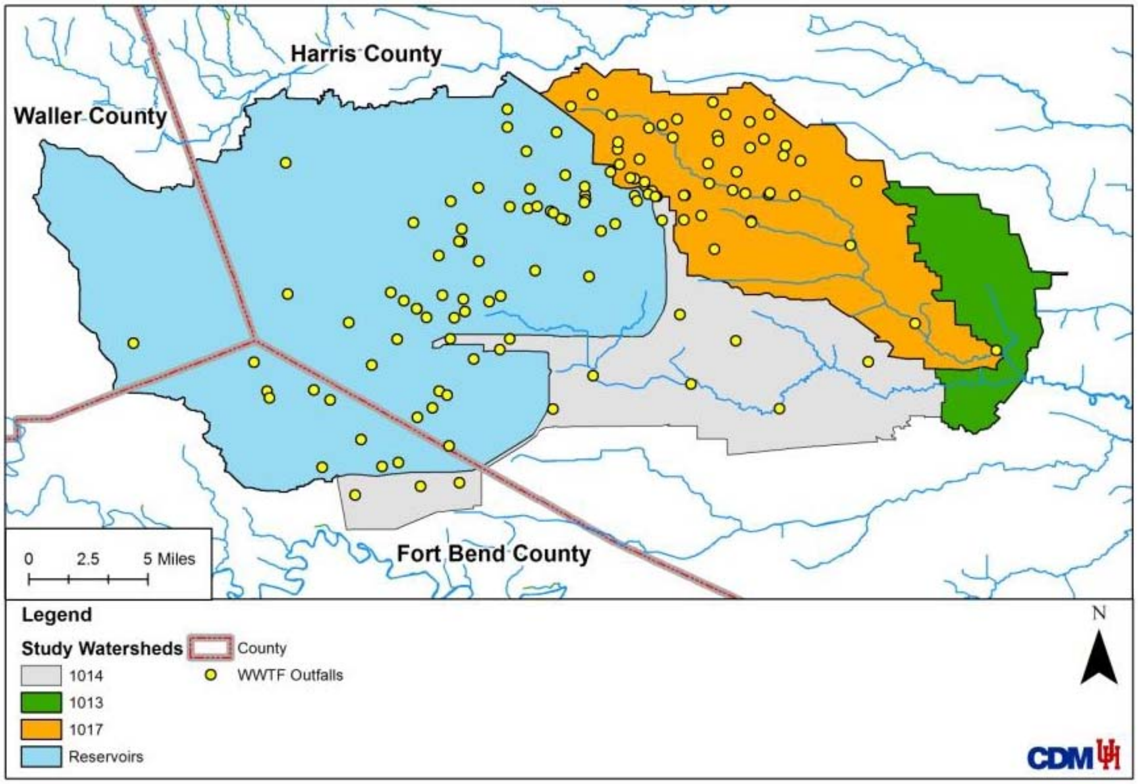

Figure 3.2 WWTPs Discharger Locations

TMDL, three different types of WWTP loads were estimated: dry weather effluent discharges, intermediate condition effluent discharges and biosolid discharges. Each of these will be described in more detail subsequently.

3.1.1.1 DRY WEATHER EFFLUENT DISCHARGES

Flows and loads associated with typical, dry weather WWTP discharges were estimated based upon site-specific data available from sampling and supplied by WWTPs in the watershed. Self-reported flows from plants were obtained from TCEQ and US EPA databases for the between April 1999 through October 2003 (database included in **Appendix A** of this report**)**. `

The permitted flows are shown in **Table 3.2** while monthly self-reported flows for each plant are shown in **Table 3.3**.

Also presented in **Table 3.3** are concentrations of *E. coli* measured in the WWTP effluent by the project team in 2001 (presented as average of peak and off-peak samples) and again in 2006. Detailed results of this sampling are presented in **Appendix A** of this report. Bacterial levels in effluent from the WWTPs is typically low, with approximately 5-10% of the facilities exceeding the single sample standard for *E. coli*. Measured concentrations from both sampling efforts ranged from less than the detection limit (< 1 MPN/dL) to over 200,000 MPN/dL, with flow weighted means for the watersheds calculated to be between 4 MPN/dL and 6 MPN/dL. Loads for these plants using the most recent bacteria data from 2006 are shown in **Table 3.4**.

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Table 3.2 Permitted Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Facility Type[1]	Facility Name	County	Type[2]	Permitted Flow (MGD)
Buffalo Bayou Above Tidal						
1014	02731-000	SS	DANIEL VALVE COMPANY	Harris	D	0.012
	10495-030	SS	HOUSTON, CITY OF	Harris	W	26.4
	10495-109	SS	HOUSTON, CITY OF	Harris	W	12
	10495-135	SS	HOUSTON, CITY OF	Harris	W	3.5
	10584-001	SS	MEMORIAL VILLAGE WAT	Harris	W	3.05
	12233-001	SS	UA HOLDINGS 1994-5	Harris	D	0.005
	12346-001	SS	WEST PARK MUD	Harris	D	0.5
	12355-001	SS	ELEVEN TEN ROSALIE	Harris	D	0.005
	12427-001	SS	GEORGE AIVAZIAN	Harris	D	0.001
	12682-001	SS	HARRIS CO MUD 216	Harris	D	0.4
	12830-001	SS	ROBINSON, J.W.	Harris	D	0.006
	13021-001	SS	BIG OAKS MUD	Fort Bend	D	0.3
	13228-001	SS	FORT BEND CO MUD 050	Fort Bend	D	0.09
	14070-001	SS	WEATHERFORD PETCO	Harris	D	0.0108
	14117-001	SS	AQUASOURCE UTILITY	Harris	D	0.45
	14182-001	SS	ANN ARUNDEL FARMS	Fort Bend	D	0.075
	Watershed Total Permitted Flow					46.8048
Addicks and Barker Reservoir Watersheds						
Reservoirs	02229-000	SS	IGLOO PRODUCTS CORPORATION	Waller	D	0.03
	03153-000	SS	TOSHIBA INTERNATIONAL CORPORATION	Harris	D	0.1
	10706-001	SS	KATY, CITY OF	Fort Bend	W	3.45
	10932-001	SS	HARRIS COUNTY, TEXAS	Harris	D	0.042
	11152-001	SS	WEST MEMORIAL MUD	Harris	W	6.48
	11284-001	SS	WESTLAKE MUD 001	Harris	W	1.2
	11290-001	SS	JACKRABBIT ROAD PUD	Harris	W	5.1
	11414-001	SS	SASSON, ELI	Harris	D	0.06
	11472-001	SS	SPENCER ROAD PUD	Harris	D	0.98
	11486-001	SS	HARRIS CO MUD 070	Harris	W	1.2
	11523-001	SS	HARRIS CO MUD 102	Harris	W	1.3
	11598-001	SS	WILLIAMSBURG REG SA	Harris	W	2
	11682-001	SS	LANGHAM CREEK UD	Harris	W	2
	11696-002	SS	ADDICKS UD	Harris	D	0.4
	11792-002	SS	HARRIS CO MUD 105	Harris	W	1.25
	11836-001	SS	HARRIS CO MUD 149	Harris	D	0.645
	11883-001	SS	CASTLEWOOD MUD	Harris	W	1.367
	11893-001	SS	MEMORIAL MUD	Harris	W	3

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Table 3.2 Permitted Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Facility Type[1]	Facility Name	County	Type[2]	Permitted Flow (MGD)
	11906-001	SS	HARRIS CO MUD 157	Harris	W	1.2
	11917-001	SS	HARRIS CO MUD 071	Harris	D	0.7
	11935-001	SS	NORTHWEST HC MUD 016	Harris	D	0.33
	11947-001	SS	HARRIS CO MUD 208	Harris	W	6.7
	11969-001	SS	MAYDE CREEK MUD	Harris	W	2
	11989-001	SS	FRY ROAD MUD	Harris	D	0.533
	12110-001	SS	KATY ISD	Harris	D	0.1
	12124-001	SS	HARRIS CO MUD 185	Harris	D	0.675
	12128-001	SS	HORSEPEN BAYOU MUD	Harris	D	0.95
	12140-001	SS	WEST HC MUD 007	Harris	D	0.5
	12189-001	SS	TEX-SUN PARKS, LC	Harris	D	0.15
	12209-001	SS	HARRIS CO MUD 127	Harris	D	0.5
	12223-001	SS	WEST HC MUD 015	Harris	D	0.35
	12247-001	SS	WEST HC MUD 017	Harris	D	0.275
	12289-001	SS	GREEN TRAILS MUD	Harris	D	0.99
	12298-001	SS	FORT BEND CO MUD 034	Harris	D	0.2
	12304-001	SS	CHIMNEY HILL MUD	Harris	D	0.9
	12310-001	SS	R&K WEIMAN MHP	Harris	D	0.03
	12356-001	SS	HARRIS CO MUD 345	Harris	D	0.71
	12370-001	SS	FORT BEND CO MUD 037	Fort Bend	D	0.175
	12447-001	SS	HARRIS CO MUD 196	Harris	D	0.5
	12466-001	SS	OCEANEERING INTER.	Harris	D	0.003
	12474-001	SS	HARRIS CO MUD 166	Harris	D	0.125
	12479-001	SS	NOTTINGHAM COUNTRY MUD	Harris	W	1.3
	12516-001	SS	WEST HOUSTON AIRPORT	Harris	D	0.002
	12685-001	SS	MOODY CORP	Harris	D	0.1
	12726-001	SS	HARRIS CO MUD 155	Harris	D	0.64
	12802-001	SS	HARRIS CO MUD 238	Harris	D	0.35
	12834-001	SS	HARRIS CO MUD 167	Harris	D	0.294
	12841-001	SS	ROLLING CREEK UD	Harris	D	0.25
	12858-001	SS	HARRIS COUNTY, TEXAS	Harris	D	0.026
	12927-001	SS	HARRIS CO MUD 276	Harris	D	0.48
	12949-001	SS	HARRIS CO MUD 284	Harris	D	0.1
	13172-002	SS	CINCO MUD 001	Fort Bend	D	0.91
	13245-001	SS	GRAND LAKES MUD 004	Fort Bend	D	0.9
	13328-001	SS	REMINGTON MUD 002	Harris	W	1.1
	13484-001	SS	529 #35, LTD	Harris	D	0.125
	13558-001	SS	CINCO MUD 001	Fort Bend	W	3.3
	13674-001	SS	NOTTINGHAM COUNTRY	Harris	D	0.051

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Table 3.2 Permitted Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Facility Type[1]	Facility Name	County	Type[2]	Permitted Flow (MGD)
	13775-001	SS	HARRIS FTB MUD 005	Harris	D	0.35
	13778-001	SS	FRIEDMAN, STEPHEN	Harris	D	0.01
	13921-001	SS	HARRIS COUNTY	Harris	D	0.02
	14011-001	SS	FT BEND MUD 130	Fort Bend	D	0.15
	14109-001	SS	KATY-HOCKLEY	Harris	D	0.075
	14134-001	SS	FT BEND MUD 124	Harris	D	0.4
	Watershed Total Permitted Flow					60.133
Whiteoak Bayou Above Tidal						
1017	02710-000	SS	RESTAURANT SERVICE, L.L.C.	Harris	D	0.002
	04760-000	SS	WEATHERFORD U.S., L.P.	Harris	D	0.0108
	10495-076	SS	HOUSTON, CITY OF	Harris	W	18
	10495-099	SS	HOUSTON, CITY OF	Harris	W	4
	10495-139	SS	HOUSTON, CITY OF	Harris	D	0.995
	10876-001	SS	HARRIS CO FWSD 061	Harris	W	1.6
	10876-002	SS	HARRIS CO FWSD 061	Harris	W	3
	11005-001	SS	CHAMP'S WATER CO	Harris	D	0.28
	11051-001	SS	VANCOUVER MGT	Harris	D	0.03
	11188-001	SS	ROLLING FORK PUD	Harris	D	0.49
	11193-001	SS	AQUASOURCE UTILITY	Harris	D	0.8
	11273-001	SS	HARRIS CO MUD 006	Harris	D	0.75
	11375-001	SS	AQUASOURCE UTILITY	Harris	D	0.137
	11389-001	SS	CB&I CONSTRUCTORS	Harris	D	0.045
	11485-001	SS	HARRIS CO MUD 023	Harris	D	0.75
	11538-001	SS	GULF COAST WASTE DA	Harris	W	3.2
	11563-001	SS	REID ROAD MUD 001	Harris	W	1.75
	11670-001	SS	SUNBELT FWSD	Harris	D	0.99
	11979-002	SS	WHITE OAK BEND MUD	Harris	D	0.4
	12121-001	SS	HARRIS CO MUD 170	Harris	W	2.5
	12132-001	SS	WHITE OAK OWNERS	Harris	D	0.059
	12139-001	SS	FAIRBANKS PLAZA SHOP	Harris	D	0.04
	12222-001	SS	AQUASOURCE UTILITY	Harris	D	0.25
	12342-001	SS	C & P UTILITIES	Harris	D	0.045
	12397-001	SS	DANIEL INDUSTRIES	Harris	D	0.012
	12443-001	SS	SUPERIOR DERRICK	Harris	D	0.0024
	12465-001	SS	TIFCO INDUSTRIES	Harris	D	0.035
	12552-001	SS	NCI BUILDING SYSTEMS	Harris	D	0.01
	12552-002	SS	NCI BUILDING SYSTEMS	Harris	D	0.01
	12573-001	SS	SMITH, WILLIAM D.	Harris	D	0.012

`

Table 3.2 Permitted Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Facility Type[1]	Facility Name	County	Type[2]	Permitted Flow (MGD)
	12574-001	SS	HARRIS CO MUD 130	Harris	D	0.34
	12681-001	SS	JERSEY VILLAGE	Harris	D	0.8
	12714-001	SS	HARRIS CO MUD 119	Harris	D	0.25
	12795-001	SS	NORTHWEST HC MUD 029	Harris	D	0.465
	13433-001	SS	AQUASOURCE DVLP. CO.	Harris	D	0.1
	13509-001	SS	TRINITY @ WINDFERN	Harris	D	0.028
	13578-001	SS	COOPER CAMERON CORP	Harris	D	0.008
	13623-001	SS	WEST HC MUD 021	Harris	D	0.25
	13689-001	SS	WEST HC MUD 11	Harris	W	1
	13727-001	SS	MOORPARK VILLAGE,INC	Harris	D	0.035
	13764-001	SS	ALLIANCE CH F3 GP	Harris	D	0.15
	13807-001	SS	MCDONALDS CORP.	Harris	D	0.003
	13939-001	SS	RIEDEL, ANTHONY	Harris	D	0.003
	13983-001	SS	RESTAURANT SERVICE	Harris	D	0.002
	13996-001	SS	CROW FAMILY HOLDINGS	Harris	D	0.0498
	14072-001	SS	WEST HC MUD 010	Harris	W	1.5
	14359-001	SS	HARRIS CO MUD 366	Harris	D	0.1
	Watershed Total Permitted Flow					45.289

Notes:

1. Facility Type – SS indicates sanitary sewer system
2. Type – D indicates permitted flow less than 1 MGD while W indicates flows greater than 1 MGD
3. Abbreviations:

dL - deciliter

MGD - million gallons per day

MPN - most probable number

TCEQ – Texas Commission on Environmental Quality

TPDES – Texas pollutant discharge elimination system

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Table 3.3 Self-Reported Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Sub-watershed	*E. coli* (MPN/dL)		
			2001 Sampling[1]	2006 Sampling[2]	Value Used for Load Calculations[3]
Buffalo Bayou Above Tidal Watershed (Segment 1014)					
Segment 1014	02731-000	27	nc	nc	6.1
	10495-030	33	nc	nc	6.1
	10495-109	55	nc	nc	6.1
	10495-135	35	6.3	2.0	2.0
	10584-001	53	nc	nc	6.1
	12233-001	44	nc	26.0	26.0
	12346-001	35	<1	973.5	973.5
	12355-001	56	nc	nc	6.1
	12427-001	35	2.5	nc	6.1
	12682-001	35	<1	nc	6.1
	12830-001	56	nc	nc	6.1
	13021-001	35	nc	nc	6.1
	13228-001	35	nc	nc	6.1
	14070-001	56	<1	nc	6.1
	14117-001	56	nc	<1	0.5
	14182-001	35	nc	nc	6.1
Addicks and Barker Reservoir Watershed (Reservoir Segments)					
Reservoir Watersheds	02229-000	144	nc	nc	6.1
	03153-000	104	1.6	nc	6.1
	10706-001	136	nc	nc	6.1
	10932-001	106	nc	1.0	1.0
	11152-001	153	nc	<1	0.5
	11284-001	124	8.0	32.0	32.0
	11290-001	106	nc	32,550.0	32,550.0
	11414-001	113	<1	<1	0.5
	11472-001	113	<1	<1	0.5
	11486-001	110	nc	512.0	512.0
	11523-001	108	31.0	1.8	1.8
	11598-001	150	55.1	nc	6.1
	11682-001	110	nc	2.0	2.0
	11696-002	123	nc	<1	0.5
	11792-002	120	nc	24.0	24.0
	11836-001	109	nc	207,500.0	207,500.0
	11883-001	149	0.5	nc	6.1
	11893-001	155	nc	84.0	84.0
	11906-001	117	0.5	884.0	884.0
	11917-001	185	0.6	nc	6.1
	11935-001	109	0.6	<1	0.5
	11947-001	113	nc	18.0	18.0
	11969-001	131	26.4	4.8	4.8

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Table 3.3 Self-Reported Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Sub-watershed	*E. coli* (MPN/dL)		
			2001 Sampling[1]	2006 Sampling[2]	Value Used for Load Calculations[3]
	11989-001	183	<1	nc	6.1
	12110-001	181	<1	nc	6.1
	12124-001	108	nc	<1	0.5
	12128-001	113	18.6	16.5	16.5
	12140-001	125	<1	nc	6.1
	12189-001	183	nc	nc	6.1
	12209-001	119	nc	<1	0.5
	12223-001	114	4.0	2.0	2.0
	12247-001	183	<1	nc	6.1
	12289-001	148	5.8	100.0	100.0
	12298-001	178	<1	nc	6.1
	12304-001	113	1.8	nc	6.1
	12310-001	113	<1	<1	0.5
	12356-001	146	nc	nc	6.1
	12370-001	135	nc	nc	6.1
	12447-001	116	nc	3.0	3.0
	12466-001	105	149.5	nc	6.1
	12474-001	108	nc	8.0	8.0
	12479-001	147	54.3	nc	6.1
	12516-001	123	nc	nc	6.1
	12685-001	113	<1	<1	0.5
	12726-001	115	81.2	<1	0.5
	12802-001	124	4.6	1.0	1.0
	12834-001	119	<1	<1	0.5
	12841-001	119	nc	<1	0.5
	12858-001	133	nc	nc	6.1
	12927-001	108	nc	2.0	2.0
	12949-001	119	<1	4.0	4.0
	13172-002	133	nc	nc	6.1
	13245-001	133	nc	56.0	6.1
	13328-001	116	nc	nc	56.0
	13484-001	105	<1	nc	6.1
	13558-001	133	nc	nc	6.1
	13674-001	155	nc	166.0	166.0
	13775-001	171	nc	nc	6.1
	13778-001	108	nc	<1	0.5
	13921-001	122	1.8	0.8	0.8
	14011-001	135	nc	nc	6.1
	14109-001	151	nc	nc	6.1
	14134-001	171	nc	nc	6.1
Whiteoak Bayou Watershed					

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Table 3.3 Self-Reported Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Sub-watershed	*E. coli* (MPN/dL)		
			2001 Sampling[1]	2006 Sampling[2]	Value Used for Load Calculations[3]
Segment 1017	02710-000	4	nc	nc	4.4
	04760-000	4	nc	nc	4.4
	10495-076	2	nc	2.0	2.0
	10495-099	7	nc	1.0	1.0
	10495-139	1	<1	nc	4.4
	10876-001	13	4.4	342.0	342.0
	10876-002	13	5.2	794.0	794.0
	11005-001	17	1.3	<1	0.5
	11051-001	4	46.8	5.5	5.5
	11188-001	4	<1	<1	0.5
	11193-001	2	711.4	1.0	0.5
	11273-001	4	1.0	<1	0.5
	11375-001	4	17.8	<1	0.5
	11389-001	4	1.8	1.0	1.0
	11485-001	4	0.8	<1	0.5
	11538-001	4	nc	5.0	5.0
	11563-001	10	14.4	11.0	11.0
	11670-001	4	17.0	1.0	1.0
	11979-002	10	nc	1.0	1.0
	12121-001	11	13.3	2.0	2.0
	12132-001	40	<1	17.0	16.5
	12139-001	2	1,039.9	nc	4.4
	12222-001	2	14,812.0	<1	0.5
	12342-001	4	1.3	1.0	1.0
	12397-001	10	nc	179.0	179.0
	12443-001	4	7.4	33.0	33.0
	12465-001	13	96.8	1.0	1.0
	12552-001	4	nc	nc	4.4
	12552-002	4	nc	nc	4.4
	12573-001	9	nc	nc	4.4
	12574-001	10	1.3	0.5	0.5
	12681-001	10	nc	<1	0.5
	12714-001	9	1.3	6.0	6.0
	12795-001	11	176.1	118.0	118.0
	13433-001	4	<1	<1	0.5
	13509-001	4	71.2	<1	0.5
	13578-001	4	<1	nc	4.4
	13623-001	4	<1	<1	0.5
	13689-001	4	176.5	105.0	105.0
	13727-001	4	<1	26.5	26.5
	13764-001	42	nc	9.0	9.0

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Table 3.3 Self-Reported Flow and Measured Bacteria for WWTPs located in the Buffalo and Whiteoak Bayou Watersheds

Segment	TPDES Number	Sub-watershed	*E. coli* (MPN/dL)		
			2001 Sampling[1]	2006 Sampling[2]	Value Used for Load Calculations[3]
	13807-001	4	<1	9.0	9.0
	13939-001	4	nc	11,190.0	11,190.0
	13983-001	4	nc	<1	0.5
	13996-001	2	nc	nc	4.4
	14072-001	10	9.0	<1	0.5
	14359-001	9	nc	nc	4.4

Notes:
1. Facility Type – SS indicates sanitary sewer system
2. Type – D indicates permitted flow less than 1 MGD while W indicates flows greater than 1 MGD
3. Values < detection limit treated as 1/2 detection limit

Abbreviations:
dL - deciliter
MGD - million gallons per day
MPN - most probable number
nc – Not collected
NPDES – national pollutant discharge elimination system
TCEQ – Texas Commission on Environmental Quality
TPDES - Texas Pollutant Discharge Elimination System

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Table 3.4 WWTP Flow, *E. coli* Concentration and Load During Dry Weather Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load[1] (MPN/day)
Buffalo Bayou Above Tidal Watershed					
1014	02731-000	27	1.67E-03	6.1	3.87E+05
	10495-030	33	9.52E+00	6.1	2.21E+09
	10495-135	35	5.41E-01	2	4.09E+07
	12346-001	35	1.80E-01	973.5	6.63E+09
	12427-001	35	5.08E-05	6.1	1.18E+04
	12682-001	35	4.07E-02	6.1	9.46E+06
	13021-001	35	1.43E-01	6.1	3.33E+07
	13228-001	35	3.90E-02	6.1	9.05E+06
	14182-001	35	2.17E-02	6.1	5.03E+06
	12233-001	44	6.48E-04	26	6.37E+05
	10584-001	53	2.98E+00	6.1	6.92E+08
	10495-109	55	4.42E+00	6.1	1.03E+09
	12355-001	56	3.19E-04	6.1	7.42E+04
	12830-001	56	2.18E-03	6.1	5.05E+05
	14070-001	56	1.46E-03	6.1	3.39E+05
	14117-001	56	9.77E-02	<1	1.85E+06
	Watershed Summary		1.80E+01	n/a	1.07E+10
Whiteoak Bayou Above Tidal Watershed					
1017	10495-139	1	4.83E-01	4.4	7.95E+07
	10495-076	2	8.70E+00	2	6.58E+08
	11193-001	2	5.06E-01	<1	9.57E+06
	12139-001	2	2.38E-02	4.4	3.92E+06
	12222-001	2	6.75E-02	<1	1.28E+06
	13996-001	2	1.63E-03	4.4	2.68E+05
	02710-000	4	8.38E-04	4.4	1.38E+05
	04760-000	4	1.46E-03	4.4	2.40E+05
	11051-001	4	3.45E-02	5.5	7.18E+06
	11188-001	4	2.53E-01	<1	4.78E+06
	11273-001	4	4.22E-01	<1	7.98E+06
	11375-001	4	9.68E-02	<1	1.83E+06
	11389-001	4	9.34E-03	<1	1.77E+05
	11485-001	4	4.07E-01	<1	7.70E+06
	11538-001	4	1.04E+00	5	1.97E+08
	11670-001	4	3.25E-01	1	1.23E+07
	12342-001	4	1.90E-02	1	7.20E+05
	12443-001	4	1.31E-03	33	1.63E+06
	12552-001	4	5.81E-03	4.4	9.56E+05
	12552-002	4	4.74E-03	4.4	7.81E+05
	13433-001	4	1.17E-02	<1	2.21E+05

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Table 3.4 WWTP Flow, *E. coli* Concentration and Load During Dry Weather Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load[1] (MPN/day)
	13509-001	4	1.33E-02	<1	2.52E+05
	13578-001	4	6.32E-03	4.4	1.04E+06
	13623-001	4	7.23E-02	<1	1.37E+06
	13689-001	4	3.37E-01	105	1.34E+09
	13727-001	4	7.03E-03	26.5	7.05E+06
	13807-001	4	7.48E-04	9	2.54E+05
	13939-001	4	1.16E-03	11190	4.90E+08
	13983-001	4	8.85E-04	<1	1.67E+04
	10495-099	7	1.70E+00	1	6.42E+07
	12573-001	9	9.73E-03	4.4	1.60E+06
	12714-001	9	1.44E-01	6	3.26E+07
	14359-001	9	3.13E-02	4.4	5.16E+06
	11563-001	10	6.68E-01	11	2.78E+08
	11979-002	10	1.89E-01	1	7.14E+06
	12397-001	10	4.37E-03	179	2.96E+07
	12574-001	10	1.22E-01	<1	2.30E+06
	12681-001	10	1.83E-01	<1	3.46E+06
	14072-001	10	1.01E+00	<1	1.91E+07
	12121-001	11	9.32E-01	2	7.04E+07
	12795-001	11	1.91E-01	118	8.51E+08
	10876-001	13	8.69E-01	342	1.12E+10
	10876-002	13	8.81E-01	794	2.65E+10
	12465-001	13	5.18E-03	1	1.96E+05
	11005-001	17	1.47E-01	<1	2.78E+06
	12132-001	40	3.91E-02	16.5	2.44E+07
	13764-001	42	5.65E-02	9	1.92E+07
	Watershed Summary		2.00E+01	n/a	4.19E+10
Addicks and Barker Reservoir Watersheds					
Reservoir	03153-000	104	1.02E-02	6.1	2.37E+06
	12466-001	105	1.27E-03	6.1	2.96E+05
	13484-001	105	4.20E-02	6.1	9.76E+06
	10932-001	106	1.91E-02	1	7.22E+05
	11290-001	106	2.54E+00	32550	3.13E+12
	11523-001	108	7.85E-01	1.75	5.19E+07
	12124-001	108	2.51E-01	<1	4.75E+06
	12474-001	108	1.48E-02	8	4.48E+06
	12927-001	108	4.60E-03	2	3.48E+05
	13778-001	108	1.05E-03	<1	1.98E+04
	11836-001	109	2.91E-01	207500	2.28E+12
	11935-001	109	1.45E-01	<1	2.74E+06

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Table 3.4 WWTP Flow, *E. coli* Concentration and Load During Dry Weather Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load[1] (MPN/day)
	11486-001	110	5.46E-01	512	1.06E+10
	11682-001	110	4.43E-01	2	3.35E+07
	11414-001	113	4.06E-02	<1	7.67E+05
	11472-001	113	3.83E-01	<1	7.24E+06
	11947-001	113	1.81E+00	18	1.23E+09
	12128-001	113	5.19E-01	16.5	3.24E+08
	12304-001	113	3.48E-01	6.1	8.08E+07
	12310-001	113	2.07E-02	<1	3.91E+05
	12685-001	113	7.00E-02	<1	1.32E+06
	12223-001	114	1.96E-01	2	1.48E+07
	12726-001	115	2.92E-01	<1	5.52E+06
	12447-001	116	1.94E-01	3	2.20E+07
	13328-001	116	2.66E-02	56	5.62E+07
	11906-001	117	3.07E-01	884	1.03E+10
	12209-001	119	2.36E-01	<1	4.46E+06
	12834-001	119	6.37E-02	<1	1.20E+06
	12841-001	119	4.30E-02	<1	8.13E+05
	12949-001	119	2.31E-02	4	3.49E+06
	11792-002	120	2.25E-01	24	2.04E+08
	13921-001	122	6.24E-03	1	2.36E+05
	11696-002	123	1.25E-01	<1	2.36E+06
	12516-001	123	9.38E-04	6.1	2.18E+05
	11284-001	124	5.74E-01	32	6.95E+08
	12802-001	124	1.53E-01	1	5.78E+06
	12140-001	125	1.39E-01	6.1	3.21E+07
	11969-001	131	6.35E-01	4.75	1.14E+08
	12858-001	133	6.06E-03	6.1	1.41E+06
	13172-002	133	3.16E-01	6.1	7.34E+07
	13245-001	133	1.31E-01	6.1	3.04E+07
	13558-001	133	9.36E-01	6.1	2.17E+08
	12370-001	135	1.11E-01	6.1	2.57E+07
	14011-001	135	8.26E-03	6.1	1.92E+06
	10706-001	136	1.13E+00	6.1	2.62E+08
	02229-000	144	7.67E-03	6.1	1.78E+06
	12356-001	146	1.48E-01	6.1	3.43E+07
	12479-001	147	4.28E-01	6.1	9.95E+07
	12289-001	148	5.21E-01	100	1.97E+09
	11883-001	149	5.45E-01	6.1	1.27E+08
	11598-001	150	6.93E-01	6.1	1.61E+08
	14109-001	151	1.37E-03	6.1	3.18E+05

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Table 3.4 WWTP Flow, *E. coli* Concentration and Load During Dry Weather Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load[1] (MPN/day)
	11152-001	153	1.62E+00	<1	3.07E+07
	11893-001	155	1.31E+00	84	4.17E+09
	13674-001	155	3.32E-02	166	2.09E+08
	13775-001	171	9.41E-02	6.1	2.19E+07
	14134-001	171	1.27E-02	6.1	2.94E+06
	12298-001	178	8.37E-02	6.1	1.94E+07
	12110-001	181	6.70E-02	6.1	1.56E+07
	11989-001	183	2.89E-01	6.1	6.71E+07
	12189-001	183	6.21E-02	6.1	1.44E+07
	12247-001	183	1.86E-01	6.1	4.31E+07
	11917-001	185	3.13E-01	6.1	7.27E+07
	Watershed Summary		2.06E+01	n/a	5.44E+12

Notes:
[1] The load was calculated for values less than the detection limit using ½ the detection limit for the concentration

Abbreviations:
dL - deciliter
MGD - million gallons per day
MPN – most probable number
n/a – not applicable
nc – not collected

3.1.1.2 INTERMEDIATE CONDITION EFFLUENT DISCHARGES

During intermediate conditions, which were defined as bayou flows near the observed median flow, WWTPs may have an increased effluent discharge as an artifact of rainfall infiltration and inflow. These conditions were included in load estimates for the two study watersheds.

To estimate intermediate condition flows, effluent flow data from the City of Houston were used to develop a regression equation describing the relationship between WWTP flow and

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rainfall totals during the previous 12 hours. The City of Houston WWTP data from four plants (10495-030, 10495-076, 10495-099 and 10495-109) and resulting relationship are presented in more detail in **Appendix A**. As 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 WWTPs. Based upon an examination of observed flows from the City of Houston database, 0.25 in was found to be appropriate. Bacteria concentrations associated with these flows were assumed to be the same as under dry weather conditions.

The calculated flow and loads from WWTPs under intermediate conditions are presented in Table 3.5. 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 WWTP intermediate flow times the dry weather *E. coli* concentration in most probable number (MPN) per dL to give the total MPN per day.

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Table 3.5 WWTP Flow, *E. coli* Concentration and Load During Intermediate Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load (MPN/day)
Buffalo Bayou Above Tidal Watershed					
1014	02731-000	27	1.75E-03	6.1	4.07E+05
	10495-030	33	1.00E+01	6.1	2.33E+09
	10495-135	35	5.69E-01	2	4.30E+07
	12346-001	35	1.89E-01	973.5	6.97E+09
	12427-001	35	5.34E-05	6.1	1.24E+04
	12682-001	35	4.28E-02	6.1	9.95E+06
	13021-001	35	1.51E-01	6.1	3.50E+07
	13228-001	35	4.10E-02	6.1	9.52E+06
	14182-001	35	2.28E-02	6.1	5.29E+06
	12233-001	44	6.81E-04	26	6.69E+05
	10584-001	53	3.14E+00	6.1	7.28E+08
	10495-109	55	4.65E+00	6.1	1.08E+09
	12355-001	56	3.36E-04	6.1	7.80E+04
	12830-001	56	2.29E-03	6.1	5.31E+05
	14070-001	56	1.53E-03	6.1	3.56E+05
	14117-001	56	1.03E-01	<1	1.94E+06
	Watershed Summary		1.90E+01	n/a	1.12E+10
Whiteoak Bayou Above Tidal Watershed					
1017	10495-139	1	5.08E-01	4.4	8.36E+07
	10495-076	2	9.15E+00	2	6.92E+08
	11193-001	2	5.32E-01	<1	1.01E+07
	12139-001	2	2.50E-02	4.4	4.12E+06
	12222-001	2	7.10E-02	<1	1.34E+06
	13996-001	2	1.71E-03	4.4	2.82E+05
	02710-000	4	8.81E-04	4.4	1.45E+05
	04760-000	4	1.53E-03	4.4	2.53E+05
	11051-001	4	3.63E-02	5.5	7.55E+06
	11188-001	4	2.66E-01	<1	5.02E+06
	11273-001	4	4.44E-01	<1	8.39E+06
	11375-001	4	1.02E-01	<1	1.92E+06
	11389-001	4	9.82E-03	<1	1.86E+05
	11485-001	4	4.28E-01	<1	8.10E+06
	11538-001	4	1.10E+00	5	2.07E+08
	11670-001	4	3.41E-01	1	1.29E+07
	12342-001	4	2.00E-02	1	7.57E+05
	12443-001	4	1.38E-03	33	1.72E+06
	12552-001	4	6.11E-03	4.4	1.01E+06
	12552-002	4	4.99E-03	4.4	8.21E+05
	13433-001	4	1.23E-02	<1	2.33E+05

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Table 3.5 WWTP Flow, *E. coli* Concentration and Load During Intermediate Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load (MPN/day)
	13509-001	4	1.40E-02	<1	2.65E+05
	13578-001	4	6.65E-03	4.4	1.09E+06
	13623-001	4	7.61E-02	<1	1.44E+06
	13689-001	4	3.54E-01	105	1.41E+09
	13727-001	4	7.40E-03	26.5	7.41E+06
	13807-001	4	7.86E-04	9	2.68E+05
	13939-001	4	1.22E-03	11190	5.15E+08
	13983-001	4	9.30E-04	<1	1.76E+04
	10495-099	7	1.78E+00	1	6.75E+07
	12573-001	9	1.02E-02	4.4	1.68E+06
	12714-001	9	1.51E-01	6	3.43E+07
	14359-001	9	3.29E-02	4.4	5.42E+06
	11563-001	10	7.02E-01	11	2.92E+08
	11979-002	10	1.99E-01	1	7.51E+06
	12397-001	10	4.60E-03	179	3.11E+07
	12574-001	10	1.28E-01	<1	2.42E+06
	12681-001	10	1.92E-01	<1	3.63E+06
	14072-001	10	1.06E+00	<1	2.01E+07
	12121-001	11	9.80E-01	2	7.41E+07
	12795-001	11	2.00E-01	118	8.94E+08
	10876-001	13	9.14E-01	342	1.18E+10
	10876-002	13	9.27E-01	794	2.78E+10
	12465-001	13	5.45E-03	1	2.06E+05
	11005-001	17	1.55E-01	<1	2.93E+06
	12132-001	40	4.11E-02	16.5	2.56E+07
	13764-001	42	5.94E-02	9	2.02E+07
	Watershed Summary		2.10E+01	n/a	4.41E+10
Addicks and Barker Reservoir Watersheds					
Reservoir	03153-000	104	1.08E-02	6.1	2.50E+06
	12466-001	105	1.34E-03	6.1	3.11E+05
	13484-001	105	4.42E-02	6.1	1.03E+07
	10932-001	106	2.01E-02	1	7.59E+05
	11290-001	106	2.67E+00	32550	3.29E+12
	11523-001	108	8.25E-01	1.75	5.46E+07
	12124-001	108	2.64E-01	<1	4.99E+06
	12474-001	108	1.56E-02	8	4.71E+06
	12927-001	108	4.84E-03	2	3.66E+05
	13778-001	108	1.10E-03	<1	2.09E+04
	11836-001	109	3.06E-01	207500	2.40E+12
	11935-001	109	1.53E-01	<1	2.88E+06

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Table 3.5 WWTP Flow, *E. coli* Concentration and Load During Intermediate Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load (MPN/day)
	11486-001	110	5.74E-01	512	1.11E+10
	11682-001	110	4.66E-01	2	3.52E+07
	11414-001	113	4.27E-02	<1	8.07E+05
	11472-001	113	4.03E-01	<1	7.62E+06
	11947-001	113	1.90E+00	18	1.29E+09
	12128-001	113	5.46E-01	16.5	3.40E+08
	12304-001	113	3.66E-01	6.1	8.50E+07
	12310-001	113	2.18E-02	<1	4.11E+05
	12685-001	113	7.36E-02	<1	1.39E+06
	12223-001	114	2.06E-01	2	1.56E+07
	12726-001	115	3.07E-01	<1	5.80E+06
	12447-001	116	2.04E-01	3	2.32E+07
	13328-001	116	2.79E-02	56	5.91E+07
	11906-001	117	3.23E-01	884	1.08E+10
	12209-001	119	2.48E-01	<1	4.69E+06
	12834-001	119	6.69E-02	<1	1.27E+06
	12841-001	119	4.52E-02	<1	8.55E+05
	12949-001	119	2.43E-02	4	3.67E+06
	11792-002	120	2.36E-01	24	2.14E+08
	13921-001	122	6.56E-03	1	2.48E+05
	11696-002	123	1.31E-01	<1	2.49E+06
	12516-001	123	9.87E-04	6.1	2.29E+05
	11284-001	124	6.04E-01	32	7.31E+08
	12802-001	124	1.61E-01	1	6.08E+06
	12140-001	125	1.46E-01	6.1	3.38E+07
	11969-001	131	6.67E-01	4.75	1.20E+08
	12858-001	133	6.37E-03	6.1	1.48E+06
	13172-002	133	3.32E-01	6.1	7.71E+07
	13245-001	133	1.38E-01	6.1	3.20E+07
	13558-001	133	9.84E-01	6.1	2.29E+08
	12370-001	135	1.17E-01	6.1	2.71E+07
	14011-001	135	8.69E-03	6.1	2.02E+06
	10706-001	136	1.18E+00	6.1	2.75E+08
	02229-000	144	8.07E-03	6.1	1.87E+06
	12356-001	146	1.55E-01	6.1	3.61E+07
	12479-001	147	4.51E-01	6.1	1.05E+08
	12289-001	148	5.47E-01	100	2.07E+09
	11883-001	149	5.73E-01	6.1	1.33E+08
	11598-001	150	7.28E-01	6.1	1.69E+08
	14109-001	151	1.44E-03	6.1	3.34E+05

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Table 3.5 WWTP Flow, *E. coli* Concentration and Load During Intermediate Conditions

Segment	TPDES Number	Sub-watershed	Flow (MGD)	*E. coli* (MPN/dL)	Load (MPN/day)
	11152-001	153	1.71E+00	<1	3.23E+07
	11893-001	155	1.38E+00	84	4.39E+09
	13674-001	155	3.49E-02	166	2.19E+08
	13775-001	171	9.90E-02	6.1	2.30E+07
	14134-001	171	1.33E-02	6.1	3.09E+06
	12298-001	178	8.80E-02	6.1	2.04E+07
	12110-001	181	7.05E-02	6.1	1.64E+07
	11989-001	183	3.04E-01	6.1	7.05E+07
	12189-001	183	6.53E-02	6.1	1.52E+07
	12247-001	183	1.95E-01	6.1	4.54E+07
	11917-001	185	3.29E-01	6.1	7.65E+07
	Watershed Summary		2.16E+01	n/a	5.72E+12

Abbreviations:
dL - deciliter
MGD - million gallons per day
MPN – most probable number

3.1.1.3 BIOSOLID DISCHARGES

In addition to effluent discharges, this study also examined the loading from biosolids. Anecdotal evidence and observations at WWTPs has demonstrated that occasionally during large rainfall events, biosolid releases may occur from plants that are carrying a solids blanket. The releases result in higher concentrations of bacteria in the effluent because of the presence of sludge from the WWTP being carried out in the discharge.

Assumptions regarding the occurrence of biosolids were made to match observations of elevated flow after rainfall events observed in City of Houston WWTP flow data (see **Appendix A** for more detail**)**. Based upon these data, biosolid 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

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intermediate condition flows, flows associated with biosolid releases were calculated for a rainfall event equivalent to 0.5 inches. As the first 0.25 inches of the rainfall event are considered intermediate events and not biosolids, the actual rainfall amount that was input into the flow equation was 0.25. The biosolid flow was considered to be an incremental flow in addition to the intermediate condition flow.

Biosolid releases had a higher concentration of bacteria associated with them that was determined based upon TCEQ sampling data presented in **Appendix A**. These data were collected from WWTP biosolid releases occurring that were observed by TCEQ personnel. The TCEQ personnel found that fecal coliform concentrations of stream samples near biosolid releases ranged from 90 to 153,000 cfu/dL. A geometric mean of 4,146 cfu/dL was found. This corresponds to an *E. coli* concentration of 2,612 MPN/dL, using the ratio of the two bacteria standards (126/200).

As biosolid releases were assumed to occur only during wet weather, the daily load presented in **Table 3.6** was adjusted to account for days with precipitation. Houston has 74 days of precipitation out of the year according to National Oceanic and Atmospheric Administration (NOAA) statistics for the rain gage located at Addicks Reservoir (National Oceanic and Atmospheric Administration 2001). The final flows and loads associated with the biosolid releases are shown in **Table 3.6**.

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Table 3.6 WWTP Flow, *E. coli* Concentration and Load During Biosolid Releases

Segment	TCEQ Permit #	Sub-watershed	*E. coli* (MPN/dL)	Biosolid Flow (MGD)	Biosolid Load (MPN/day)
Buffalo Bayou Above Tidal Watershed					
1014	02731-000	27	2,612	1.05E-04	1.03E+07
	10495-030	33	2,612	5.98E-01	5.90E+10
	10495-135	35	2,612	3.40E-02	3.35E+09
	12346-001	35	2,612	1.13E-02	1.12E+09
	12427-001	35	2,612	3.19E-06	3.15E+05
	12682-001	35	2,612	2.56E-03	2.52E+08
	13021-001	35	2,612	9.00E-03	8.89E+08
	13228-001	35	2,612	2.45E-03	2.42E+08
	14182-001	35	2,612	1.36E-03	1.34E+08
	12233-001	44	2,612	4.06E-05	4.01E+06
	10584-001	53	2,612	1.87E-01	1.85E+10
	10495-109	55	2,612	2.78E-01	2.74E+10
	12355-001	56	2,612	2.00E-05	1.98E+06
	12830-001	56	2,612	1.37E-04	1.35E+07
	14070-001	56	2,612	9.16E-05	9.04E+06
	14117-001	56	2,612	6.13E-03	6.06E+08
	Watershed Summary			1.13E+00	1.12E+11
Addicks and Barker Reservoir Watersheds					
Reservoir	03153-000	104	2,612	6.42E-04	6.34E+07
	12466-001	105	2,612	8.00E-05	7.90E+06
	13484-001	105	2,612	2.64E-03	2.60E+08
	10932-001	106	2,612	1.20E-03	1.18E+08
	11290-001	106	2,612	1.59E-01	1.57E+10
	11523-001	108	2,612	4.93E-02	4.86E+09
	12124-001	108	2,612	1.58E-02	1.56E+09
	12474-001	108	2,612	9.29E-04	9.17E+07
	12927-001	108	2,612	2.89E-04	2.85E+07
	13778-001	108	2,612	6.58E-05	6.50E+06
	11836-001	109	2,612	1.83E-02	1.80E+09
	11935-001	109	2,612	9.11E-03	8.99E+08
	11486-001	110	2,612	3.42E-02	3.38E+09
	11682-001	110	2,612	2.78E-02	2.75E+09
	11414-001	113	2,612	2.55E-03	2.52E+08
	11472-001	113	2,612	2.40E-02	2.37E+09

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Table 3.6 WWTP Flow, *E. coli* Concentration and Load During Biosolid Releases

Segment	TCEQ Permit #	Sub-watershed	*E. coli* (MPN/dL)	Biosolid Flow (MGD)	Biosolid Load (MPN/day)
	11947-001	113	2,612	1.14E-01	1.12E+10
	12128-001	113	2,612	3.26E-02	3.22E+09
	12304-001	113	2,612	2.19E-02	2.16E+09
	12310-001	113	2,612	1.30E-03	1.28E+08
	12685-001	113	2,612	4.39E-03	4.34E+08
	12223-001	114	2,612	1.23E-02	1.22E+09
	12726-001	115	2,612	1.83E-02	1.81E+09
	12447-001	116	2,612	1.22E-02	1.20E+09
	13328-001	116	2,612	1.67E-03	1.65E+08
	11906-001	117	2,612	1.93E-02	1.90E+09
	12209-001	119	2,612	1.48E-02	1.46E+09
	12834-001	119	2,612	4.00E-03	3.95E+08
	12841-001	119	2,612	2.70E-03	2.67E+08
	12949-001	119	2,612	1.45E-03	1.43E+08
	11792-002	120	2,612	1.41E-02	1.39E+09
	13921-001	122	2,612	3.92E-04	3.87E+07
	11696-002	123	2,612	7.85E-03	7.75E+08
	12516-001	123	2,612	5.89E-05	5.82E+06
	11284-001	124	2,612	3.60E-02	3.56E+09
	12802-001	124	2,612	9.60E-03	9.48E+08
	12140-001	125	2,612	8.74E-03	8.63E+08
	11969-001	131	2,612	3.98E-02	3.93E+09
	12858-001	133	2,612	3.80E-04	3.76E+07
	13172-002	133	2,612	1.98E-02	1.96E+09
	13245-001	133	2,612	8.23E-03	8.13E+08
	13558-001	133	2,612	5.87E-02	5.80E+09
	12370-001	135	2,612	6.96E-03	6.87E+08
	14011-001	135	2,612	5.19E-04	5.12E+07
	10706-001	136	2,612	7.07E-02	6.98E+09
	02229-000	144	2,612	4.82E-04	4.76E+07
	12356-001	146	2,612	9.27E-03	9.15E+08
	12479-001	147	2,612	2.69E-02	2.66E+09
	12289-001	148	2,612	3.27E-02	3.23E+09
	11883-001	149	2,612	3.42E-02	3.38E+09
	11598-001	150	2,612	4.35E-02	4.29E+09

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Table 3.6 WWTP Flow, *E. coli* Concentration and Load During Biosolid Releases

Segment	TCEQ Permit #	Sub-watershed	*E. coli* (MPN/dL)	Biosolid Flow (MGD)	Biosolid Load (MPN/day)
	14109-001	151	2,612	8.59E-05	8.49E+06
	11152-001	153	2,612	1.02E-01	1.01E+10
	11893-001	155	2,612	8.24E-02	8.14E+09
	13674-001	155	2,612	2.09E-03	2.06E+08
	13775-001	171	2,612	5.91E-03	5.84E+08
	14134-001	171	2,612	7.95E-04	7.85E+07
	12298-001	178	2,612	5.25E-03	5.19E+08
	12110-001	181	2,612	4.21E-03	4.15E+08
	11989-001	183	2,612	1.81E-02	1.79E+09
	12189-001	183	2,612	3.90E-03	3.85E+08
	12247-001	183	2,612	1.17E-02	1.15E+09
	11917-001	185	2,612	1.97E-02	1.94E+09
	Watershed Summary			1.29E+00	1.28E+11
Whiteoak Bayou Above Tidal Watershed					
1017	10495-139	1	2,612	3.03E-02	2.99E+09
	10495-076	2	2,612	5.46E-01	5.39E+10
	11193-001	2	2,612	3.18E-02	3.14E+09
	12139-001	2	2,612	1.49E-03	1.48E+08
	12222-001	2	2,612	4.24E-03	4.18E+08
	13996-001	2	2,612	1.02E-04	1.01E+07
	02710-000	4	2,612	5.26E-05	5.19E+06
	04760-000	4	2,612	9.16E-05	9.04E+06
	11051-001	4	2,612	2.17E-03	2.14E+08
	11188-001	4	2,612	1.59E-02	1.57E+09
	11273-001	4	2,612	2.65E-02	2.62E+09
	11375-001	4	2,612	6.08E-03	6.00E+08
	11389-001	4	2,612	5.86E-04	5.79E+07
	11485-001	4	2,612	2.56E-02	2.52E+09
	11538-001	4	2,612	6.55E-02	6.46E+09
	11670-001	4	2,612	2.04E-02	2.01E+09
	12342-001	4	2,612	1.19E-03	1.18E+08
	12443-001	4	2,612	8.21E-05	8.11E+06
	12552-001	4	2,612	3.65E-04	3.60E+07
	12552-002	4	2,612	2.98E-04	2.94E+07
	13433-001	4	2,612	7.35E-04	7.25E+07

Table 3.6 WWTP Flow, *E. coli* Concentration and Load During Biosolid Releases

Segment	TCEQ Permit #	Sub-watershed	*E. coli* (MPN/dL)	Biosolid Flow (MGD)	Biosolid Load (MPN/day)
	13509-001	4	2,612	8.36E-04	8.26E+07
	13578-001	4	2,612	3.97E-04	3.92E+07
	13623-001	4	2,612	4.54E-03	4.48E+08
	13689-001	4	2,612	2.11E-02	2.09E+09
	13727-001	4	2,612	4.42E-04	4.36E+07
	13807-001	4	2,612	4.69E-05	4.63E+06
	13939-001	4	2,612	7.26E-05	7.17E+06
	13983-001	4	2,612	5.55E-05	5.48E+06
	10495-099	7	2,612	1.07E-01	1.05E+10
	12573-001	9	2,612	6.11E-04	6.03E+07
	12714-001	9	2,612	9.02E-03	8.91E+08
	14359-001	9	2,612	1.97E-03	1.94E+08
	11563-001	10	2,612	4.19E-02	4.14E+09
	11979-002	10	2,612	1.19E-02	1.17E+09
	12397-001	10	2,612	2.75E-04	2.71E+07
	12574-001	10	2,612	7.65E-03	7.55E+08
	12681-001	10	2,612	1.15E-02	1.13E+09
	14072-001	10	2,612	6.33E-02	6.25E+09
	12121-001	11	2,612	5.85E-02	5.77E+09
	12795-001	11	2,612	1.20E-02	1.18E+09
	10876-001	13	2,612	5.45E-02	5.39E+09
	10876-002	13	2,612	5.53E-02	5.46E+09
	12465-001	13	2,612	3.25E-04	3.21E+07
	11005-001	17	2,612	9.24E-03	9.12E+08
	12132-001	40	2,612	2.46E-03	2.43E+08
	13764-001	42	2,612	3.55E-03	3.50E+08
	Watershed Summary			1.26E+00	1.24E+11

Abbreviations:

dL – deciliter
MGD - million gallons per day
MPN – most probable number
WWTP – wastewater treatment plant

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3.1.2 SANITARY STORM SEWER OVERFLOWS

Sanitary sewer overflows (SSOs) are releases of partially treated or 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 to be part of the WWTP discharge load for this TMDL, these overflows typically make their way to the storm water conveyance system which then carries the overflows to the bayou.

3.1.2.1 ESTIMATION OF SSO OCCURRENCE

SSOs occur under both wet and dry weather conditions. SSO flow and bacteria load estimates were conducted two separate ways: (1) using a City of Houston database for SSOs inside Houston city limits to empirically calculate the number of SSOs and (2) using a combination of SSO occurrence by age of pipe and housing age since SSO data were not available. A map of the SSO locations identified by the City of Houston in their database is presented in **Figure 3.3**. These two methods are discussed in detail in **Appendix B**. The calculated number of SSOs is shown in **Table 3.7**.

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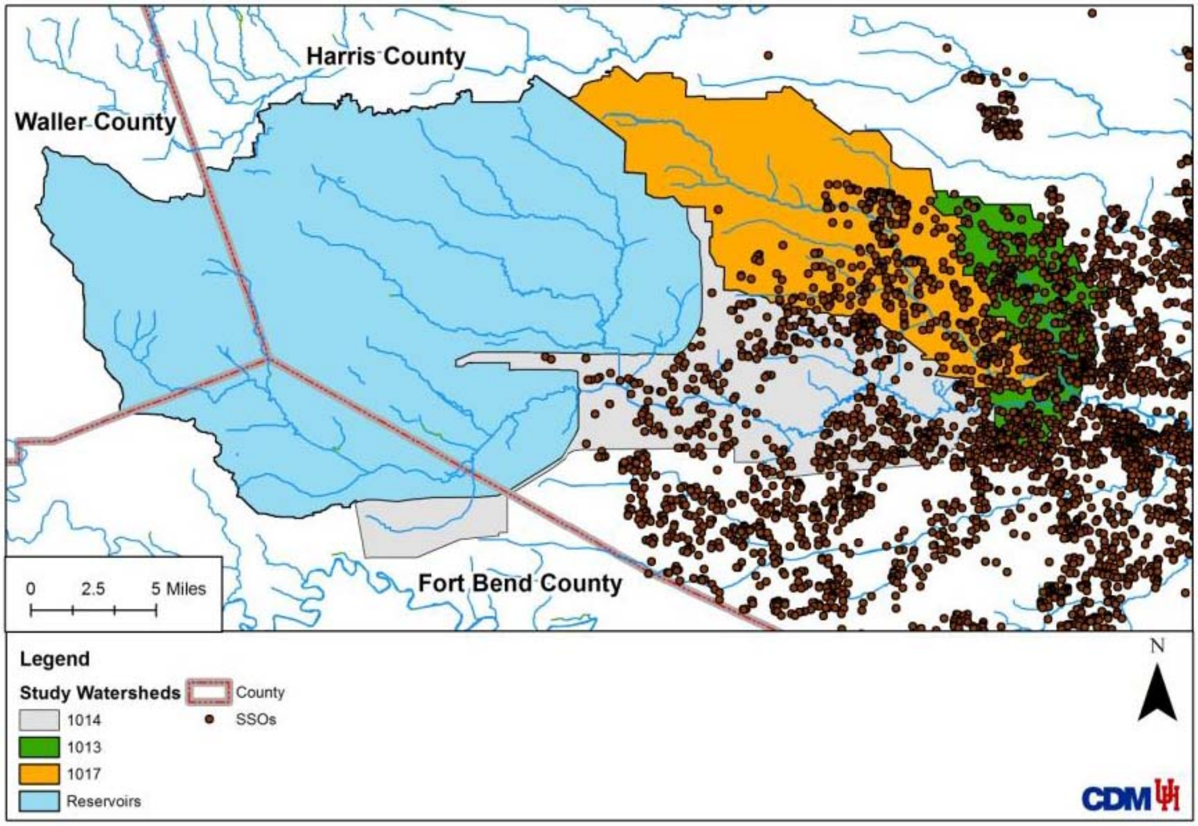

Figure 3.3 SSO Locations Recorded by the City of Houston

Table 3.7 Calculated Number of SSOs

Segment	Subwatershed	Dry SSOs per year	Intermediate SSOs per year	Wet SSOs per year
Buffalo Bayou Tidal Watershed				
1013	5	29	29	12
	6	8	8	2
	36	6	6	3
	37	11	11	2
	38	8	8	3
	46	0	0	2
	47	1	1	1
	48	16	16	3
	49	13	13	3
	Watershed Total		92	31
Buffalo Bayou Above Tidal Watershed				
1014	26	11	11	2
	27	4	4	0
	28	1	1	0

Table 3.7 Calculated Number of SSOs

Segment	Subwatershed	Dry SSOs per year	Intermediate SSOs per year	Wet SSOs per year
	33	5	5	2
	34	2	2	1
	35	0	0	0
	39	9	9	2
	44	5	5	2
	45	7	7	6
	50	5	5	1
	51	11	11	7
	52	7	7	4
	53	3	3	1
	54	3	3	2
	55	1	1	0
	56	1	1	0
	Watershed Total		75	30
Addicks and Barker Reservoir Watershed				
Reservoirs	101	0	0	0
	102	0	0	0
	103	0	0	0
	104	0	0	0
	105	0	0	0
	106	0	0	0
	107	1	1	0
	108	2	2	1
	109	2	2	0
	110	3	3	1
	111	0	0	0
	112	0	0	0
	113	5	5	2
	114	3	3	1
	115	3	3	1
	116	0	0	0
	117	2	2	1
	118	2	2	1
	119	5	5	1
	120	3	3	1
	121	1	1	0
	122	0	0	0
	123	1	1	0
	124	0	0	0
	125	1	1	0
	126	0	0	0
	127	0	0	0
	128	0	0	0
	129	0	0	0
	130	0	0	0
	131	1	1	0
	132	0	0	0

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Table 3.7 Calculated Number of SSOs

Segment	Subwatershed	Dry SSOs per year	Intermediate SSOs per year	Wet SSOs per year
	133	3	3	1
	134	1	1	0
	135	1	1	0
	136	0	0	0
	137	0	0	0
	138	0	0	0
	139	0	0	0
	140	0	0	0
	141	0	0	0
	142	0	0	0
	143	0	0	0
	144	0	0	0
	145	0	0	0
	146	0	0	0
	147	0	0	0
	148	3	3	1
	149	1	1	0
	150	3	3	1
	151	2	2	0
	152	1	1	0
	153	1	1	0
	154	0	0	0
	155	0	0	0
	156	2	2	1
	171	2	2	0
	172	0	0	0
	173	0	0	0
	174	0	0	0
	175	0	0	0
	176	0	0	0
	177	0	0	0
	178	0	0	0
	180	0	0	0
	181	2	2	1
	182	0	0	0
	183	2	2	1
	184	1	1	0
	185	0	0	0
	186	0	0	0
	187	0	0	0
	188	0	0	0
	Watershed Total		60	16
Whiteoak Bayou Above Tidal Watershed				
1017	1	12	12	5
	2	4	4	2
	3	7	7	5
	4	8	8	2

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Table 3.7 Calculated Number of SSOs

Segment	Subwatershed	Dry SSOs per year	Intermediate SSOs per year	Wet SSOs per year
	7	5	5	5
	8	2	2	1
	9	2	2	1
	10	5	5	1
	11	2	2	1
	12	1	1	0
	13	3	3	1
	17	8	8	2
	40	8	8	1
	41	8	8	0
	42	11	11	0
	43	5	5	3
	Watershed Total		91	30

Abbreviation:
SSO - sanitary sewer overflow

3.1.2.2 DETERMINATION OF FLOW AND *E. COLI* LOAD FROM SSOS

Using either data obtained from the City of Houston database or the estimated number of SSOs for outside the City of Houston limits, the flow and load associated with each SSO was estimated. The number of wet and dry SSOs was partitioned using the calculated percentage of wet SSOs in the City of Houston database, 27%.

SSO flows were estimated using volumes obtained from the US EPA SSO Report (2004). The volume from each dry SSO was assumed to be 1,000 gallons and the SSO was assumed to occur for one day. This assumption is supported by the fact that over 85% of the SSOs recorded in the City of Houston database were resolved within 1 day. For wet weather, the US EPA reported a median volume of 14,400 gallons per wet weather SSO. Wet weather SSOs were also assumed to occur over a 1 day period.

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The *E. coli* concentration associated with the SSOs was determined through a sampling effort undertaken to characterize SSO discharges in and around the Buffalo and Whiteoak Bayou watersheds presented in **Appendix B**. As described in **Appendix B**, SSOs were difficult to locate and sample and thus WWTP influent was sampled instead during both wet and dry conditions. Results are presented in **Table 3.8**. One dry weather SSO, however, was observed on the campus of the University of Houston on June 28, 2005 and the concentrations associated with the overflow are also presented in the table.

The *E. coli* concentration applied for dry weather SSOs was 4.70×10^6 MPN/dL, the geometric mean of all sampled dry weather WWTP influent and SSOs. For wet weather SSOs, the geometric mean of sampled wet weather influent was reduced by an order of magnitude based upon the US EPA Report to Congress (2004) which states "… concentrations of fecal coliform found in CSOs 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/dL.

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Table 3.8 Measured concentrations of *E. coli* in wastewater

Sample ID	Date	*E. coli* Concentration (MPN/dL)	Classification
SSO	6/28/2005	8.90E+05	Dry
Wastewater Influent 2	9/8/2005	1.94E+07	Dry
Turkey Creek Influent	8/4/2004	3.23E+06	Dry
Turkey Creek Influent	8/5/2004	7.27E+06	Dry
Turkey Creek Influent	8/6/2004	7.11E+06	Dry
West District Influent	8/4/2004	7.49E+06	Dry
West District Influent	8/5/2004	1.15E+06	Dry
West District Influent	8/6/2004	9.62E+06	Dry
Turkey Creek Influent, Wet Weather	3/2/2005	1.93E+06	Wet
Turkey Creek Influent, Wet Weather	4/11/2005	6.19E+06	Wet
West District Influent, Wet Weather	3/2/2005	3.80E+06	Wet
West District Influent, Wet Weather	3/7/2005	3.41E+06	Wet
West District Influent, Wet Weather	4/11/2005	3.40E+06	Wet

Dry Influent Geometric Mean (MPN/dL): 4.70E+06
Wet Influent Geometric Mean (MPN/dL): 3.50E+06

Abbreviations:
dL – deciliter
MPN - most probable number
SSO - sanitary sewer overflow

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 scaled back by a delivery factor, which is a measure of how many SSO releases actually make it to a water body. Although the US EPA SSO Report to Congress (2004) reports a delivery rate of 73%, analyses completed in previous project studies (presented in **Appendix B**) show that 43% and 39% of the volume released in SSO would have the potential to reach Buffalo and Whiteoak Bayous, respectively.

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The final calculated flows and loads are presented in **Table 3.9** for both dry and wet weather. The flows shown in the **Table 3.9** were calculated by multiplying the estimated number of SSOs per year, the delivery ratio, and the flow reported by the EPA together to give the flow in MGD (million gallons per day). This value was divided by the number of wet or dry days to obtain the daily flow. The loads were calculated by multiplying the number of SSOs per year, the estimated SSO flow (in MGD), the measured bacteria concentration from sampling, and the delivery ratio together to give the total MPN per day.

As SSO events releases were assumed to occur during both wet and dry weather, the daily loads presented in **Table 3.9** were adjusted to account for days with precipitation. Houston has 74 days of precipitation greater than 0.01 in out of the year according to NOAA statistics for the rain gage located at Addicks Reservoir (NOAA 2001). Therefore, yearly loads were calculated and divided by 291 days to obtain a non-wet weather load.

Table 3.9 Estimates of SSO Flow and *E. coli* Loads

Segment	Sub-watershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
		Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)
Buffalo Bayou Tidal Watershed							
1013	5	4.27E-05	7.60E+09	4.27E-05	7.60E+09	1.02E-03	1.36E+10
	6	1.15E-05	2.04E+09	1.15E-05	2.04E+09	1.56E-04	2.06E+09
	36	9.49E-06	1.69E+09	9.49E-06	1.69E+09	2.22E-04	2.95E+09
	37	1.66E-05	2.96E+09	1.66E-05	2.96E+09	1.56E-04	2.06E+09
	38	1.23E-05	2.18E+09	1.23E-05	2.18E+09	2.45E-04	3.24E+09
	46	3.95E-07	7.04E+07	3.95E-07	7.04E+07	2.00E-04	2.65E+09
	47	1.58E-06	2.81E+08	1.58E-06	2.81E+08	4.45E-05	5.90E+08
	48	2.37E-05	4.22E+09	2.37E-05	4.22E+09	2.67E-04	3.54E+09
	49	1.98E-05	3.52E+09	1.98E-05	3.52E+09	2.45E-04	3.24E+09
	Watershed Total	1.38E-04	2.46E+10	1.38E-04	2.46E+10	2.56E-03	3.39E+10
Buffalo Bayou Above Tidal Watershed							

Table 3.9 Estimates of SSO Flow and *E. coli* Loads

Segment	Sub-watershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
		Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)
1014	26	1.66E-05	2.96E+09	1.66E-05	2.96E+09	1.33E-04	1.77E+09
	27	6.33E-06	1.13E+09	6.33E-06	1.13E+09	2.22E-05	2.95E+08
	28	1.08E-06	1.93E+08	1.08E-06	1.93E+08	1.82E-05	2.42E+08
	33	7.91E-06	1.41E+09	7.91E-06	1.41E+09	2.00E-04	2.65E+09
	34	2.37E-06	4.22E+08	2.37E-06	4.22E+08	4.45E-05	5.90E+08
	35	3.95E-07	7.04E+07	3.95E-07	7.04E+07	0.00E+00	0.00E+00
	39	1.34E-05	2.39E+09	1.34E-05	2.39E+09	2.00E-04	2.65E+09
	44	7.51E-06	1.34E+09	7.51E-06	1.34E+09	1.33E-04	1.77E+09
	45	1.11E-05	1.97E+09	1.11E-05	1.97E+09	4.89E-04	6.49E+09
	50	7.51E-06	1.34E+09	7.51E-06	1.34E+09	1.11E-04	1.47E+09
	51	1.62E-05	2.89E+09	1.62E-05	2.89E+09	6.00E-04	7.96E+09
	52	9.88E-06	1.76E+09	9.88E-06	1.76E+09	3.56E-04	4.72E+09
	53	4.74E-06	8.44E+08	4.74E-06	8.44E+08	1.11E-04	1.47E+09
	54	4.35E-06	7.74E+08	4.35E-06	7.74E+08	1.33E-04	1.77E+09
	55	1.98E-06	3.52E+08	1.98E-06	3.52E+08	0.00E+00	0.00E+00
	56	7.91E-07	1.41E+08	7.91E-07	1.41E+08	2.22E-05	2.95E+08
	Watershed Total	1.12E-04	2.00E+10	1.12E-04	2.00E+10	2.58E-03	3.41E+10
Addicks and Barker Reservoir Watershed							
Reservoirs	101	1.12E-09	2.00E+05	1.12E-09	2.00E+05	1.89E-08	2.50E+05
	102	2.65E-07	4.72E+07	2.65E-07	4.72E+07	4.45E-06	5.90E+07
	103	6.62E-08	1.18E+07	6.62E-08	1.18E+07	1.11E-06	1.48E+07
	104	4.28E-07	7.62E+07	4.28E-07	7.62E+07	7.19E-06	9.53E+07
	105	3.04E-07	5.41E+07	3.04E-07	5.41E+07	5.11E-06	6.77E+07
	106	5.50E-07	9.79E+07	5.50E-07	9.79E+07	9.24E-06	1.22E+08
	107	2.14E-06	3.81E+08	2.14E-06	3.81E+08	3.59E-05	4.76E+08
	108	2.63E-06	4.69E+08	2.63E-06	4.69E+08	4.42E-05	5.86E+08
	109	2.31E-06	4.11E+08	2.31E-06	4.11E+08	3.88E-05	5.14E+08
	110	5.13E-06	9.13E+08	5.13E-06	9.13E+08	8.62E-05	1.14E+09
	111	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	112	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	113	8.06E-06	1.44E+09	8.06E-06	1.44E+09	1.36E-04	1.80E+09
	114	4.77E-06	8.49E+08	4.77E-06	8.49E+08	8.01E-05	1.06E+09
	115	4.65E-06	8.27E+08	4.65E-06	8.27E+08	7.81E-05	1.04E+09
	116	6.06E-07	1.08E+08	6.06E-07	1.08E+08	1.02E-05	1.35E+08
	117	2.87E-06	5.11E+08	2.87E-06	5.11E+08	4.82E-05	6.39E+08
	118	3.43E-06	6.10E+08	3.43E-06	6.10E+08	5.76E-05	7.63E+08
	119	7.00E-06	1.25E+09	7.00E-06	1.25E+09	1.18E-04	1.56E+09
	120	4.88E-06	8.69E+08	4.88E-06	8.69E+08	8.20E-05	1.09E+09
	121	8.70E-07	1.55E+08	8.70E-07	1.55E+08	1.46E-05	1.94E+08
	122	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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Table 3.9 Estimates of SSO Flow and *E. coli* Loads

Segment	Sub-watershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
		Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)
	123	2.04E-06	3.63E+08	2.04E-06	3.63E+08	3.43E-05	4.55E+08
	124	5.01E-07	8.93E+07	5.01E-07	8.93E+07	8.43E-06	1.12E+08
	125	1.35E-06	2.41E+08	1.35E-06	2.41E+08	2.27E-05	3.01E+08
	126	1.03E-07	1.83E+07	1.03E-07	1.83E+07	1.73E-06	2.29E+07
	127	2.04E-10	3.62E+04	2.04E-10	3.62E+04	3.42E-09	4.53E+04
	128	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	129	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	130	5.45E-08	9.70E+06	5.45E-08	9.70E+06	9.15E-07	1.21E+07
	131	2.11E-06	3.75E+08	2.11E-06	3.75E+08	3.54E-05	4.69E+08
	132	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	133	3.73E-06	6.64E+08	3.73E-06	6.64E+08	6.26E-05	8.30E+08
	134	1.30E-06	2.31E+08	1.30E-06	2.31E+08	2.18E-05	2.89E+08
	135	8.03E-07	1.43E+08	8.03E-07	1.43E+08	1.35E-05	1.79E+08
	136	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	137	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	138	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	139	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	140	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	141	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	142	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	143	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	144	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	145	8.48E-08	1.51E+07	8.48E-08	1.51E+07	1.43E-06	1.89E+07
	146	6.01E-07	1.07E+08	6.01E-07	1.07E+08	1.01E-05	1.34E+08
	147	3.12E-08	5.55E+06	3.12E-08	5.55E+06	5.24E-07	6.95E+06
	148	4.89E-06	8.70E+08	4.89E-06	8.70E+08	8.21E-05	1.09E+09
	149	1.66E-06	2.96E+08	1.66E-06	2.96E+08	2.79E-05	3.70E+08
	150	3.75E-06	6.67E+08	3.75E-06	6.67E+08	6.30E-05	8.35E+08
	151	2.23E-06	3.98E+08	2.23E-06	3.98E+08	3.75E-05	4.98E+08
	152	1.07E-06	1.90E+08	1.07E-06	1.90E+08	1.79E-05	2.38E+08
	153	1.80E-06	3.20E+08	1.80E-06	3.20E+08	3.02E-05	4.01E+08
	154	1.86E-08	3.30E+06	1.86E-08	3.30E+06	3.12E-07	4.13E+06
	155	6.17E-07	1.10E+08	6.17E-07	1.10E+08	1.04E-05	1.37E+08
	156	3.09E-06	5.50E+08	3.09E-06	5.50E+08	5.19E-05	6.88E+08
	171	2.37E-06	4.22E+08	2.37E-06	4.22E+08	3.99E-05	5.28E+08
	172	3.72E-07	6.62E+07	3.72E-07	6.62E+07	6.25E-06	8.28E+07
	173	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	174	2.72E-09	4.84E+05	2.72E-09	4.84E+05	4.57E-08	6.06E+05
	175	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	176	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

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Table 3.9 Estimates of SSO Flow and *E. coli* Loads

Segment	Sub-watershed	Dry Conditions		Intermediate Conditions		Wet Conditions	
		Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)	Flow to stream (MGD)	Load to stream (MPN/day)
	177	1.24E-07	2.20E+07	1.24E-07	2.20E+07	2.08E-06	2.75E+07
	178	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	180	3.75E-07	6.68E+07	3.75E-07	6.68E+07	6.31E-06	8.36E+07
	181	2.77E-06	4.92E+08	2.77E-06	4.92E+08	4.65E-05	6.16E+08
	182	4.98E-07	8.86E+07	4.98E-07	8.86E+07	8.36E-06	1.11E+08
	183	2.95E-06	5.24E+08	2.95E-06	5.24E+08	4.95E-05	6.56E+08
	184	7.45E-07	1.33E+08	7.45E-07	1.33E+08	1.25E-05	1.66E+08
	185	5.96E-07	1.06E+08	5.96E-07	1.06E+08	1.00E-05	1.33E+08
	186	3.18E-07	5.66E+07	3.18E-07	5.66E+07	5.34E-06	7.08E+07
	187	1.24E-07	2.21E+07	1.24E-07	2.21E+07	2.08E-06	2.76E+07
	188	6.68E-09	1.19E+06	6.68E-09	1.19E+06	1.12E-07	1.49E+06
	Watershed Total	9.40E-05	1.67E+10	9.40E-05	1.67E+10	1.58E-03	2.09E+10
Whiteoak Bayou Above Tidal Watershed							
1017	1	1.58E-05	2.81E+09	1.58E-05	2.81E+09	3.43E-04	4.55E+09
	2	5.38E-06	9.57E+08	5.38E-06	9.57E+08	1.82E-04	2.41E+09
	3	9.32E-06	1.66E+09	9.32E-06	1.66E+09	3.83E-04	5.08E+09
	4	1.04E-05	1.86E+09	1.04E-05	1.86E+09	1.75E-04	2.32E+09
	7	6.45E-06	1.15E+09	6.45E-06	1.15E+09	3.63E-04	4.81E+09
	8	2.87E-06	5.11E+08	2.87E-06	5.11E+08	4.03E-05	5.35E+08
	9	3.15E-06	5.60E+08	3.15E-06	5.60E+08	5.29E-05	7.01E+08
	10	6.73E-06	1.20E+09	6.73E-06	1.20E+09	1.13E-04	1.50E+09
	11	3.25E-06	5.79E+08	3.25E-06	5.79E+08	5.46E-05	7.24E+08
	12	1.00E-06	1.79E+08	1.00E-06	1.79E+08	1.69E-05	2.24E+08
	13	4.16E-06	7.40E+08	4.16E-06	7.40E+08	6.98E-05	9.26E+08
	17	1.04E-05	1.85E+09	1.04E-05	1.85E+09	1.82E-04	2.41E+09
	40	1.11E-05	1.98E+09	1.11E-05	1.98E+09	1.01E-04	1.34E+09
	41	1.04E-05	1.85E+09	1.04E-05	1.85E+09	2.02E-05	2.67E+08
	42	1.51E-05	2.68E+09	1.51E-05	2.68E+09	2.02E-05	2.67E+08
	43	6.81E-06	1.21E+09	6.81E-06	1.21E+09	2.42E-04	3.21E+09
	Watershed Total	1.22E-04	2.18E+10	1.22E-04	2.18E+10	2.36E-03	3.13E+10

Abbreviations:
dL – deciliter
MGD – million gallons per day
MPN - most probable number
SSO - sanitary sewer overflow

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3.1.3 REGULATED STORMWATER DISCHARGES

A municipal separate storm sewer system (MS4) is a publicly owned conveyance system that collects storm water and discharges to waters of the State. As these discharges are regulated by the US EPA under the National Pollutant Discharge Elimination System (NPDES) program, they must be incorporated into the TMDL as part of the Waste Load Allocation (WLA) even though storm water has many diffuse sources. In addition to the MS4 permit, other permitted discharges can occur from industrial stormwater dischargers as well as small- and medium-sized MS4s.

The flow and loading from these regulated stormwater discharges sources is described in the following sections.

3.1.4 DRY WEATHER STORM SEWER DISCHARGES

Dry weather storm sewer (DWSS) discharges through pipes were sampled during 2001 to estimate *E. coli* loads. Locations of the discharges are shown in **Figure 3.4**. The details of the sampling are presented in **Appendix C** but will be briefly described in this section as well.

The DWSS sampling was conducted along the entire length of the main stem of Buffalo and Whiteoak Bayous. It should be noted that sampling was only conducted downstream of the reservoirs in Buffalo Bayou. Samples were collected only during dry conditions, which for this sampling was 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, as it would be impossible to determine if dry weather flows were occurring.

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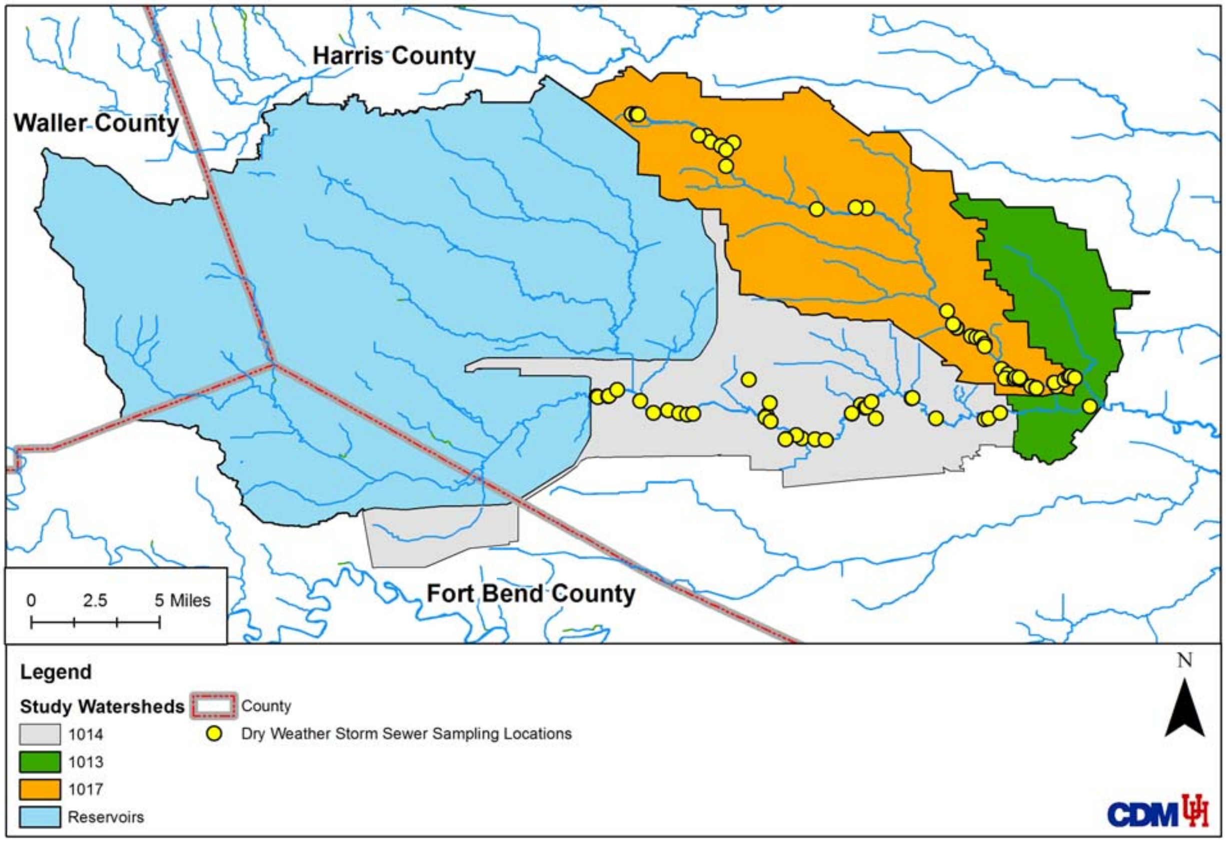

Figure 3.4 Dry Weather Storm Sewer Discharge Locations

The loads were calculated using measured flow and concentration from the sampling effort. For the purposes of this TMDL, 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 bacteria loading for these conditions (i.e., event mean concentrations lump all sources of loading not just those

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from wet weather conditions) as will be described in the subsequent section.

Using data reported at the Addicks Reservoir rain gage maintained by the NOAA (National Climatic Data Center 2003), it was found that 74 days of the year on average experience rainfall greater than 0.01 in and thus DWSS discharges were assumed to occur during the remaining 291 days.

A summary of loads on a subwatershed basis are presented in **Table 3.10**. The flows shown in the table were calculated by summing of all DWSS 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 to ensure DWSS were only counted on dry weather days in MGD. The bacteria loading from DWSS 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 found to be in subwatershed 43, with a load of 2.22×10^{11} MPN/day. The smallest non-zero load was found to be 7.44×10^{5} MPN/day in subwatershed 44.

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Table 3.10 Summary of dry weather regulated stormwater discharges

Segment	Sub-watershed	Flow (MG per dry day)	Load (MPN/dry day)
Buffalo Bayou Below Tidal Watershed			
1013	47	5.35E-04	1.47E+07
	Watershed total	5.35E-04	1.47E+07
Buffalo Bayou Above Tidal Watershed			
1014	34	4.10E-02	2.57E+09
	35	3.72E-02	3.14E+07
	39	2.13E-01	2.53E+08
	44	3.02E-04	7.43E+05
	45	4.08E-02	1.55E+10
	50	4.74E-03	1.49E+08
	52	8.08E-02	5.48E+10
	53	6.35E-03	1.32E+08
	54	1.40E-01	1.79E+11
	55	5.15E-02	2.05E+10
	Watershed total	6.15E-01	2.72E+11
Whiteoak Bayou Above Tidal Watershed			
1017	4	3.71E-03	1.11E+07
	7	1.34E-02	3.79E+07
	10	2.46E-02	1.28E+09
	11	1.27E-02	1.79E+07
	13	1.06E-02	8.62E+06
	40	1.41E-01	4.88E+08
	41	5.71E-02	3.16E+09
	42	1.00E-01	2.24E+10
	43	3.16E-01	2.21E+11
	Watershed total	6.80E-01	2.49E+11

Abbreviations:
MGD - million gallons
MPN - most probable number
MS4 - municipal separate storm sewer system

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3.1.5 INTERMEDIATE AND WET WEATHER STORM SEWER DISCHARGES

Stormwater runoff has been sampled several times throughout the course of this project. Results of the sampling are presented in **Section 2.4.2** and **Appendix D**.

Bacteria loading from watershed sources during wet weather can be simulated using a water quality model or a simpler approach using the curve number method (Natural Resource Conservation Service, 1986) and measured *E. coli* event mean concentrations (EMCs) from local sampling. This bacteria load accounts for any loading deposited on the watershed by animals, but does not account for direct deposition into the stream. Direct deposition was treated as a separate source in **Section 3.2.2**

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 as 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 upon the curve number method and using land use data combined with STATSGO soils data presented in **Section 2**. 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 in of rain, based upon 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. It is important to note that 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 to fall on rainy days during a given year. This is an important consideration as the TMDL must be calculated on a daily basis.

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 and thus assumptions were made to determine the appropriate EMC for each land cover type. As the collected data were fecal coliform, rather than *E. coli*, the fecal coliform data were transformed to *E. coli* 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 3.11**. Wet weather loads were assumed to occur only on wet days, and thus the loads were corrected to only account for 74 days of rainfall that typically occur in Houston.

As the instream intermediation condition is a mixed flow regime, comprised of flows associated with WWTP effluent as well as runoff, wet weather storm sewer loads were also estimated. It is important to note that the instream intermediate condition is not based on a specific amount of rainfall but rather is based on balancing the flow in the bayou to make up what is not contributed by wastewater flows towards the median flow in the bayou. The bacteria load for the instream intermediate condition was determined proportionally to reflect the same addition of bacteria load as was required for flow.

Loads calculated using the simple approach described in this section are presented in **Table 3.12** for the intermediate and wet weather scenarios. The largest *E. coli* load from wet weather MS4 discharges occurred in subwatershed 1 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 with a load of 1.29 x 10^{11} MPN/day.

Table 3.11 Summary of Assumptions used for Wet Weather Calculations

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

Abbreviations:
cfu - colony forming units
dL – deciliter
EMC - event mean concentration
MPN – most probable number

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Table 3.12 Summary of Wet Weather Storm Sewer Loads

Segment	Sub-watershed	Intermediate Condition		Wet Weather Condition	
		Flow (MGD)	*E. coli* Load (MPN/day)	Flow (MGD)	*E. coli* Load (MPN/day)
Buffalo Bayou Tidal Watershed					
1013	5	4.19E-01	6.94E+11	2.40E+01	3.96E+13
	6	2.69E-01	4.46E+11	1.54E+01	2.55E+13
	36	2.00E-01	3.50E+11	1.14E+01	2.00E+13
	37	1.67E-01	2.87E+11	9.52E+00	1.64E+13
	38	1.62E-01	2.77E+11	9.24E+00	1.58E+13
	46	7.53E-02	1.30E+11	4.30E+00	7.42E+12
	47	6.11E-02	1.08E+11	3.49E+00	6.15E+12
	48	1.89E-01	3.15E+11	1.08E+01	1.80E+13
	49	2.49E-01	4.13E+11	1.42E+01	2.36E+13
	Watershed total	1.79E+00	3.02E+12	1.02E+02	1.73E+14
Buffalo Bayou Above Tidal Watershed					
1014	26	5.30E+00	8.84E+12	1.60E+01	2.67E+13
	27	3.77E+00	6.41E+12	1.14E+01	1.94E+13
	28	6.53E-01	1.06E+12	1.97E+00	3.20E+12
	33	4.30E+00	7.36E+12	1.30E+01	2.23E+13
	34	9.21E-01	1.43E+12	2.78E+00	4.31E+12
	35	4.04E+00	6.70E+12	1.22E+01	2.03E+13
	39	5.99E+00	9.91E+12	1.81E+01	3.00E+13
	44	4.66E+00	8.11E+12	1.41E+01	2.45E+13
	45	3.77E+00	6.36E+12	1.14E+01	1.92E+13
	50	3.40E+00	5.89E+12	1.03E+01	1.78E+13
	51	3.23E+00	5.50E+12	9.77E+00	1.66E+13
	52	4.71E+00	8.13E+12	1.42E+01	2.46E+13
	53	6.09E+00	1.04E+13	1.84E+01	3.15E+13
	54	3.11E+00	5.27E+12	9.40E+00	1.59E+13
	55	4.42E+00	7.50E+12	1.34E+01	2.27E+13
	56	4.70E+00	8.02E+12	1.42E+01	2.43E+13
	Watershed total	6.31E+01	1.07E+14	1.91E+02	3.23E+14
Addicks and Barker Reservoir Watershed					
Reservoir	101	4.38E-02	4.76E+10	1.73E-01	1.88E+11
	102	1.32E-01	2.15E+11	5.22E-01	8.51E+11
	103	7.01E-01	1.22E+12	2.77E+00	4.82E+12
	104	6.68E-01	1.09E+12	2.64E+00	4.31E+12
	105	9.02E-01	1.55E+12	3.56E+00	6.13E+12
	106	7.05E-01	1.07E+12	2.78E+00	4.25E+12
	107	6.59E-01	1.03E+12	2.60E+00	4.07E+12
	108	1.05E+00	1.71E+12	4.15E+00	6.76E+12
	109	5.58E-01	8.92E+11	2.21E+00	3.53E+12
	110	1.53E+00	2.46E+12	6.05E+00	9.72E+12
	111	3.08E-01	3.28E+11	1.22E+00	1.30E+12
	112	1.32E-01	1.41E+11	5.22E-01	5.56E+11
	113	2.97E+00	4.83E+12	1.17E+01	1.91E+13
	114	1.65E+00	2.63E+12	6.52E+00	1.04E+13

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Table 3.12 Summary of Wet Weather Storm Sewer Loads

Segment	Sub-watershed	Intermediate Condition		Wet Weather Condition	
		Flow (MGD)	*E. coli* Load (MPN/day)	Flow (MGD)	*E. coli* Load (MPN/day)
	115	1.86E+00	3.12E+12	7.34E+00	1.23E+13
	116	5.87E-01	9.31E+11	2.32E+00	3.68E+12
	117	6.59E-01	1.04E+12	2.60E+00	4.12E+12
	118	9.32E-01	1.48E+12	3.68E+00	5.86E+12
	119	1.09E+00	1.70E+12	4.30E+00	6.72E+12
	120	5.01E-01	7.86E+11	1.98E+00	3.10E+12
	121	9.76E-01	1.10E+12	3.86E+00	4.35E+12
	122	1.23E-01	1.31E+11	4.87E-01	5.18E+11
	123	3.95E-01	6.27E+11	1.56E+00	2.48E+12
	124	1.20E+00	1.93E+12	4.72E+00	7.62E+12
	125	1.50E+00	2.48E+12	5.93E+00	9.80E+12
	126	9.01E-01	1.37E+12	3.56E+00	5.42E+12
	127	3.35E-01	4.07E+11	1.32E+00	1.61E+12
	128	5.51E-01	7.47E+11	2.18E+00	2.95E+12
	129	1.43E-01	2.07E+11	5.64E-01	8.16E+11
	130	4.35E-01	6.31E+11	1.72E+00	2.49E+12
	131	5.57E-01	8.94E+11	2.20E+00	3.53E+12
	132	1.03E-01	1.10E+11	4.08E-01	4.35E+11
	133	2.80E+00	4.67E+12	1.11E+01	1.84E+13
	134	5.57E-01	7.68E+11	2.20E+00	3.04E+12
	135	1.60E+00	2.57E+12	6.32E+00	1.01E+13
	136	2.83E-01	4.82E+11	1.12E+00	1.90E+12
	137	2.93E-01	4.67E+11	1.16E+00	1.85E+12
	138	4.07E-01	6.41E+11	1.61E+00	2.53E+12
	139	3.79E-01	4.96E+11	1.50E+00	1.96E+12
	140	2.15E-01	3.01E+11	8.50E-01	1.19E+12
	141	1.49E+00	1.92E+12	5.87E+00	7.60E+12
	142	3.04E-02	3.25E+10	1.20E-01	1.29E+11
	143	1.64E+00	2.57E+12	6.48E+00	1.01E+13
	144	4.02E-01	4.39E+11	1.59E+00	1.73E+12
	145	1.18E+00	1.73E+12	4.65E+00	6.85E+12
	146	4.42E-01	7.33E+11	1.75E+00	2.89E+12
	147	2.86E-02	3.56E+10	1.13E-01	1.41E+11
	148	2.15E+00	3.40E+12	8.51E+00	1.34E+13
	149	3.44E-01	5.82E+11	1.36E+00	2.30E+12
	150	5.57E-01	8.64E+11	2.20E+00	3.42E+12
	151	6.67E-01	1.07E+12	2.64E+00	4.25E+12
	152	9.92E-01	1.68E+12	3.92E+00	6.63E+12
	153	8.74E-01	1.41E+12	3.45E+00	5.56E+12
	154	1.51E-01	2.52E+11	5.95E-01	9.96E+11
	155	4.50E-01	7.34E+11	1.78E+00	2.90E+12
	156	3.11E+00	4.97E+12	1.23E+01	1.97E+13
	171	1.24E+00	1.94E+12	4.89E+00	7.68E+12
	172	3.92E-01	5.84E+11	1.55E+00	2.31E+12

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Table 3.12 Summary of Wet Weather Storm Sewer Loads

Segment	Sub-watershed	Intermediate Condition		Wet Weather Condition	
		Flow (MGD)	*E. coli* Load (MPN/day)	Flow (MGD)	*E. coli* Load (MPN/day)
	173	5.78E-02	6.15E+10	2.28E-01	2.43E+11
	174	9.75E-02	1.64E+11	3.85E-01	6.49E+11
	175	1.83E-01	3.11E+11	7.24E-01	1.23E+12
	176	3.78E-01	5.93E+11	1.49E+00	2.34E+12
	177	9.06E-02	1.48E+11	3.58E-01	5.84E+11
	178	1.07E+00	1.55E+12	4.24E+00	6.13E+12
	180	9.84E-02	1.70E+11	3.89E-01	6.73E+11
	181	8.76E-01	1.42E+12	3.46E+00	5.60E+12
	182	1.88E-01	3.13E+11	7.44E-01	1.24E+12
	183	1.01E+00	1.67E+12	4.00E+00	6.61E+12
	184	2.34E-01	4.05E+11	9.25E-01	1.60E+12
	185	1.55E-01	2.61E+11	6.13E-01	1.03E+12
	186	8.99E-02	1.57E+11	3.55E-01	6.21E+11
	187	8.82E-02	1.14E+11	3.48E-01	4.49E+11
	188	2.40E-01	3.26E+11	9.50E-01	1.29E+12
	Watershed total	5.24E+01	8.19E+13	2.07E+02	3.24E+14
Whiteoak Bayou Above Tidal Watershed					
1017	1	2.42E+00	4.09E+12	3.54E+01	6.00E+13
	2	1.92E+00	3.29E+12	2.82E+01	4.82E+13
	3	8.43E-01	1.37E+12	1.24E+01	2.00E+13
	4	1.84E+00	3.04E+12	2.69E+01	4.45E+13
	7	4.19E-01	6.82E+11	6.14E+00	1.00E+13
	8	1.90E-01	3.10E+11	2.79E+00	4.54E+12
	9	6.57E-01	1.09E+12	9.63E+00	1.60E+13
	10	1.03E+00	1.69E+12	1.51E+01	2.48E+13
	11	3.79E-01	6.20E+11	5.56E+00	9.10E+12
	12	1.65E-01	2.67E+11	2.42E+00	3.91E+12
	13	4.99E-01	8.09E+11	7.32E+00	1.19E+13
	17	4.61E-01	7.57E+11	6.77E+00	1.11E+13
	40	4.01E-01	6.73E+11	5.88E+00	9.87E+12
	41	6.57E-01	1.12E+12	9.64E+00	1.65E+13
	42	6.66E-01	1.11E+12	9.76E+00	1.63E+13
	43	1.43E+00	2.44E+12	2.09E+01	3.58E+13
	Watershed total	1.40E+01	2.34E+13	2.05E+02	3.43E+14

Abbreviation:
MGD - million gallons per day
MPN - most probable number

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3.2 UNREGULATED SOURCES

In addition to the regulated point source discharges, there are also nonpoint sources of bacteria as well. These sources include on-site sewage facilities, direct deposition and sediment resuspension and will be discussed in the following sections.

3.2.1 ON-SITE SEWAGE FACILITIES

On-site sewage facilities (OSSFs), or septic systems, are a potential source of bacteria to the Buffalo and Whiteoak Bayou watersheds. When designed, installed and maintained properly, septic systems should not be a source of indicator bacteria to surface water. Studies examining septic systems as a source of indicator bacteria generally note that there is very little loading that might be expected from well operated facilities (Weiskel et al. 1996; Young and Thackston 1999). However, the US EPA considers improperly maintained septic systems to be one of the largest threats to groundwater in the nation (H-GAC 2005). In areas such as Houston where water tables are generally high and clay soils inhibit sewage infiltration, surface water pollution is a concern as well.

Harris County provided a database resulting from an inventory of open discharge of sewage effluent into road side ditches (database and comparison with 1990 Census data presented in **Appendix E**). These data were only evaluated to determine if failing septic systems were identified in subwatersheds entirely covered by municipal utility districts (MUDs). Failing septics located in subwatersheds more than 99% covered by MUDs were excluded and assumed to have been addressed by connecting to the MUD sanitary system. The MUD coverage map presented in **Figure 3.5**.

The number of septic systems for regions outside of Harris County were 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 $7.34x10^{-5}$ septic systems/acre. The failing septic system estimates by subwatershed are provided in **Table 3.13**. The reservoir subwatersheds have the largest number of failing septic systems, as would be expected since they are more rural in nature.

The flows and loads associated with failing septic systems were estimated using the assumptions presented in **Appendix E**.

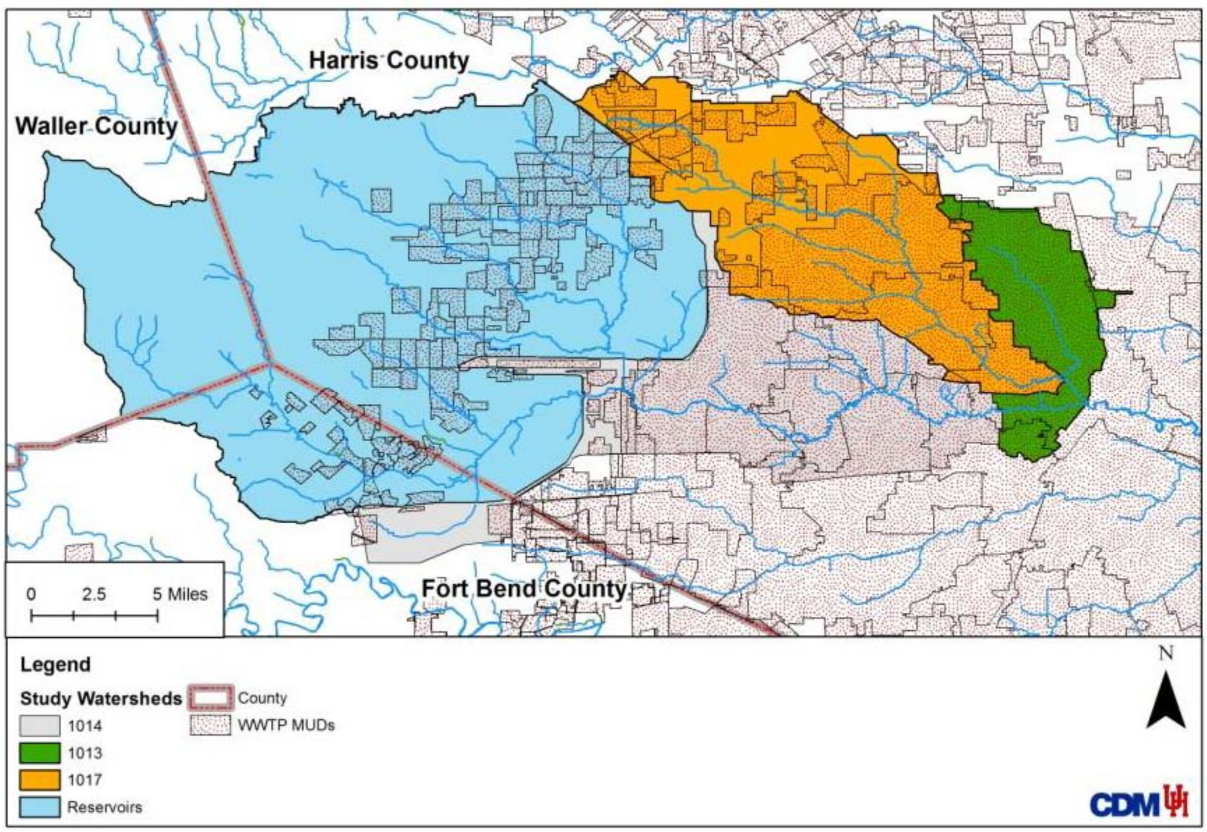

Figure 3.5 MUD Coverage Map

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Table 3.13 Number of Septic Systems in Buffalo and Whiteoak Bayous

Sub-watershed	Segment	No. failing septic systems
1	1017	2.00
2	1017	0.00
3	1017	0.00
4	1017	4.00
5	1013	0.00
6	1013	0.00
7	1017	0.00
8	1017	0.00
9	1017	0.00
10	1017	0.00
11	1017	0.00
12	1017	0.00
13	1017	0.00
17	1017	0.00
26	1014	0.00
27	1014	0.00
28	1014	0.00
33	1014	0.00
34	1014	0.00
35	1014	0.48
36	1013	0.00
37	1013	0.00
38	1013	0.00
39	1014	0.00
40	1017	0.00
41	1017	0.00
42	1017	0.00
43	1017	0.00
44	1014	0.00
45	1014	0.00
46	1013	0.00
47	1013	0.00
48	1013	0.00
49	1013	0.00
50	1014	0.00
51	1014	0.00
52	1014	0.00
53	1014	0.00
54	1014	0.00
55	1014	0.00
56	1014	0.00
101	Reservoir	0.00
102	Reservoir	0.00
117	Reservoir	0.00
118	Reservoir	5.00
119	Reservoir	0.00
120	Reservoir	0.00
121	Reservoir	0.00
122	Reservoir	0.00
123	Reservoir	0.00
124	Reservoir	0.00
125	Reservoir	0.00
126	Reservoir	0.00
127	Reservoir	0.00
128	Reservoir	0.03
129	Reservoir	0.00
130	Reservoir	0.00
131	Reservoir	0.00
132	Reservoir	0.05
133	Reservoir	0.01
134	Reservoir	0.02
135	Reservoir	0.10
136	Reservoir	0.78
137	Reservoir	0.06
138	Reservoir	0.33
139	Reservoir	0.35
140	Reservoir	0.00
141	Reservoir	0.00
142	Reservoir	1.00
143	Reservoir	0.00
144	Reservoir	0.00
145	Reservoir	0.00
146	Reservoir	0.00
147	Reservoir	0.00
148	Reservoir	0.00
149	Reservoir	0.07
150	Reservoir	0.05
151	Reservoir	0.21
152	Reservoir	0.00
153	Reservoir	0.00
154	Reservoir	0.00
155	Reservoir	0.00
156	Reservoir	0.00
171	Reservoir	0.00
172	Reservoir	0.00
173	Reservoir	0.00

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Table 3.13 Number of Septic Systems in Buffalo and Whiteoak Bayous

Sub-watershed	Segment	No. failing septic systems
103	Reservoir	1.00
104	Reservoir	0.00
105	Reservoir	4.00
106	Reservoir	0.00
107	Reservoir	0.00
108	Reservoir	1.00
109	Reservoir	0.00
110	Reservoir	0.00
111	Reservoir	0.00
112	Reservoir	0.00
113	Reservoir	0.00
114	Reservoir	0.00
115	Reservoir	0.00
116	Reservoir	0.00

Sub-watershed	Segment	No. failing septic systems
174	Reservoir	0.00
175	Reservoir	0.01
176	Reservoir	0.78
177	Reservoir	0.07
178	Reservoir	0.36
180	Reservoir	0.05
181	Reservoir	0.23
182	Reservoir	0.00
183	Reservoir	0.11
184	Reservoir	0.15
185	Reservoir	0.10
186	Reservoir	0.05
187	Reservoir	0.01
188	Reservoir	0.40

The amount of sewage from the septic system ultimately delivered to the stream was determined using subwatershed-specific delivery rate. The delivery rate was determined by locating the centroid of each zip code area in the watershed and calculating the perpendicular distance to the stream. The delivery ratios were assigned based upon distance from the stream as shown in **Figure 3.6**, with delivery rates doubling every 500 ft. The calculated delivery rates for each subwatershed are shown in **Table 3.14**.

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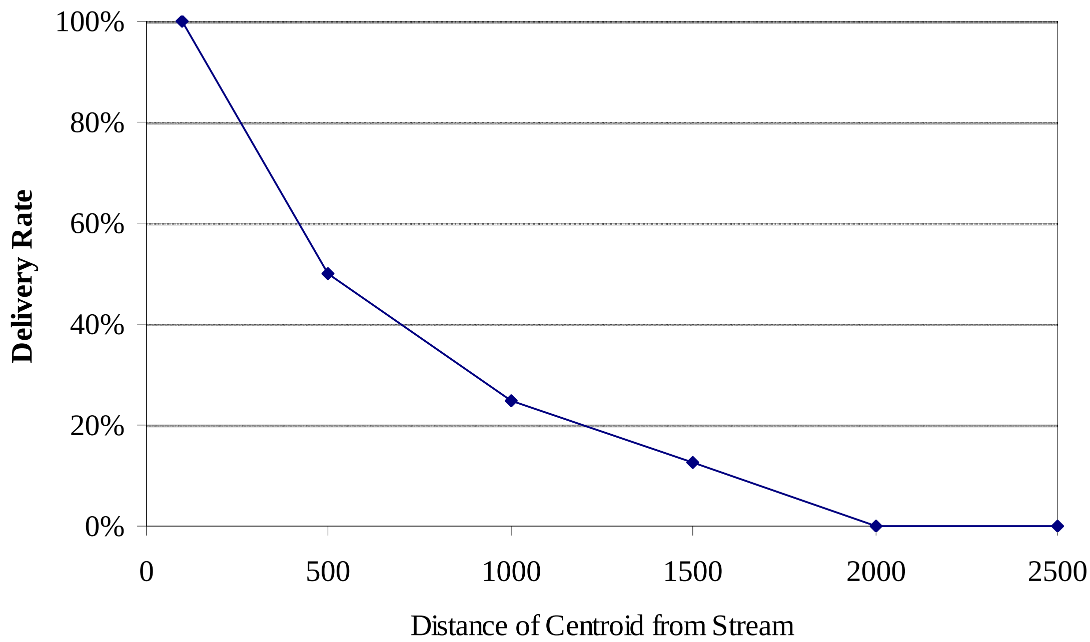

Figure 3.6 Relationship between Delivery Rate and Centroid Distance from Stream

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Table 3.14 Summary of Delivery Rates by Subwatershed

Subwatershed	Segment	Delivery Rate
1	1017	100%
2	1017	41%
3	1017	24%
4	1017	24%
5	1013	50%
6	1013	32%
7	1017	100%
8	1017	0%
9	1017	45%
10	1017	49%
11	1017	0%
12	1017	1%
13	1017	17%
17	1017	11%
26	1014	0%
27	1014	0%
28	1014	1%
33	1014	0%
34	1014	0%
35	1014	18%
36	1013	0%
37	1013	0%
38	1013	0%
39	1014	0%
40	1017	0%
41	1017	0%
42	1017	0%
43	1017	0%
44	1014	0%
45	1014	0%
46	1013	0%
47	1013	0%
48	1013	0%
49	1013	0%
50	1014	0%
51	1014	0%
52	1014	0%
53	1014	0%
54	1014	0%
55	1014	0%
56	1014	88%
101	Reservoir	1%
102	Reservoir	21%
103	Reservoir	0%
104	Reservoir	31%
105	Reservoir	50%

`

Table 3.14 Summary of Delivery Rates by Subwatershed

Subwatershed	Segment	Delivery Rate
106	Reservoir	13%
107	Reservoir	13%
108	Reservoir	50%
109	Reservoir	0%
110	Reservoir	25%
111	Reservoir	0%
112	Reservoir	33%
113	Reservoir	19%
114	Reservoir	0%
115	Reservoir	14%
116	Reservoir	5%
117	Reservoir	13%
118	Reservoir	13%
119	Reservoir	13%
120	Reservoir	1%
121	Reservoir	5%
122	Reservoir	1%
123	Reservoir	50%
124	Reservoir	50%
125	Reservoir	0%
126	Reservoir	0%
127	Reservoir	44%
128	Reservoir	0%
129	Reservoir	0%
130	Reservoir	0%
131	Reservoir	0%
132	Reservoir	0%
133	Reservoir	50%
134	Reservoir	0%
135	Reservoir	22%
136	Reservoir	45%
137	Reservoir	13%
138	Reservoir	50%
139	Reservoir	50%
140	Reservoir	0%
141	Reservoir	0%
142	Reservoir	0%
143	Reservoir	0%
144	Reservoir	0%
145	Reservoir	0%
146	Reservoir	15%
147	Reservoir	13%
148	Reservoir	29%
149	Reservoir	50%
150	Reservoir	13%
151	Reservoir	13%

`

Table 3.14 Summary of Delivery Rates by Subwatershed

Subwatershed	Segment	Delivery Rate
152	Reservoir	1%
153	Reservoir	4%
154	Reservoir	0%
155	Reservoir	13%
156	Reservoir	50%
171	Reservoir	0%
172	Reservoir	0%
173	Reservoir	0%
174	Reservoir	0%
175	Reservoir	0%
176	Reservoir	0%
177	Reservoir	0%
178	Reservoir	0%
180	Reservoir	13%
181	Reservoir	13%
182	Reservoir	0%
183	Reservoir	50%
184	Reservoir	0%
185	Reservoir	0%
186	Reservoir	0%
187	Reservoir	13%
188	Reservoir	25%

The flow and bacteria loads associated with failing septic systems are presented in **Table 3.15**. 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 give 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 give the bacteria load in MPN/day.

The watersheds with the highest overall septic loads are subwatersheds 1, located in Whiteoak Bayou, and 105, located in the reservoir watershed, with 7.06×10^{10} MPN/day.

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Table 3.15 Septic System Flow and Loading

Segment	Subwatershed	Flow (MGD)	*E. coli* (MPN/day)
Buffalo Bayou Tidal Watershed			
1013	5	0.00E+00	0.00E+00
	6	0.00E+00	0.00E+00
	36	0.00E+00	0.00E+00
	37	0.00E+00	0.00E+00
	38	0.00E+00	0.00E+00
	46	0.00E+00	0.00E+00
	47	0.00E+00	0.00E+00
	48	0.00E+00	0.00E+00
	49	0.00E+00	0.00E+00
	Watershed Total	0.00E+00	0.00E+00
Buffalo Bayou Above Tidal Watershed			
1014	26	0.00E+00	0.00E+00
	27	0.00E+00	0.00E+00
	28	0.00E+00	0.00E+00
	33	0.00E+00	0.00E+00
	34	0.00E+00	0.00E+00
	35	1.70E-05	3.07E+09
	39	0.00E+00	0.00E+00
	44	0.00E+00	0.00E+00
	45	0.00E+00	0.00E+00
	50	0.00E+00	0.00E+00
	51	0.00E+00	0.00E+00
	52	0.00E+00	0.00E+00
	53	0.00E+00	0.00E+00
	54	0.00E+00	0.00E+00
	55	0.00E+00	0.00E+00
	56	0.00E+00	0.00E+00
	Watershed Total	1.70E-05	3.07E+09
Whiteoak Bayou Above Tidal Watershed			
1017	1	3.91E-04	7.06E+10
	2	0.00E+00	0.00E+00
	3	0.00E+00	0.00E+00
	4	1.88E-04	3.40E+10
	7	0.00E+00	0.00E+00
	8	0.00E+00	0.00E+00
	9	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00
	12	0.00E+00	0.00E+00
	13	0.00E+00	0.00E+00
	17	0.00E+00	0.00E+00
	40	0.00E+00	0.00E+00

`

Table 3.15 Septic System Flow and Loading

Segment	Subwatershed	Flow (MGD)	*E. coli* (MPN/day)
	41	0.00E+00	0.00E+00
	42	0.00E+00	0.00E+00
	43	0.00E+00	0.00E+00
	Watershed Total	5.79E-04	1.05E+11
Addicks and Barker Reservoir Watersheds			
Reservoir	101	0.00E+00	0.00E+00
	102	0.00E+00	0.00E+00
	103	0.00E+00	0.00E+00
	104	0.00E+00	0.00E+00
	105	3.91E-04	7.06E+10
	106	0.00E+00	0.00E+00
	107	0.00E+00	0.00E+00
	108	9.77E-05	1.77E+10
	109	0.00E+00	0.00E+00
	110	0.00E+00	0.00E+00
	111	0.00E+00	0.00E+00
	112	0.00E+00	0.00E+00
	113	0.00E+00	0.00E+00
	114	0.00E+00	0.00E+00
	115	0.00E+00	0.00E+00
	116	0.00E+00	0.00E+00
	117	0.00E+00	0.00E+00
	118	1.22E-04	2.21E+10
	119	0.00E+00	0.00E+00
	120	0.00E+00	0.00E+00
	121	0.00E+00	0.00E+00
	122	0.00E+00	0.00E+00
	123	0.00E+00	0.00E+00
	124	0.00E+00	0.00E+00
	125	0.00E+00	0.00E+00
	126	0.00E+00	0.00E+00
	127	0.00E+00	0.00E+00
	128	0.00E+00	0.00E+00
	129	0.00E+00	0.00E+00
	130	0.00E+00	0.00E+00
	131	0.00E+00	0.00E+00
	132	0.00E+00	0.00E+00
	133	1.21E-06	2.18E+08
	134	0.00E+00	0.00E+00
	135	4.46E-06	8.07E+08
	136	6.81E-05	1.23E+10
	137	1.43E-06	2.58E+08
	138	3.23E-05	5.84E+09
	139	3.44E-05	6.21E+09
	140	0.00E+00	0.00E+00

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Table 3.15 Septic System Flow and Loading

Segment	Subwatershed	Flow (MGD)	*E. coli* (MPN/day)
	141	0.00E+00	0.00E+00
	142	0.00E+00	0.00E+00
	143	0.00E+00	0.00E+00
	144	0.00E+00	0.00E+00
	145	0.00E+00	0.00E+00
	146	2.32E-08	4.19E+06
	147	0.00E+00	0.00E+00
	148	0.00E+00	0.00E+00
	149	6.35E-06	1.15E+09
	150	1.29E-06	2.33E+08
	151	5.17E-06	9.35E+08
	152	0.00E+00	0.00E+00
	153	0.00E+00	0.00E+00
	154	0.00E+00	0.00E+00
	155	0.00E+00	0.00E+00
	156	0.00E+00	0.00E+00
	171	0.00E+00	0.00E+00
	172	0.00E+00	0.00E+00
	173	0.00E+00	0.00E+00
	174	0.00E+00	0.00E+00
	175	0.00E+00	0.00E+00
	176	0.00E+00	0.00E+00
	177	0.00E+00	0.00E+00
	178	0.00E+00	0.00E+00
	180	1.10E-06	1.99E+08
	181	5.71E-06	1.03E+09
	182	0.00E+00	0.00E+00
	183	1.03E-05	1.87E+09
	184	0.00E+00	0.00E+00
	185	0.00E+00	0.00E+00
	186	0.00E+00	0.00E+00
	187	3.65E-07	6.59E+07
	188	1.97E-05	3.56E+09
	Watershed Total	8.02E-04	1.45E+11

Abbreviations:
MGD - million gallons per day
MPN - most probable number

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3.2.2 DIRECT DEPOSITION WILDLIFE CONTRIBUTIONS

The bayou and its surrounding area provide a good habitat for many different types of wildlife, such as water fowl, raccoon, and other mammals. The estimated animal population and potential bacteria loads associated with direct deposition into the bayou will be discussed in this section. Direct deposition in this TMDL only accounts for loading into the bayous directly, or within a very small buffer area along the streams. Any loading deposited on the watershed will be carried via runoff to the bayous during rainfall events and accounted for in the regulated stormwater discharge portion of the load estimate presented in **Section 3.1.5.**

The following sections describe the direct deposition loading from waterfowl and mammals included in this study.

3.2.2.1 WATERFOWL

Waterfowl densities for several waterfowl species, including the White Ibis, White-Faced Ibis, Great Blue Heron, Great Egret, and Neotropic Cormorant, were estimated using the reference *Birds of North America*. For species without population densities, their population density was estimated as the average of the known population densities. The percentage contribution from the waterfowl was assumed to be 50%, based upon the assumption that the birds nest and sleep 50% of the time away from the stream. Reported estimates are provided in **Table 3.16**, along with estimated population densities other species of waterfowl known to inhabit the watershed.

Loading from waterfowl were estimated using fecal bacteria production rates specified in the literature. The value used for calculations was 1.05×10^8 MPN/day.

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Table 3.16 Waterfowl and their Estimated Population Densities

Species of waterfowl	Population Density (pairs/acre)	Percent Contribution
American Pigeon	2.94E-04	50%
Barn Swallow	2.94E-04	50%
Black Bellied Whistling	2.94E-04	50%
Black-crowned Night Heron	2.94E-04	50%
Blue winged teal	2.94E-04	50%
Blue-gray Gnatcatcher	2.94E-04	50%
Cackling Goose	2.94E-04	50%
Canada Goose	2.94E-04	50%
Canvasback	2.94E-04	50%
cinnamon teal	2.94E-04	50%
Double-crested cormorant	2.94E-04	50%
Duck	2.94E-04	50%
Fulvours Whistling Duck	2.94E-04	50%
Gadwall	2.94E-04	50%
Golden-crowned kinglet	2.94E-04	50%
Great Blue Heron	8.27E-04	50%
Great Egret	6.08E-04	50%
Green Heron	2.94E-04	50%
Gree-w8inged Teal	2.94E-04	50%
Hooded Merganser	2.94E-04	50%
Lesser Grebe	2.94E-04	50%
Lesser Scaup	2.94E-04	50%
Little Blue Heron	2.94E-04	50%
Mallard	2.94E-04	50%
Mottled Duck	2.94E-04	50%
Neotropic Cormorant	5.69E-05	50%
Northern Pintail	2.94E-04	50%
Northern shoveler	2.94E-04	50%
Pled-billed Grebe	2.94E-04	50%
Redhead	2.94E-04	50%
Ring-necked Duck	2.94E-04	50%
Roseate Spoonbill	3.25E-05	50%
Ross's Goose	2.94E-04	50%
Ruby-crowned kinglet	2.94E-04	50%
Snow Goose	2.94E-04	50%
Tricolored Heron	2.94E-04	50%
White Ibis	2.81E-05	50%
White-faced Ibis	2.15E-04	50%
Wood Duck	2.94E-04	50%
Yellow Crowned Night Heron	2.94E-04	50%
Yellow-crowned Night Heron	2.94E-04	50%

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3.2.2.2 BRIDGE CROSSINGS

Bridge crossings over major tributaries that provide roosting places feral rock doves nest were also included in the model as a source of direct deposition. Observations suggested that the birds only roosted on bridge supports that run parallel to the bayou (see **Figure 3.7**). Therefore, bridge locations were determined using data exported from the TSARP HEC-RAS models (presented in **Appendix F**); bridges included in this analysis were limited to those 50 ft in width or greater as smaller bridges have support systems that appear to prevent roosting directly over the bayou. Therefore, for narrow sections of the bayou (i.e., Whiteoak Bayou and

Figure 3.7 Photograph of Feral Rock Doves Roosting and Nesting Under Bridge (Photo courtesy of Linda D. Pechacek, P.E.)

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the reservoir watershed in Upper Buffalo Bayou) it was assumed that two supports might be located close enough to the bayou for the birds to contribute 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 doves were assumed to roost with 1 foot 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 the feral rock doves was estimated using the same *E. coli* production value as for waterfowl. The loading was calculated as multiplication of 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.

3.2.2.3 MAMMALS

In addition to birds and waterfowl contributions to direct deposition in the bayou, an estimate of mammals that might be found near the water was also 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/stream buffer acre based upon 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 United States, and using these data coupled with watershed-specific population, housing size and area as shown in **Appendix F**, 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.

Loading for these animals was estimated using fecal bacteria deposition rates reported in the literature. Detailed discussion on loading estimates is presented in **Appendix F**. The value used for calculations was 2.03 x 10^9 MPN/day. It was assumed that mammals would spend only 5% of their time in or very near to the bayou.

3.2.2.4 LOADING CALCULATIONS

Direct deposition load was calculated as the multiplication of stream length, stream width, mammal or waterfowl density, and fecal production rate to yield the mammalian direct deposition loading in MPN/day. Pigeon contributions were added to this total. The stream length was measured from GIS layers while stream width estimated by segment from digital elevation model (DEM) files. In addition, a small buffer (10 ft) was included on either side of the stream and included as part of the zone of potential direct deposition.

The bacteria loads associated with direct deposition are presented in **Table 3.17**. The loads presented in the table are the sum of direct deposition from waterfowl, feral rock doves and mammals. The watershed with the highest overall direct deposition load is in subwatershed 26 with a load of 1.90 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 bacteria is subwatershed 105, located in the reservoir watersheds.

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Table 3.17 Calculated Loads from Direct Deposition

Segment	Subwatershed	*E. coli* Load (MPN/day)
Buffalo Bayou Tidal Watershed		
1013	5	6.02E+09
	6	5.20E+09
	36	6.72E+09
	37	1.07E+10
	38	4.36E+09
	46	5.67E+09
	47	1.25E+10
	48	8.75E+09
	49	5.50E+09
	Watershed Total	6.55E+10
Buffalo Bayou Above Tidal Watershed		
1014	26	2.47E+10
	27	1.29E+10
	28	3.29E+09
	33	2.09E+10
	34	3.79E+09
	35	4.37E+09
	39	1.69E+10
	44	1.63E+09
	45	1.33E+10
	50	8.56E+09
	51	2.06E+09
	52	2.21E+10
	53	1.27E+10
	54	1.13E+10
	55	6.05E+09
	56	6.62E+09
	Watershed Total	1.71E+11
Addicks and Barker Reservoir Watershed		
Reservoir	101	6.23E+09
	102	2.25E+09
	103	2.59E+09
	104	7.37E+09
	105	3.75E+08
	106	9.33E+09
	107	7.35E+09
	108	7.52E+09
	109	1.34E+09
	110	8.64E+09
	111	5.81E+09
	112	4.27E+09

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Table 3.17 Calculated Loads from Direct Deposition

Segment	Subwatershed	*E. coli* Load (MPN/day)
	113	9.84E+09
	114	2.58E+09
	115	3.65E+09
	116	5.34E+08
	117	7.64E+09
	118	8.07E+09
	119	1.16E+10
	120	6.65E+09
	121	7.00E+09
	122	1.05E+09
	123	1.89E+09
	124	2.63E+09
	125	3.77E+09
	126	1.07E+09
	127	1.52E+10
	128	5.30E+09
	129	3.79E+09
	130	7.90E+09
	131	4.96E+09
	132	7.25E+09
	133	2.56E+09
	134	3.72E+09
	135	7.71E+09
	136	2.67E+09
	137	3.07E+09
	138	5.71E+09
	139	2.55E+09
	140	1.25E+09
	141	7.25E+09
	142	5.75E+09
	143	1.43E+10
	144	1.18E+10
	145	7.23E+09
	146	2.49E+09
	147	1.46E+09
	148	4.52E+09
	149	5.75E+09
	150	5.34E+09
	151	1.30E+09
	152	7.70E+09
	153	4.82E+09
	154	9.03E+09

`

Table 3.17 Calculated Loads from Direct Deposition

Segment	Subwatershed	*E. coli* Load (MPN/day)
	155	2.94E+09
	156	2.38E+09
	171	6.76E+09
	172	4.15E+09
	173	4.27E+09
	174	3.48E+09
	175	2.89E+09
	176	6.88E+09
	177	2.04E+09
	178	1.06E+10
	180	6.72E+08
	181	4.29E+09
	182	1.73E+09
	183	1.53E+09
	184	7.31E+08
	185	3.37E+09
	186	4.94E+08
	187	3.95E+08
	188	1.25E+10
	Watershed Total	3.66E+11
Whiteoak Bayou Above Tidal Watershed		
1017	1	1.87E+10
	2	1.72E+10
	3	5.53E+09
	4	1.68E+10
	7	8.89E+09
	8	3.20E+09
	9	9.32E+09
	10	6.36E+09
	11	2.90E+09
	12	3.08E+09
	13	6.57E+09
	17	7.40E+09
	40	6.65E+09
	41	7.84E+09
	42	3.89E+09
	43	7.29E+09
	Watershed Total	1.32E+11

Abbreviation:
MPN - most probable number

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3.2.3 SEDIMENT RESUSPENSION

Sediment on stream beds is resuspended when shear stress exerted on the stream bed exceeds the critical shear stress for incipient motion. Factors influencing the bed shear stress include the density of sediment particles, the diameter of sediment particles, and the consolidation of the stream bed. Based on work conducted by Hjulstrom in 1935, typical velocities that cause stream bed erosion exceed 2.95 ft/s for clay-sized (d < 0.004 mm) particles. This TMDL project has undertaken several sediment studies as shown in **Appendix G** and their studies show that many areas of the bayou exhibit high concentrations of *E. coli* in the sediments. Scouring results in stream sediment with associated bacteria being resuspended and thus contributing to the overlying water concentrations of *E. coli*.

Sediment resuspension can be determined using a transient water quality/sediment model or using a basic approach to determine the amount of time resuspension would be expected based on the Hjulstrom velocity criterion. It is important to note that this approach is intended to give an approximate rate of flow, as flow and velocity are not related in a one-to-one fashion.

Velocity data were obtained from data reported by the USGS collected to support the confirmation and update of stage-discharge rating curves at flow gauging locations (velocity data and plots of flow measurements are presented in **Appendix G**) and approximate flow when velocities were near 2.95 ft/s were estimated as shown in **Table 3.18** as well as the percentage of the time that resuspension is expected to occur during wet weather. These data suggest that sediment resuspension would only occur during high flow conditions. In the concrete lined portions of Whiteoak Bayou, velocities are higher than 2.95 ft/s more than 50% of the time and thus sediment build-up and resuspension would be minimal.

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

By multiplying the occurrence of resuspension flows, the average sediment scour rate, and estimates of bayou width and stream lengths, the resuspension *E. coli* load was calculated as shown in **Table 3.18**. As the 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 while the subwatershed with the smallest non-zero contribution is subwatershed 45, with a loading of 1.29 x 10^{10} MPN/day.

Table 3.18 Occurrence of Shear Velocities

Segment	Bayou	Stream Bed Type	Occurrence of Resuspension On Wet Days
1017	Whiteoak	Concrete	[1]
1017	Whiteoak	Earthen	7%
1013	Buffalo	Earthen	1%
1014	Buffalo	Earthen	1%
Reservoirs	Buffalo	Earthen	7%

Note:
[1] In the concrete lined portions of Whiteoak Bayou, velocities are higher than 2.95 ft/s more than 50% of the time and thus sediment build-up and resuspension would be minimal.

Abbreviations:
cfs – cubic feet per second
USGS – United States Geological Survey

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Table 3.19 Calculated *E. coli* Loads from Resuspension

Segment	Sub-watershed	Resuspension Loads (MPN/day)
Buffalo Bayou Tidal Watershed		
1013	5	4.84E+11
	6	5.44E+11
	36	1.21E+11
	37	1.21E+11
	38	1.04E+11
	46	1.62E+11
	47	1.15E+11
	48	2.10E+11
	49	2.42E+11
	Watershed Total	2.10E+12
Buffalo Bayou Above Tidal Watershed		
1014	26	4.77E+11
	27	3.92E+11
	28	1.45E+11
	33	3.93E+11
	34	1.67E+11
	35	1.74E+10
	39	3.94E+11
	44	7.19E+10
	45	4.99E+11
	50	2.02E+11
	51	9.05E+10
	52	3.60E+11
	53	4.73E+11
	54	3.22E+11
	55	1.79E+11
	56	2.90E+10
	Watershed Total	4.21E+12
Addicks and Barker Reservoir Watershed		
Reservoir	101	2.03E+12
	102	7.35E+11
	103	8.44E+11
	104	1.97E+12
	105	1.22E+11
	106	3.04E+12
	107	2.40E+12
	108	2.24E+12
	109	4.38E+11
	110	2.38E+12
	111	1.89E+12
	112	1.39E+12
	113	2.78E+12
	114	6.25E+11
	115	9.73E+11

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Table 3.20 Calculated *E. coli* Loads from Resuspension

Segment	Sub-watershed	Resuspension Loads (MPN/day)
	116	1.74E+11
	117	2.27E+12
	118	2.42E+12
	119	3.13E+12
	120	1.95E+12
	121	2.28E+12
	122	3.42E+11
	123	4.00E+11
	124	8.57E+11
	125	1.23E+12
	126	3.48E+11
	127	4.96E+12
	128	1.73E+12
	129	1.24E+12
	130	2.58E+12
	131	1.62E+12
	132	2.37E+12
	133	1.87E+11
	134	7.80E+11
	135	2.08E+12
	136	8.70E+11
	137	7.86E+11
	138	1.86E+12
	139	8.31E+11
	140	4.06E+11
	141	2.37E+12
	142	1.88E+12
	143	4.68E+12
	144	3.86E+12
	145	2.36E+12
	146	8.12E+11
	147	4.77E+11
	148	1.26E+12
	149	1.01E+12
	150	1.31E+12
	151	4.25E+11
	152	1.86E+12
	153	1.57E+12
	154	2.95E+12
	155	9.60E+11
	156	5.61E+11
	171	2.20E+12
	172	9.22E+11
	173	1.39E+12
	174	1.13E+12

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Table 3.21 Calculated *E. coli* Loads from Resuspension

Segment	Sub-watershed	Resuspension Loads (MPN/day)
	175	9.41E+11
	176	2.24E+12
	177	6.64E+11
	178	3.45E+12
	180	2.19E+11
	181	1.40E+12
	182	3.48E+11
	183	2.84E+11
	184	2.38E+11
	185	8.83E+11
	186	1.61E+11
	187	1.29E+11
	188	4.06E+12
	Watershed Total	1.11E+14
Whiteoak Bayou Above Tidal Watershed		
1017	1	1.37E+12
	2	1.59E+12
	3	0.00E+00
	4	1.22E+12
	7	5.89E+11
	8	3.84E+11
	9	9.58E+11
	10	5.23E+11
	11	2.68E+11
	12	3.69E+11
	13	4.70E+11
	17	5.70E+11
	40	0.00E+00
	41	0.00E+00
	42	0.00E+00
	43	0.00E+00
	Watershed Total	8.30E+12

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3.2.4 BACTERIA REGROWTH AND DIE-OFF

Die-off of bacteria has been well-studied in both laboratory and in-situ studies. Bacteria die-off is typically influenced by physical conditions, such as the presence of ultraviolet light, salinity and temperature. Bacteria regrowth has also been noted to occur, especially with regard to wastewater treatment plant discharges. For this TMDL, studies were conducted to examine regrowth and die-off as presented in **Appendix H**. These studies examined in-situ *E. coli* dynamics and determined that although regrowth might occur, the net result of all dynamic bacteria processes is die-off, with an average rate of 1.5 per day.

3.2.5 UPSTREAM LOADS

Segments 1014 and 1013 have upstream loads that must be included in the load allocation calculation. The upstream loads are simply the load from the upstream segment added to the total load for a given downstream segment. Loads from the reservoir watersheds are added to Segment 1014, and loads from Segment 1014 are included in the total load for Segment 1013.

CHAPTER 4 : LINKAGE OF SOURCES AND RECEIVING WATER

In this TMDL, three different approaches were developed to determine load allocations. These three approaches, load duration curves, the bacteria load estimator spreadsheet tool and a water quality model in HSPF, are described in this section.

4.1 LOAD DURATION CURVES

Load duration curves (LDCs) are a method for characterizing water quality data at different flow regimes and the ability to evaluate dynamic systems, unlike a mass balance approach where the waterbody is evaluated under steady state conditions. This section describes the data used to develop load duration curves as well how the TMDL was calculated.

4.1.1 FLOW DURATION CURVES

The first step in the preparation of LDCs is the development of flow duration curves. Flows were estimated at segment boundaries using daily USGS flows data for the period from January 1, 2001 through September 30, 2003. **Figure 4.1** shows the flow duration curves for all evaluated USGS gauges. These curves present the fraction of flow that exceed a given flow at each gauge. Flows in the bayous ranged from 0.2 cfs at gauge 08072730 to over 19,000 at gauge 08074500. It is important to note that flow duration curves were not prepared for stations with only stage data and for partial flow record stations, such as gauge 08074000.

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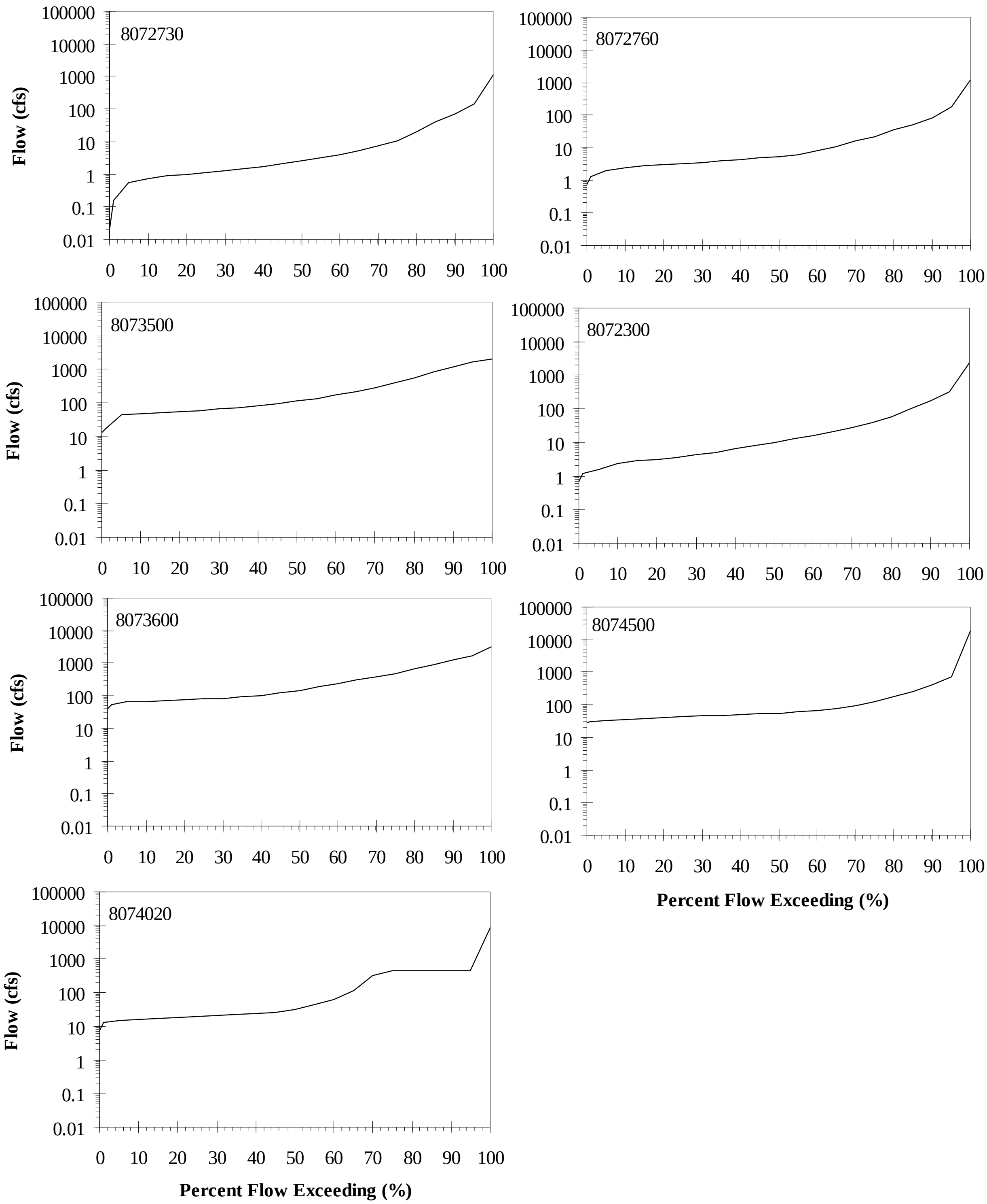

Figure 4.1 Flow Duration Curves for Buffalo and Whiteoak Bayous

4.1.2 BACTERIA DATA

Bacteria data are required to develop LDCs, in addition to flow data. **Figure 4.2** presents the locations of the USGS and TCEQ bacteria monitoring stations used to develop the LDCs. Because some flow gauges did not have co-located bacteria sampling stations, the closest sampling site to the flow gauge was used in the LDC calculations.

Data collected by the TCEQ during routine monitoring from January 1, 2001 through September 30, 2003 were used to develop the LDCs. These data are presented in **Figure 4.3** and demonstrate the wide range in concentrations observed in the bayous. As there was only one data point collected for station 11155, this station was excluded from LDC development.

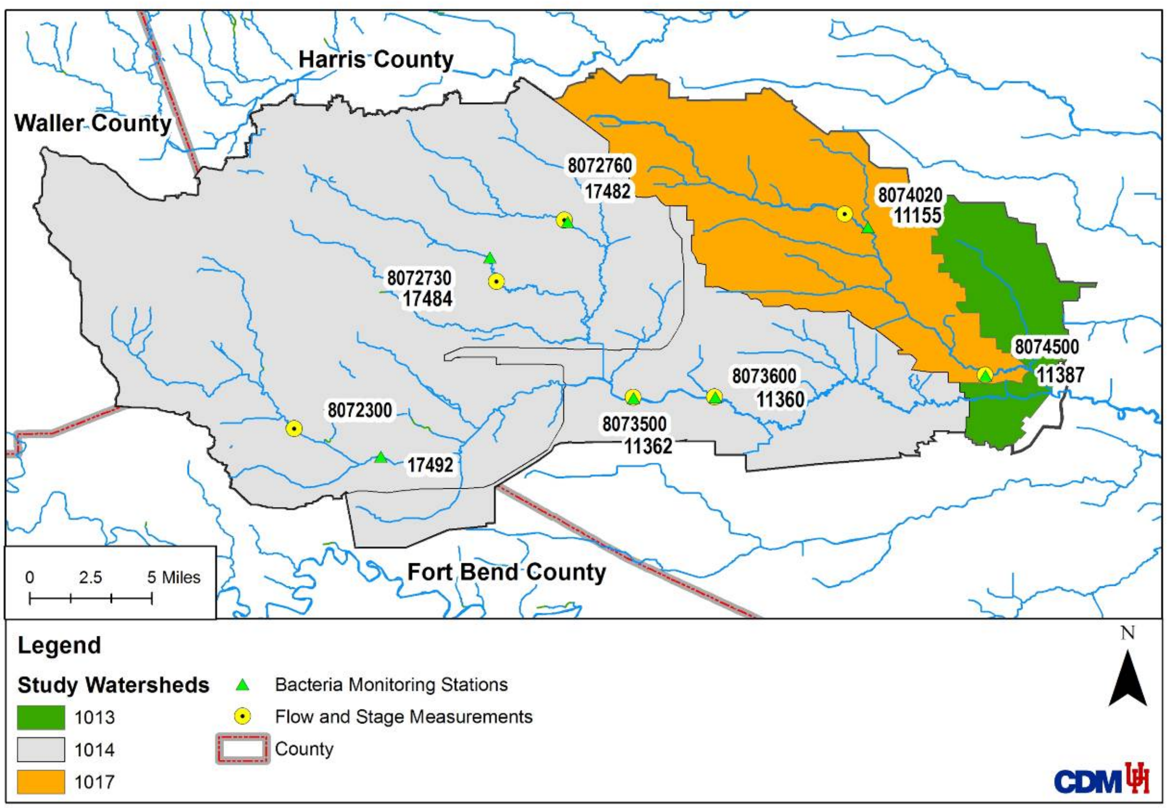

Figure 4.2 Location of Bacteria and USGS Stations Used for LDC Development
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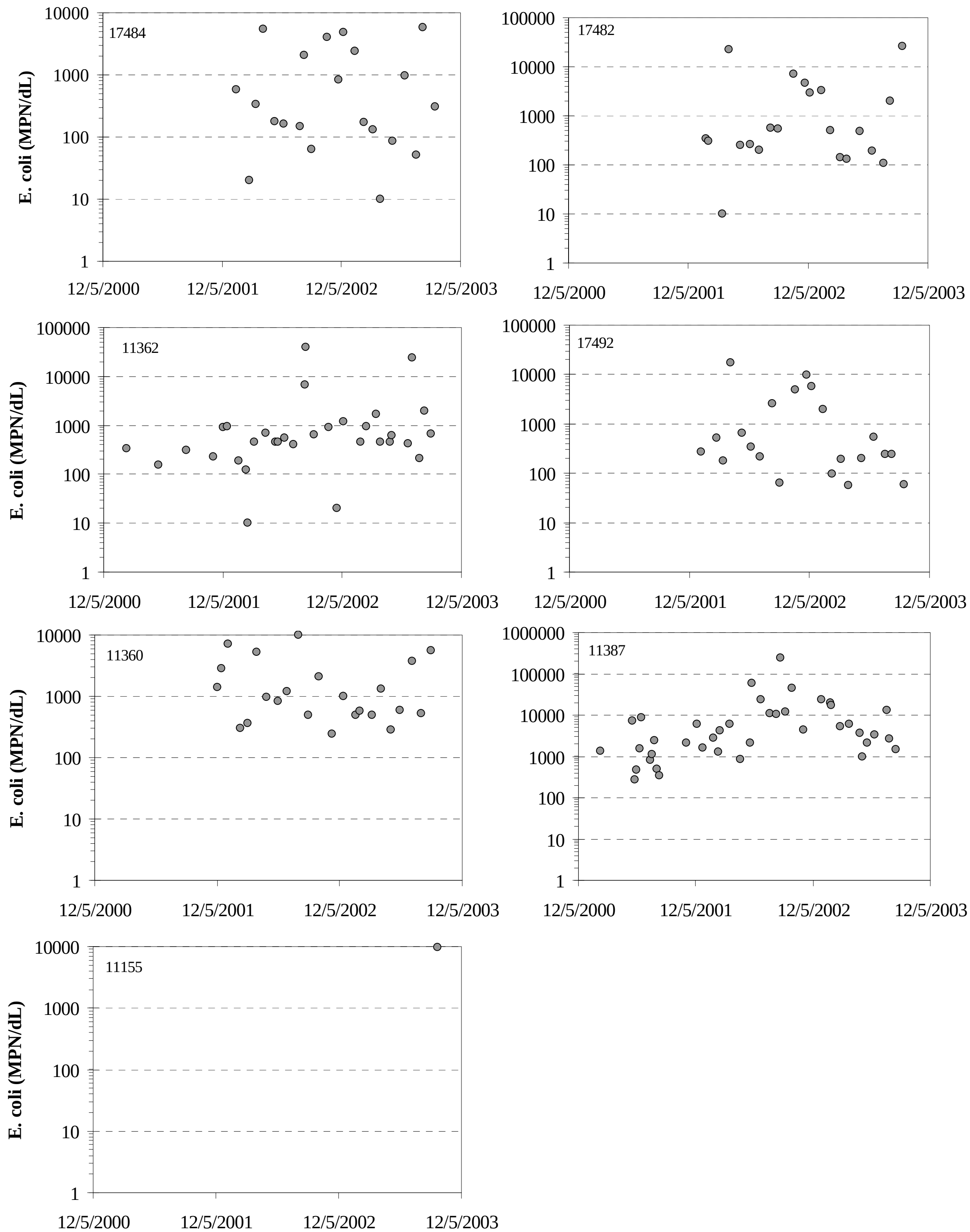

Figure 4.3 Bacteria Data Used to Develop LDCs

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4.1.3 LOAD DURATION CURVES

LDCs are similar to flow duration curves, but they present the percentage of days that the bacteria load is exceeded instead of the percent of days that the flow is exceeded. To develop the LDC, bacteria data were first joined with their respective daily flows in a database and the calculated daily loads were plotted on the LDC (shown as triangles). In addition, the flow duration curves presented in Figure 4.1 were used to calculate the TMDL over the range of bayou flows by multiplying the daily flow times the single sample water quality standard of 394 MPN/dL. The developed LDCs are presented in **Figure 4.4**.

Three flow regimes were classified on the load duration curve, with dry condition flows being defined as between the 0^{th} and 30^{th} percentiles, intermediate conditions between the 30^{th} and 70^{th} percentiles and the wet condition defined as the 70^{th} percentile or higher. The median of the observed loads were calculated for each of the three flow regimes and plotted on **Figure 4.4** as a red line.

As can be seen, 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 than exceedances of the TMDL below the reservoir (i.e., 11362 and 11360). Exceedances of the TMDL in Whiteoak Bayou (i.e., 11387) are similar in magnitude to Buffalo Bayou.

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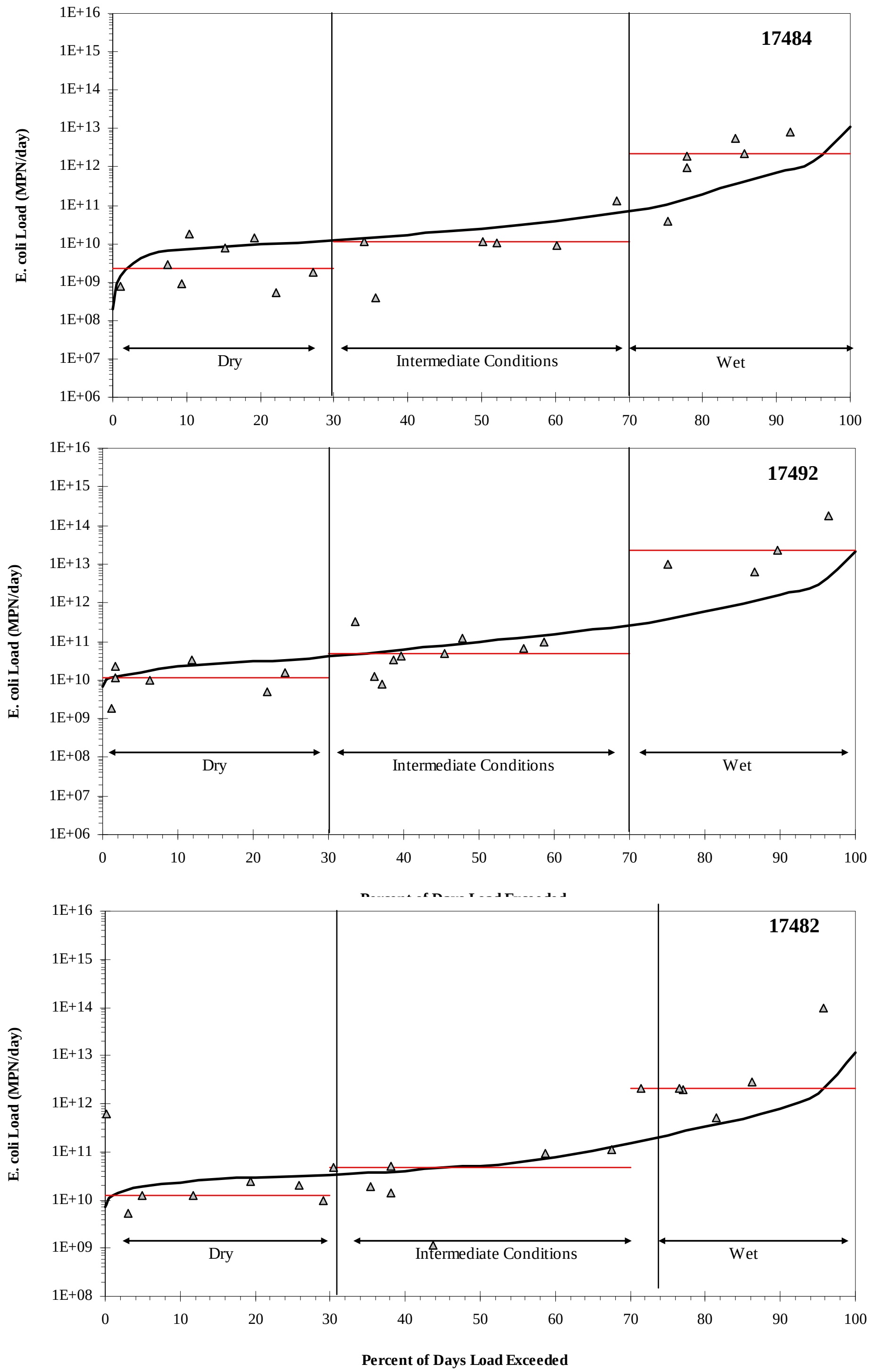

Figure 4.4 Load Duration Curves

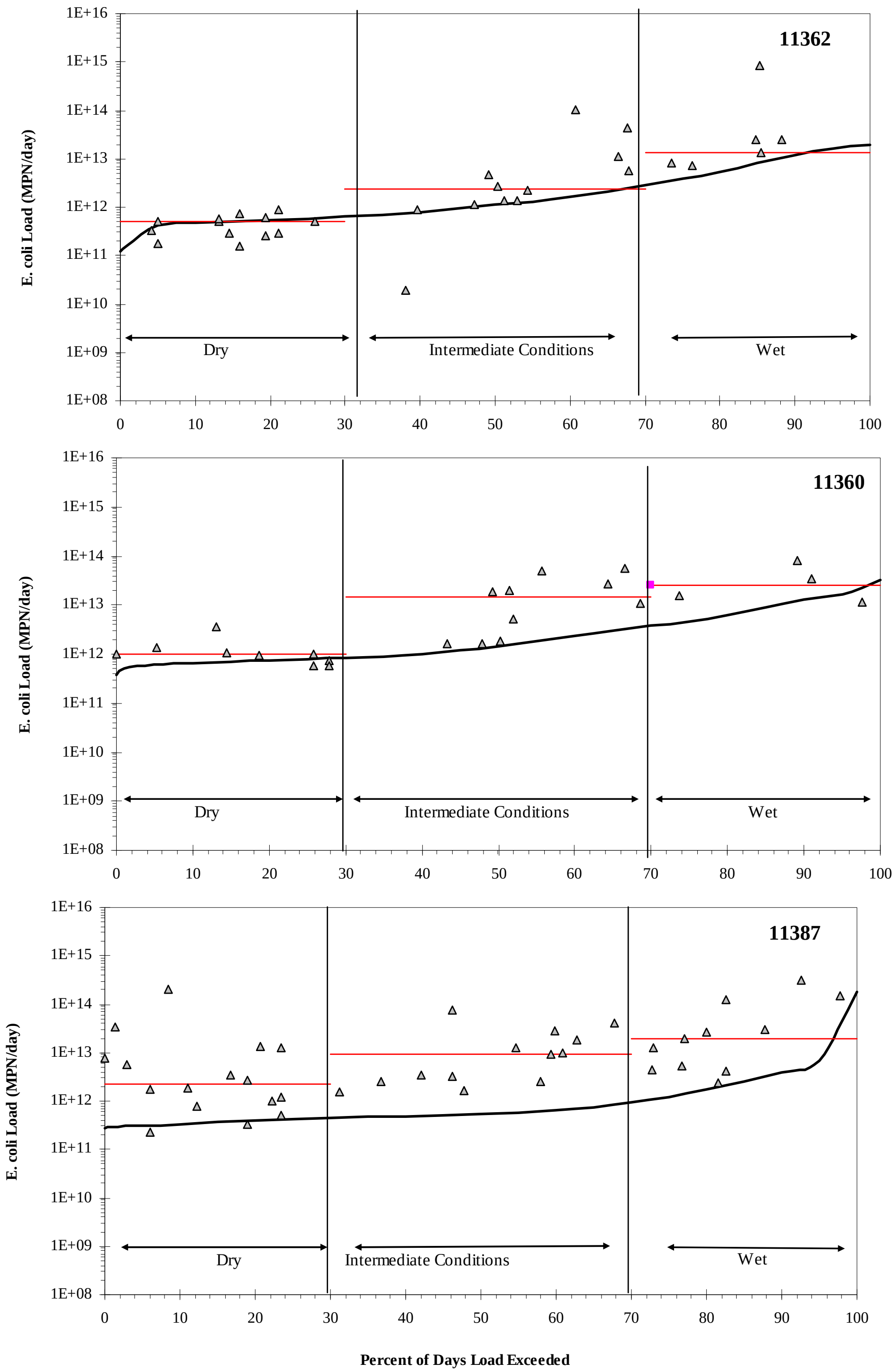

Figure 4.4 Load Duration Curves, Continued

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4.2 BACTERIA LOAD ESTIMATOR SPREADSHEET TOOL

The Bacteria Load Estimator Spreadsheet Tool (BLEST) was developed to determine bacteria loads on a segment by segment basis for Buffalo and Whiteoak bayous. This tool is designed to calculate or estimate the bacteria load reductions for each segment needed to attain the water quality standard for the segment. BLEST does not incorporate the temporal variations associated with pathogen loads, but only examines a typical day in time based upon a fixed time interval. Unlike LDCs, however, BLEST allows an evaluation of loads on a subbasin basis.

4.2.1 BLEST SET-UP

The bacteria sources included in BLEST are divided into the waste load allocation (point sources), the load allocations (nonpoint sources), and the upstream load. The waste load allocation sources include:

1. Wastewater treatment plant discharges;
2. Sanitary sewer overflows; and
3. Municipal separate storm sewer system (MS4) dry and wet discharges.

Sources included in the load allocation include the following:

1. Septic system discharges;
2. Sediment resuspension from the stream bed;
3. Nonpoint source direct input to the bayou (via birds, wildlife and other non-managed animals); and
4. Net die-off, settling and other unaccounted processes.

The loads for the three different conditions were determined using data collected for this

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project and described previously in this document. When actual data were not available, literature values were used to calculate bacteria loading instead. The data used to develop bacteria loads in BLEST have been previously described in Chapter 3.

BLEST evaluates bacteria loading under dry, intermediate and wet conditions. As previously described, dry conditions are representative of extended dry weather periods where bayou flow is mainly wastewater discharge, wet weather conditions are representative of stream conditions caused by rainfall events and intermediate conditions are representative of a mixed flow regime of wastewater discharge and rainfall runoff.

Some 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 MS4 discharge loads, on the other hand, are expected during periods of high flow that might follow a large runoff event. Finally, WWTP 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.

The calculations performed for wasteload and load allocations will be presented in **Chapter 5**, along with a required percent reductions for these loads. This following sections provide a summary of these loads for each segment.

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4.2.2 RESERVOIR WATERSHED SEGMENTS

In the reservoir segments, the total in-stream load estimated from sources acting under dry weather was 1,331.22 billion MPN/day, as shown in **Table 4.1**. The TMDL target, also the same as the contact recreational target, is calculated as the estimated flow multiplied by the water quality standard, is 98.16 billion MPN/day, about an order of magnitude less than the load estimated in the stream. The dry weather total load reflects the sum of dry weather WWTP discharges, SSOs, dry weather storm sewer flows, OSSFs, direct deposition as well as losses associated with die-off, settling and other unaccounted processes. The majority of the *E. coli* loading in this segment under dry weather conditions stems from WWTP discharges. As the reservoir watersheds are the headwaters of Buffalo Bayou, there are no upstream sources of 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, direct deposition loads as well as losses associated with die-off, settling and other unaccounted 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 upon the flow duration curve, the total estimated bacteria load was 98,225.36 billion MPN/day while the TMDL target was calculated to be 1,096.73 billion MPN/day. The sources acting under wet weather include wastewater treatment plans, which are assumed to have increased

Table 4.1 BLEST Output for Reservoir Watersheds Segment

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
WWTPs						
WWTP Discharges	20.58	5,438.79	21.64	5,719.04	21.64	5,719.04
WWTP 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 Sewer 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/dL)	20.58	98.16	74.03	353.08	229.94	1,096.73
TMDL Target	-	98.16	-	353.08	-	1,096.73

Abbreviations: MGD = million gallons per day, MPN = most probable number, MS4 = municipal separate storm sewer system, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTP = wastewater treatment plant

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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, is the largest contributor to bacteria loading in the reservoir watersheds.

4.2.3 SEGMENT 1014

The BLEST output for Segment 1014, shown here in **Table 4.2**, is calculated similarly to the output presented for the reservoir watershed segments. The one primary difference between the two segments is that Segment 1014 reflects the influence of upstream inputs from the reservoir watersheds, included in the Upstream Sources block of the BLEST output.

Under dry weather conditions, bacteria loading for Segment 1014 was estimated to be 1,437.82 billion MPN/day, while the TMDL target is calculated to be 186.94 billion MPN/day. This is an increase of 88.78 billion MPN/day increase from the Reservoir Watershed Segment TMDL target to Segment 1014. *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, while the TMDL target load was calculated to be 2,101.84 billion MPN/day.

4.2.4 SEGMENT 1013

Output for Segment 1013 for BLEST is presented in **Table 4.3**. Under dry weather conditions, 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

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Table 4.2 BLEST Output for Segment 1014

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
WWTPs						
WWTP Discharges	18.00	10.66	18.93	11.21	18.93	11.21
WWTP 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 Sewer 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/dL)	39.19	186.94	156.63	747.05	440.67	2,101.84
TMDL Target		186.94		747.05		2,101.84

Abbreviations: MGD = million gallons per day, MPN = most probable number, MS4 = municipal separate storm sewer system, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTP = wastewater treatment plant

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Table 4.3 BLEST Output for Segment 1013

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
WWTPs	0.00	0.00	0.00	0.00	0.00	0.00
WWTP Discharges	-	-	-	-	0.00	0.00
WWTP Biosolid Releases						
SSO	1.38E-04	24.56	1.38E-04	24.56	2.56E-03	33.90
SSO - All Conditions						
Regulated Storm Water Discharges	5.36E-04	0.01	5.36E-04	0.01	-	-
Dry Weather Storm Sewer Discharges	-	-	1.79	3,019.07	102.38	172,505.86
Wet Weather Storm Sewer Discharges -		0.00		0.00		0.00
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/dL)	39.19	186.94	158.42	755.60	543.05	2,590.16
TMDL Target	-	186.94	-	755.60	-	2,590.16

Abbreviations: MGD = million gallons per day, MPN = most probable number, MS4 = municipal separate storm sewer system, Q = flow, OSSF = on-site sewage facility, SSO = sanitary sewer overflows, WWTP = wastewater treatment plant

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WWTP discharges in this segment. The TMDL target was calculated to be 186.94 billion MPN/day.

Under intermediate conditions, in-stream 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 in-stream load.

Finally, under wet weather conditions the in-stream 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 in-stream loading for wet weather was derived from storm sewer discharges associated with regulated stormwater discharges.

4.2.5 SEGMENT 1017

The BLEST output for Segment 1017 is presented in **Table 4.4**. As shown in the table, dry weather in-stream *E. coli* loads were calculated to be 122.49 billion MPN/day, with the largest source of bacteria loading being associated with dry weather storm sewer discharges. The TMDL target load was determined to be 98.79 billion MPN/day. WWTP loads in Segment 1017 are lower than those observed in the reservoir watershed segments, but greater than those observed in Segments 1013 and 1014.

Under intermediate conditions, in-stream bacteria loads were calculated to be 5,334.25 billion MPN/day, while the TMDL target was determined to be 170.34 billion MPN/day, more than one order of magnitude less than the in-stream load. The largest source of loading in

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Table 4.4 BLEST Output for Segment 1017

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
WWTPs						
WWTP Discharges	20.03	41.94	21.06	44.10	21.06	44.10
WWTP 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 Sewer 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/dL)	20.71	98.79	35.71	170.34	227.20	1,083.66
TMDL Target	-	98.79	-	170.34	-	1,083.66

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intermediate stream flow conditions is residual loading from wet weather sources, similar to Buffalo Bayou.

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

4.3 HSPF

This section summarizes the development of two HSPF models for the simulation of *E. coli* in Buffalo and Whiteoak Bayous. The models include bacteria associated with the water column, suspended sediments and sediments on the streambed. Sediment transport as well as scour and deposition were simulated. Bacteria build-up and wash-off 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 bacteria sources**
  - Constant inputs
  - Time-varying inputs

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- **Fate and transport**
  - Die-off

The following subsections provide a discussion of each of these processes and the approach used to incorporate these processes into the HSPF models.

4.3.1 PHYSICAL INPUT DATA

The HSPF model requires a significant amount of input data as discussed in the following sections. HSPF requires information to describe Buffalo and Whiteoak Bayous, including;

(1) subwatersheds,

(2) meteorologic data,

(3) land use data and

(4) hydrologic data such as reach length and slope to characterize the modeled reaches.

4.3.1.1 DELINEATION OF SUBWATERSHEDS

The Buffalo and Whiteoak Bayou watersheds cover a total of 465 square miles within the San Jacinto River basin in Texas. As HSPF is a lumped parameter model, it requires model input to be developed on a subwatershed basis. Subwatersheds have similar hydrologic properties and the delineated watersheds for estimating source loads were based upon subwatersheds used for floodplain modeling by the HCFCD (Harris County Flood Control District 1995; Harris County Flood Control District 2004). The subwatersheds were modified slightly so that boundaries matched water quality sampling locations where possible. The individual subwatersheds are shown **Figure 4.5** along with the number scheme used to identify them for all modeling efforts.

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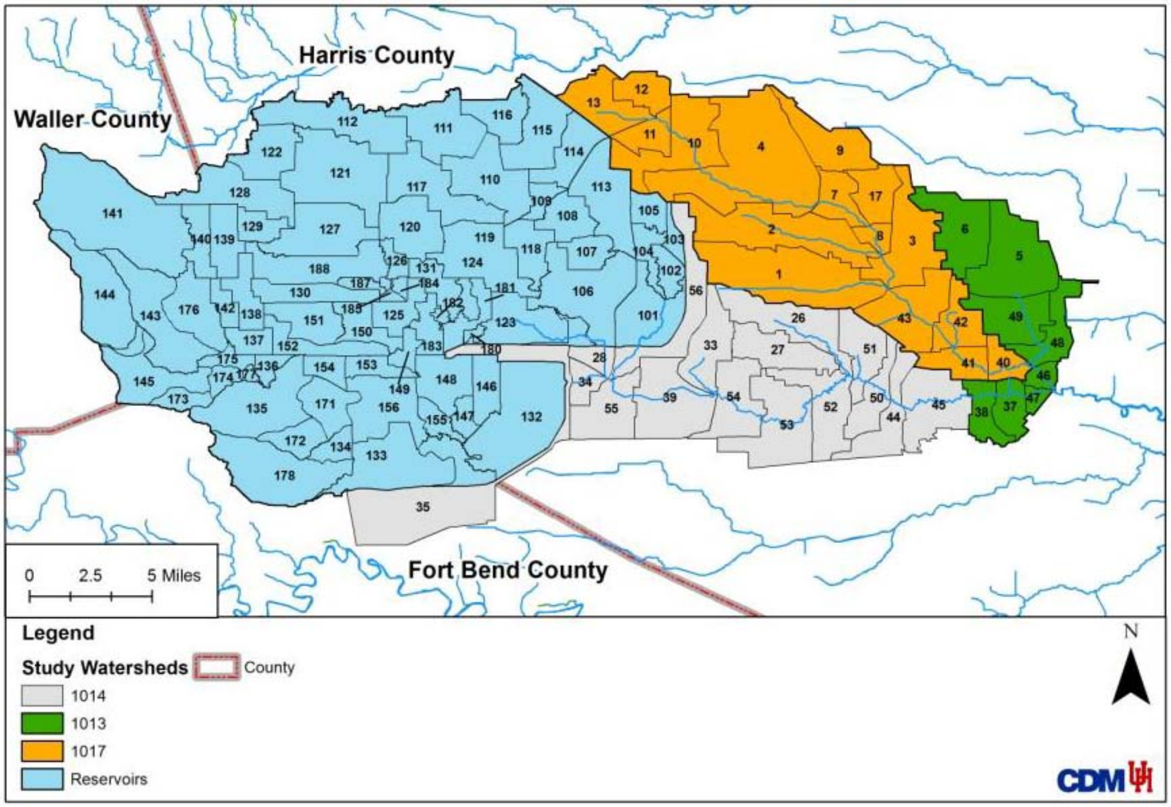

Figure 4.5 Subwatershed Identification Numbers

4.3.1.2 METEOROLOGIC DATA

Rainfall data from December 1, 2000 through September 30, 2003 were obtained from the City of Houston and the Harris County Office of Emergency Management. Gauges assigned to each subwatershed are shown in **Figure 4.6**. Data from December 2000 were used to run the model for one month to allow the model hydrology to equilibrate. These data were processed into Watershed Data Management (WDM) files that HSPF uses to input and output time series.

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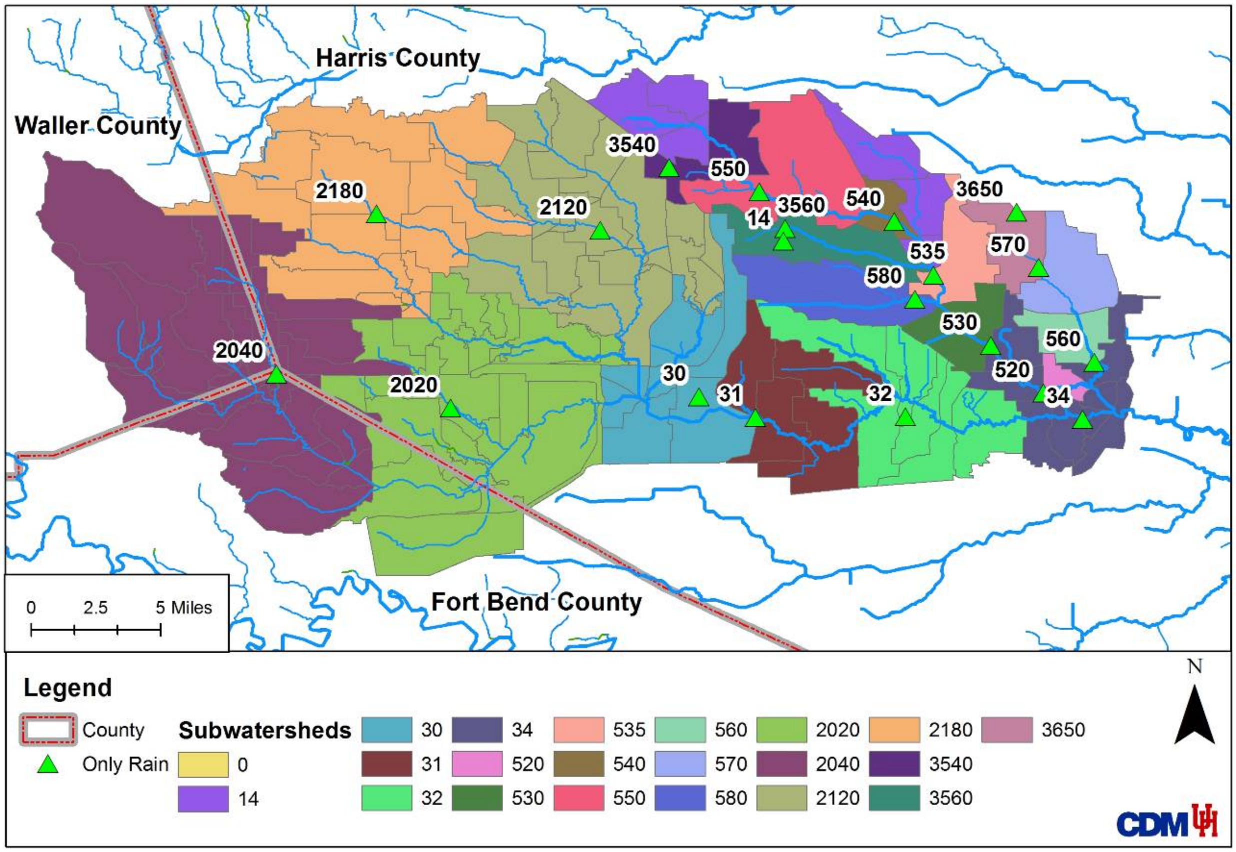

Figure 4.6 Rain Gauge Locations and Subwatersheds Assigned to Gauge Data

Both potential evaporation and potential evapotranspiration data are also required by HSPF. Evaporation is the process by which water is transformed into water vapor and evapotranspiration is plant transpiration combined with evaporation from the soil. Hourly evaporation data are not available for Houston. Therefore, the average monthly evaporation for quadrangles 812 and 813 were taken from the Texas Water Development Board (TWDB) and converted to hourly evaporation. The data from the TWDB were only available for 2001 and 2002, and thus 2003 monthly evaporation was assumed to be the average of 2001 and 2002. The

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monthly evaporation data were disaggregated to daily values by applying the pattern provided in the US EPA Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) program. The final processed data are provided in **Figure 4.7**.

The HSPF model also requires evapotranspiration to simulate fecal bacteria concentrations. Daily evapotranspiration data were obtained from the Texas ETNetwork, a system maintained by Texas A&M University. No data were available for Houston, therefore the sites closest to Houston were used instead; these sites include Ft. Bend, Victoria and Jackson. The data sets for all three sites were incomplete, but Victoria had the most complete record and therefore it was chosen to supply the primary PEVT data set. Data gaps in the Victoria data were filled first using the Jackson data (as it had a higher correlation coefficient to the Victoria data than Ft. Bend). If data were not available from the Jackson data, the Ft. Bend data were utilized.

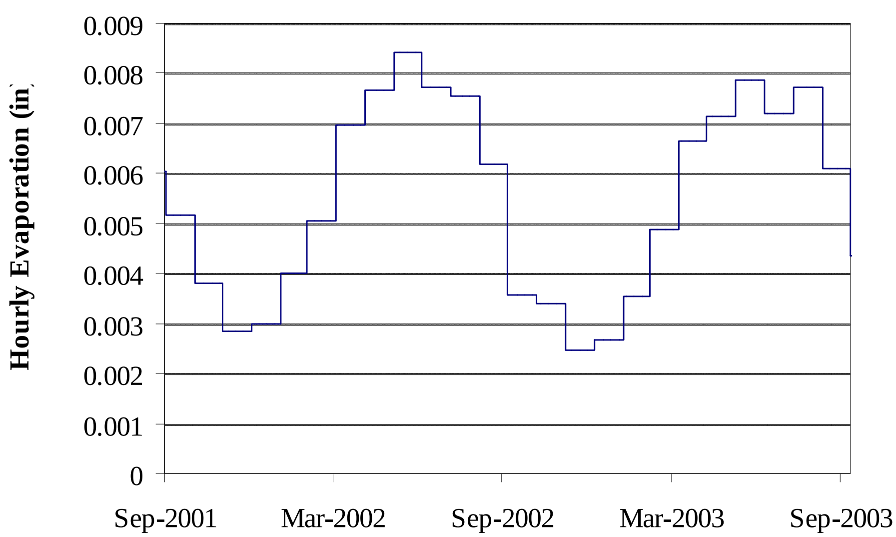

Figure 4.7 Evaporation Model Input

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Data gaps still existed in the data after supplementing the Victoria data with data from Ft. Bend and Jackson. These gaps were filled using one of two methods: (1) the average of the PEVT data surrounding the gap and (2) assuming a constant value equal to the first data point prior to the data gap (this was used for large data gaps). The final PEVT data set is presented in **Figure 4.8**. As can be seen in **Figure 4.8**, the PEVT varies during the year, with the maximum PEVT occurring during the summer.

4.3.1.3 LAND USE DISCRETIZATION

There were two development phases for the HSPF models, with corresponding land use data sets. The first HSPF model development phase focused on Whiteoak Bayou and the watersheds in Buffalo Bayou below the reservoirs.

Land use data for Whiteoak Bayou and the lower part of the Buffalo Bayou watershed were obtained from the 2001 Houston-Galveston Area Council (H-GAC) Land Use/Land Cover dataset. The H-GAC land use data are based primarily on classifications of land cover derived

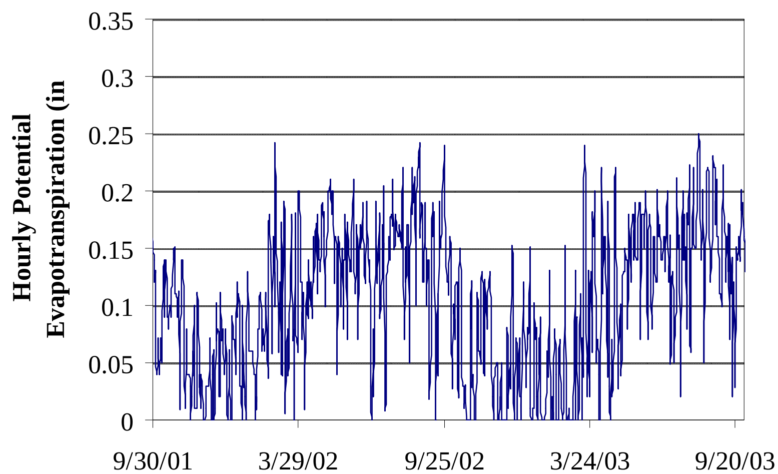

Figure 4.8 Evapotranspiration Model Input

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from year 2000 satellite image data and aerial photography as well as other sources of information such as 2000 U.S. Census data and Landsat satellite imagery.

These land use data are shown in **Figure 4.9**. As the figure shows, the H-GAC land use data include estimates for the following categories of land use/land cover: residential (predominantly single family subdivisions, single family residence, and mobile homes), commercial (all developed non-residential uses, some apartment complexes), open land (undeveloped land, including parks and rights of way), water and other (indeterminate land classifications that are primarily open land and/or water).

In HSPF, the modeled area is divided into pervious and impervious subwatersheds. The pervious subwatersheds are considered to be land segments that have adequate infiltration to affect the water budget. The model does not calculate infiltration in impervious subwatersheds (Bicknell et al. 1996). To convert the land use areas provided by H-GAC to pervious and impervious areas, the following assumptions were made:

a) Residential – 50% impervious;

b) Commercial – 100% impervious;

c) Open land – 100% pervious;

d) Water – 100% impervious; and

e) Other - 50% impervious.

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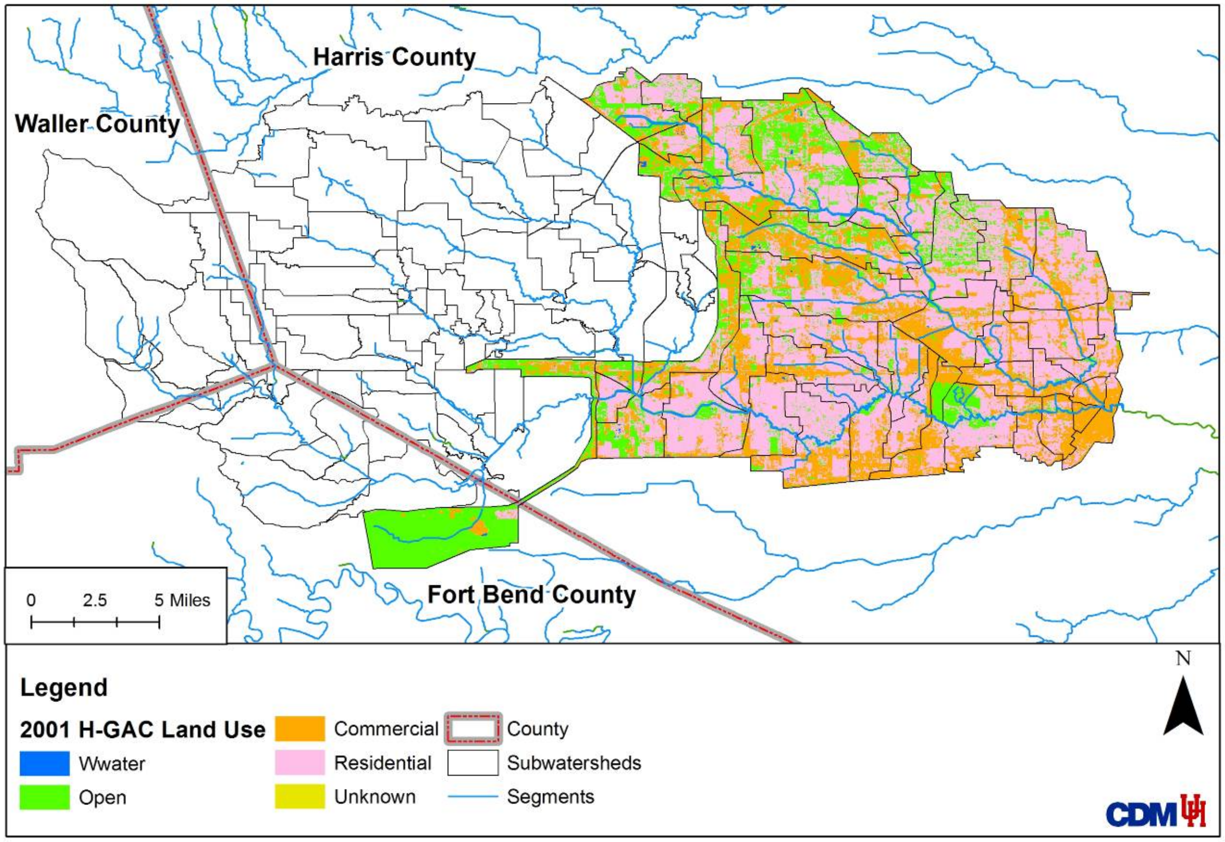

Figure 4.9 Land Use Data (H-GAC, 2001b)

The second development phase of the model focused on including the watershed in the reservoirs. These data were obtained from an updated H-GAC land use/land cover data set published in 2002. As shown in **Figure 4.10**, the land use includes estimates for low-intensity (developed land commonly with single-family housing, suburban neighborhoods), high-intensity (heavily built-up urban centers and large constructed surfaces), cultivated (areas that have been planted, tilled or harvest), grassland (land with herbaceous cover such as pastures, hayfields, lawns or other managed grassy areas such as parks), woody land (includes areas such as shrub,

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deciduous, evergreen and mixed forests), open water, woody wetland (wetland with woody vegetation), non-woody wetland (all other wetlands) and transitional land (land changing from one land cover to another).

To convert the 2002 H-GAC land use to pervious and impervious areas for input into HSPF,, the following assumptions were made:

a) Low Intensity Developed – 50% impervious;

b) High Intensity Developed – 100% impervious;

c) Cultivated Land – 0% impervious;

d) Grassland – 100% impervious;

e) Woody Land - 0% impervious;

g) Open Water - 100% impervious;

h) Woody Wetland - 0% impervious;

i) Non-woody Wetland -0% impervious; and

j) Transitional- 50% impervious.

A summary of the pervious and impervious land use distributions is presented in **Figure 4.10**. In general, the watershed closer to the central business district of Houston have the highest percent impervious cover with the lowest in the upper parts of the reservoir watersheds.

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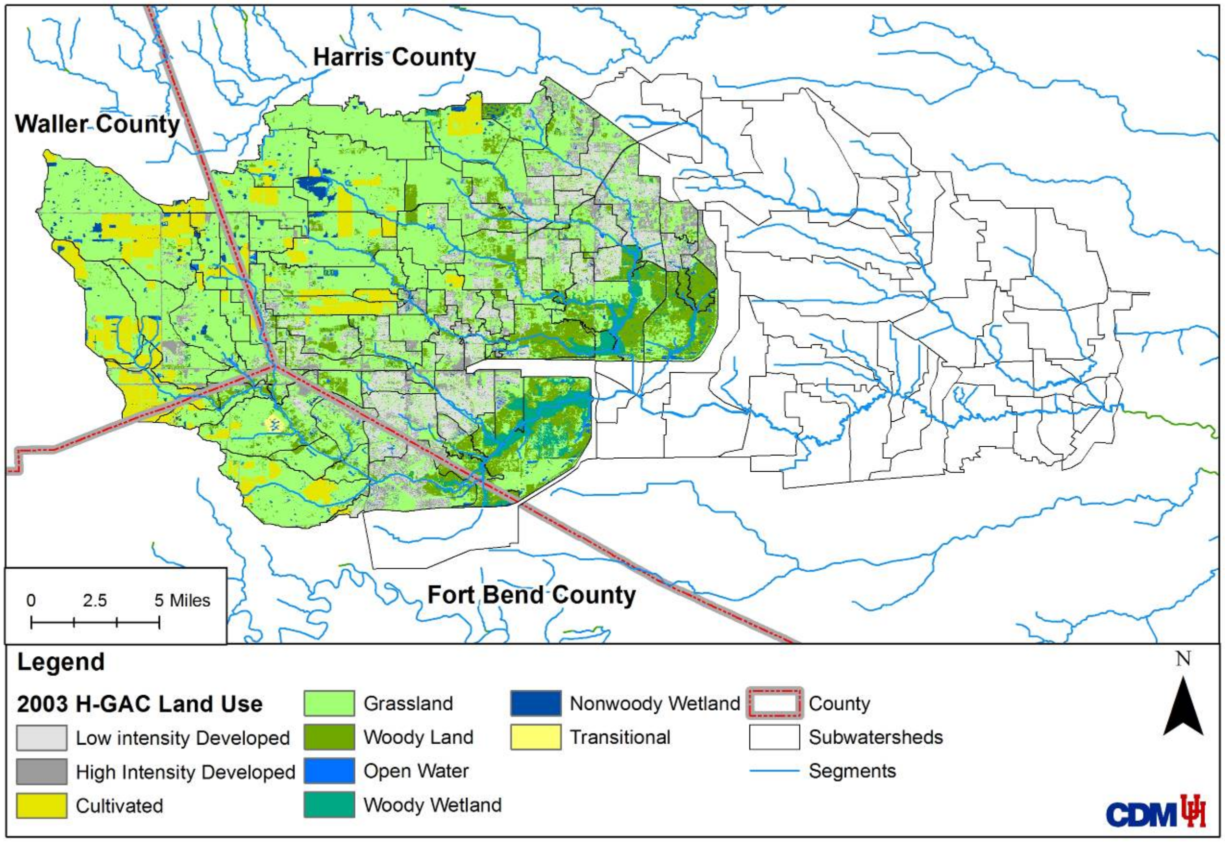

Figure 4.10 Land Use Data (H-GAC, 2003)

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Table 4.5 Watershed Areas and Percent Impervious Cover

Segment	Sub-watershed	Pervious	Impervious	Percent Impervious
Buffalo Bayou Tidal Watershed				
1013	5	2,211.70	3,056.83	58%
	6	1,826.95	2,018.67	52%
	37	397	1171	75%
	38	497	1133	70%
	46	141.78	527.69	79%
	47	8.49	449.35	98%
	48	905.95	1,367.03	60%
	49	1,157.17	1,858.44	62%
	Watershed Total	7,146.04	11,582.01	62%
Buffalo Bayou Above Tidal Watershed				
1014	26	1787	2301	56%
	27	1129	1736	61%
	28	480	407	46%
	33	1149	1851	62%
	34	565	475	46%
	35	7400	1306	15%
	39	2184	2495	53%
	44	867	1808	68%
	45	2082	1857	47%
	50	638	1365	68%
	51	1014	1505	60%
	52	1373	2140	61%
	53	1964	2970	60%
	54	1441	1819	56%
	55	1684	1491	47%
	56	1569	2048	57%
	Watershed Total	27,326.00	27,574.00	50%
Addicks and Barker Reservoir Watershed				
Res	101	3411.2	79.5	2%
	102	922.7	84	8%
	103	258.2	347.8	57%
	104	718.8	373.9	34%
	105	663	459.5	41%
	106	5044.7	360.1	7%
	107	1001.8	314.7	24%
	108	1287.8	579.8	31%
	109	467.6	291	38%
	110	3065.1	804.6	21%
	111	3639.8	8	0%
	112	4448	3.2	0%
	113	2273.3	1595.3	41%
	114	1494.8	790.9	35%
	115	2398.2	1038.5	30%

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Table 4.5 Watershed Areas and Percent Impervious Cover

Segment	Sub-watershed	Pervious	Impervious	Percent Impervious
	116	1708.4	312.5	15%
	117	3627.3	343.1	9%
	118	1425.8	513.1	26%
	119	3631.3	647.2	15%
	120	2644.7	311.9	11%
	121	6169.2	43.4	1%
	122	2483.2	41.2	2%
	123	3036.7	123	4%
	125	1482.7	219	13%
	126	897.3	254.2	22%
	127	3946.9	56.6	1%
	128	3770.4	340.3	8%
	129	1168	77.3	6%
	130	1858.1	98.7	5%
	131	1083.5	160.3	13%
	132	6947.4	129.9	2%
	133	2891.8	1140.5	28%
	134	437.8	16.2	4%
	135	4236.3	355.1	8%
	136	396.3	136.1	26%
	137	820.1	78.1	9%
	138	1335.8	119.6	8%
	139	1792	75.7	4%
	140	1466.9	95.9	6%
	141	10415.2	372.8	3%
	142	1202.1	397.2	25%
	143	4518.3	1006.7	18%
	144	4921.5	242.4	5%
	145	3404.1	600.6	15%
	146	1340	275.7	17%
	147	710.7	17.9	2%
	148	1435.7	1074.2	43%
	149	534.3	196.1	27%
	150	1327.8	292.7	18%
	151	1825.9	375.2	17%
	152	1361.2	521.1	28%
	153	631.9	445.4	41%
	154	1080.2	244.6	18%
	155	668.1	252.3	27%
	156	2083.9	1616.5	44%
	171	1031.4	277.2	21%
	172	1089.8	79.2	7%
	173	928.4	56.5	6%
	174	595.7	45.6	7%

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Table 4.5 Watershed Areas and Percent Impervious Cover

Segment	Sub-watershed	Pervious	Impervious	Percent Impervious
	175	615.5	82.3	12%
	176	2712.6	139.6	5%
	177	134.7	24.4	15%
	178	4663.7	111.1	2%
	180	174.9	58.7	25%
	181	594.6	206.6	26%
	182	76.3	61.1	44%
	183	506.4	309.4	38%
	184	150	131.6	47%
	185	91.3	57.6	39%
	186	57.2	45.4	44%
	187	411.4	8.4	2%
	188	3948.4	420.3	10%
	Watershed Total	145,596.10	22,866.10	14%
Whiteoak Bayou Above Tidal Watershed				
1017	1	3,196.83	4,489.15	58%
	2	2,493.41	3,741.58	60%
	3	2,567.58	1,844.39	42%
	4	6,299.35	4,836.16	43%
	7	975.26	838.03	46%
	8	416.62	345.46	45%
	9	1,645.73	1,532.43	48%
	10	2,366.44	2,258.85	49%
	11	662.52	835.87	56%
	12	970.47	722.26	43%
	13	1,695.05	1,219.30	42%
	17	1,151.85	846.21	42%
	40	436.69	779.06	64%
	41	480.22	1,215.44	72%
	42	853.23	1,317.56	61%
	43	1,321.49	2,830.07	68%
	Watershed Total	27,532.74	29,651.82	52%

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4.3.1.4 SOIL CHARACTERISTICS

A characterization of the surface soils and texture is needed for HSPF modeling and to provide an indication of the infiltration capacity of the subwatersheds. The STATSGO (State Soil Geographic Database) information was used for this purpose. This dataset, presented previously in **Section 2**, is publicly available through the US Department of Agriculture **–** Natural Resource Conservation Service (NRCS) and provides general soil data at a scale of 1:250,000 (Natural Resource Conservation Service 1986).

According to the US EPA (2000), soils in hydric group C correspond to HSPF infiltration parameter values between 0.05 and 0.1 in/hr. Hydric group D soils are estimated to have infiltration parameters around 0.01 to 0.05 in/hr. Therefore, the abundance of soils with hydric group D classifications guided the selection of infiltration parameters towards lower infiltration rates.

4.3.1.5 HYDROLOGIC CHARACTERISTICS

In order for HSPF to route water flow downstream, it must be supplied with rating curves that describe the reach response to a volume of water. Additionally, other flow inputs such as those from point sources and dry weather storm sewer discharges, as well as the upstream input from the reservoirs on Buffalo Bayou require routing factors as well. Reach lengths and slopes shown in **Table 4.6** were used in conjunction with rating curves developed in HEC-RAS to provide input for the hydrologic parameters and FTABLE information.

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Table 4.6 Reach Lengths and Slopes used in HSPF

Sub-watershed	Segment	Reach Length (miles)	Slope
1	1017	5.782	0.001
2	1017	6.703	0.001
3	1017	1.459	0.001
4	1017	5.135	0.001
5	1017	2.042	0.002
6	1017	2.296	0.002
7	1017	2.488	0.001
8	1017	1.621	0.002
9	1017	4.046	0.001
10	1017	2.21	0.001
11	1017	1.133	0.001
12	1017	1.558	0.001
13	1017	1.986	0.001
17	1017	2.405	0.001
26	1014	4.11	0.002
27	1014	3.38	0.003
28	1014	1.25	0.003
33	1014	3.39	0.001
34	1014	1.44	0.001
35	1014	0.15	0.000
36	1013	1.04	0.001
37	1013	1.04	0.001
38	1014	0.9	0.000
39	1014	3.4	0.001
40	1017	2.023	0.001
41	1017	1.955	0.001
42	1017	1.3	0.001
43	1017	2.349	0.001
44	1014	0.62	0.001
45	1014	4.3	0.000
46	1013	1.396	0.001
47	1013	0.99	0.001
48	1013	1.813	0.002
49	1013	2.088	0.001
50	1014	1.74	0.000
51	1014	0.78	0.001
52	1014	3.1	0.000
53	1014	4.08	0.000
54	1014	2.78	0.001
55	1014	1.54	0.001
56	1014	0.25	0.000
101	Reservoirs	3.15	0.001
102	Reservoirs	1.14	0.001
103	Reservoirs	1.31	0.001
117	Reservoirs	3.53	0.002
118	Reservoirs	3.75	0.001
119	Reservoirs	4.86	0.001
120	Reservoirs	3.03	0.001
121	Reservoirs	3.54	0.001
122	Reservoirs	0.53	0.001
123	Reservoirs	0.62	0.000
124	Reservoirs	1.33	0.001
125	Reservoirs	1.91	0.001
126	Reservoirs	0.54	0.001
127	Reservoirs	7.7	0.000
128	Reservoirs	2.68	0.000
129	Reservoirs	1.92	0.001
130	Reservoirs	4	0.001
131	Reservoirs	2.51	0.000
132	Reservoirs	3.67	0.001
133	Reservoirs	0.29	0.001
134	Reservoirs	1.21	0.001
135	Reservoirs	3.23	0.001
136	Reservoirs	1.35	0.001
137	Reservoirs	1.22	0.000
138	Reservoirs	2.89	0.001
139	Reservoirs	1.29	0.001
140	Reservoirs	0.63	0.001
141	Reservoirs	3.67	0.001
142	Reservoirs	2.91	0.001
143	Reservoirs	7.26	0.001
144	Reservoirs	5.99	0.001
145	Reservoirs	3.66	0.001
146	Reservoirs	1.26	0.001
147	Reservoirs	0.74	0.001
148	Reservoirs	1.95	0.001
149	Reservoirs	1.57	0.002
150	Reservoirs	2.03	0.001
151	Reservoirs	0.66	0.004
152	Reservoirs	2.89	0.001
153	Reservoirs	2.44	0.002
154	Reservoirs	4.57	0.001
155	Reservoirs	1.49	0.000
156	Reservoirs	0.87	0.002
171	Reservoirs	3.42	0.001
172	Reservoirs	1.43	0.003
173	Reservoirs	2.16	0.001
174	Reservoirs	1.76	0.000

Table 4.6 Reach Lengths and Slopes used in HSPF

Sub-watershed	Segment	Reach Length (miles)	Slope
104	Reservoirs	3.06	0.001
105	Reservoirs	0.19	0.000
106	Reservoirs	4.72	0.001
107	Reservoirs	3.72	0.000
108	Reservoirs	3.47	0.001
109	Reservoirs	0.68	0.000
110	Reservoirs	3.7	0.002
111	Reservoirs	2.94	0.001
112	Reservoirs	2.16	0.001
113	Reservoirs	4.31	0.001
114	Reservoirs	0.97	0.001
115	Reservoirs	1.51	0.002
116	Reservoirs	0.27	0.000

Sub-watershed	Segment	Reach Length (miles)	Slope
175	Reservoirs	1.46	0.001
176	Reservoirs	3.48	0.001
177	Reservoirs	1.03	0.001
178	Reservoirs	5.35	0.001
180	Reservoirs	0.34	0.001
181	Reservoirs	2.17	0.001
182	Reservoirs	0.54	0.001
183	Reservoirs	0.44	0.001
184	Reservoirs	0.37	0.001
185	Reservoirs	1.37	0.000
186	Reservoirs	0.25	0.002
187	Reservoirs	0.2	0.003
188	Reservoirs	6.3	0.001

Another important hydrologic characteristic associated with the Buffalo Bayou HSPF model is the operation of the Addicks and Barker Reservoirs. Both these reservoirs are operated by the U.S. Army Corps of Engineers (USACE) for flood control and the operation is based on the observed flow at the Piney Point gage maintained by the USGS. As a general rule, the combined release of the two reservoirs cannot exceed the difference between the observed flow at the Piney Point gage and 2,000 cfs. When the flow at Piney Point exceeds or is anticipated to exceed 2,000 cfs, the gates of the two reservoirs are typically closed and no discharge occurs until the Piney Point flow drops below 2,000 cfs again and the threat of additional rain has passed. In addition, releases from the reservoirs are limited to approximately 2,000 cfs.

Through the use of the Special Actions function in HSPF, the opening and closing of the reservoir gates was simulated. This was achieved by setting up two dummy subwatersheds (991 and 992) where the observed time series of reservoir releases were entered through the WDM file into the model. The FTABLES for the two subwatersheds immediately upstream of the

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reservoir gates (123 and 132) were then modified to include an additional column with outflow being zero for simulating gate closing conditions.

Based on the value of the observed release at a given time step, the Special Actions listed selects one of the two columns of the FTABLES for reservoir release calculations. For example, if the observed flow is zero in a given time step, the FTABLE column that produces zero outflow will be selected and therefore the gates are totally closed. If the observed flow is greater than zero, then the FTABLE column that produces limits the combined flow of the reservoirs to 2,000 cfs will be selected. Limitations of this analysis include the inability to simulate partially closed gates.

4.3.2 HYDROLOGY SET-UP AND CALIBRATION

The first step in developing the HSPF model, after preparation of the physical data, was to set up the hydrology inputs and calibrate the model. This section describes that process.

4.3.2.1 MODEL INPUTS

There are several bacteria inputs that have flow associated with them. These sources include WWTPs, 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. The remaining sources must be input into HSPF as a point source.

Buffalo and Whiteoak Bayous are dominated by WWTP flows under dry weather conditions and thus these discharges are critical to any simulation. For this TMDL project, 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 development of this algorithm is detailed **Appendix I**. The time-varying flow associated with each plant was processed into a WDM file and input as a point source into their respective subbasins.

The remaining source flows, including SSOs, dry weather storm sewer discharges and OSSFs, were input into the model as a constant flow. Flows used for these inputs are described in **Section 3**.

4.3.2.2 CALIBRATION

The model calibration and validation was focused on achieving a reasonable water balance for overall, low, and high flows or volumes. The USGS gauges used for the calibration are shown in **Figure 4.11**.

The overall flow calibration and validation was conducted by examining the total volume over the corresponding simulation period, from January 1, 2001 through September 30, 2003. The calibration period was January 1, 2001 through September 30, 2002. Validation was conducted from October 1, 2002 through September 30, 2003. The model was run from December 1, 2000 to January 1, 2001 to allow the model to equilibrate and thus this period was excluded from all analyses. The calibration process involved adjusting model parameters within ranges appropriate for the watershed. These ranges were determined based upon watershed characteristics, such as sloped, infiltration potential and roughness, as well as literature value ranges and model limitations. It was during this calibration process that runoff flows were adjusted. The ranges of parameters as well as their final values for both models are shown in **Table 4.7** for Whiteoak Bayou and **Table 4.10** for Buffalo Bayou.

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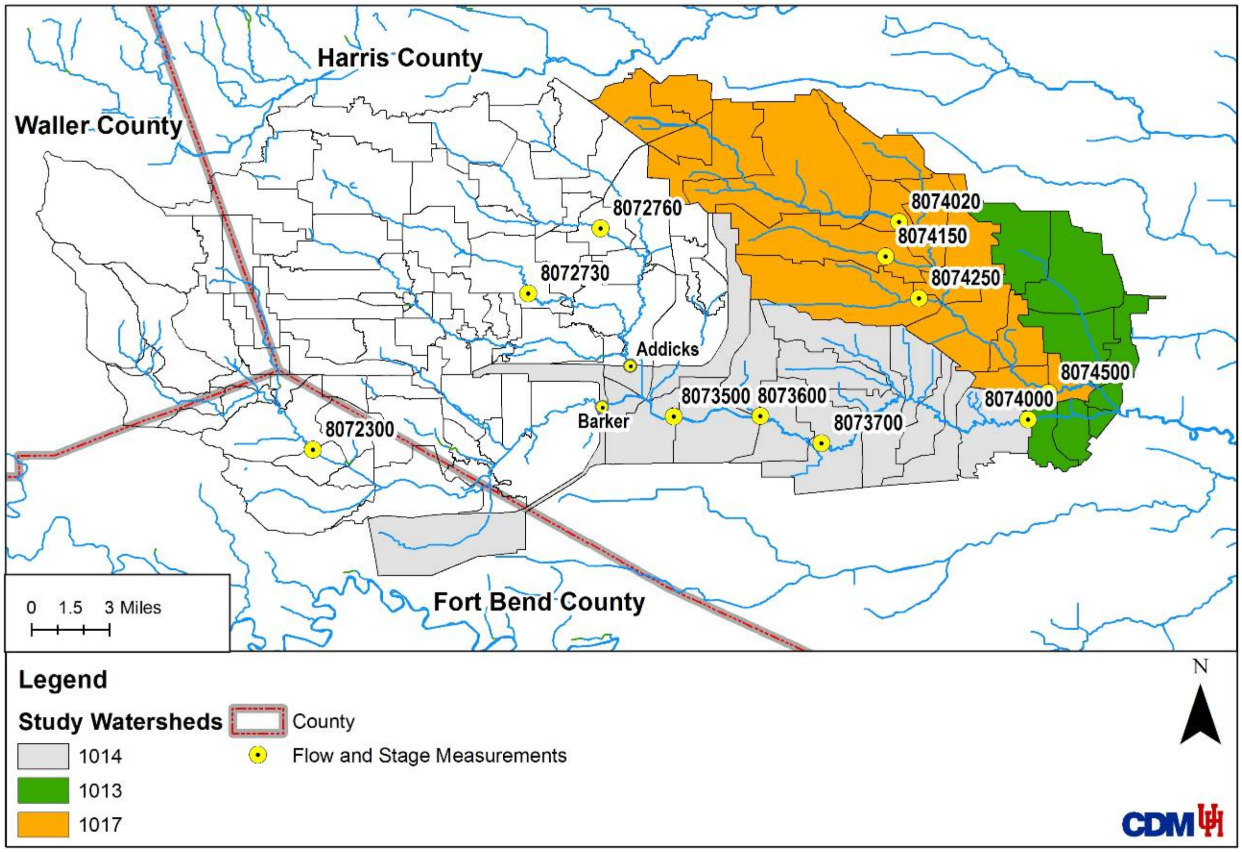

Figure 4.11 USGS Calibration Locations

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Table 4.7 HSPF Hydrology Parameters for Whiteoak Bayous

	Parameter	Units	Model Value	Min Literature/ Observe Val	Max Literature/ Observe Val
PWAT-PARM2	FOREST	none	1	0	0.5
	LZSN	inches	3-15	6	10.2
	INFILT	inches/hour	0.01 - 0.05	0.01	0.05
	LSUR	feet	306	200	500
	SLSUR	none	0.001	0.01	0.0001
	KVARY	1/inches	0	0	3
	AGWRC	1/day	0.85 - 0.9	0.92	0.99
PWAT-PARM3	PETMAX	deg F	40	35	45
	PETMIN	deg F	35	30	35
	INFEXP	none	2	2	2
	INFILD	none	2	2	2
	DEEPFR	none	0	0	0.2
	BASETP	none	0.02 - 0.03	0	0.5
	AGWETP	none	0	0	0.05
PWAT-PARM4	CEPSC	inches	0.1	0.1	0.25
	UZSN	inches	0.5 - 6	0.14	1.21
	NSUR	complex	0.35	0.15	0.35
	INTFW	none	1.5	1	3
	IRC	1/day	0.3 - 0.9	0.5	0.7
	LZETP	none	0.1 - 0.3	0.2	0.7
PWAT-PARM5	FZG	/inches	1	none	none
	FZGL	none	0.1	none	none
PWAT-STATE1	CEPS	inches	0.01	none	none
	SURS	inches	0.01	none	none
	UZS	inches	0.3	none	none
	IFWS	inches	0.01	none	none
	LZS	inches	1.5	none	none
	AGWS	inches	0.01	none	none
	GWVS	inches	0.01	none	none
IWAT-PARM2	LSUR	feet	150	30.5	5685
	SLSUR	none	0.001	none	none
	NSUR		0.25	0.03	0.1
	RETSC	feet	0 – 0.8	0.03	0.1
IWAT-PARM3	PETMAX	deg F	40	none	none
	PETMIN	deg F	35	none	none
IWAT-STATE1	RETS	inches	0.01	none	none
	SURS	inches	0.01	none	none
HYDR-PRAM2	LEN	miles	1.3 - 6.703	none	none
	DELTH	feet	5.4 - 40	none	none
	STCOR	feet	-6.3 - 111.7	none	none
	KS	none	0.5	0.5	0.5
	DB15/DB50	inches	0.0154	0.01	0.02

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Table 4.8 HSPF Hydrology Parameters for Buffalo Bayous

	Parameter	Units	Model Value	Min Literature/ Observe Val	Max Literature/ Observe Val
PWAT-PARM2	FOREST	none	1	0	0.5
	LZSN	inches	6 - 10	6	10.2
	INFILT	inches/hour	0.01 - 0.10	0.01	0.05
	LSUR	feet	150 - 500	200	500
	SLSUR	none	0.0001	0.01	0.0001
	KVARY	1/inches	0	0	3
	AGWRC	1/day	0.85 - 0.9	0.92	0.99
PWAT-PARM3	PETMAX	deg F	40	35	45
	PETMIN	deg F	35	30	35
	INFEXP	none	2	2	2
	INFILD	none	2	2	2
	DEEPFR	none	0.1 - 0.2	0	0.2
	BASETP	none	0.05 - 0.2	0	0.5
	AGWETP	none	0	0	0.05
PWAT-PARM4	CEPSC	inches	0.1 - 0.2	0.1	0.25
	UZSN	inches	0.14 - 1.21	0.14	1.21
	NSUR	complex	0.3	0.15	0.35
	INTFW	none	1.0	1	3
	IRC	1/day	0.3 - 0.7	0.5	0.7
	LZETP	none	0.5	0.2	0.7
PWAT-PARM5	FZG	/inches	1	none	none
	FZGL	none	0.1	none	none
PWAT-STATE1	CEPS	inches	0.01	none	none
	SURS	inches	1 - 2	none	none
	UZS	inches	0.5	none	none
	IFWS	inches	0.5	none	none
	LZS	inches	1.5 - 5.0	none	none
	AGWS	inches	1.0	none	none
	GWVS	inches	0.01	none	none
IWAT-PARM2	LSUR	feet	13.4 - 9379.8	30.5	5685
	SLSUR	none	0.001 - 0.05	none	none
	NSUR	none	0.05	0.03	0.1
	RETSC	feet	0.1	0.03	0.1
IWAT-PARM3	PETMAX	deg F	40	none	none
	PETMIN	deg F	35	none	none
IWAT-STATE1	RETS	inches	0.01	none	none
	SURS	inches	0.01	none	none
HYDR-PRAM2	LEN	miles	0.15 - 7.7	none	none
	DELTH	feet	0.01 - 53.1	none	none
	STCOR	feet	-15 - 165	none	none
	KS	none	0.1 - 0.5	0.5	0.5
	DB15/DB50	inches	0.002871 - 0.007739	0.01	0.02

`

The resulting calibration was achieved after adjusting the parameters to achieve good agreement between USGS flows and model output. An assessment of the calibration and validation is presented in **Table 4.9** for Whiteoak Bayou. The calibration and validation for Whiteoak Bayou shows that a generally good fit was obtained between the model and observed USGS flows, as errors were generally less than 25%. Under low flow conditions, errors were greater in the tributary calibration points for Brickhouse Gully and Cole Creek. Plots of model results and observed USGS flows are presented in **Figure 4.12**.

In Buffalo Bayou, similar results were obtained as shown in **Table 4.10** and with errors generally less than 30%, although Buffalo Bayou at Westheimer exhibited percent errors of 58%. Although adjustments were made to the stream calibration for this site to reduce the error, the validation shows only a 1% error, suggesting that there might be an anomaly in the calibration flow record rather than a systematic error. Comparison plots between modeled and observed flow values are shown in **Figure 4.13** for all of the stream gages.

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Table 4.9 Whiteoak Bayou Hydrology Calibration and Validation

Calibration (1/1/2001 - 9/30/2002)

Data Source	Location	Total Volume[1]	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Cole Creek (08074150)	4.30E+04	7.6	2.26	2.68	9.67E+03	1.52E+04
	Heights (08074500)	2.75E+05	24.9	2.75	3.62	9.45E+04	1.21E+05
	Alabonson (08074020)	3.09E+04	5.28E+00	1.19	1.32	4.21E+03	8.54E+03
	Brickhouse (08074250)	4.93E+04	2.02E+00	0.18	0.28	2.72E+04	3.00E+04
Modeled	Cole Creek (08074150)	4.90E+04	4.3	0.96	1.14	7.47E+03	1.67E+04
	Heights (08074500)	2.74E+05	22.6	2.71	3.19	7.62E+04	1.08E+05
	Alabonson (08074020)	3.29E+04	4.42E+00	1.07E+00	1.20	5.75E+03	8.83E+03
	Brickhouse (08074250)	4.75E+04	3.42E+00	7.44E-02	0.16	1.31E+04	2.06E+04
Error[3]	Cole Creek (08074150)	14%	-43%	-58%	-57%	-23%	10%
	Heights (08074500)	0%	-9%	-1%	-12%	-19%	-11%
	Alabonson (08074020)	7%	-16%	-10%	-9%	36%	3%
	Brickhouse (08074250)	-4%	69%	-59%	-42%	-52%	-31%

Validation (10/1/2002 - 9/30/2003)

Data Source	Location	Total Volume[1]	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Cole Creek (08074150)	1.35E+04	18.3	3.71	4.19	4.56E+03	2.64E+03
	Heights (08074500)	1.43E+05	33.3	2.96	3.53	3.62E+04	2.91E+04
	Alabonson (08074020)	5.90E+04	1.01E+01	1.39	1.70	1.73E+04	1.05E+04
	Brickhouse (08074250)	2.35E+04	2.97E+00	0.22	0.34	6.99E+03	3.77E+03
Modeled	Cole Creek (08074150)	3.30E+04	6.1	1.00	1.24	6.51E+03	8.17E+03
	Heights (08074500)	1.75E+05	34.9	2.69	4.04	4.32E+04	3.48E+04
	Alabonson (08074020)	6.81E+04	1.16E+01	1.11E+00	1.60	2.00E+04	9.78E+03
	Brickhouse (08074250)	2.47E+04	4.24E+00	4.03E-02	0.20	5.66E+03	6.60E+03
Error[3]	Cole Creek (08074150)	145%	-67%	-73%	-70%	43%	210%
	Heights (08074500)	22%	5%	-9%	14%	19%	20%
	Alabonson (08074020)	16%	14%	-20%	-6%	15%	-7%
	Brickhouse (08074250)	5%	43%	-82%	-42%	-19%	75%

Notes:
1. All volumes are in acre-ft, flow is in acre-ft/hr
2. Storm volumes were calculated for calibration using storms on 3/18/2001, 3/29/2001, 5/30/2001, 6/11/2001, 7/3/2001, 8/11/2001, 9/23/2001, 12/15/2001, 5/27/2002, and 8/6/2002
   Storm volumes for validation were calculated using storms on 10/28/2002, 12/12/2002, 6/26/2003, 7/2/2003, and 9/4/2003.
3. Error percentages calculated as (Model value – USGS value) / USGS value; 0% indicates a perfect match

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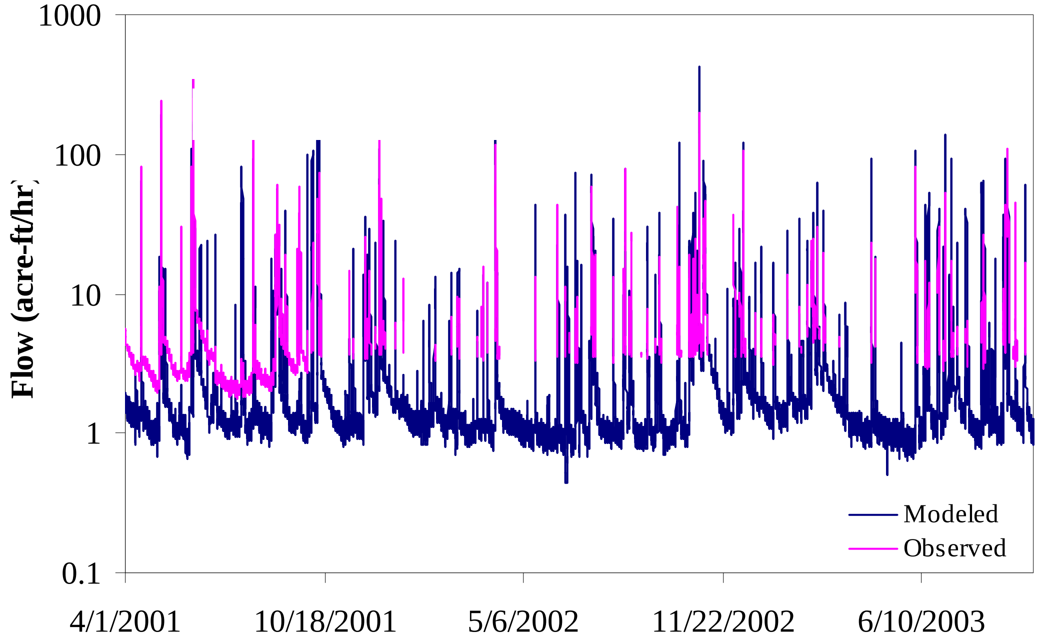
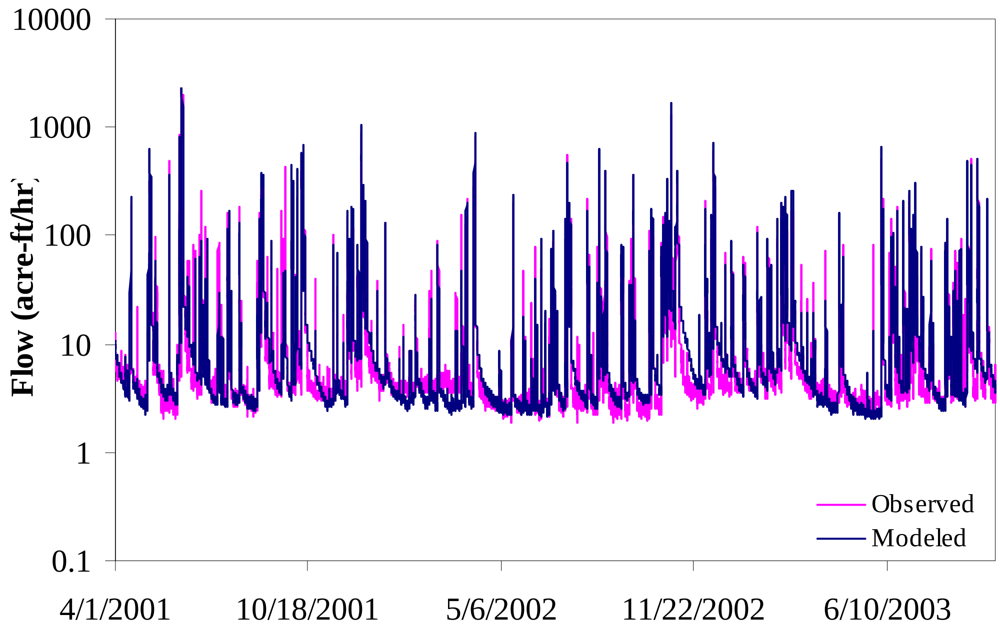


(A) Cole Creek (08074150)



(B) Heights Blvd (08074500)

Figure 4.12 Comparison of Model and Observed Flows in Whiteoak Bayou

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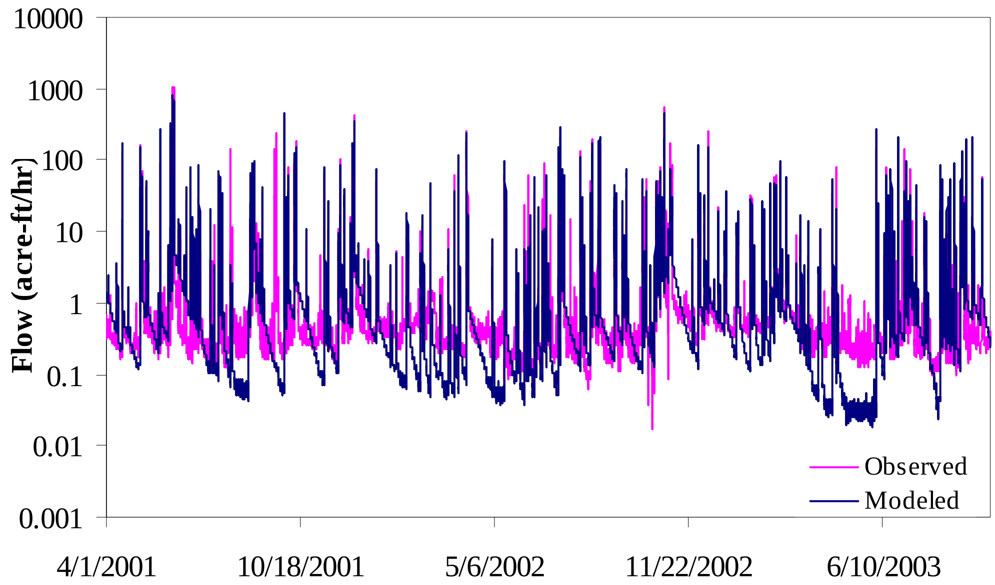

(C) Brickhouse Gully (08074250)

Figure 4.15 Calibration Plots for *E. coli* in Whiteoak Bayou, continued

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Table 4.10 Buffalo Bayou Hydrology Calibration and Validation

Calibration (1/1/2001 - 9/30/2002)

Data Source	Location	Total Volume[1]	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Barker	1.97E+05	44.4	0.00	2.50	6.62E+03	3.47E+04
	Addicks	2.21E+05	47.4	0.00	3.20	7.51E+03	5.89E+04
	BB @ Westheimer (08072300)	6.34E+04	11.2	0.17	0.30	9.83E+03	9.84E+03
	Langham @ Little York (08072760)	4.85E+04	6.5	0.18	0.28	8.58E+03	1.17E+04
	Bear Crk @ Clay Rd (08072730)	3.46E+04	5.0	0.06	0.09	9.10E+03	1.22E+04
	Dairy Ashford (08073500)	4.07E+05	98.5	3.76	4.96	2.66E+04	9.94E+04
	West Belt (08073600)	4.75E+05	108.6	5.31	6.44	4.40E+04	1.25E+05
	Shepherd[4] (08074000)	7.38E+05	162.7	5.22	8.94	9.63E+04	2.19E+05
Modeled	Barker	2.22E+05	58.3	0.00	1.20	7.16E+03	3.79E+04
	Addicks	2.23E+05	71.3	1.70	2.30	1.05E+04	7.00E+04
	BB @ Westheimer (08072300)	1.00E+05	12.9	0.18	0.29	1.18E+04	1.70E+04
	Langham @ Little York (08072760)	4.08E+04	5.3	0.28	0.49	7.12E+03	7.70E+03
	Bear Crk @ Clay Rd (08072730)	3.79E+04	5.6	0.10	0.20	6.47E+03	1.32E+04
	Dairy Ashford (08073500)	5.14E+05	115.0	3.70	5.00	3.43E+04	1.33E+05
	West Belt (08073600)	5.35E+05	116.0	3.70	5.10	4.30E+04	1.40E+05
	Shepherd[4] (08074000)	7.04E+05	148.0	6.10	9.70	9.12E+04	2.19E+05
Error[3]	Barker	13%	31%	-[4]	-52%	8%	9%
	Addicks	1%	50%	-[4]	-28%	40%	19%
	BB @ Westheimer (08072300)	58%	16%	6%	-3%	21%	73%
	Langham @ Little York (08072760)	-16%	-18%	57%	75%	-17%	-34%
	Bear Crk @ Clay Rd (08072730)	9%	13%	73%	120%	-29%	9%
	Dairy Ashford (08073500)	26%	17%	-2%	1%	29%	34%
	West Belt (08073600)	13%	7%	-30%	-21%	-2%	12%
	Shepherd[4] (08074000)	-5%	-9%	17%	9%	-5%	0%

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Table 4.10 Buffalo Bayou Hydrology Calibration and Validation

Validation (10/1/2002 - 9/30/2003)

Data Source	Location	Total Volume[1]	90th Percentile Flow	10th Percentile Flow	30th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Barker	1.49E+05	62.9	0	2.5	2.12E+04	1.39E+04
	Addicks	1.56E+05	75.9	0	2.9	2.58E+04	1.93E+04
	BB @ Westheimer (08072300)	6.61E+04	19.3	0.2	0.4	1.54E+04	3.00E+03
	Langham @ Little York (08072760)	-[5]	-[5]	-[5]	-[5]	-[5]	-[5]
	Bear Crk @ Clay Rd (08072730)	2.17E+04	6.6	0.1	0.1	5.50E+03	1.69E+03
	Dairy Ashford (08073500)	2.87E+05	121.1	3.8	5.3	4.50E+04	3.14E+04
	West Belt (08073600)	3.48E+05	142.1	5.8	7.5	6.17E+04	4.07E+04
	Shepherd[4] (08074000)	4.34E+05	191.0	4.9	11.1	8.62E+04	5.71E+04
Modeled	Barker	1.48E+05	70.9	0	1.3	2.42E+04	1.50E+04
	Addicks	1.66E+05	82.8	1.6	2.9	2.48E+04	1.59E+04
	BB @ Westheimer (08072300)	6.65E+04	16.4	0.1	0.3	1.91E+04	4.98E+03
	Langham @ Little York (08072760)	-[5]	-[5]	-[5]	-[5]	-[5]	-[5]
	Bear Crk @ Clay Rd (08072730)	2.43E+04	6.7	0.1	0.3	6.07E+03	1.53E+03
	Dairy Ashford (08073500)	3.60E+05	154.0	3.2	6.3	6.11E+04	3.83E+04
	West Belt (08073600)	3.75E+05	156.0	3.3	6.7	6.47E+04	4.04E+04
	Shepherd[4] (08074000)	4.48E+05	168.0	5.7	13.5	8.01E+04	5.98E+04
Error[3]	Barker	-1%	13%	-[4]	-48%	14%	8%
	Addicks	6%	9%	-[4]	0%	-4%	-18%
	BB @ Westheimer (08072300)	1%	-15%	-54%	-36%	24%	66%
	Langham @ Little York (08072760)	-[5]	-[5]	-[5]	-[5]	-[5]	-[5]
	Bear Crk @ Clay Rd (08072730)	12%	2%	98%	102%	10%	-9%
	Dairy Ashford (08073500)	26%	27%	-17%	19%	36%	22%
	West Belt (08073600)	8%	10%	-43%	-11%	5%	-1%
	Shepherd[4] (08074000)	3%	-12%	15%	22%	-7%	5%

Notes:

1. All volumes are in acre-ft, flow is in acre-ft/hr
2. Storm volumes were calculated for calibration using storms on 3/18/2001, 3/29/2001, 5/30/2001, 6/11/2001, 7/3/2001, 8/11/2001, 9/23/2001, 12/15/2001, 5/27/2002, and 8/6/2002
   Storm volumes for validation were calculated using storms on 10/28/2002, 12/12/2002, 6/26/2003, 7/2/2003, and 9/4/2003.
3. Error percentages calculated as (Model value – USGS value) / USGS value; 0% indicates a perfect match
4. Division by zero and thus cannot calculate error
5. Inadequate data for validation

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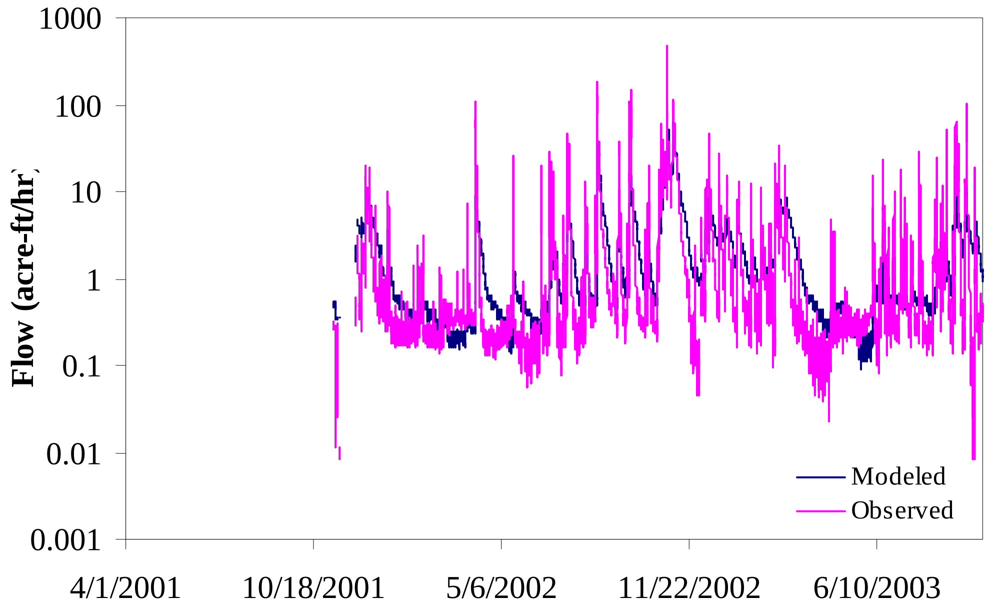
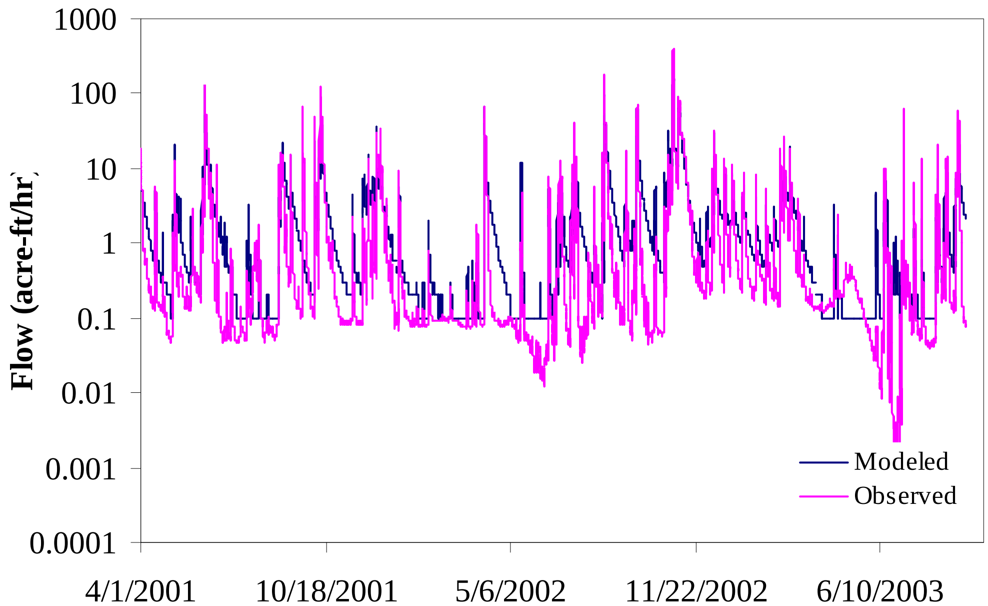


(A) Langham Creek (08072760)



(B) Bear Creek (08072730)

Figure 4.13 Comparison of Model and Observed Flows in Buffalo Bayou

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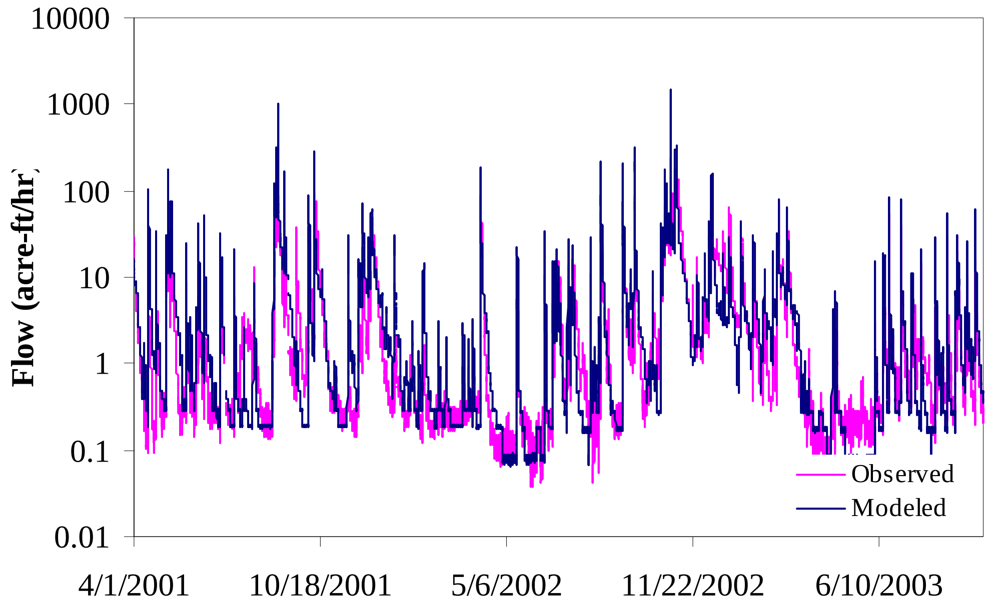
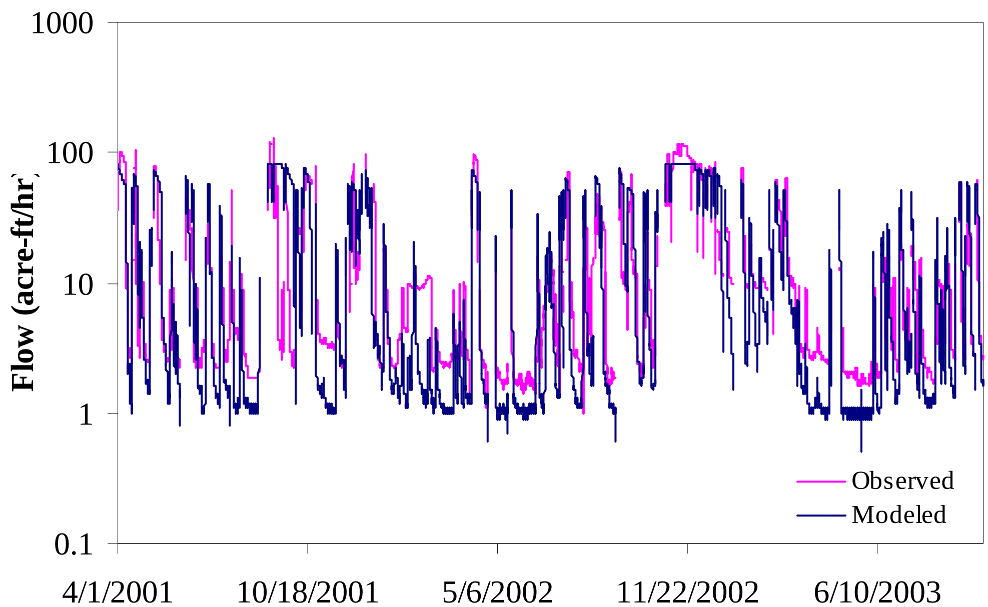
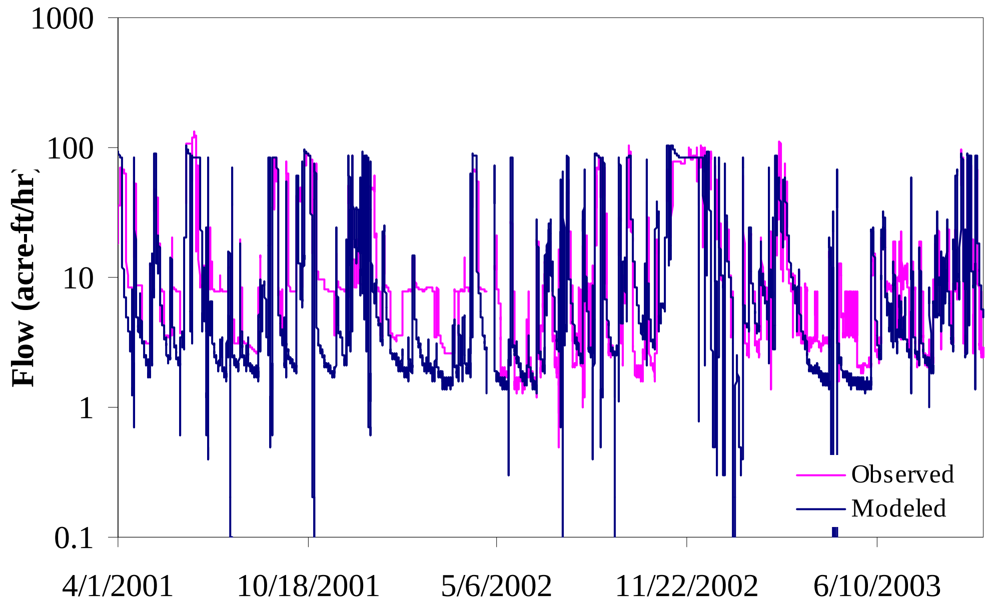


(C) Buffalo Bayou at Westheimer (08072300)

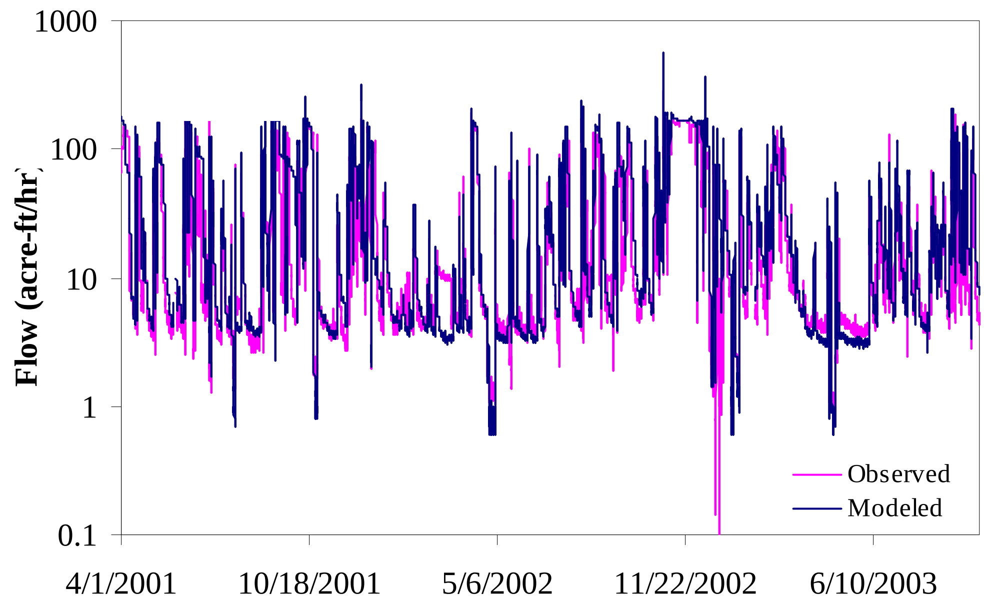


(D) Barker Reservoir Discharge

Figure 4.13 Comparison of Model and Observed Flows in Buffalo Bayou, continued

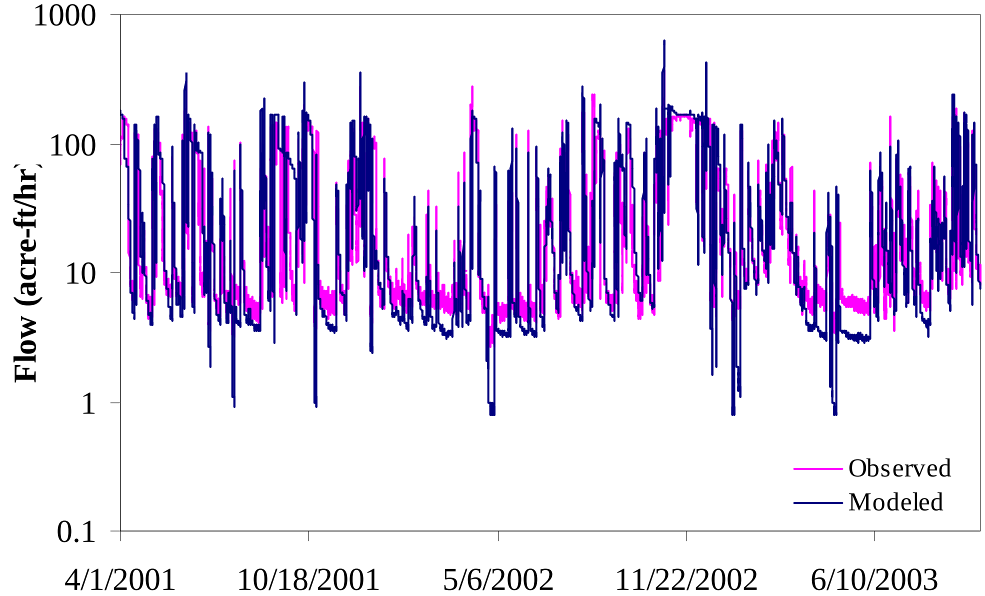


(E) Addicks Reservoir Discharge

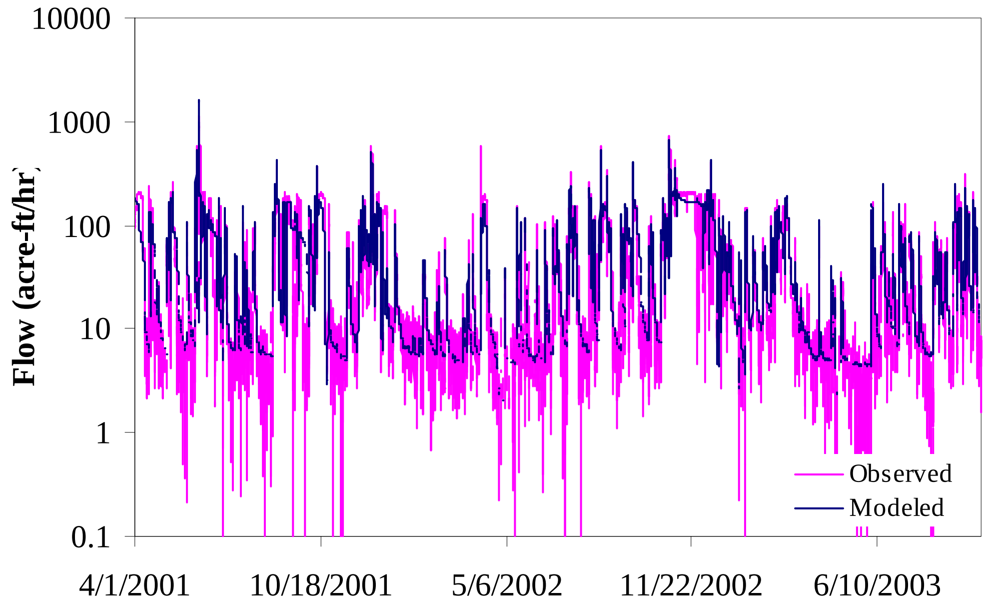


(F) Dairy Ashford (08073500)

Figure 4.13 Comparison of Model and Observed Flows in Buffalo Bayou, continued



(F) West Belt (08073600)



(G) Shepherd (08074000)

Figure 4.13 Comparison of Model and Observed Flows in Buffalo Bayou, continued

4.3.3 BACTERIA SET-UP AND CALIBRATION

After the models were set-up and calibrated for hydrology, the next step was to implement bacteria sources and calibrate the model for observed bacteria levels throughout the watershed. This section describes the model inputs and calibration process of bacteria levels.

4.3.3.1 INPUTS

Inputs to simulate the fate and transport of *E. coli* in HSPF include WWTPs, SSOs, dry weather storm sewer discharges, wet weather storm sewer discharges, OSSFs, direct deposition, and sediment resuspension. In addition, the HSPF model also simulates losses of bacteria through die-off and settling. SSOs, dry weather storm sewer discharges, OSSFs, and direct deposition are all input directly into HSPF as a point source. The calculation of these loads is described in **Section 3**. The remaining sources, WWTPs, wet weather storm sewer discharges, sediment resuspension and bacteria losses are simulated in HSPF as dynamic processes. The WWTP input is determined by taking the time-varying flow calculated for the hydrology calibration and multiplying it by concentrations specified in **Section 3**. The remaining sources are simulated explicitly in HSPF.

4.3.3.2 CALIBRATION

The development of bacteria parameters for calibration HSPF focused on matching the distribution of bacteria concentrations in the bayous so that all modeled values were within the 95% confidence interval of the observed data. Water quality gauges used to calibrate the models are presented in **Figure 4.14**. In addition, the model parameters were maintained within a pre-

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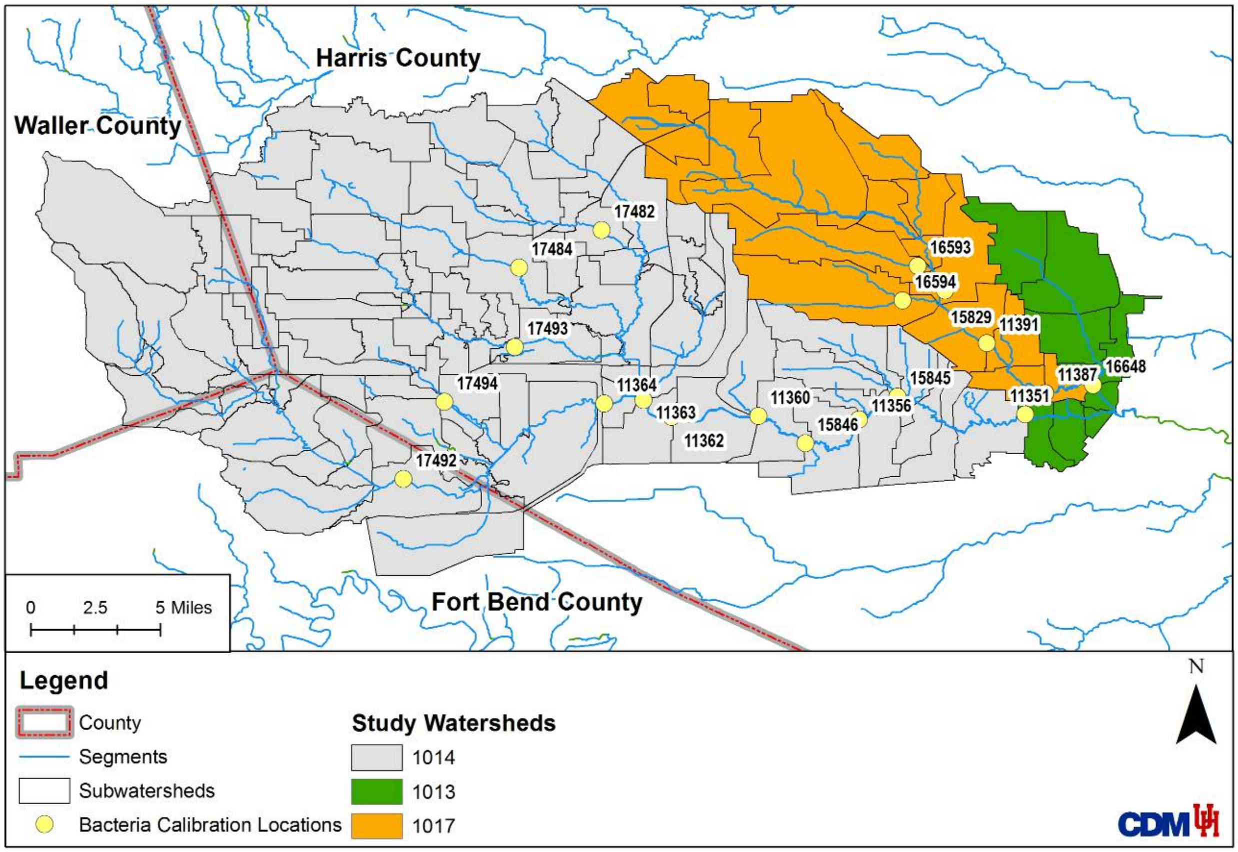

Figure 4.14 Bacteria Concentration Calibration Locations

determined range of values that were specified based upon watershed-specific data and literature values. The range of parameters and parameter values used in the models are presented in **Table 4.11** for Whiteoak Bayou and **Table 4.12** for Buffalo Bayou.

The statistical and graphical comparison of the final calibration to observed values is presented in **Table 4.13** for Whiteoak Bayou and Figure 4.15 presents a graphical comparison of the model results and observed values. As the figures show, the model reproduces the range of

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Table 4.11 HSPF Bacteria Parameters for Whiteoak Bayous

Model Section	Parameter	Units	Model Value	Minimum Estimated Value	Maximum Estimated Value
PERVIOUS QUAL - INPUT	SQO	quantity/acre	8.11E+08 - 4.56E+10		
	POTFW	quantity/ton	5.7E+07	5.7E+07	5.7E+09
	POTFS	quantity/ton	5.7E+07	5.7E+07	5.7E+09
	ACQOP	quantity/acre/day	8.47E+08 - 4.79E+10		
	SQOLIM	quantity/acre	1.15E+10 - 4.05E+10		
	WSQOP	inches/hour	0.23 - 0.26		
	IOQC	quantity/feet^3	0		
	AOQC	quantity/feet^3	0		
IMPERV QUAL INPUT	SQO	quantity/acre	5.3E+08 - 2.9E+10		
	POTFW	quantity/ton	5.72E+07	5.72E+07	5.72E+09
	ACQOP	quantity/acre/day	5.58E+08 - 3.07E+10		
	SQOLIM	quantity/acre	1.69E+09 - 4.05E+10		
	WSQOP	inches/hour	0.23 - 0.26	0.2	3
GQ-GEN DECAY	FSTDEC	/day	0.8	0.24	2.54
	THFST	none	1.024		
GQ-SED DECAY	KSUSP	none	0.011 - 0.45	0.02	0.8634
	THSUSP	none	1.024		
	KBED	none	0.011 - 0.111	0.02	0.8634
	THBED	none	1.024		
GQ -KD	ADPM1	liters/milligram	50000	0	2.92E+09
	ADPM2	liters/milligram	70000	0	2.92E+09
	ADPM3	liters/milligram	500000	0	2.92E+09
	ADPM4	liters/milligram	0.0000001	0	2.92E+09
	ADPM5	liters/milligram	0.0000001	0	2.92E+09
	ADPM6	liters/milligram	0.00001	0	2.92E+09

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Table 4.12 HSPF Bacteria Parameters for Buffalo Bayous

Model Section	Parameter	Units	Model Value	Minimum Estimated Value	Maximum Estimated Value
PERVIOUS QUAL - INPUT	SQO	quantity/acre	0 - 5.26E+09		
	POTFW	quantity/ton	5.7E+07	5.7E+07	5.7E+09
	POTFS	quantity/ton	5.7E+07	5.7E+07	5.7E+09
	ACQOP	quantity/acre/day	0 - 5.50E+09		
	SQOLIM	quantity/acre	0 - 1.10E+10		
	WSQOP	inches/hour	0.2 - 0.7		
	IOQC	quantity/feet^3	0		
	AOQC	quantity/feet^3	0		
IMPERV QUAL INPUT	SQO	quantity/acre	7.6E+08 - 7.5E+09		
	POTFW	quantity/ton	5.72E+07	5.72E+07	5.72E+09
	ACQOP	quantity/acre/day	3.81E+08 - 3.75E+09		
	SQOLIM	quantity/acre	7.62E+08 - 7.50E+09		
	WSQOP	inches/hour	0.2 - 0.7	0.2	3
GQ-GEN DECAY	FSTDEC	/day	1.5 - 2.0	0.24	2.54
	THFST	none	1.024		
GQ-SED DECAY	KSUSP	none	0.03	0.02	0.8634
	THSUSP	none	1.024		
	KBED	none	0.03	0.02	0.8634
	THBED	none	1.024		
GQ -KD	ADPM1	liters/milligram	50000	0	2.92E+09
	ADPM2	liters/milligram	50000	0	2.92E+09
	ADPM3	liters/milligram	50000	0	2.92E+09
	ADPM4	liters/milligram	0.0000001	0	2.92E+09
	ADPM5	liters/milligram	0.0000001	0	2.92E+09
	ADPM6	liters/milligram	0.00001	0	2.92E+09

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Table 4.13 Whiteoak Bayou Calibration for Bacteria Geometric Means (MPN/dL)

	Heights Blvd (11387)			**Little Whiteoak Bayou (16648)**			**Ella (11391)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	4062.9	2879.0	-29%	10767.9	12181.1	13%	3185.9	3274.4	3%
High Flow [2]	7341.0	5615.4	-24%	14764.1	23217.7	57%	6639.8	6387.7	-4%
Low Flow [3]	2108.9	1600.3	-24%	12485.4	12251.8	-2%	1391.7	1929.0	39%
Flow < median	6646.3	6170.0	-7%	9193.5	17662.5	92%	4962.0	5830.5	18%
Flow > median	3084.2	1878.7	-39%	13224.4	7122.1	-46%	2265.7	2100.8	-7%

	Cole Creek @ Bolvia (16593)			**West 43rd (15829)**			**Brickhouse Gully (16594)**		
	Observed	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	2639.1	1747.7	-34%	2086.1	2552.4	22%	3860.5	6007.9	56%
High Flow [2]	3723.9	3629.5	-3%	4798.2	5148.9	7%	14872.5	5160.8	-65%
Low Flow [3]	1182.3	698.2	-41%	1396.2	1034.9	-26%	1600.8	5901.5	269%
Flow < median	5143.7	4745.0	-8%	2433.1	5277.3	117%	5420.9	5576.9	3%
Flow > median	1431.5	699.6	-51%	1811.7	1311.5	-28%	2665.7	6516.2	144%

Notes:
[1] Error statistics for geometric means are calculated as (observed - modeled)/observed
[2] High flow is considered periods when flow is greater than 70th percentile
[3] Low flow is considered periods when flow is less than 30th percentile

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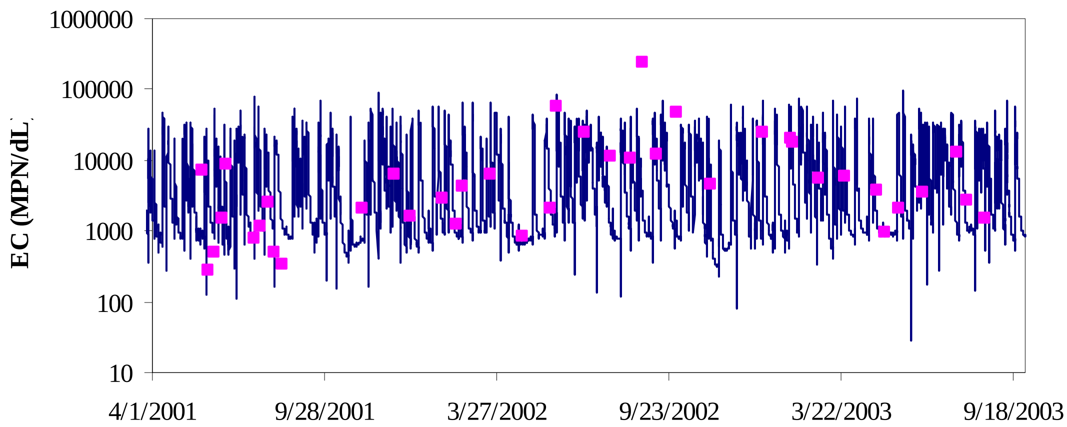
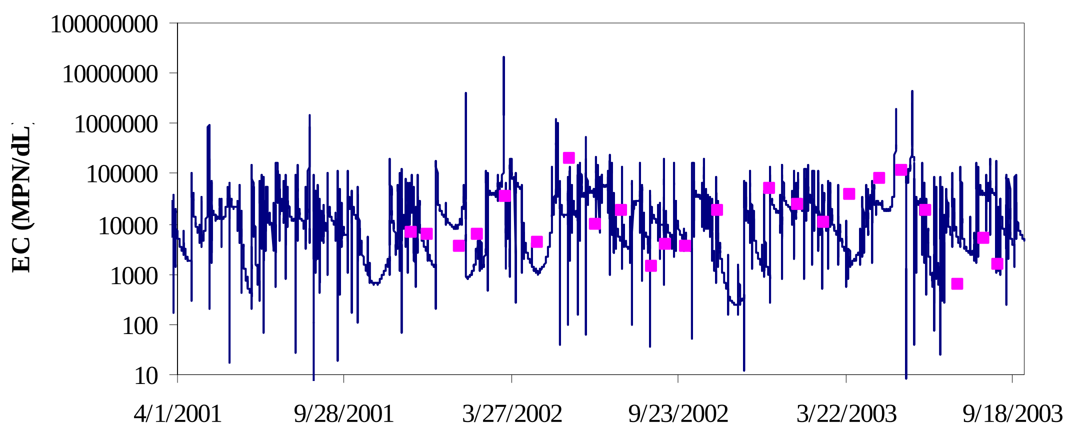


(A) Heights Blvd (11387)



(B) Little Whiteoak Bayou (16648)

Figure 4.15 Calibration Plots for *E. coli* in Whiteoak Bayou

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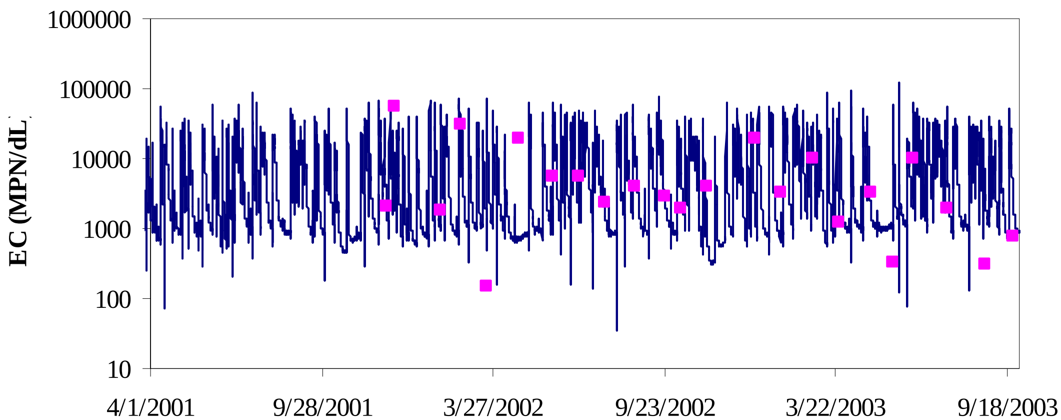
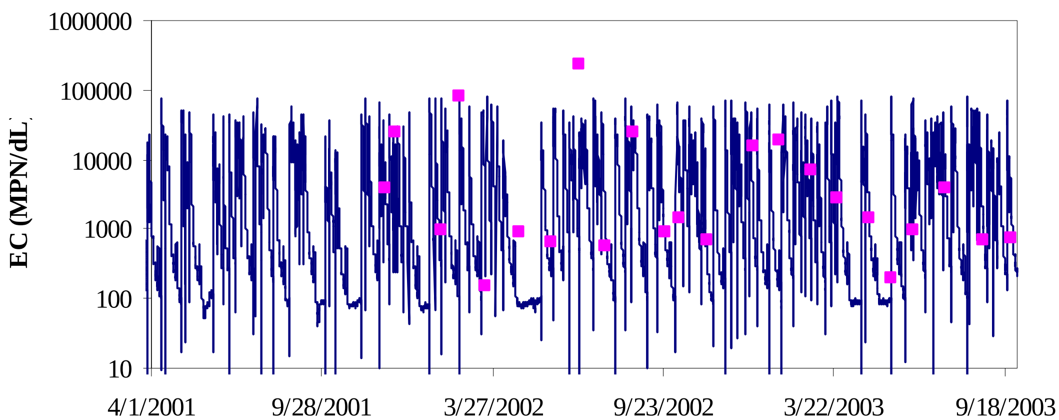


(C)

Ella Blvd (11391)



(D) Cole Creek (16593)

Figure 4.15 Calibration Plots for *E. coli* in Whiteoak Bayou, continued

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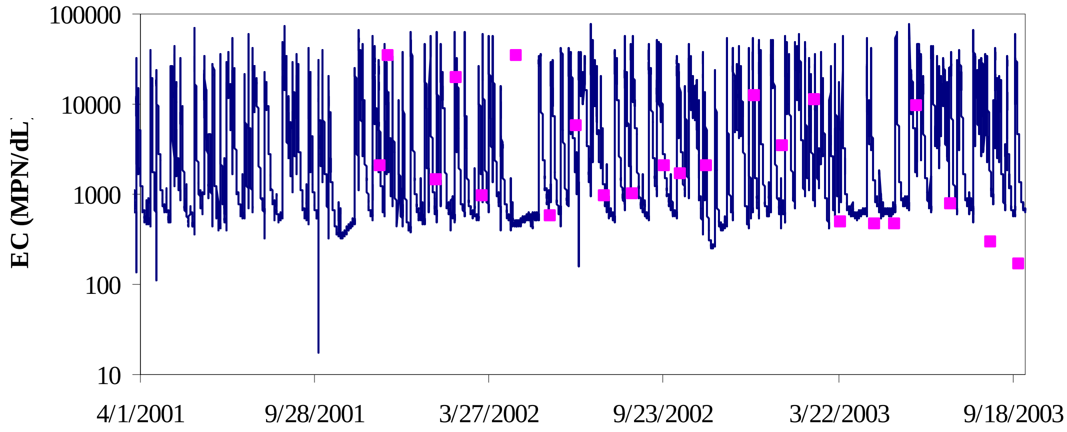
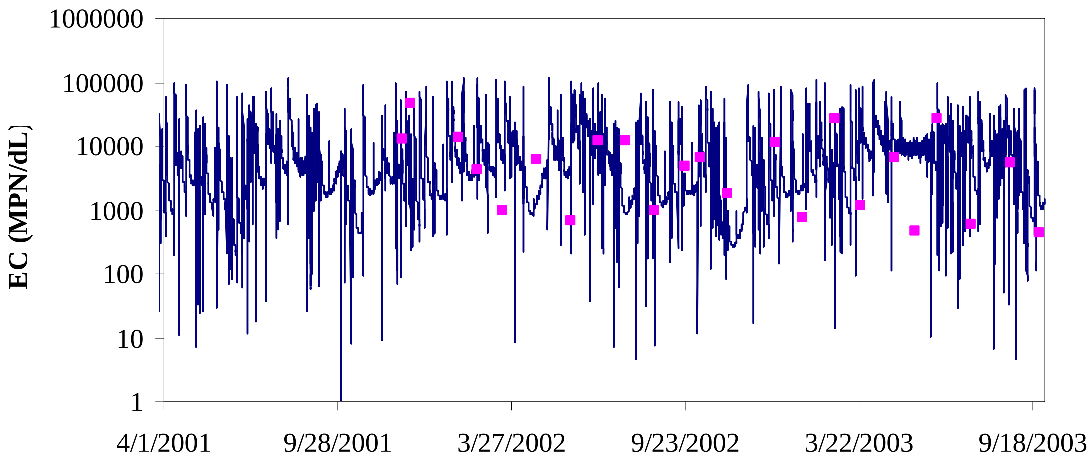


(E) West 43rd (15829)



(F) Brickhouse Gully (16594)

Figure 4.15 Calibration Plots for *E. coli* in Whiteoak Bayou, continued

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concentrations noted in the observed values. The majority of the overall errors in the statistical model comparison were less than 30%, 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 are shown in Figure 4.16. 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 intersect for the model and observed points suggesting that the concentrations are not that different from at statistical perspective.

The Buffalo Bayou model results are presented in Table 4.14 and graphic comparisons of modeled and observed values are shown in Figure 4.17 for Buffalo Bayou. The majority of the model results errors are 30% or less during the overall flow condition. Low and high flow conditions exhibit higher degrees of error, with some errors exceeding 100%. The low flow error generally exhibits the highest percent errors of all flow conditions.

Two calibration locations that exhibit high percent errors are the Langham Creek and Eldridge calibration locations exhibit very high percent errors. These errors were investigated to determine if they could be reduced by adjusting the model calibration. Based upon this evaluation, it was determined that several WWTPs in the Langham Creek watershed had very high concentrations of bacteria measured in their discharge during the 2006 sampling conducted by the TCEQ. The effect of these WWTPs is perpetuated downstream of the creek, causing

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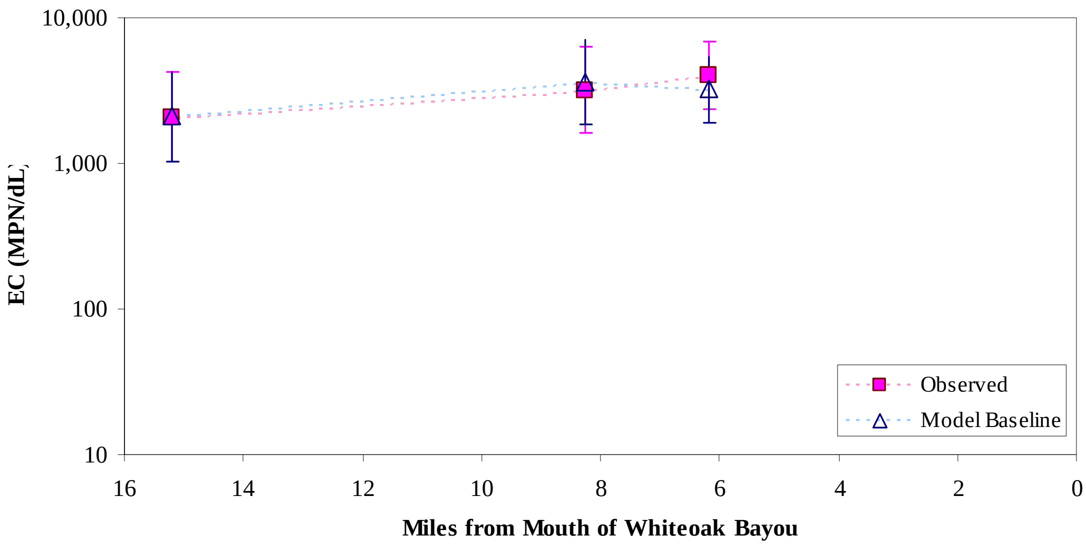
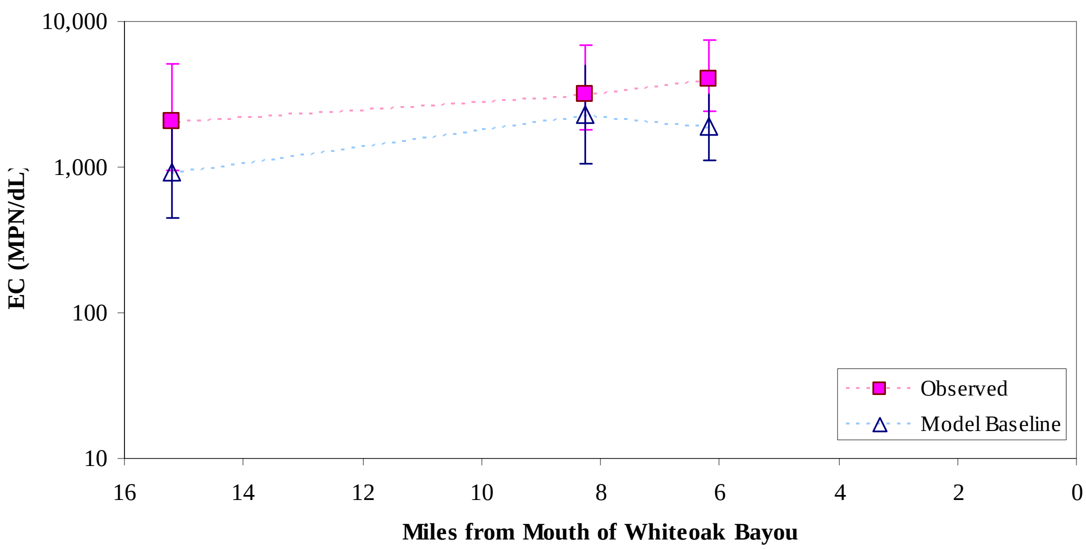


(A) Paired Geometric Means Under All Flow Conditions



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

Figure 4.16 Longitudinal Plots for Whiteoak Bayou

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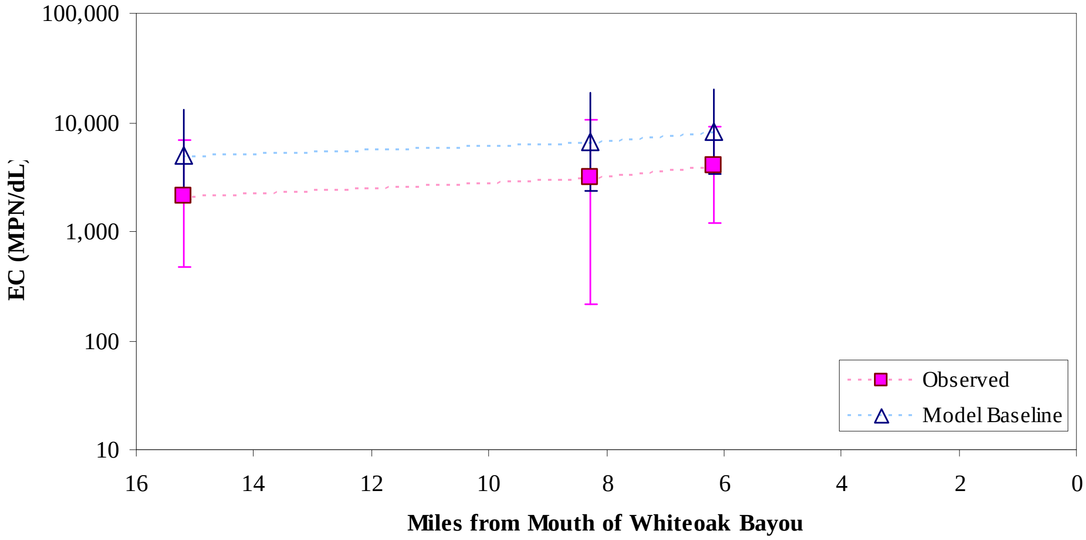

(C) Paired Geometric Means When Flows are Greater than Median

Figure 4.16 Longitudinal Plots for Whiteoak Bayou, continued

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Table 4.14 Buffalo Bayou Calibration for Bacteria Geometric Means (MPN/dL)

	Langham Creek at SH 6 (17842)			Bear Creek @ Old Greenhouse (17484)			Buffalo Bayou @ Peek Rd. (17492)		
	Observed	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error**	**Observed**	**Modeled**	**Error**
Overall	545.0	5731.5	952%	372.4	372.6	0%	567.7	690.1	22%
High Flow [2]	2949.0	3789.6	29%	4759.3	257.9	-95%	6244.7	615.3	-90%
Low Flow [3]	179.6	8945.7	4881%	97.6	639.8	555%	204.2	852.0	317%
Flow < median	206.4	7565.0	3564%	131.8	507.4	285%	209.6	862.9	312%
Flow > median	1785.3	4082.6	129%	1052.3	273.7	-74%	1282.7	574.8	-55%

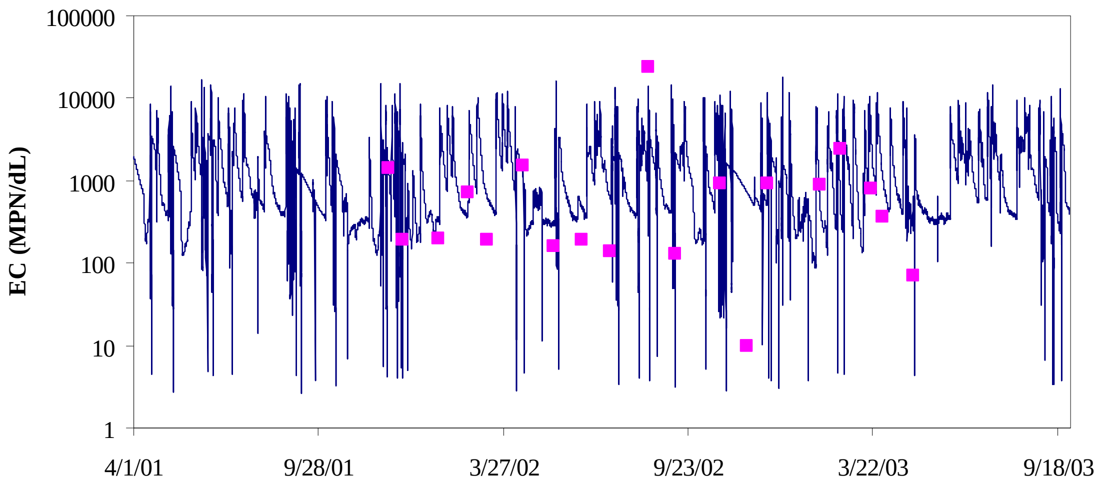
	S. Mayde Creek @ Groeschek Rd. (17493)			Mason Creek @ Park Pine Rd. (17494)			Addicks (11163)		
	Observed	**Modeled**	**Error[1]**	**Modeled**	**Error[1]**	**Error[1]**	**Observed**	**Modeled**	**Error**
Overall	414.7	384.4	-7%	1147.1	818.8	-29%	495	2,956	497%
High Flow [2]	4731.4	425.4	-91%	6119.9	1616.3	-74%	436	1,582	263%
Low Flow [3]	122.2	445.0	264%	1076.6	319.6	-70%	382	4,408	1055%
Flow < median	95.2	503.8	429%	464.7	412.6	-11%	446	2,093	369%
Flow > median	1807.0	293.3	-84%	2402.4	1434.3	-40%	570	3,799	566%

	Highway 6 (11364)			Eldridge (11363)			Dairy Ashford (11362)		
	Observed	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error[1]**
Overall	414.3	548.1	32%	579.2	2,328.2	302%	1,244.0	2,230.8	79%
High Flow [2]	734.7	1,590.3	116%	746.8	2,038.8	173%	4,137.7	3,051.9	-26%
Low Flow [3]	169.3	434.3	157%	302.8	3,194.1	955%	351.6	2,376.2	576%
Flow < median	263.3	407.4	55%	905.6	1,867.7	106%	3,508.0	2,261.9	-36%
Flow > median	772.9	824.3	7%	338.8	3,033.0	795%	354.6	2,193.7	519%

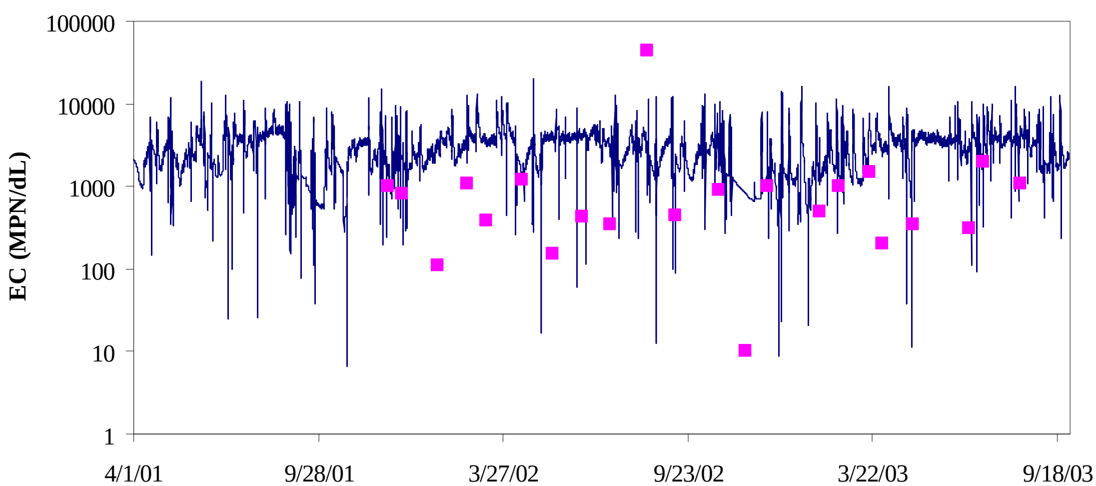
	West Belt (11360)			Briar Forest (15846)			Voss (11356)		
	Observed	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error[1]**
Overall	2,695.8	2,387.8	-11%	2,707.2	2,303.6	-15%	993.3	1,551.8	56%
High Flow [2]	5,797.7	3,255.3	-44%	10,157.9	3,369.5	-67%	1,810.6	1,997.1	10%
Low Flow [3]	611.3	1,998.0	227%	442.2	1,728.5	291%	408.1	1,477.9	262%
Flow < median	5,120.0	2,819.3	-45%	752.9	1,730.0	130%	489.2	1,256.4	157%
Flow > median	1,004.8	1,849.4	84%	6,822.1	2,832.9	-58%	2,181.8	1,962.0	-10%

	Chimney Rock (15845)			Shepherd (11351)		
	Observed	**Modeled**	**Error[1]**	**Observed**	**Modeled**	**Error[1]**
Overall	1,402.7	1565.8	12%	4,192.8	2,948.7	-30%
High Flow [2]	2,561.7	2046.4	-20%	7,469.4	3,582.5	-52%
Low Flow [3]	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%

Notes:
[1] Error statistics for geometric means are calculated as (observed - modeled)/observed
[2] High flow is considered periods when flow is greater than 70th percentile
[3] Low flow is considered periods when flow is less than 30th percentile



(A) Highway 6 (11364)



(B) Eldridge (11363)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou

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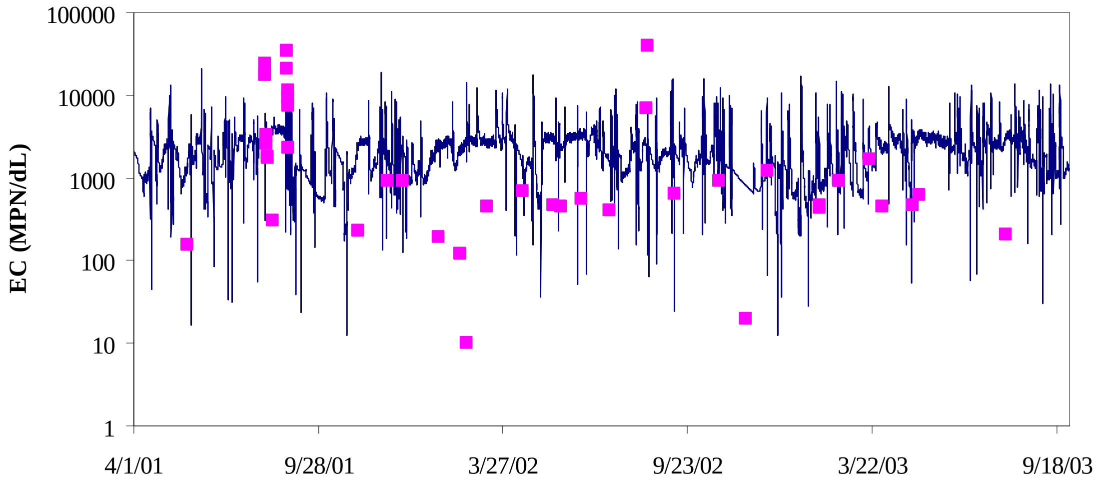
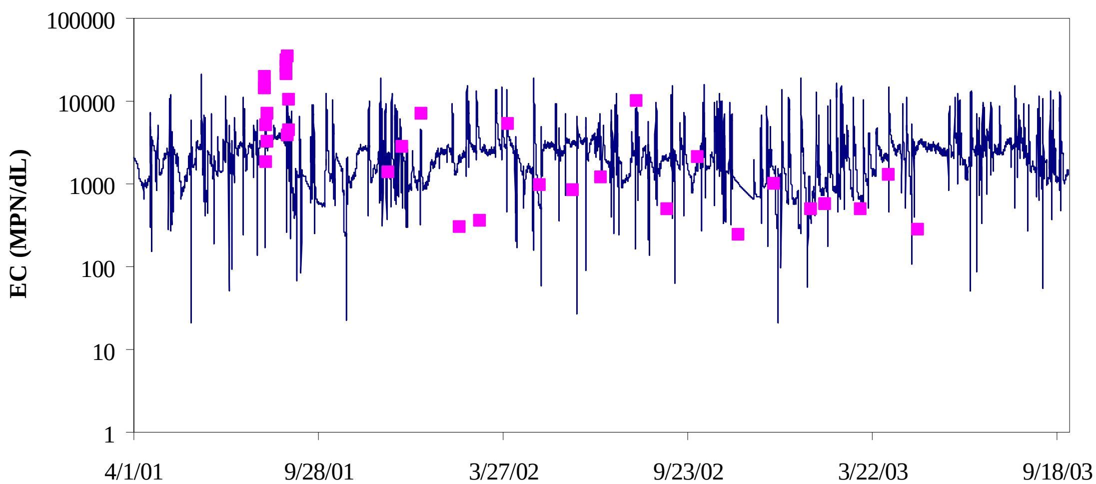


(C) Dairy Ashford (11362)



(D) West Belt (11360)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou, continued

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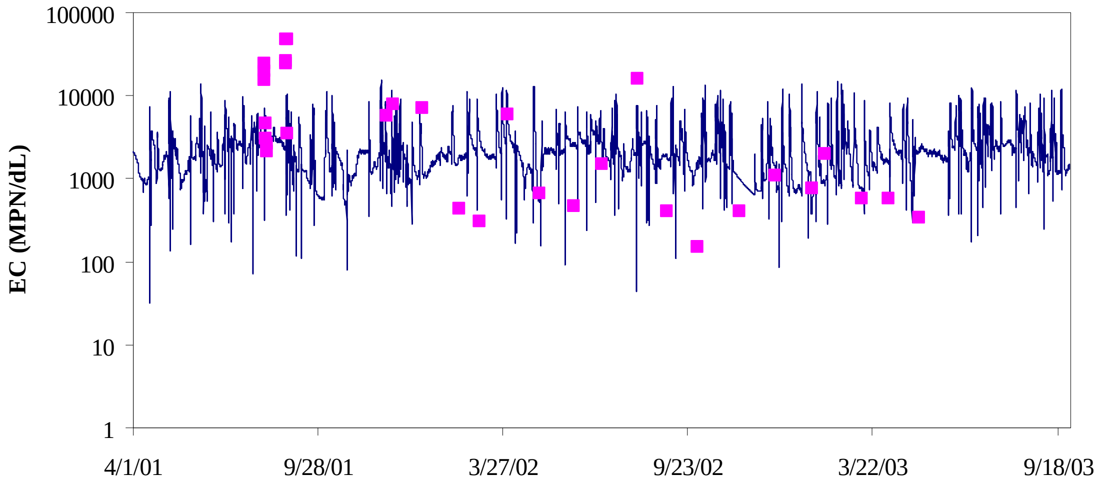
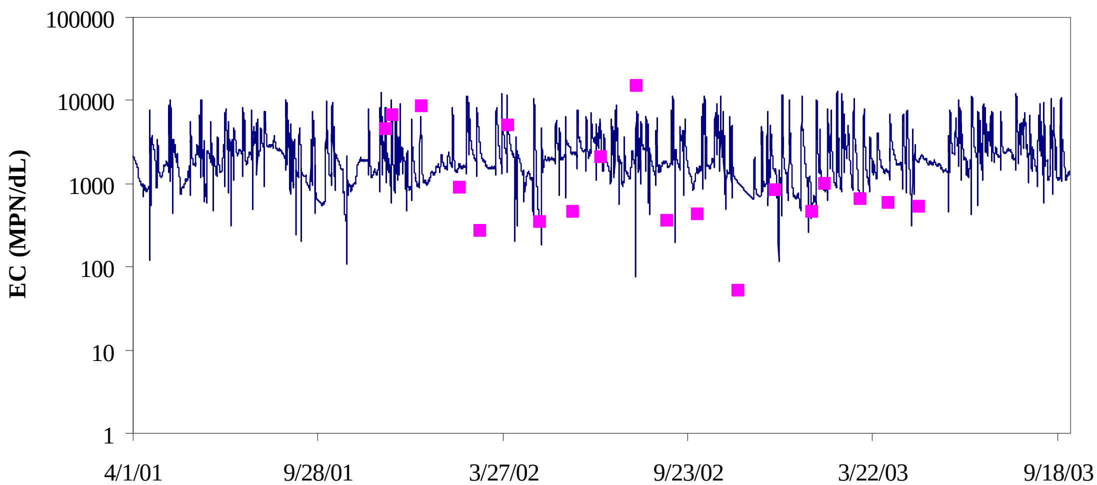


(E) Briar Forest (15846)



(F) Voss (11356)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou, continued

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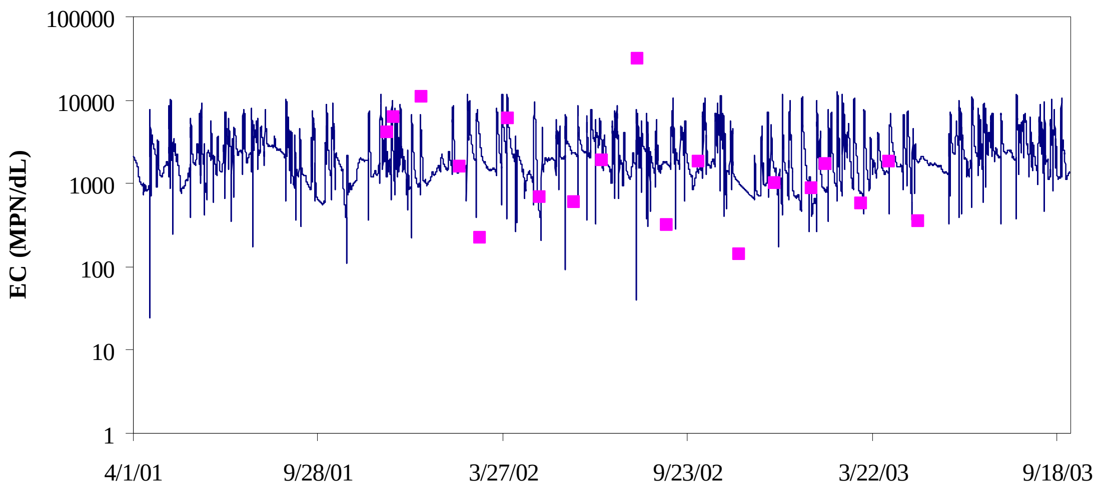
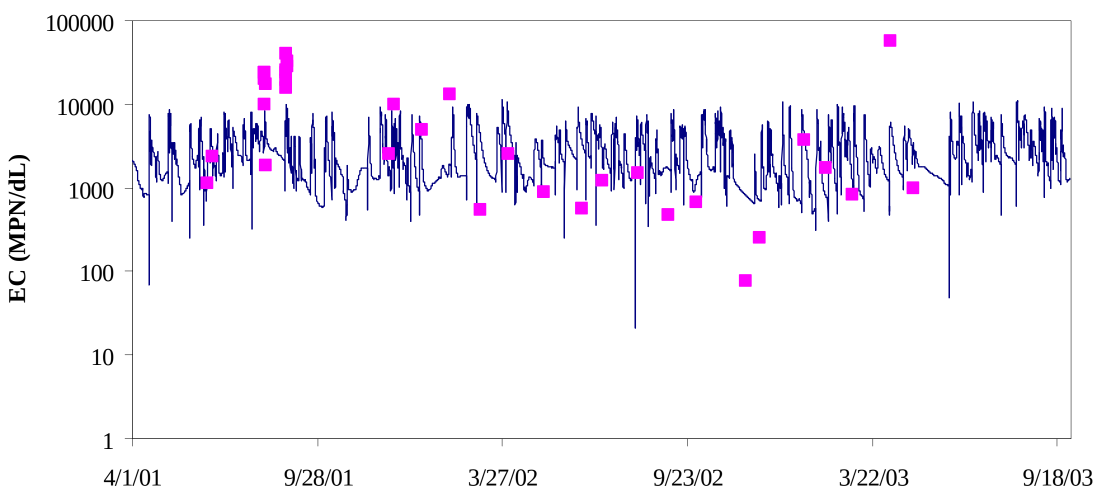


(G) Chimney Rock (15845)



(H) Shepherd (11351)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou, continued

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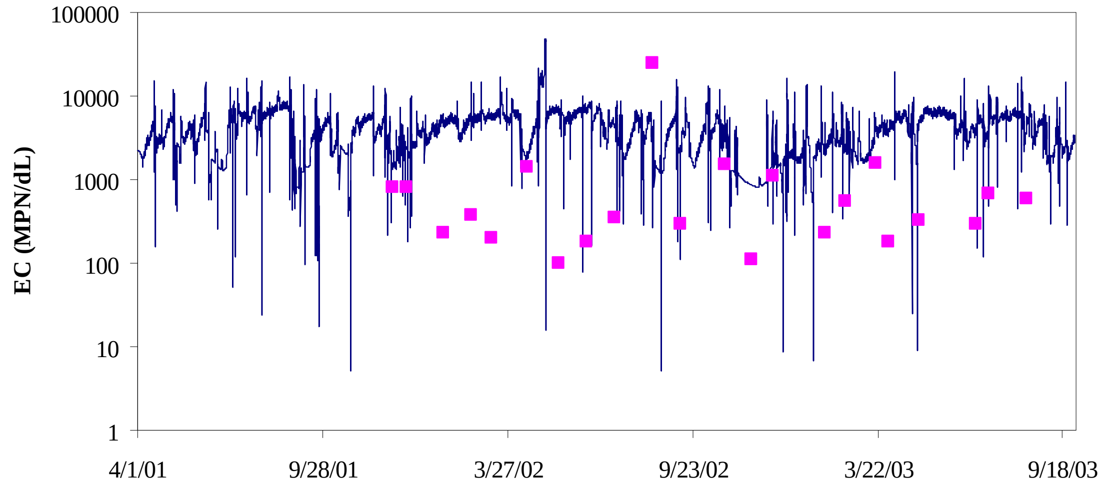
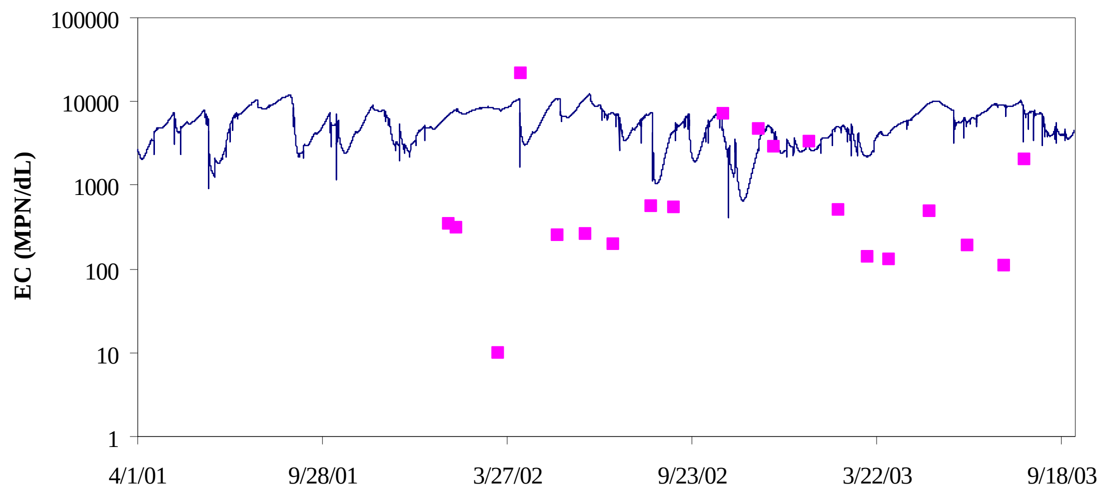


(I) Addicks (11613)



(J) Langham Creek (17482)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou, continued

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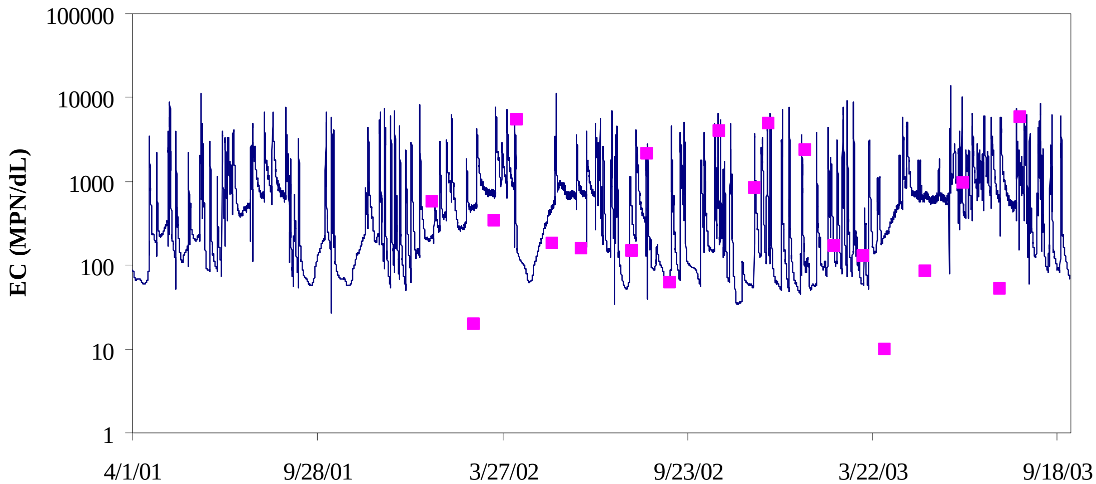
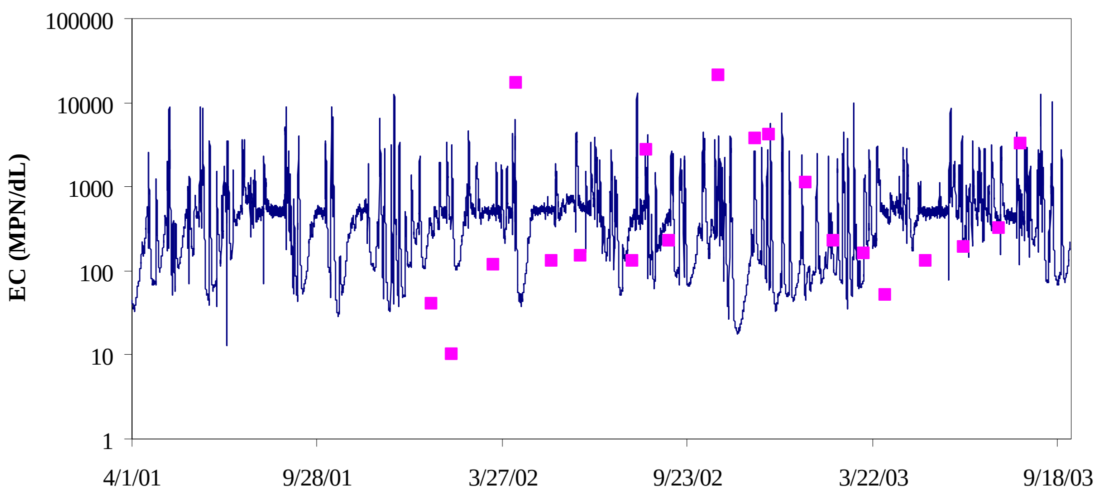


(K) Bear Creek (17484)



(L) South Mayde (17493)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou, continued

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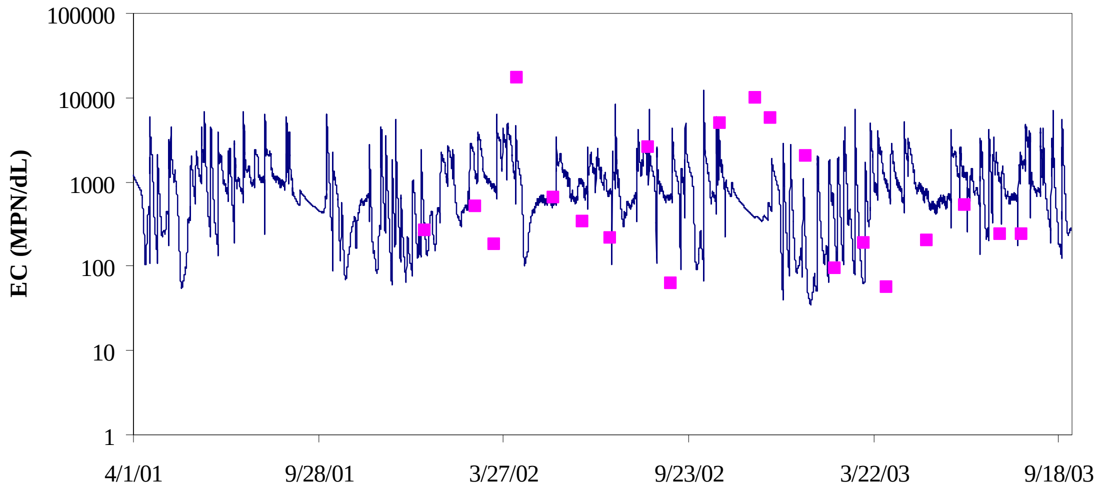
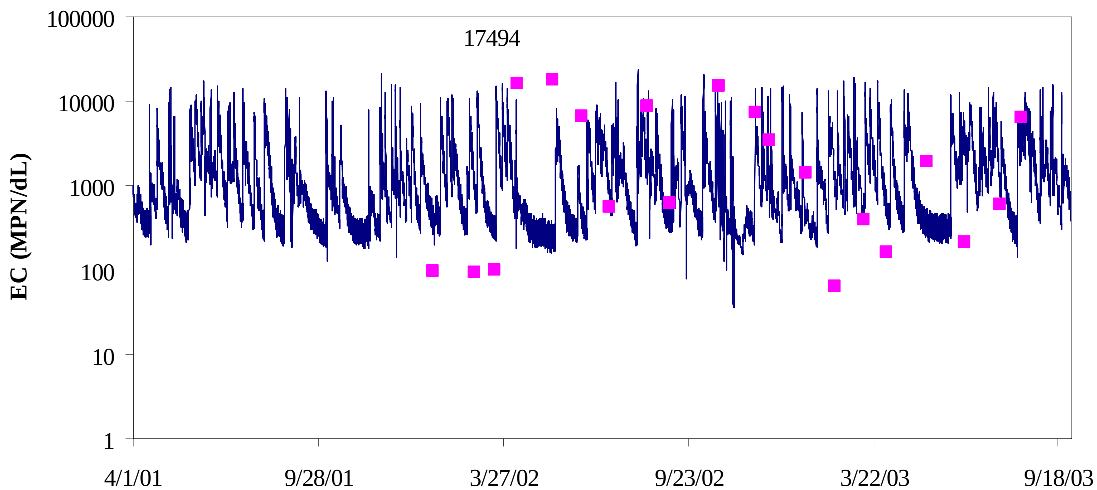


(M) Buffalo Bayou at Peek Rd (17492)



(N) Mason Creek (17494)

Figure 4.17 Calibration Plots for *E. coli* in Buffalo Bayou, continued

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overprediction of bacteria concentrations at Addicks, Eldridge, and Dairy Ashford. Although these plants appear to cause bacteria levels above observed levels, the WWTP concentrations were measured and therefore not adjusted to improve the model calibration.

Finally, a comparison of paired model and observed geometric means are shown in Figure 4.18. These plots demonstrate similar findings to Whiteoak Bayou, namely that the variability in observed values is generally quite large and 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 geometric mean concentrations. The only point that does not match well is located at Eldridge, which has already been explained.

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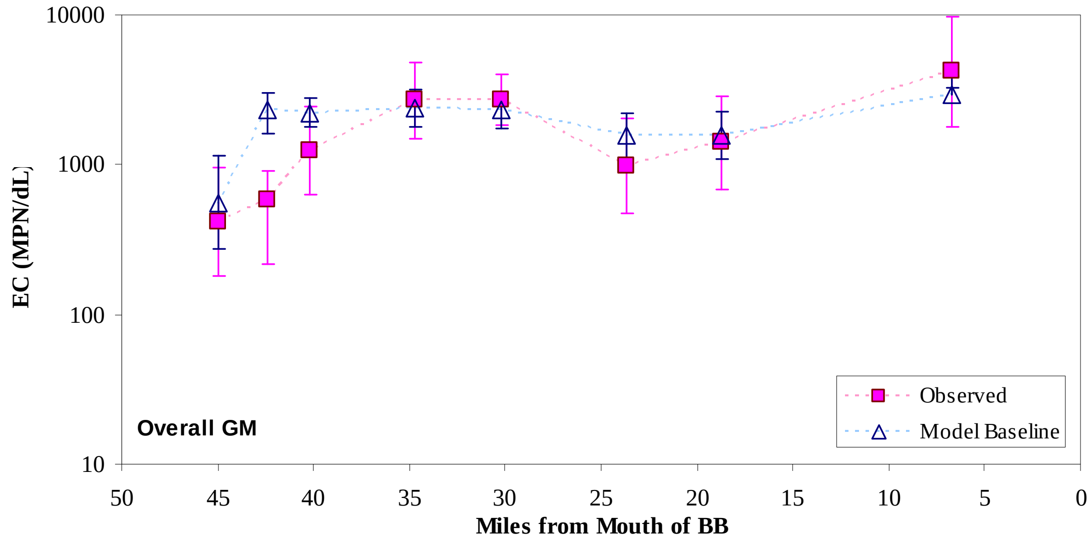
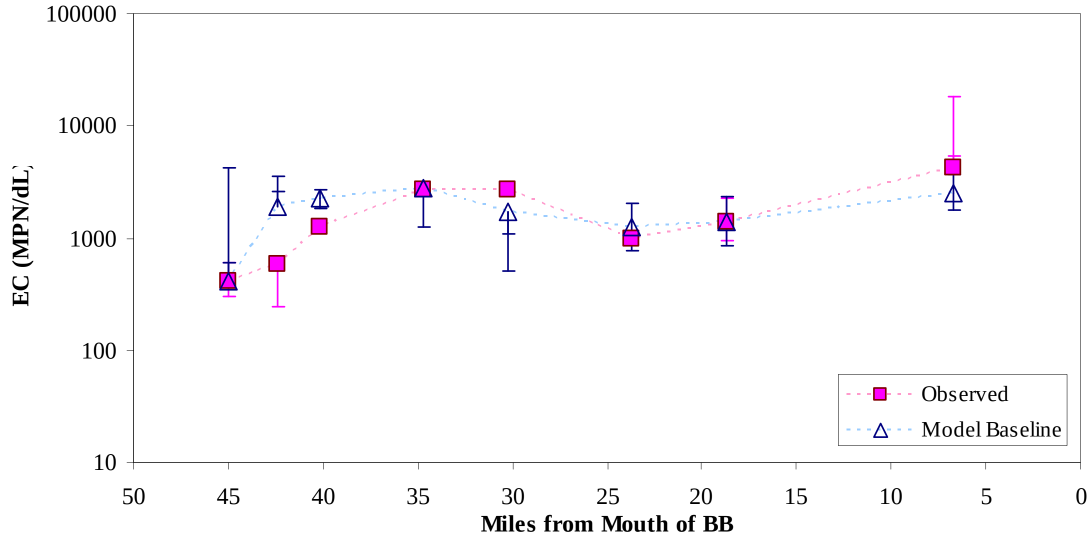


(A) Paired Geometric Means Under All Conditions



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

Figure 4.18 Longitudinal Plots for Buffalo Bayou

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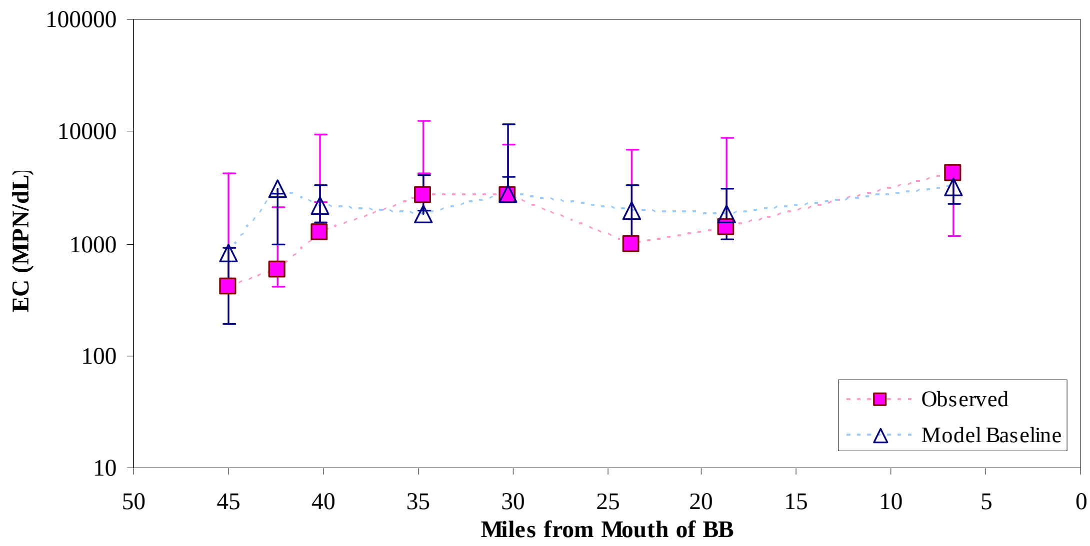

(C) Paired Geometric Means When Flows are Greater than Median

Figure 4.18 Longitudinal Plots for Buffalo Bayou, Continued

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CHAPTER 5 : SOURCE EVALUATION

The TMDL calculated for each segment is the maximum amount of pollutant that the stream can receive without exceeding the water quality standard. The TMDL can be distributed into several types of loadings, including the waste load allocation (WLA) and the load allocation (LA). The waste load allocation for the purposes of this TMDL project is comprised of the following sources:

- WWTP Discharges;
- Dry and Wet SSO Discharges; and
- Dry and Wet Storm Sewer Discharges.

The sources of loading that are considered part of the load allocation include:

- OSSFs;
- Direct Deposition; and
- Any other unaccounted processes such as die-off or regrowth.

Several means of evaluating sources have been developed for this TMDL. Available control options depend on the number, location, and character of pollutant sources.

5.1 LOAD DURATION CURVES

Although load duration curves (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. In addition, the remaining USGS gauges in the Buffalo Bayou watershed are not located at a segment boundary. Therefore,

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load reductions based upon the LDCs were only developed for segment 1017 and are shown in Table 5.1.

Load duration curves are based upon the entire flow regime, as described in Chapter 4, but the analysis of them focused on just three flow regimes: dry or low flow (flows less than 30^{th} percentile), intermediate conditions (between the 30^{th} and 70^{th} percentiles) and wet or high flow conditions (flows greater than the 70^{th} percentile). The observed load was calculated as the median value of the observed loads plotted on the LDC for each flow regime of interest, while the TMDL was the median of the single sample water quality standard load for each flow condition. As can be seen from the table, load reductions ranged from 85% under dry weather conditions to over 90% under intermediate weather conditions. These loads are comparable to those listed in Table 5.1, where load reductions between 85% and 94% were needed for the Whiteoak Bayou watershed.

The US EPA (2006) specifies a methodology in their document "An Approach for Using Load Duration Curves in the Development of TMDLS" for calculated the WLA for continuous discharges. According to this document, the load should be calculated as the permitted flow from all WWTPs discharging to the segment multiplied by the single sample standard, which is 691 billion MPN/day.

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Table 5.1 Load Duration Curve Allocations for Segment 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 – Continuous	671	671	671	671
	WLA - Non-continuous	0	0	0	1,175
	LA	0	0	0	1,175
TMDL [2]		490	334	526	3,022
Percent Reduction		91%	85%	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

Because of the large number of WWTPs that routinely discharge well below their permitted flows, the WLA for continuous discharges is greater than the TMDL for the dry and intermediate flow conditions, as well as the overall flow condition. This left no remaining load to distribute to the LA or non-continuous WLA (which is considered to be MS4 dischargers). Under wet weather conditions, the remaining load was distributed evenly between the WLA – Non-continuous and LA, although the distribution between the two scenarios could be adjusted based upon any number of criteria, such as the estimated contributions from each source or the ability to control the loads under wet weather conditions.

5.2 BLEST

BLEST, as described in Section 4, is a spreadsheet approach that accounts for all the potential sources of bacteria loading in the watershed, based upon measured data or literature values. Using the loads predicted by BLEST, waste load and load allocations were determined for Buffalo and Whiteoak Bayous. A summary of estimated loads along with the allocated loads and required percent reductions is presented in **Table 5.2**.

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The bacteria load was distributed between the WLA and LA for the BLEST allocations. The WLA was calculated as 90% of the available loading, once the upstream loads had been removed. The remaining 10% of the load was allocated to the LA. The TMDL target was calculated using the geometric mean concentration of 126 MPN/dL, to be representative of long-term conditions. Finally, the upstream input loading was calculated as the upstream flow from WWTPs multiplied by 63 MPN/dL added to the flow from the remaining sources multiplied by 126 MPN/dL, the geometric mean standard.

The allocations are presented in **Table 5.2** and range from 98.16 billion MPN/day under dry weather conditions in the Reservoirs Watershed to over 2,590.16 billion MPN/day in Segment 1013 under wet weather conditions.

Table 5.2 Allocated Loads (billion MPN/day) and Percent Reductions using BLEST

Description		1013			1014		
		Dry	Intermediate	Wet	Dry	Intermediate	Wet
Existing	WLA	24.57	3,043.64	172,539.76	303.46	107,198.49	323,372.43
	LA	-4.49	-2,349.91	-133571.85	-196.87	-83,240.38	-250277.80
Allocated	WLA	82.80	94.76	531.75	124.07	401.02	953.81
	LA	9.20	10.53	59.08	13.79	44.56	105.98
	Upstream	94.94	650.31	1,999.32	49.08	301.47	1,042.05
TMDL		186.94	755.60	2,590.16	186.94	747.05	2,101.84

Description		1017			Reservoirs		
		Dry	Intermediate	Wet	Dry	Intermediate	Wet
Existing	WLA	312.65	23,670.12	342,738.34	5,455.53	87,672.19	329,645.70
	LA	5.79E-04	5.79E-04	5.79E-04	-4,124.31	-67,995.95	-231,390.34
Allocated	WLA	88.91	153.31	975.30	88.34	317.77	987.06
	LA	9.88	17.03	108.37	9.82	35.31	109.67
	Upstream	0.00	0.00	0.00	0.00	0.00	0.00
TMDL		98.79	170.34	1,083.66	98.16	353.08	1,096.73

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5.3 HSPF

The final method that was used to evaluate load reductions and distribution was the HSPF model. The HSPF model was evaluated for three load reductions scenarios, 75%, 85% and 95% reductions of both load and wasteload allocations. The load reductions were implemented across the watershed but the WLAs reductions were implemented separated from the LA reductions. The 75% reduction was selected as the starting point for reductions as it was consistent with the low-end of reductions determined using BLEST and the LDC. Each of the reduction scenarios was evaluated for a total of four flow conditions: all flow conditions, dry weather conditions (flows less than the 30^{th} percentile), intermediate conditions (flows between the 30^{th} and 70^{th} percentiles) and wet weather (flows greater than the 70^{th} 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. In order for the stream to be considered unimpaired, the geometric mean of routine monitoring samples must be less than 126 MPN/dL and the single sample standard exceedances must be less than 25%. Results for Segment 1013 from the Whiteoak and Buffalo Bayou models were combined into a single dataset and used for analysis.

The results of the percent exceedances analysis are presented in **Table 5.3** and cumulative frequency plots of daily *E. coli* concentrations are shown in **Figure 5.1 through 5.4** for each segment. As shown in the table, the LA reductions had very 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 of an impact. In Segment 1013, the 75% reduction scenario reduced the percent exceedances from 100% to between 85% and

Table 5.3 Percent Exceedance of Single Sample Standard for HSPF Model Runs

Segment 1013 - Buffalo Bayou Tidal

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

Segment 1014

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

Segment 1017

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

Reservoirs

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

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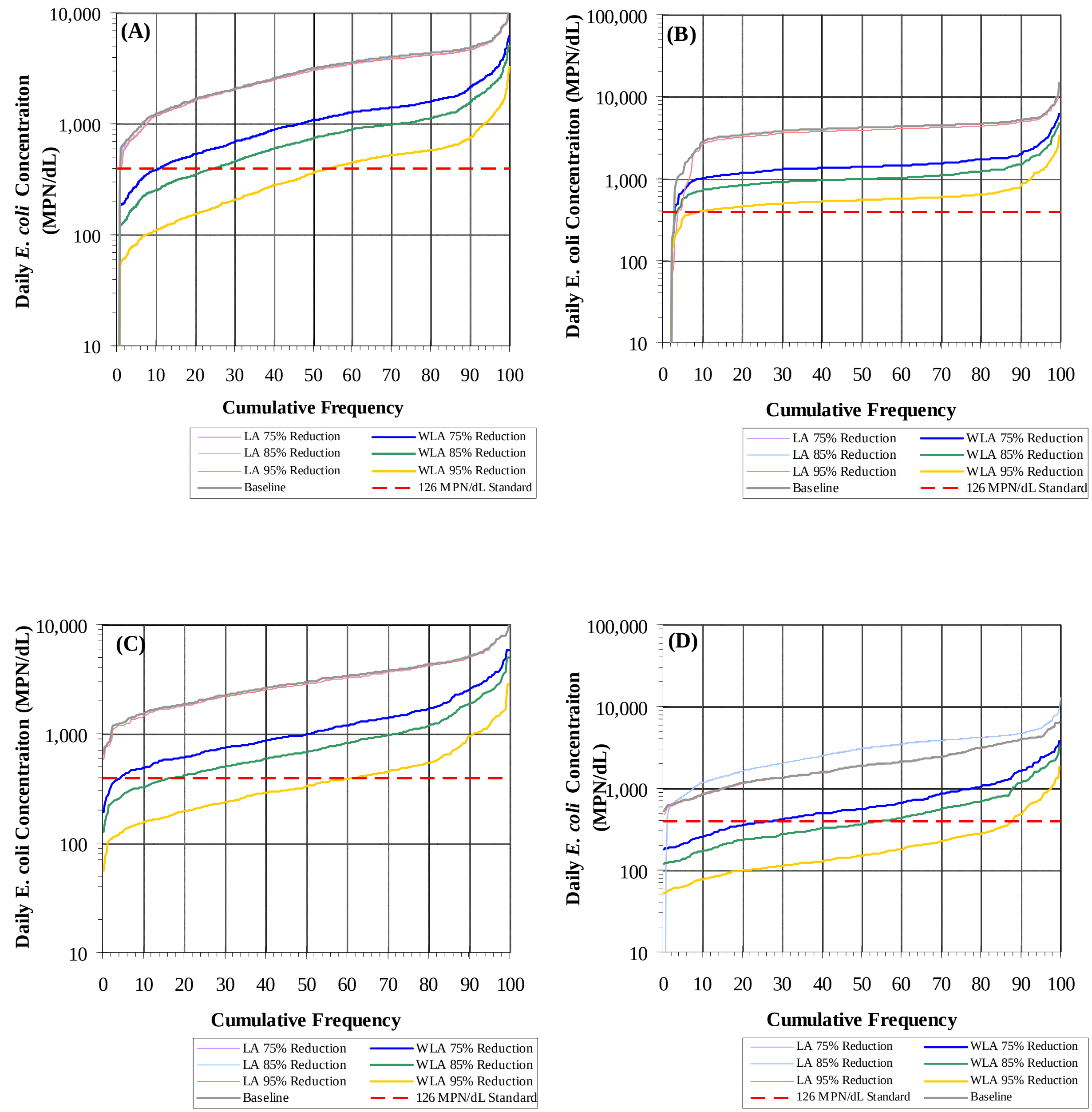

Figure 5.1 Cumulative Frequency Plots for Reservoir Segments under (A) all conditions, (B) dry weather conditions, (C) Intermediate conditions and (D) wet weather conditions.

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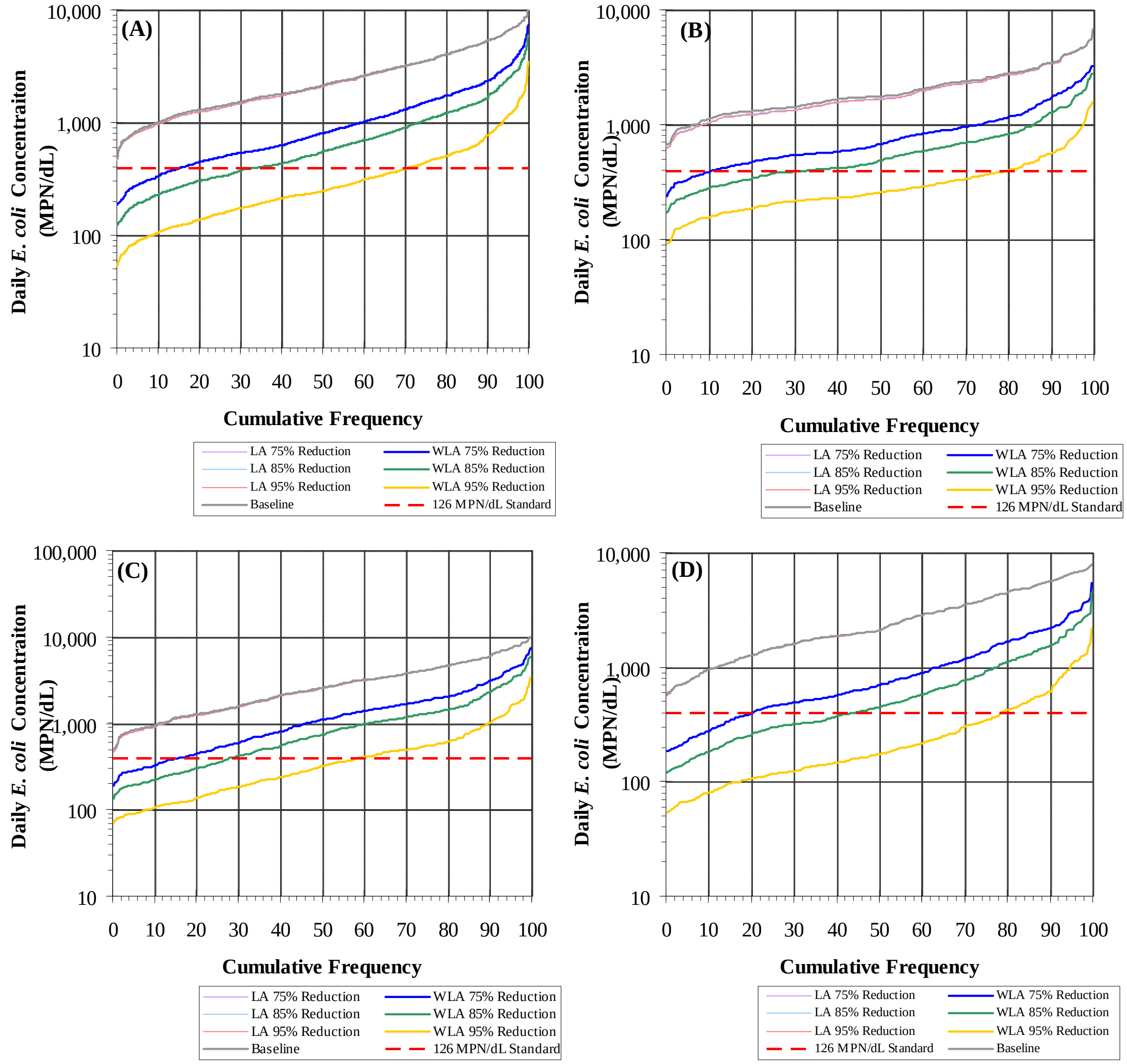

Figure 5.2 Cumulative Frequency Plots for Segment 1014 under (A) all conditions, (B) dry weather conditions, (C) Intermediate conditions and (D) wet weather conditions.

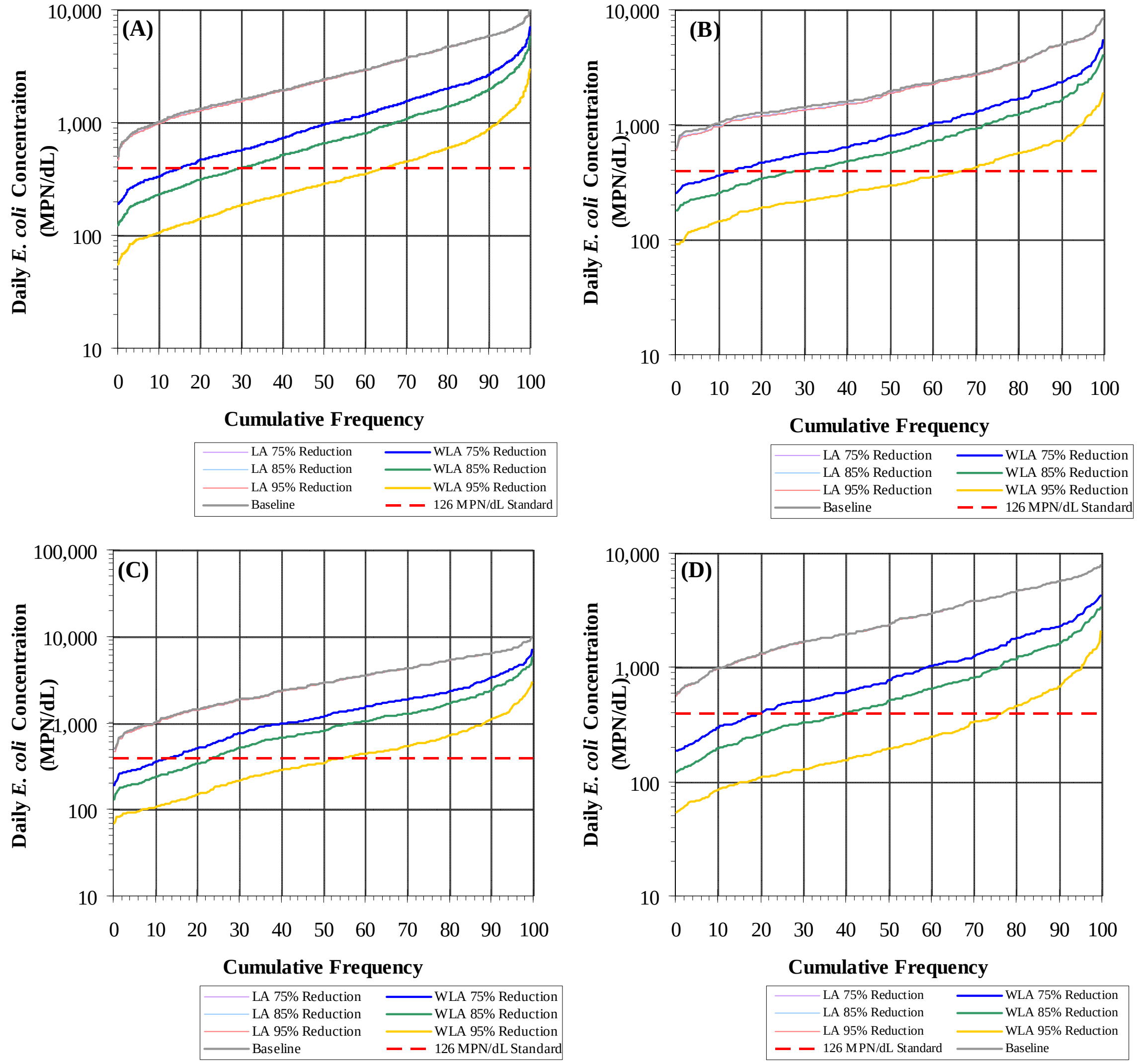

Figure 5.3 Cumulative Frequency Plots for Segment 1013 under (A) all conditions, (B) dry weather conditions, (C) Intermediate conditions and (D) wet weather conditions.

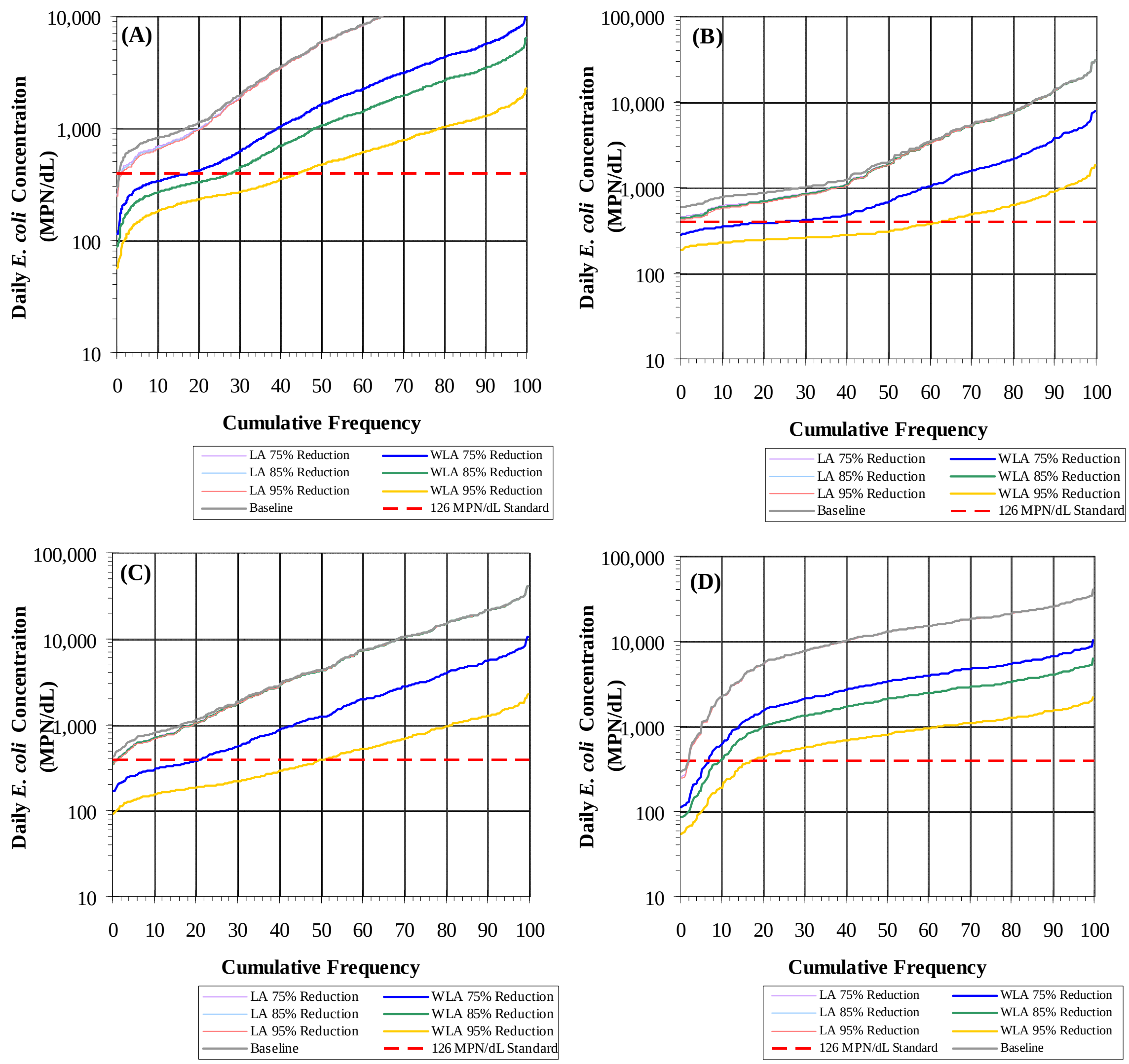

Figure 5.4 Cumulative Frequency Plots for Segment 1017 under (A) all conditions, (B) dry weather conditions, (C) Intermediate conditions and (D) wet weather conditions.

89% depending on the flow conditions. The 95% reduction reduced the percent exceedances to 29% in dry weather, thus meeting the single sample standard criterion. For the other segments, a similar pattern is observed, with the 95% reductions resulting in some flow conditions meeting the single sample standard criterion.

In **Table 5.4**, the results of the reductions on the geometric mean of the entire simulation period is presented. Unlike the percent exceedances runs, the model results generally come close to the geometric mean standard but never drop below. Although the model has the ability to simulate a bacteria concentration every hour to obtain an average daily *E. coli* concentration, samples cannot be collected with such frequency. Instead, TCEQ collects routine monitoring samples at most monitoring stations approximately once per month. Therefore, the geometric mean of the minimum and maximum daily values for each month were tabulated as shown in **Table 5.5**. These values give an 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 do fall below the water quality standard for all segments except Segment 1013 when the WLA is reduced by 95%.

These findings suggest that a combination of WLA and LA reductions will be required across the watershed, and reductions greater than 95% will be necessary to achieve water quality standards under all three flow conditions. Any number of combinations can be implemented to meet the TMDL target load, based upon the needs of those in the watersheds.

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Table 5.4 Geometric Mean of Entire HSPF Simulation Period

Segment 1013

Source Reduced	% Reduction	All	Dry	Intermediate	Wet
Baseline		3,241	2,292	3,820	3,685
WLA	1,091	843	1,301	1,119	814
	736	595	873	725	540
	321	293	370	291	220
LA	3,188	2,212	3,776	3,670	2,388
	3,181	2,201	3,770	3,669	2,386
	3,174	2,190	3,765	3,667	2,385

Segment 1014

Source Reduced	% Reduction	All	Dry	Intermediate	Wet
Baseline		2,236	1,894	2,476	2,305
WLA	75%	858	748	1031	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

Segment 1017

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

Reservoirs

Source Reduced	% Reduction	All	Dry	Intermediate	Wet
Baseline		2,612	3,248	2,879	1,846
WLA	75%	933	1214	1050	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

Table 5.5 Monthly Geometric Mean Over HSPF Simulation Period

Segment 1013

Source Reduced	% Reduction	Minimum	Maximum
Baseline		1,080	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

Segment 1014

Source Reduced	% Reduction	Minimum	Maximum
Baseline		1,651	3,968
WLA	75%	358	3616
	85%	247	2759
	95%	120	1274
LA	75%	1,009	6,702
	85%	1,003	6,699
	95%	997	6,697

Reservoirs

Source Reduced	% Reduction	Minimum	Maximum
Baseline		824	5,968
WLA	75%	303	3005
	85%	211	2278
	95%	100	1164
LA	75%	753	5,869
	85%	734	5,855
	95%	710	5,843

Segment 1017

Source Reduced	% Reduction	Minimum	Maximum
Baseline		804	28,131
WLA	75%	319	7,226
	85%	249	4,436
	95%	169	1,643
LA	75%	678	28,070
	85%	661	28,058
	95%	644	28,050

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5.4 SUMMARY OF LOAD ALLOCATION METHODS

As shown in the previous section, three different methods were used to evaluate bacteria loading and the required reductions to meet the TMDL for each segment. Findings from the three models are fairly consistent. They all predict greater than a 70% 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% reduction in WLA and LAs to meet the water quality standard. Thus, all three methods are consistent in their findings and ultimately suggest that large reductions in loading under all three flow conditions will be required to meet the TMDL target loads.

5.5 UNCERTAINTY AND CONSERVATIVE ASSUMPTIONS

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

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CHAPTER 6 : PUBLIC PARTICIPATION

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

A total of 18 meetings have been held between May 2000 and July 2007 to present both project status reports from the TCEQ as well as updates on the technical aspects of the project as well. The meetings were held at project milestones and were also used to solicit input and feedback from the stakeholders. Stakeholder input was invaluable as it provided local insight to the project staff.

Websites housed at the TCEQ (http://www.tceq.state.tx.us/implementation/water/tmdl/22-buffalobayou_group.html) and the Houston-Galveston Area Council (http://www.h-gac.com/community/water/tmdl/notes/ default.aspx) provided access to meeting summaries, presentations, ground rules and a list of stakeholder group members. The websites were frequently update to ensure that absent stakeholders and the public were informed of meetings and their findings.

A summary of the stakeholder group involvement and the presentations given at the meetings is included in Appendix J.

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CHAPTER 7 : REFERENCES

Bicknell, B.R., J. C. Imhoff, J. L Kittle, and A. S. Donigian. (1996). “Hydrologic Simulation Program – Fortran User’s Manual for Release 11.” Environmental Research Laboratory, Athens, Georgia.

H-GAC. (2001a). "2001 Draft Basin Summary Report" Houston, TX.

H-GAC. (2001b). "H-GAC Land Use Estimates Year 2000, Raz Level." Houston, TX.

H-GAC. (2002). "Land Cover Classification." Houston, TX.

H-GAC. (2005). "Gulf Coast Regional Water Quality Management Plan Update: 2005; Appendix III: On-site sewer facilities - Considerations, Solutions, and Resources." H-GAC, Houston, TX.

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.

Natural Resource Conservation Service. (1994). “STATSGO Soils.” Downloaded from Texas Natural Resources Information System, http://www.tnris.state.tx.us, July 2002.

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

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.

Soil Survey Division Natural Resources Conservation Service United States Department of Agriculture. (1994). "Official Soil Series Descriptions." http://www.statlab.iastate.edu/soils accessed August 8, 2002.

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

TCEQ. 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 commission on June 13, 2007 and by US EPA on August 28, 2007.

US EPA. (2000). "BASINS Technical Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF." Document Number 823-R00-012, Washington, D.C.

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

US EPA. (2006). "An Approach for Using Load Duration Curves in the Development of TMDLS."

Weiskel, P. K., Howes, B. L., and Heufleder, G. R. (1996). "Coliform Contamination of Coastal Embayment: Sources and Transport Pathways." Environmental Science and Technology, 30(6), 1872-1881.
`

Young, K. D., and Thackston, E. L. (1999). "Housing Density and Bacterial Loading in Urban Streams." Journal of Environmental Engineering, 125(12), 1177-1180.

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