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

Contract No. 582-6-70860
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FINAL REPORT

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CHAPTER 1 : INTRODUCTION

Buffalo Bayou (Segments 1013 and 1014) and Whiteoak Bayou (Segment 1017) are considered impaired water bodies for contact recreation because they do not meet pathogen water quality standards. As a result, the two bayous were placed on the Texas Clean Water Act 303(d) List in 1996, and the current study was initiated in 2001. In 2002, eleven (11) tributaries of these bayous were placed on the 303(d) list for not meeting pathogen water quality standards. The purpose of this study is to provide the TCEQ with the information and assistance necessary for the prEPAration of a Total Maximum Daily Load (TMDL) for the pathogen impairments in Buffalo and Whiteoak Bayous and their listed tributaries.

There have been several work orders comprising this study since the inception of the project. During Fiscal Year 2001, Work Order 1 consisted of analysis of historical information for current levels and trends as well as an assessment of the major sources of bacteria to the two bayous. Work Order 2, completed in Fiscal Year 2002 included the investigation of suspected sources of bacteria, including sediment, wastewater treatment plants, and dry weather storm sewer flows. A water quality model was developed as a part of Work Order. In Fiscal Year 2003, Work Order 5 was completed and the scope included investigation of bacteria in sediment, potential load allocations and best management practices that may be practical for application in the study watersheds. During Fiscal Year 2004, Work Order 6 consisted of the identification and characterization of additional potential sources of bacteria into the bayous. Tasks in Work Order 8, completed in Fiscal Year 2005, focused on completing source data collection, as well as refining and developing load allocation methodologies.

This document is the Final Report for Work Order 1 under contract 582-6-70860. The report presents the load reductions calculated over the past year using the Bacteria Load

Estimator Spreadsheet Tool (BLEST). Chapter 2 describes stakeholder activities while Chapter 3 presents BLEST and load reduction calculations. Conclusions and future work are included in Chapter 4.

CHAPTER 2 : STAKEHOLDER/PUBLIC EDUCATION AND INVOLVEMENT

The University of Houston supported the stakeholder process facilitated by the Houston Galveston Area Council (HGAC) and Mary Jane Naquin, an independent consultant. The following support tasks were performed by the University of Houston:

- Development of informational materials summarizing the technical aspects of the project for electronic and hard copy distribution at stakeholder meetings including documents, maps, and quarterly reports;
- Preparation of responses to questions and information requests from stakeholders;
- Providing rationale for whether or not certain requests by stakeholders for refinement in technical analysis can be achieved;
- Participation in stakeholder meeting on November 1, 2005
- Preparation of slides and participation in stakeholder meeting February 7, 2006 (Slides attached in Appendix A);
- Preparation of web-based project informational briefs;
- Attendance of a Refinement Opportunities/Reducing Uncertainty in TMDLs meeting on May 3, 2006, with Chairman Kathleen White; and
- Provision of technical expertise on issues related to microbiological, public health, urban wastewater infrastructure, and water quality.

CHAPTER 3 : 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 (WQ) standard for the segment. BLEST estimates load reductions for a fixed time interval and a given segment and does not incorporate the temporal variations associated with pathogen loads. BLEST, however, does allow an evaluation of loads on a subbasin basis.

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

1. Wastewater treatment plant discharges; and
2. Municipal separate storm sewer system (MS4) discharges.

Sources included in the load allocation include the following:

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

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

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

Finally, the wet weather condition is reflective of flows that are received at the peak of a typical Houston rainfall event (defined as precipitation of 0.8 inches over 24 hours). Therefore, the wet weather condition implemented in BLEST incorporates bacteria sources that may be acting only under high flow conditions such as bed sediment resuspension.

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

3.1 LOCATION OF SEGMENTS

The two study watersheds, Buffalo and Whiteoak Bayous, are made up of three water quality segments, segments 1013, 1014, and 1017. The segment boundaries are defined by TCEQ and are shown in Figure 3.1. Segment 1013 is the tidal portion of Buffalo Bayou, with the upper part of the segment being defined just upstream of where the bayou crosses Shepherd

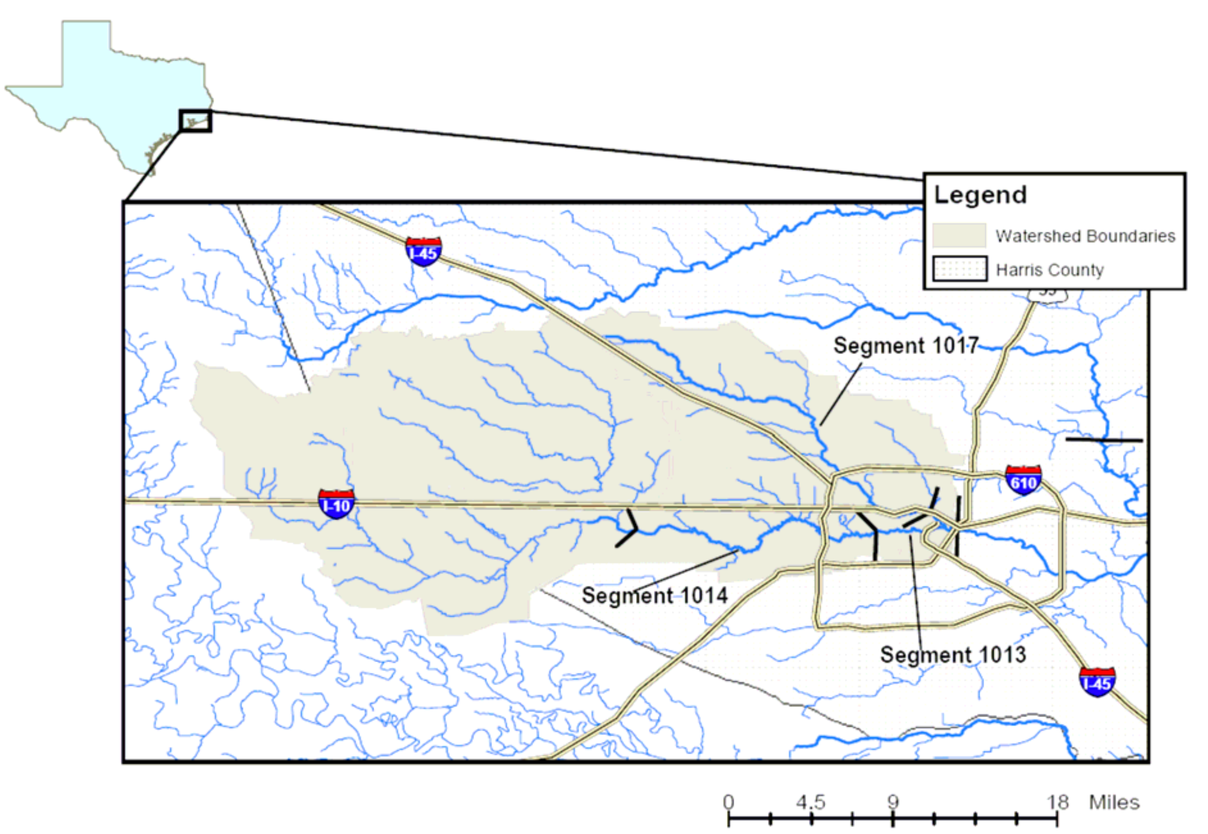


Figure 3.1. Locations of Segments in the Buffalo and Whiteoak Bayou Watersheds

Drive and the segment ending about 100 m north of US 59. This segment also encompasses the lower portion of Whiteoak Bayou, from the confluence of Little Whiteoak Bayou downstream. Segment 1014 is located in the above-tidal portion of Buffalo Bayou. Segment 1017 is the above-tidal portion of Whiteoak Bayou. In addition to the load analyses that were conducted for each of the segments, an analysis of the loading entering Segment 1014 has also been completed and is denoted as "Mouth of Reservoir Watersheds" for the purposes of this discussion.

The analyses described in this report are completed using subwatersheds. The subwatersheds were previously discussed in the Final Report for Work Order 2 (2002) in Section 5.1 and the Final Report for Work Order 8 (2005) in Section 10.3. These subwatersheds are based upon Harris County Flood Control District watersheds used for hydrology and hydraulics modeling, and were modified slightly to match water quality modeling needs. The subwatersheds are presented in Figure 3.2.

3.2 WASTE LOAD ALLOCATIONS

The waste load allocation of a total maximum daily load (TMDL) includes all bacteria sources regulated through environmental permitting. In the Buffalo and Whiteoak Bayou bacteria TMDLs, this includes wastewater treatment plant (WWTP) discharges and municipal separate storm sewer system (MS4) discharges. The load estimation methods for these sources will be described in the next section.

3.2.1 WASTEWATER TREATMENT PLANT DISCHARGES

Wastewater treatment plant (WWTP) effluent makes up a large portion of the bayou flow under dry weather conditions. As such, these discharges have the potential to make up a large portion of the bacteria load because of their nature. Flows and loads were estimated for WWTPs during dry weather, wet weather and releases associated with biosolid releases. The development of these values is described in the following section.

3.2.1.1 WWTP EFFLUENT

Flows and loads associated with typical 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

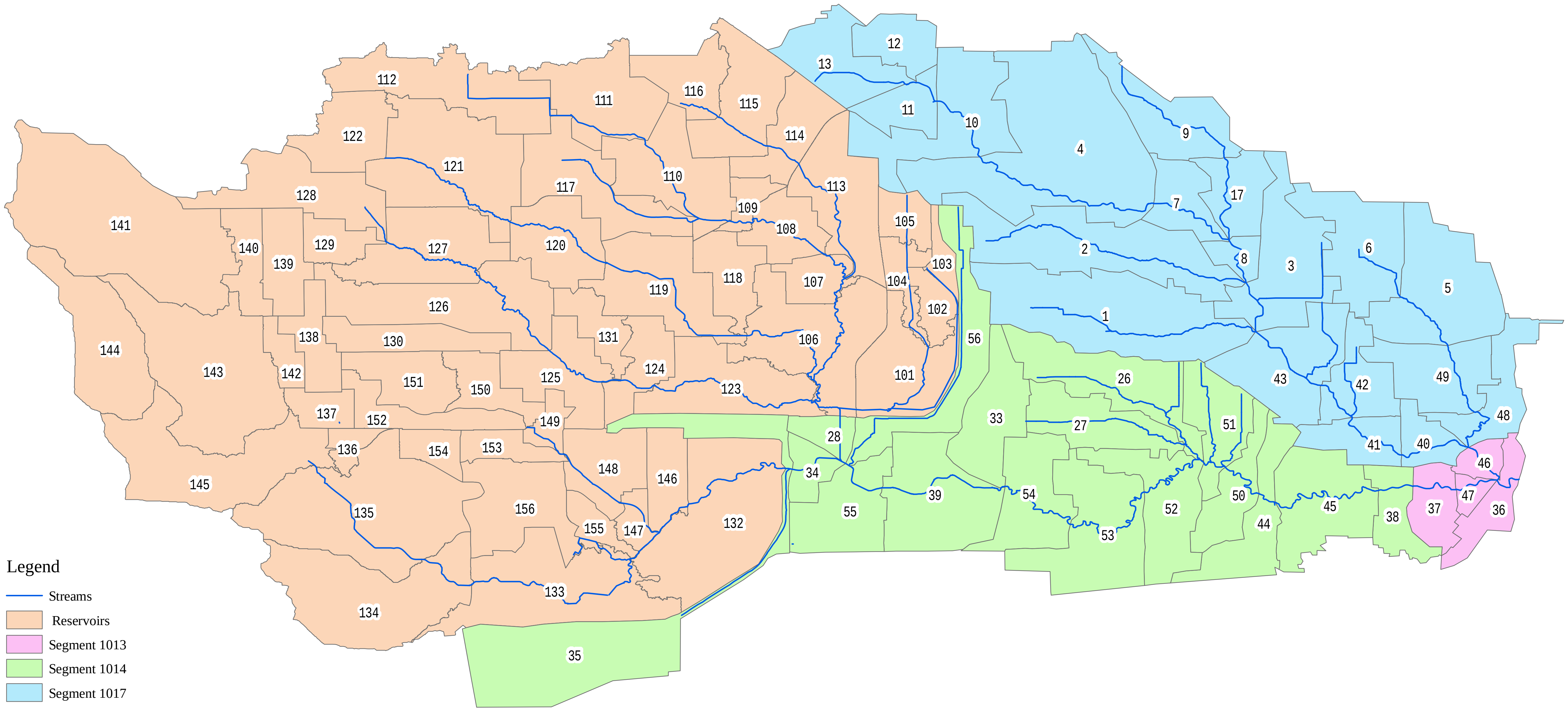


Figure 3.2: Subbasins Used in the Bacteria Loading Estimator Spreadsheet tool

period between 1999 and 2003 and reported in Appendix G of the Final Report for Work Order 8 (2006). The monthly self-reported flows were averaged to determine a daily flow as shown in Table 3.1.

Loads from these sources were developed using monthly self-reported flows and measured bacteria concentrations, when available. Bacteria concentrations used in the calculation of WWTP loads were measured in 2001 at a total of 75 municipal and industrial WWTPs in the two watersheds in the study. Results of this sampling were reported in the Final Report for Work Order 2 (2003). Samples were collected at peak periods (early morning) and off-peak periods (mid-morning) and the average of the two reported periods was used to calculate the bacteria load for each sampled plant. Watershed-specific geometric means of the sampled plants were calculated and applied for the plants that did not have bacteria samples. The geometric mean for Buffalo Bayou was calculated as 2.4 MPN/dL for peak periods and 1.4 MPN/dL for off-peak times. In Whiteoak Bayou, the geometric means were found to be higher: 4.0 MPN/dL for peak periods and 3.0 MPN/dL for off-peak periods. Bacteria concentrations used to calculate the loading for each plant are shown in Table 3.1, as are the final dry condition loads. The loads were calculated by multiplying the average self-reported flows (in deciliters (dL) per day) times the *E. coli* concentration in most probable number (MPN) per dL to give the total MPN per day.

Table 3.1. WWTP Self-reported Flow, *E. coli* and Load During Dry Weather Conditions

WWTP	Subbasin	Avg. Self-reported Flow (MGD)[1]	E. coli (MPN/dL)	Load (MPN/day)
10495-139	1	0.483	0.5	9.13E+06
10495-076	2	8.7	3.5	1.15E+09
11193-001	2	0.506	711.4	1.36E+10
12139-001	2	0.0238	1039.9	9.36E+08
12222-001	2	0.0675	14812.0	3.78E+10
13996-001	2	0.00163	3.5	2.15E+05
02710-000	4	0.000838	3.5	1.11E+05
04760-000	4	0.00146	3.5	1.93E+05
11051-001	4	0.0345	46.8	6.11E+07
11188-001	4	0.253	0.5	4.78E+06
11273-001	4	0.422	1.0	1.64E+07
11375-001	4	0.0968	17.8	6.53E+07
11389-001	4	0.00934	1.8	6.36E+05
11485-001	4	0.407	0.8	1.15E+07
11538-001	4	1.04	3.5	1.38E+08
11670-001	4	0.325	17.0	2.08E+08
12342-001	4	0.019	1.3	9.00E+05
12443-001	4	0.00131	7.4	3.67E+05
12552-001	4	0.00581	3.5	7.69E+05
12552-002	4	0.00474	3.5	6.28E+05
13433-001	4	0.0117	0.5	2.21E+05
13509-001	4	0.0133	71.2	3.59E+07
13578-001	4	0.00632	0.5	1.20E+05
13623-001	4	0.0723	0.5	1.37E+06
13689-001	4	0.337	176.5	2.25E+09
13727-001	4	0.00703	0.5	1.33E+05
13807-001	4	0.000748	0.5	1.41E+04
13939-001	4	0.00116	3.5	1.53E+05
13983-001	4	0.000885	3.5	1.17E+05
10495-099	7	1.7	3.5	2.25E+08
12573-001	9	0.00973	3.5	1.29E+06
12714-001	9	0.144	1.3	6.88E+06
14359-001	9	0.0313	3.5	4.15E+06
11563-001	10	0.668	14.4	3.62E+08
11979-002	10	0.189	3.5	2.50E+07
12397-001	10	0.00437	3.5	5.79E+05
12574-001	10	0.122	1.3	5.88E+06
12681-001	10	0.183	3.5	2.42E+07
14072-001	10	1.01	8.9	3.40E+08
12121-001	11	0.932	13.3	4.68E+08
12795-001	11	0.191	176.1	1.27E+09
10876-001	13	0.869	4.4	1.45E+08
10876-002	13	0.881	5.2	1.74E+08
12465-001	13	0.00518	96.8	1.90E+07
11005-001	17	0.147	1.3	7.24E+06
02731-000	27	0.00167	1.9	1.18E+05
10495-030	33	9.52	1.9	6.72E+08
10495-135	35	0.541	6.3	1.30E+08

Table 3.1. WWTP Self-reported Flow, E. coli and Load During Dry Weather Conditions, continu

WWTP	Subbasin	Avg. Self-reported Flow (MGD)[1]	E. coli (MPN/dL)	Load (MPN/day)
12346-001	35	0.18	0.5	3.40E+06
12427-001	35	0.0000508	2.5	4.77E+03
12682-001	35	0.0407	0.5	7.70E+05
13021-001	35	0.143	1.9	1.01E+07
13228-001	35	0.039	1.9	2.75E+06
14182-001	35	0.0217	1.9	1.53E+06
12132-001	40	0.0391	0.5	7.40E+05
13764-001	42	0.0565	3.5	7.49E+06
12233-001	44	0.000648	1.9	4.57E+04
10584-001	53	2.98	1.9	2.10E+08
10495-109	55	4.42	1.9	3.12E+08
12355-001	56	0.000319	1.9	2.25E+04
12830-001	56	0.00218	1.9	1.54E+05
14070-001	56	0.00146	0.5	2.76E+04
14117-001	56	0.0977	1.9	6.90E+06
03153-000	104	0.0102	1.6	6.18E+05
12466-001	105	0.00127	149.5	7.20E+06
13484-001	105	0.042	0.5	7.94E+05
10932-001	106	0.0191	1.9	1.35E+06
11290-001	106	2.54	1.9	1.79E+08
11523-001	108	0.785	31.0	9.19E+08
12124-001	108	0.251	1.9	1.77E+07
12474-001	108	0.0148	1.9	1.04E+06
12927-001	108	0.0046	1.9	3.25E+05
13778-001	108	0.00105	1.9	7.40E+04
11836-001	109	0.291	1.9	2.05E+07
11935-001	109	0.145	0.6	3.20E+06
11486-001	110	0.546	1.9	3.85E+07
11682-001	110	0.443	1.9	3.13E+07
11414-001	113	0.0406	0.5	7.67E+05
11472-001	113	0.383	0.5	7.24E+06
11947-001	113	1.81	1.9	1.28E+08
12128-001	113	0.519	18.6	3.65E+08
12304-001	113	0.348	1.8	2.37E+07
12310-001	113	0.0207	0.5	3.91E+05
12685-001	113	0.07	0.5	1.32E+06
12223-001	114	0.196	4.0	2.94E+07
12726-001	115	0.292	81.2	8.96E+08
12447-001	116	0.194	1.9	1.37E+07
13328-001	116	0.0266	1.9	1.87E+06
11906-001	117	0.307	0.5	5.80E+06
12209-001	119	0.236	1.9	1.67E+07
12834-001	119	0.0637	0.5	1.20E+06
12841-001	119	0.043	1.9	3.04E+06
12949-001	119	0.0231	0.5	4.37E+05
11792-002	120	0.225	1.9	1.59E+07
13921-001	122	0.00624	1.8	4.13E+05
11696-002	123	0.125	1.9	8.82E+06
12516-001	123	0.000938	1.9	6.62E+04

Table 3.1. WWTP Self-reported Flow, E. coli and Load During Dry Weather Conditions, continu

WWTP	Subbasin	Avg. Self-reported Flow (MGD)[1]	E. coli (MPN/dL)	Load (MPN/day)
11284-001	124	0.574	8.0	1.74E+08
12802-001	124	0.153	4.6	2.63E+07
12140-001	125	0.139	0.5	2.63E+06
11969-001	131	0.635	26.4	6.34E+08
12858-001	133	0.00606	1.9	4.28E+05
13172-002	133	0.316	1.9	2.23E+07
13245-001	133	0.131	1.9	9.25E+06
13558-001	133	0.936	1.9	6.61E+07
12370-001	135	0.111	1.9	7.82E+06
14011-001	135	0.00826	1.9	5.83E+05
10706-001	136	1.13	1.9	7.95E+07
02229-000	144	0.00767	1.9	5.41E+05
12356-001	146	0.148	1.9	1.04E+07
12479-001	147	0.428	54.3	8.80E+08
12289-001	148	0.521	5.8	1.15E+08
11883-001	149	0.545	0.5	1.03E+07
11598-001	150	0.693	55.1	1.44E+09
14109-001	151	0.00137	1.9	9.66E+04
11152-001	153	1.62	1.9	1.15E+08
11893-001	155	1.31	1.9	9.27E+07
13674-001	155	0.0332	1.9	2.35E+06
13775-001	171	0.0941	1.9	6.64E+06
14134-001	171	0.0127	1.9	8.94E+05
12298-001	178	0.0837	0.5	1.58E+06
12110-001	181	0.067	0.5	1.27E+06
11989-001	183	0.289	0.5	5.46E+06
12189-001	183	0.0621	1.9	4.38E+06
12247-001	183	0.186	0.5	3.51E+06
11917-001	185	0.313	0.6	6.51E+06

Notes:
1. Average of self-reported flow between April 1, 1999 through October 1, 2003
2. Abbreviations:
   MGD - million gallons per day
   MPN - most probable number
   dL - deciliter

When rainfall occurs in a watershed, infiltration and inflow enters sanitary sewer collection systems and subsequently affects wastewater treatment plants. Intermediate condition events are considered those when rainfall is between 0.25 and 0.5 inches of rainfall per day. Rainfall greater than 0.5 inches represents conditions under which biosolid releases may occur and these conditions will be described in the next section. The increased flow into the system results in more water reaching the plant and may potentially overload the plant. The additional flow associated with intermediate conditions was determined using the regression equation, previously described in Section 9.4.2 of the Final Report for Work Order 8 (2005). The additional flow estimated from the regression equation was added to the dry weather flow. The concentrations associated with WWTP discharges during intermediate conditions were assumed to be the same as those under dry weather conditions shown in Table 3.1. The flow and load associated with intermediate condition discharges is presented in Table 3.2. The flow associated with the discharges from the WWTPs during intermediate conditions is higher than that during dry weather conditions as are the bacteria loads.

Table 3.2. WWTP Flow and Loading during Intermediate Conditions

TCEQ Permit #	Subbasin	Flow (MGD)	E. coli (MPN/dL)	Load (MPN/day)
10495-139	1	5.08E-01	0.5	9.60E+06
10495-076	2	9.15E+00	3.5	1.21E+09
11193-001	2	5.32E-01	711.4	1.43E+10
12139-001	2	2.50E-02	1039.9	9.84E+08
12222-001	2	7.10E-02	14812.0	3.97E+10
13996-001	2	1.71E-03	3.5	2.27E+05
02710-000	4	8.81E-04	3.5	1.17E+05
04760-000	4	1.54E-03	3.5	2.03E+05
11051-001	4	3.63E-02	46.8	6.42E+07
11188-001	4	2.66E-01	0.5	5.02E+06
11273-001	4	4.44E-01	1.0	1.72E+07
11375-001	4	1.02E-01	17.8	6.86E+07
11389-001	4	9.82E-03	1.8	6.68E+05
11485-001	4	4.28E-01	0.8	1.21E+07
11538-001	4	1.09E+00	3.5	1.45E+08
11670-001	4	3.42E-01	17.0	2.19E+08
12342-001	4	2.00E-02	1.3	9.46E+05
12443-001	4	1.38E-03	7.4	3.86E+05
12552-001	4	6.11E-03	3.5	8.09E+05
12552-002	4	4.98E-03	3.5	6.60E+05
13433-001	4	1.23E-02	0.5	2.33E+05
13509-001	4	1.40E-02	71.2	3.77E+07
13578-001	4	6.65E-03	0.5	1.26E+05
13623-001	4	7.60E-02	0.5	1.44E+06
13689-001	4	3.54E-01	176.5	2.36E+09
13727-001	4	7.39E-03	0.5	1.40E+05
13807-001	4	7.87E-04	0.5	1.49E+04
13939-001	4	1.22E-03	3.5	1.61E+05
13983-001	4	9.31E-04	3.5	1.23E+05
10495-099	7	1.79E+00	3.5	2.36E+08
12573-001	9	1.02E-02	3.5	1.35E+06
12714-001	9	1.51E-01	1.3	7.24E+06
14359-001	9	3.29E-02	3.5	4.36E+06
11563-001	10	7.02E-01	14.4	3.81E+08
11979-002	10	1.99E-01	3.5	2.63E+07
12397-001	10	4.60E-03	3.5	6.09E+05
12574-001	10	1.28E-01	1.3	6.18E+06
12681-001	10	1.92E-01	3.5	2.55E+07
14072-001	10	1.06E+00	8.9	3.58E+08
12121-001	11	9.80E-01	13.3	4.92E+08
12795-001	11	2.01E-01	176.1	1.33E+09
10876-001	13	9.14E-01	4.4	1.53E+08
10876-002	13	9.26E-01	5.2	1.83E+08
12465-001	13	5.45E-03	96.8	1.99E+07
11005-001	17	1.55E-01	1.3	7.61E+06
02731-000	27	1.76E-03	1.9	1.24E+05
10495-030	33	1.00E+01	1.9	7.07E+08
10495-135	35	5.69E-01	6.3	1.36E+08
12346-001	35	9.28E-03	0.5	1.75E+05

Table 3.2. WWTP Flow and Loading during Intermediate Conditions, continued

TCEQ Permit #	Subbasin	Flow (MGD)	E. coli (MPN/dL)	Load (MPN/day)
12427-001	35	5.34E-05	2.5	5.01E+03
12682-001	35	4.28E-02	0.5	8.10E+05
13021-001	35	1.50E-01	1.9	1.06E+07
13228-001	35	4.10E-02	1.9	2.89E+06
14182-001	35	2.28E-02	1.9	1.61E+06
12132-001	40	4.11E-02	0.5	7.78E+05
13764-001	42	5.94E-02	3.5	7.88E+06
12233-001	44	6.81E-04	1.9	4.81E+04
10584-001	53	3.13E+00	1.9	2.21E+08
10495-109	55	4.65E+00	1.9	3.28E+08
12355-001	56	3.35E-04	1.9	2.37E+04
12830-001	56	2.29E-03	1.9	1.62E+05
14070-001	56	1.54E-03	0.5	2.90E+04
14117-001	56	1.03E-01	1.9	7.25E+06
03153-000	104	1.07E-02	1.6	6.50E+05
12466-001	105	1.34E-03	149.5	7.58E+06
13484-001	105	4.42E-02	0.5	8.35E+05
10932-001	106	2.01E-02	1.9	1.42E+06
11290-001	106	2.67E+00	1.9	1.88E+08
11523-001	108	8.25E-01	31.0	9.66E+08
12124-001	108	2.64E-01	1.9	1.86E+07
12474-001	108	1.56E-02	1.9	1.10E+06
12927-001	108	4.84E-03	1.9	3.41E+05
13778-001	108	1.10E-03	1.9	7.79E+04
11836-001	109	3.06E-01	1.9	2.16E+07
11935-001	109	1.52E-01	0.6	3.37E+06
11486-001	110	5.74E-01	1.9	4.05E+07
11682-001	110	4.66E-01	1.9	3.29E+07
11414-001	113	4.27E-02	0.5	8.07E+05
11472-001	113	4.03E-01	0.5	7.62E+06
11947-001	113	1.90E+00	1.9	1.34E+08
12128-001	113	5.46E-01	18.6	3.84E+08
12304-001	113	3.66E-01	1.8	2.49E+07
12310-001	113	2.18E-02	0.5	4.11E+05
12685-001	113	7.36E-02	0.5	1.39E+06
12223-001	114	2.06E-01	4.0	3.09E+07
12726-001	115	3.07E-01	81.2	9.42E+08
12447-001	116	2.04E-01	1.9	1.44E+07
13328-001	116	2.80E-02	1.9	1.97E+06
11906-001	117	3.23E-01	0.5	6.10E+06
12209-001	119	2.48E-01	1.9	1.75E+07
12834-001	119	6.70E-02	0.5	1.27E+06
12841-001	119	4.52E-02	1.9	3.19E+06
12949-001	119	2.43E-02	0.5	4.59E+05
11792-002	120	2.37E-01	1.9	1.67E+07
13921-001	122	6.56E-03	1.8	4.34E+05
11696-002	123	1.31E-01	1.9	9.28E+06
12516-001	123	9.86E-04	1.9	6.96E+04
11284-001	124	2.96E-02	8.0	8.97E+06

Table 3.2. WWTP Flow and Loading during Intermediate Conditions, continued

TCEQ Permit #	Subbasin	Flow (MGD)	E. coli (MPN/dL)	Load (MPN/day)
12802-001	124	1.61E-01	4.6	2.77E+07
12140-001	125	1.46E-01	0.5	2.77E+06
11969-001	131	6.68E-01	26.4	6.67E+08
12858-001	133	6.37E-03	1.9	4.50E+05
13172-002	133	3.32E-01	1.9	2.34E+07
13245-001	133	1.38E-01	1.9	9.73E+06
13558-001	133	9.84E-01	1.9	6.95E+07
12370-001	135	1.17E-01	1.9	8.23E+06
14011-001	135	8.69E-03	1.9	6.13E+05
10706-001	136	1.19E+00	1.9	8.36E+07
02229-000	144	8.07E-03	1.9	5.69E+05
12356-001	146	1.56E-01	1.9	1.10E+07
12479-001	147	4.50E-01	54.3	9.25E+08
12289-001	148	5.48E-01	5.8	1.21E+08
11883-001	149	5.73E-01	0.5	1.08E+07
11598-001	150	7.29E-01	55.1	1.52E+09
14109-001	151	1.44E-03	1.9	1.02E+05
11152-001	153	1.70E+00	1.9	1.20E+08
11893-001	155	1.38E+00	1.9	9.75E+07
13674-001	155	3.49E-02	1.9	2.47E+06
13775-001	171	9.90E-02	1.9	6.99E+06
14134-001	171	1.34E-02	1.9	9.40E+05
12298-001	178	8.80E-02	0.5	1.66E+06
12110-001	181	7.05E-02	0.5	1.33E+06
11989-001	183	3.04E-01	0.5	5.74E+06
12189-001	183	6.53E-02	1.9	4.61E+06
12247-001	183	1.96E-01	0.5	3.69E+06
11917-001	185	3.29E-01	0.6	6.85E+06

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

3.2.1.2 BIOSOLID RELEASES FROM WWTP DISCHARGES

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. 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 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 Section 9.4.2.2 of the Final Report for Work Order 8 (2005). 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 4,416 cfu/dL was found. This corresponds to an *E. coli* concentration of 2,612 MPN/dL, using the ratio of the two bacteria standards.

As biosolid releases were assumed to occur only during wet weather, the daily load presented in Table 3.3 was adjusted to account for days with precipitation. Houston has 74 days of precipitation out of the year according to 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 3.3.

Table 3.3. WWTP Biosolid Release Flow and Loading

TCEQ Permit #	Subbasin	Biosolid Flow (MGD)	E. coli (MPN/dL)	Biosolid Load (MPN/day)
10495-139	1	3.03E-02	2,612	2.99E+09
10495-076	2	5.46E-01	2,612	5.39E+10
11193-001	2	3.18E-02	2,612	3.14E+09
12139-001	2	1.49E-03	2,612	1.48E+08
12222-001	2	4.24E-03	2,612	4.18E+08
13996-001	2	1.02E-04	2,612	1.01E+07
02710-000	4	5.26E-05	2,612	5.19E+06
04760-000	4	9.16E-05	2,612	9.04E+06
11051-001	4	2.17E-03	2,612	2.14E+08
11188-001	4	1.59E-02	2,612	1.57E+09
11273-001	4	2.65E-02	2,612	2.62E+09
11375-001	4	6.08E-03	2,612	6.00E+08
11389-001	4	5.86E-04	2,612	5.79E+07
11485-001	4	2.56E-02	2,612	2.52E+09
11538-001	4	6.55E-02	2,612	6.46E+09
11670-001	4	2.04E-02	2,612	2.01E+09
12342-001	4	1.19E-03	2,612	1.18E+08
12443-001	4	8.21E-05	2,612	8.11E+06
12552-001	4	3.65E-04	2,612	3.60E+07
12552-002	4	2.98E-04	2,612	2.94E+07
13433-001	4	7.35E-04	2,612	7.25E+07
13509-001	4	8.36E-04	2,612	8.26E+07
13578-001	4	3.97E-04	2,612	3.92E+07
13623-001	4	4.54E-03	2,612	4.48E+08
13689-001	4	2.11E-02	2,612	2.09E+09
13727-001	4	4.42E-04	2,612	4.36E+07
13807-001	4	4.69E-05	2,612	4.63E+06
13939-001	4	7.26E-05	2,612	7.17E+06
13983-001	4	5.55E-05	2,612	5.48E+06
10495-099	7	1.07E-01	2,612	1.05E+10
12573-001	9	6.11E-04	2,612	6.03E+07
12714-001	9	9.02E-03	2,612	8.91E+08
14359-001	9	1.97E-03	2,612	1.94E+08
11563-001	10	4.19E-02	2,612	4.14E+09
11979-002	10	1.19E-02	2,612	1.17E+09
12397-001	10	2.75E-04	2,612	2.71E+07
12574-001	10	7.65E-03	2,612	7.55E+08
12681-001	10	1.15E-02	2,612	1.13E+09
14072-001	10	6.33E-02	2,612	6.25E+09
12121-001	11	5.85E-02	2,612	5.77E+09
12795-001	11	1.20E-02	2,612	1.18E+09
10876-001	13	5.45E-02	2,612	5.39E+09
10876-002	13	5.53E-02	2,612	5.46E+09
12465-001	13	3.25E-04	2,612	3.21E+07
11005-001	17	9.24E-03	2,612	9.12E+08
02731-000	27	1.05E-04	2,612	1.03E+07
10495-030	33	5.98E-01	2,612	5.90E+10
10495-135	35	3.40E-02	2,612	3.35E+09
12346-001	35	1.13E-02	2,612	1.12E+09

Table 3.3. WWTP Biosolid Release Flow and Loading, continued

TCEQ Permit #	Subbasin	Biosolid Flow (MGD)	E. coli (MPN/dL)	Biosolid Load (MPN/day)
12427-001	35	3.19E-06	2,612	3.15E+05
12682-001	35	2.56E-03	2,612	2.52E+08
13021-001	35	9.00E-03	2,612	8.89E+08
13228-001	35	2.45E-03	2,612	2.42E+08
14182-001	35	1.36E-03	2,612	1.34E+08
12132-001	40	2.46E-03	2,612	2.43E+08
13764-001	42	3.55E-03	2,612	3.50E+08
12233-001	44	4.06E-05	2,612	4.01E+06
10584-001	53	1.87E-01	2,612	1.85E+10
10495-109	55	2.78E-01	2,612	2.74E+10
12355-001	56	2.00E-05	2,612	1.98E+06
12830-001	56	1.37E-04	2,612	1.35E+07
14070-001	56	9.16E-05	2,612	9.04E+06
14117-001	56	6.13E-03	2,612	6.06E+08
03153-000	104	6.42E-04	2,612	6.34E+07
12466-001	105	8.00E-05	2,612	7.90E+06
13484-001	105	2.64E-03	2,612	2.60E+08
10932-001	106	1.20E-03	2,612	1.18E+08
11290-001	106	1.59E-01	2,612	1.57E+10
11523-001	108	4.93E-02	2,612	4.86E+09
12124-001	108	1.58E-02	2,612	1.56E+09
12474-001	108	9.29E-04	2,612	9.17E+07
12927-001	108	2.89E-04	2,612	2.85E+07
13778-001	108	6.58E-05	2,612	6.50E+06
11836-001	109	1.83E-02	2,612	1.80E+09
11935-001	109	9.11E-03	2,612	8.99E+08
11486-001	110	3.42E-02	2,612	3.38E+09
11682-001	110	2.78E-02	2,612	2.75E+09
11414-001	113	2.55E-03	2,612	2.52E+08
11472-001	113	2.40E-02	2,612	2.37E+09
11947-001	113	1.14E-01	2,612	1.12E+10
12128-001	113	3.26E-02	2,612	3.22E+09
12304-001	113	2.19E-02	2,612	2.16E+09
12310-001	113	1.30E-03	2,612	1.28E+08
12685-001	113	4.39E-03	2,612	4.34E+08
12223-001	114	1.23E-02	2,612	1.22E+09
12726-001	115	1.83E-02	2,612	1.81E+09
12447-001	116	1.22E-02	2,612	1.20E+09
13328-001	116	1.67E-03	2,612	1.65E+08
11906-001	117	1.93E-02	2,612	1.90E+09
12209-001	119	1.48E-02	2,612	1.46E+09
12834-001	119	4.00E-03	2,612	3.95E+08
12841-001	119	2.70E-03	2,612	2.67E+08
12949-001	119	1.45E-03	2,612	1.43E+08
11792-002	120	1.41E-02	2,612	1.39E+09
13921-001	122	3.92E-04	2,612	3.87E+07
11696-002	123	7.85E-03	2,612	7.75E+08
12516-001	123	5.89E-05	2,612	5.82E+06
11284-001	124	3.60E-02	2,612	3.56E+09

Table 3.3. WWTP Biosolid Release Flow and Loading, continued

TCEQ Permit #	Subbasin	Biosolid Flow (MGD)	E. coli (MPN/dL)	Biosolid Load (MPN/day)
12802-001	124	9.60E-03	2,612	9.48E+08
12140-001	125	8.74E-03	2,612	8.63E+08
11969-001	131	3.98E-02	2,612	3.93E+09
12858-001	133	3.80E-04	2,612	3.76E+07
13172-002	133	1.98E-02	2,612	1.96E+09
13245-001	133	8.23E-03	2,612	8.13E+08
13558-001	133	5.87E-02	2,612	5.80E+09
12370-001	135	6.96E-03	2,612	6.87E+08
14011-001	135	5.19E-04	2,612	5.12E+07
10706-001	136	7.07E-02	2,612	6.98E+09
02229-000	144	4.82E-04	2,612	4.76E+07
12356-001	146	9.27E-03	2,612	9.15E+08
12479-001	147	2.69E-02	2,612	2.66E+09
12289-001	148	3.27E-02	2,612	3.23E+09
11883-001	149	3.42E-02	2,612	3.38E+09
11598-001	150	4.35E-02	2,612	4.29E+09
14109-001	151	8.59E-05	2,612	8.49E+06
11152-001	153	1.02E-01	2,612	1.01E+10
11893-001	155	8.24E-02	2,612	8.14E+09
13674-001	155	2.09E-03	2,612	2.06E+08
13775-001	171	5.91E-03	2,612	5.84E+08
14134-001	171	7.95E-04	2,612	7.85E+07
12298-001	178	5.25E-03	2,612	5.19E+08
12110-001	181	4.21E-03	2,612	4.15E+08
11989-001	183	1.81E-02	2,612	1.79E+09
12189-001	183	3.90E-03	2,612	3.85E+08
12247-001	183	1.17E-02	2,612	1.15E+09
11917-001	185	1.97E-02	2,612	1.94E+09

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

3.2.1.3 WWTP AND BIOSOLID RELEASE LOADINGS

A summary of the load and flows associated with dry weather, intermediate and wet conditions into BLEST are presented in Table 3.4. From Table 3.4, it can be seen that the greatest flow and loading in Buffalo Bayou occurs at the mouth of the reservoir watersheds with flows under dry weather of 20.58 MGD and an *E. coli* load of 6.46 billion MPN/day. In Whiteoak Bayou (i.e., mouth of segment 1017), dry weather WWTP loads are 59.39 billion MPN/day with a flow of 20.03 MGD. Biosolid releases add approximately 1 MGD of flow in all three segments and between 111.55 and 127.55 billion MPN/day of *E. coli* load.

3.2.2 MS4 DISCHARGES

Much of Houston is regulated under a Texas Pollutant Discharge Elimination System (TPDES) Municipal Separate Storm Sewer System (MS4) permit. An MS4 is generally a publicly owned conveyance system designed to collect storm water and discharge to waters of the State. These discharges are regulated by the US EPA as a point source to the bayou and incorporated into the TMDL as part of the Waste Load Allocation even though storm water has many diffuse sources.

In the Buffalo and Whiteoak Bayou watersheds, the City of Houston along with the Texas Department of Transportation, Harris County and Harris County Flood Control District are co-permittees on the MS4 permit who collaborate within an entity called the Joint Task Force or JTF to manage the many thousands of miles of storm water conveyances in the Houston area. These conveyances drain rainfall-runoff from the city to small tributaries of the bayou.

Table 3.4. Loading and Flow from WWTPs in BLEST

E. coli Sources	Dry		Intermediate		Wet	
	Q (MGD)	Load (billion MPN/day)	Q (MGD)	Load (billion MPN/day)	Q (MGD)	Load (billion MPN/day)
Mouth of Reservoir Watersheds						
WWTP Discharges	20.58	6.46	21.64	6.80	21.64	6.80
WWTP Biosolid Releases	-	-	-	-	1.29	127.55
Total	20.58	6.46	21.64	6.80	22.93	134.34
Mouth of Segment 1014						
WWTP Discharges	18.00	1.35	18.93	1.42	18.93	1.42
WWTP Biosolid Releases	-	-	-	-	1.13	111.55
Total	18.00	1.35	18.93	1.42	20.06	112.97
Mouth of Segment 1013						
WWTP Discharges	0.00	0.00	0.00	0.00	0.00	0.00
WWTP Biosolid Releases	-	-	-	-	0.00	0.00
Total	0.00	0.00	0.00	0.00	0.00	0.00
Mouth of Segment 1017						
WWTP Discharges	20.03	59.39	21.06	62.45	21.06	62.45
WWTP Biosolid Releases	-	-	-	-	1.26	124.16
Total	20.03	59.39	21.06	62.45	22.32	186.61

Note: - indicates that the flow or load is not included for that flow scenario

Abbreviations: MGD - million gallons per day, MPN - most probable number, WWTP - wastewater treatment plant

The following section presents a summary of methods to characterize flows and *E. coli* loading from MS4 sources. The MS4 sources include dry weather storm sewer (DWSS) discharges, storm water runoff carried to the bayou via the MS4 and sanitary sewer overflows (SSOs) carried to the bayou via the MS4.

3.2.2.1 DRY WEATHER STORM SEWER DISCHARGES (DWSS)

Dry weather storm sewer (DWSS) discharges through MS4 pipes were sampled during 2001 to estimate *E. coli* loads. The details of the sampling were discussed in the Final Report for Work Order 2 Section 4.2 (2003), but will be briefly described here 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 (i.e., at the mouth of the reservoir watersheds) in Buffalo Bayou. Samples were collected only during dry weather, which was roughly defined as a period of three or more days with less than 0.1 inches of rainfall in the immediate sampling area. This was to ensure that samples were not being collected that were highly influenced by runoff. Samples were collected on foot in Whiteoak Bayou, while a canoe was used to maneuver down Buffalo Bayou.

The loads were calculated using the measured flow and concentration. 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 intermediate and 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 from intermediate/wet weather conditions) as will be described in the subsequent section.

Using data reported at the Addicks Reservoir rain gage maintained by the National

Oceanic and Atmospheric Administration (NOAA) (National Climatic Data Center 2003), it was found that 74 days of the year on average experience rainfall and thus DWSS discharges were assumed to occur during the 291 days.

A summary of loads on a subbasin basis are presented in Table 3.5. The largest *E. coli* load was found to be in Subbasin 43, with a load of 2.22 x 10^{11} MPN/day. The smallest non-zero load was found to be 7.44x10^{5} MPN/day in Subbasin 44.

Table 3.5. Summary of dry weather municipal separate storm sewer system (MS4) discharges

Subbasin	Flow (MGD)	Load (MPN/day)
4	3.71E-03	1.11E+07
7	1.34E-02	3.80E+07
10	2.46E-02	1.28E+09
11	1.27E-02	1.79E+07
13	1.07E-02	8.63E+06
34	4.11E-02	2.57E+09
35	3.73E-02	3.15E+07
39	2.13E-01	2.53E+08
40	1.42E-01	4.88E+08
41	5.91E-02	4.26E+09
42	1.00E-01	2.25E+10
43	3.91E-01	2.22E+11
44	3.03E-04	7.44E+05
45	4.08E-02	1.55E+10
47	5.36E-04	1.47E+07
50	4.75E-03	1.49E+08
52	8.09E-02	5.49E+10
53	6.36E-03	1.32E+08
54	1.40E-01	1.79E+11
55	5.16E-02	2.06E+10

Notes:
Abbreviations: MGD - million gallons per day, MPN - most probable number
MS4 - munipical separate storm sewer system

3.2.2.2 WET WEATHER MS4 SEWER SYSTEM DISCHARGES

Wet weather MS4 flow and load discharges were estimated on a subbasin basis using a simple approach that takes into account subwatershed land use, measured event mean concentrations (EMCs) of *E. coli* from local sampling, and soil types. The curve number method was used to estimate wet weather runoff and the methodology is detailed in the NRCS Technical Report 55 (NRCS, 1986).

The curve number assumptions were based upon STATSGO data obtained from the Texas Natural Resources Information System (TNRIS) website and take into account the fact that soils in the Houston area are generally non-permeable and prone to runoff (Table 3.6). Curve numbers were estimated to range between 77 and 96, except for wetlands which were assumed to have no runoff. Soil cover was generally assumed to be in good condition with soil hydrologic group D used to guide curve number selection.

It was assumed that the average rainfall event in the Houston area, equivalent to 0.8 inches of rain, based upon the average between 1943 and 1990 (National Climatic Data Center 2003), was representative of wet weather conditions. More complex analyses could involve the use of rainfall depth distributions, but for the purposes of the BLEST analyses this single average value was found to be adequate in determining non-point source loads. The wet weather flows simulated in BLEST are representative of peak flow conditions from the watershed, and are around the 90^{th} percentile flow that might be observed in Buffalo or Whiteoak Bayous.

Land cover data were obtained from the Houston-Galveston Area Council (H-GAC). These data were collected between July 2001 and February 2003 and processed into 9 different

Table 3.6. Summary of Assumptions used for Wet Weather MS4 Calculations

Land Use	CN	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	2,500	1,575
Grassland	80	2,500	1,575
Woody Land	77	1,600	1,008
Woody Wetlands	0	N/A	N/A
Nonwoody wetland	0	N/A	N/A
Transitional	94	44,632	28,118

Abbreviations: CN - curve number, cfu - colony forming units, dL - deciliter, EMC - event mean concentration, MPN - most probable number, MS4 - municipal separate storm sewer system types of land cover categories (Meyer, 2003). The categories include low intensity developed, high intensity developed, cultivated, grass land, woody land, woody wetlands, nonwoody wetlands, and transitional. The land cover data were joined with the subwatershed coverage to determine the areal extent of each land cover type within individual subwatersheds.

The assumptions made for concentrations to be associated with runoff volume are presented in Table 3.6. The event mean concentrations (EMCs) used in the analysis were obtained from two sources: the Storm Water Joint Task Force Annual Report (2002), a study with local data from the Houston area between 1992-1993 and 1998-2002, and a study conducted by Newell et al (1992) that compiled EMCs for the Houston area for years prior to 1991. The land use for the EMCs employed in this analysis did not always match the types of land cover described by H-GAC. Assumptions were therefore made about the appropriate EMC for each land cover type and the selected EMCs were converted from fecal coliform concentrations to *E. coli* as shown in Table 3.6.

To determine runoff loading for the intermediate condition, a portion of the nonpoint source flow and load were assumed to be occurring. The amount of nonpoint source load and flow accounted for the intermediate condition was based upon the amount of flow needed to be added to the dry weather scenario in order to achieve median flow. It was found that 10% of the nonpoint source runoff was needed to achieve median flows at the mouth of the reservoir watersheds, while the mouths of segments 1013 and 1017 required 3% to 4%. The mouth of segment 1014 required very little additional flow, only 0.1%, indicating that the intermediate condition in that watershed is primarily sustained by WWTP discharges.

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.

The final loads are presented in Table 3.7 for the intermediate and wet weather scenarios. The largest *E. coli* load from wet weather MS4 discharges occurred in Subbasin 1 which has one of the largest drainage areas with a high percentage of low and high intensity land uses, with 3.45×10^{12} MPN/day. The smallest load was in Subbasin 142 with a load of 6.95×10^{9} MPN/day.

3.2.2.3 SANITARY 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 system, which conveys wastewater from the source to the site of processing, usually a wastewater treatment plant or pretreatment facility. These overflows typically make their way to the storm water conveyance system which then carries the overflows to the bayou.

SSOs occur under both wet and dry weather conditions. During wet weather conditions, SSOs often result from an exceedance of the sanitary sewer conveyance capacity because of sharp increases in water volumes from inflow and infiltration into the system. These releases are often characterized by large volumes of discharge with lower concentrations of fecal pathogens that result from mixing of untreated wastewater with storm water. During dry weather conditions, the releases can be caused by pipeline leakage, damage to the system, blockages, and malfunctioning equipment. The SSOs that occur during dry weather periods exhibit variability in both discharge volume and fecal pathogen concentrations (US EPA 2004).

Table 3.7. Wet weather MS4 Load and Flow Estimates

Subbasin	Intermediate		Wet	
	EC Load MPN/day	Runoff Flow (MGD)	EC Load MPN/wet day	Runoff Flow (MGD)
1	3.45E+12	2.09	1.00E+14	60.90
2	2.73E+12	1.65	7.97E+13	47.97
3	1.21E+12	0.78	3.53E+13	22.72
4	2.61E+12	1.72	7.60E+13	50.14
5	2.67E+12	1.64	6.84E+13	41.99
6	1.71E+12	1.06	4.39E+13	27.16
7	6.00E+11	0.38	1.75E+13	11.15
8	2.66E+11	0.17	7.75E+12	4.94
9	9.34E+11	0.60	2.72E+13	17.41
10	1.46E+12	0.94	4.27E+13	27.51
11	5.39E+11	0.34	1.57E+13	9.99
12	2.35E+11	0.17	6.84E+12	4.92
13	7.11E+11	0.48	2.07E+13	13.87
17	6.60E+11	0.42	1.92E+13	12.16
26	6.82E+10	0.04	4.57E+13	28.04
27	4.85E+10	0.03	3.24E+13	19.52
28	8.22E+09	0.01	5.50E+12	3.77
33	5.52E+10	0.03	3.69E+13	22.06
34	1.19E+10	0.01	7.98E+12	5.38
35	4.73E+10	0.04	3.16E+13	25.05
36	1.27E+12	0.73	3.25E+13	18.61
37	1.05E+12	0.62	2.70E+13	15.83
38	1.03E+12	0.61	2.63E+13	15.53
39	7.72E+10	0.05	5.17E+13	32.03
40	5.76E+11	0.35	1.68E+13	10.14
41	9.42E+11	0.56	2.74E+13	16.21
42	9.57E+11	0.58	2.79E+13	16.93
43	2.05E+12	1.21	5.96E+13	35.39
44	5.98E+10	0.03	4.00E+13	23.35
45	4.84E+10	0.03	3.24E+13	20.17
46	4.76E+11	0.28	1.22E+13	7.13
47	3.86E+11	0.22	9.91E+12	5.63
48	1.20E+12	0.73	3.08E+13	18.78
49	1.59E+12	0.97	4.07E+13	24.82
50	4.37E+10	0.03	2.93E+13	17.15
51	4.16E+10	0.03	2.78E+13	16.78
52	6.05E+10	0.04	4.05E+13	24.07
53	7.83E+10	0.05	5.24E+13	31.58
54	4.00E+10	0.02	2.68E+13	16.52
55	5.66E+10	0.03	3.79E+13	23.12
56	6.00E+10	0.04	4.02E+13	24.58
101	1.98E+10	0.17	2.08E+11	1.80
102	1.41E+11	0.12	1.48E+12	1.24
103	7.47E+11	0.45	7.83E+12	4.68
104	7.13E+11	0.47	7.48E+12	4.88
105	9.56E+11	0.60	1.00E+13	6.28
106	7.07E+11	0.67	7.41E+12	6.99

Table 3.7. Wet weather MS4 Load and Flow Estimates, continued

Subbasin	Intermediate		Wet	
	EC Load MPN/day	Runoff Flow (MGD)	EC Load MPN/wet day	Runoff Flow (MGD)
107	7.13E+11	0.48	7.47E+12	5.00
108	1.10E+12	0.76	1.16E+13	7.95
109	5.99E+11	0.40	6.28E+12	4.17
110	1.61E+12	1.19	1.68E+13	12.50
111	1.14E+11	0.46	1.20E+12	4.78
112	4.21E+10	0.39	4.41E+11	4.06
113	3.18E+12	2.07	3.33E+13	21.75
114	1.77E+12	1.18	1.85E+13	12.36
115	1.95E+12	1.32	2.04E+13	13.89
116	5.73E+11	0.47	6.01E+12	4.94
117	6.39E+11	0.65	6.70E+12	6.80
118	9.89E+11	0.70	1.04E+13	7.36
119	1.12E+12	0.94	1.18E+13	9.83
120	4.86E+11	0.50	5.09E+12	5.22
121	5.95E+11	1.04	6.24E+12	10.94
122	4.11E+10	0.25	4.31E+11	2.65
123	3.96E+11	0.41	4.15E+12	4.26
124	1.27E+12	0.86	1.34E+13	8.97
125	1.58E+12	1.10	1.65E+13	11.52
126	7.63E+11	0.91	8.00E+12	9.59
127	1.76E+11	0.49	1.84E+12	5.14
128	3.64E+11	0.61	3.81E+12	6.42
129	1.10E+11	0.17	1.16E+12	1.77
130	3.15E+11	0.43	3.31E+12	4.54
131	5.58E+11	0.44	5.85E+12	4.64
132	4.67E+10	0.31	4.90E+11	3.30
133	2.93E+12	2.00	3.07E+13	21.01
134	3.24E+11	0.81	3.40E+12	8.46
135	1.53E+12	1.49	1.61E+13	15.60
136	2.94E+11	0.20	3.08E+12	2.14
137	3.01E+11	0.25	3.16E+12	2.59
138	3.89E+11	0.35	4.07E+12	3.70
139	2.65E+11	0.37	2.78E+12	3.86
140	1.45E+11	0.24	1.52E+12	2.54
141	9.19E+11	1.70	9.63E+12	17.85
142	6.95E+09	0.08	7.29E+10	0.80
143	1.47E+12	1.49	1.54E+13	15.61
144	1.07E+11	0.60	1.12E+12	6.34
145	8.29E+11	1.18	8.69E+12	12.35
146	4.64E+11	0.33	4.86E+12	3.50
147	2.20E+10	0.04	2.31E+11	0.45
148	2.31E+12	1.52	2.43E+13	15.90
149	3.59E+11	0.25	3.77E+12	2.63
150	5.76E+11	0.45	6.04E+12	4.76
151	6.87E+11	0.54	7.20E+12	5.70
152	1.04E+12	0.70	1.10E+13	7.38
153	9.34E+11	0.61	9.79E+12	6.40

Table 3.7. Wet weather MS4 Load and Flow Estimates, continued

Subbasin	Intermediate		Wet	
	EC Load MPN/day	Runoff Flow (MGD)	EC Load MPN/wet day	Runoff Flow (MGD)
154	1.48E+11	0.14	1.55E+12	1.51
155	4.76E+11	0.32	4.99E+12	3.38
156	3.34E+12	2.18	3.50E+13	22.87
171	1.31E+12	0.90	1.37E+13	9.49
172	4.08E+11	0.34	4.27E+12	3.60
173	9.74E+09	0.10	1.02E+11	1.08
174	9.61E+10	0.09	1.01E+12	0.99
175	1.86E+11	0.15	1.95E+12	1.59
176	3.32E+11	0.42	3.48E+12	4.37
177	9.63E+10	0.07	1.01E+12	0.70
178	9.51E+11	1.08	9.97E+12	11.34
180	1.03E+11	0.07	1.08E+12	0.73
181	9.37E+11	0.62	9.82E+12	6.51
182	2.01E+11	0.13	2.11E+12	1.33
183	1.08E+12	0.69	1.14E+13	7.28
184	2.48E+11	0.15	2.60E+12	1.60
185	1.65E+11	0.11	1.73E+12	1.10
186	9.50E+10	0.06	9.96E+11	0.61
187	4.63E+10	0.10	4.86E+11	1.02
188	1.45E+11	0.40	1.52E+12	4.15

Abbreviations: MGD - million gallon per day, MPN - most probable number, MS4 - municipal separate storm sewer system

SSOs have been identified as a potential source of indicator bacteria in the Buffalo and Whiteoak Bayou watersheds. As such, estimates of loads were developed for input into BLEST. Flows and bacteria loads were calculated using known occurrences of SSOs within Houston city limits. Outside Houston city limits, housing ages were used to estimate SSO occurrences because overflow data were not available. The following description of the determination of SSO loads is divided into two sections, one for within Houston city limits where the number of SSOs are known and areas outside city limits where specifics on SSOs are not known.

NUMBER OF KNOWN SSOs

The City of Houston sanitary sewage system was designed to convey sewage and storm water separately. The system contains 5,700 miles of pipeline, provides service for 1.72 million people, and extends throughout 600 square miles of the city (Bastad 1997). The City of Houston collects data on SSOs that occur within its boundaries including the locations, causes, and reported discharge volumes.

Data on known occurrences of SSOs were obtained from the City of Houston for the period between March 12, 2000 through December 9, 2003. The database was purged of duplicate records, and then the type of SSO event was classified as one of five categories that corresponded with those found in the US EPA's "Report to Congress: Blockages, Wet Weather and Infiltration/Inflow, Mechanical or Power Failures, Line Breaks, and Miscellaneous" (US EPA 2004). The data were summarized for each subbasin (Table 3.8). As can be seen, the majority of the 1,400 SSO occurrences stem from blockages within the line. This amounts to more than one SSO occurrence per day in the study watersheds.

Table 3.8. Summary of Known SSO Events in Buffalo and Whiteoak Bayou watersheds between 3/12/2000 and 12/9/2003

Subbasin	Blockage	Wet Weather	Mechnical/Power	Line Break	Miscellaneous
1	109			1	
2	15				
3	42			7	
4	5				
5	146			10	
6	29			1	
7	31				
8	10			2	
17	36			1	
26	132			1	
27	18				
28			1		
33	26				
34	5				
35					1
36	30			2	
37	35	2		1	
38				3	
38	29				
39	45				
40	39			2	
41	25			1	
42	27			5	
43	40			3	
44	19			4	
45	64			7	
46	19			5	
47	9				
48	72			7	
49	58			7	
50	18			2	
51	96			5	
52	48	2	8	4	
53	22	2			
54	9			1	
55	11				
56	5				
Total	**1,324**	**6**	**9**	**82**	**1**

Abbreviations: SSO - sanitary sewer overflow

NUMBER OF UNKNOWN SSOs

Several subwatersheds within the Buffalo and White Oak Bayous watershed do not lie within the City of Houston, and, consequently, no SSO event data were available. The US EPA found that SSO frequency correlated positively with population density and exhibited regional trends (US EPA 2004). Regression analysis was performed on SSO occurrence data, City of Houston population data, and land use data for the region. No statistically significant relationship was found either between the occurrence of overflows and population density or between overflows and land use.

Therefore, another approach was taken. It has been noted that as sewers age, the structural integrity of the piping deteriorates (US EPA 2004). Thus, it is suspected that older pipes experience more frequent SSO events. This was investigated using the City of Houston SSO database. The database was joined spatially to maintenance and wastewater piping data downloaded from the City of Houston geographic information management system (GIMS). The age of the pipes was then linked to the maintenance hole data, which was then joined with SSO information.

Figure 3.3 presents the results of this analysis. As demonstrated by the figure, older piping exhibits more SSOs than newer piping. Piping installed prior to 1940 exhibits significantly more SSOs than piping installed after 1940 ($\alpha = 0.05$), with up to 20% of the installed maintenance holes having SSO occurrences. Based upon these results, the age of piping was determined to be an adequate means of assigning SSO failure rates to regions outside the City of Houston.

Therefore, the approach used in BLEST involves compiling decadal SSO occurrence rates, determining pipe ages, and locating regions that would be covered by SSOs, since much of the outer watersheds are not yet developed. The data for Figure 3.3 were used to develop decadal SSO occurrence rates, as shown in Table 3.9. The maximum failure rate per maintenance hole was found in piping constructed during the period 1950-1959, while the lowest failure rate was found in piping from 1995-1998. The average failure rate per maintenance hole was found to be 0.0219 SSO/maintenance hole/year.

The next step in developing SSO loading rates for regions outside the City of Houston was to determine pipe ages that could be used in conjunction with the decadal SSO occurrence rates. As piping data from outside the City of Houston were not available, home ages from the 2000 census on the census community division (CCD) level were used instead. Home age was assumed to be equivalent to piping age for the purposes of this analysis. The CCDs used in this analysis are shown in Figure 3.4 and include Brookshire, Sugarland, Fulshear-Simonton, Northwest Harris, and Houston. Table 3.10 presents a summary of home construction statistics for the CCDs of interest. The percentages of homes built in the Houston area exhibit some differences between the CCDs. Fulshear-Simonton exhibits the largest recent construction efforts, while the oldest homes are found in Brookshire and Houston.

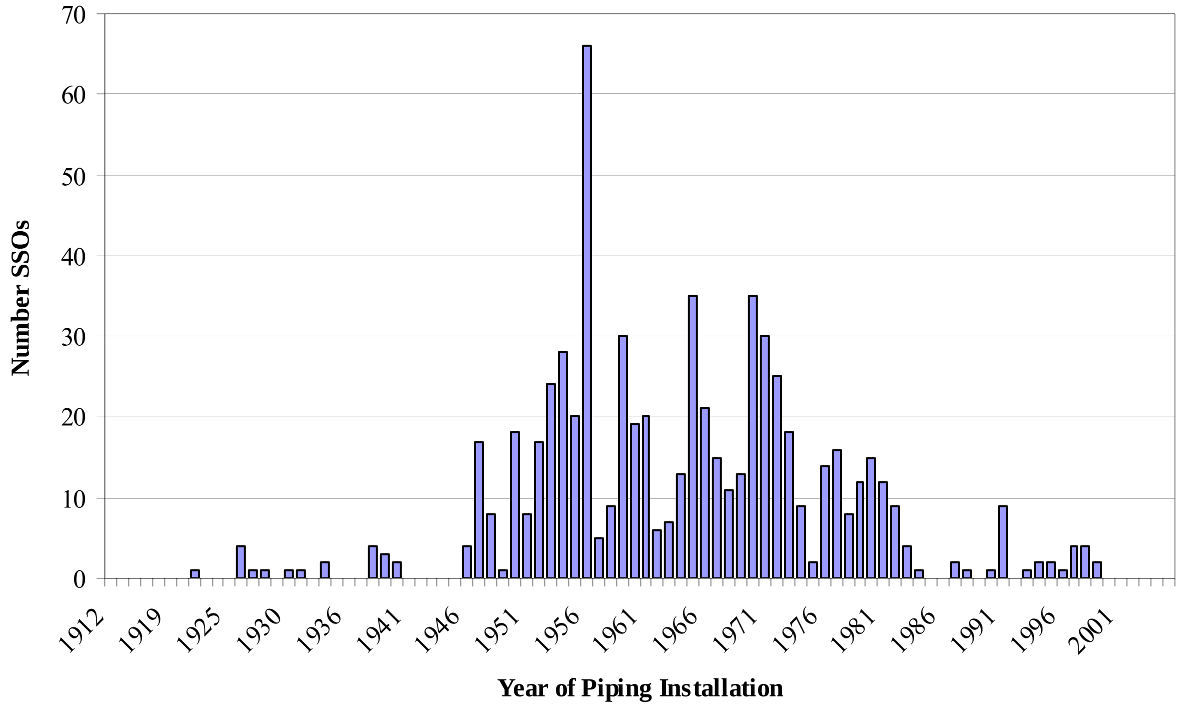


Figure 3.3. Influence of Age on SSOs in Buffalo and Whiteoak Bayous

Table 3.9. SSO distribution by pipe age[1]

Date	# SSOs	# Maintenance Holes (MH)	SSOs per MH	SSO per MH per yr[2]
Built 1999 to March 2000	2	186	1.08E-02	2.87E-03
Built 1995 to 1998	11	1514	7.27E-03	1.94E-03
Built 1990 to 1994	13	1158	1.12E-02	3.00E-03
Built 1980 to 1989	44	2902	1.52E-02	4.05E-03
Built 1970 to 1979	169	6915	2.44E-02	6.53E-03
Built 1960 to 1969	160	8887	1.80E-02	4.81E-03
Built 1950 to 1959	225	5849	3.85E-02	1.03E-02
Built 1940 to 1949	32	923	3.47E-02	9.26E-03
Built 1939 or earlier	18	482	3.73E-02	9.98E-03
Arithmetic Mean			0.0219	

[1] Not all maintenance holes could be associated with pipe age.

[2] Calculation for SSO per MH per year adjusts the number of SSOs reported over 3 year period between 3/12/2000 and 12/9/2003 to a single year. This was done by dividing the number of days i a typical year by the total number of days in the database (365/1367 = 0.267)

Abbreviations: SSO = sanitary sewer overflow, MH = maintenance hole, yr = year

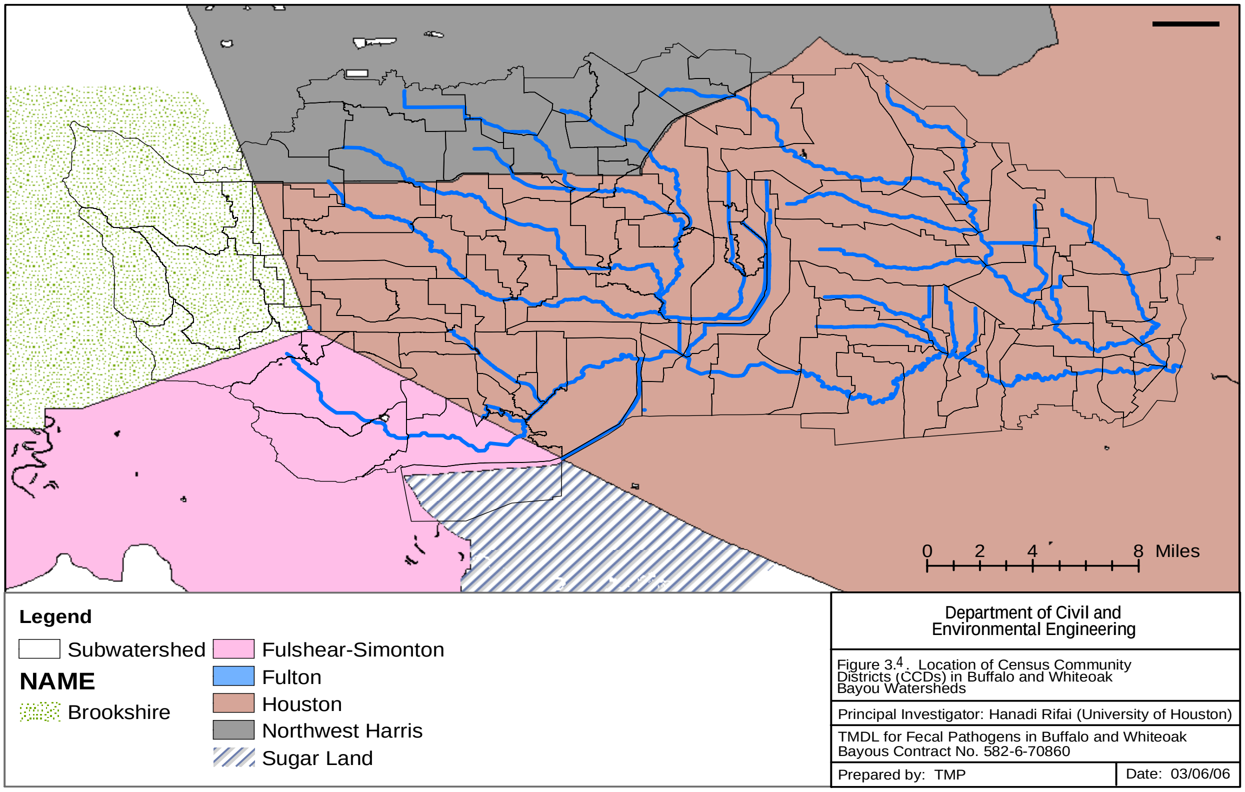
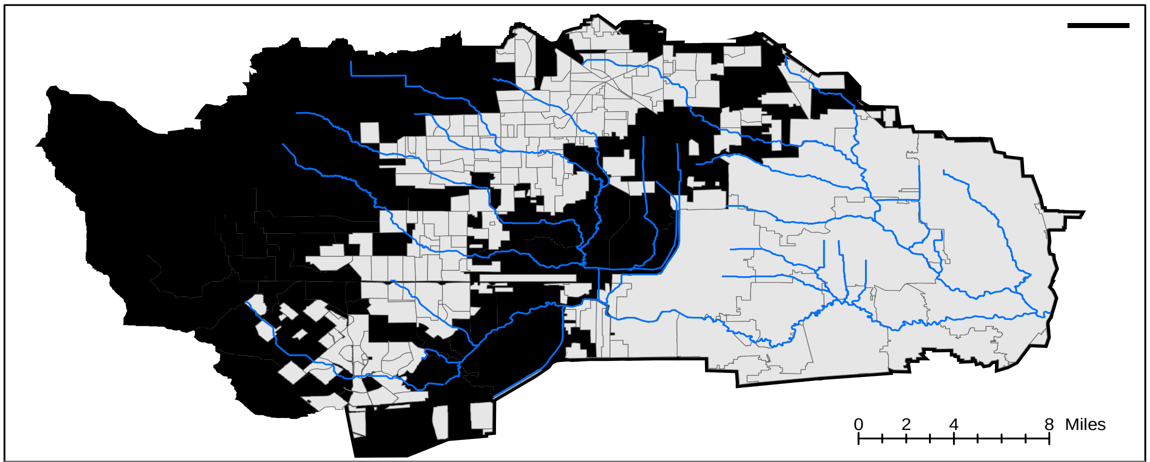


Figure 3.4. Location of Census Community Districts (CCDs) in Buffalo and Whiteoak Bayou

Table 3.10. Percentage of Houses Built in Houston-area Census Community Districts

Geography	Brookshire	Sugar Land	Fulshear-Simonton	Houston	Northwest Harris
Built 1999 to March 2000	4%	6%	20%	3%	6%
Built 1995 to 1998	14%	20%	31%	6%	12%
Built 1990 to 1994	8%	17%	21%	6%	12%
Built 1980 to 1989	25%	38%	13%	21%	36%
Built 1970 to 1979	23%	15%	8%	27%	28%
Built 1960 to 1969	10%	2%	3%	16%	4%
Built 1950 to 1959	7%	1%	2%	12%	1%
Built 1940 to 1949	6%	0%	1%	5%	0%
Built 1939 or earlier	4%	1%	1%	4%	1%
Median year structure built	1981	1988	1995	1975	1984

The final piece of information required for using age of piping to determine SSO occurrence was the density of maintenance holes in developed areas. As shown in Figure 3.5, many portions of the subbasins outside of the City of Houston have not been developed by municipal utility districts (MUDs), and therefore wastewater piping probably has not been installed. SSOs were assumed to occur only within WWTP MUD regions; any districts that were only public water supply related were excluded from the analysis. Maintenance hole density across WWTP MUDs outside was calculated using data from within the city limits. To determine maintenance hole density, the number of maintenance holes in subbasins within the City of Houston representative of residential areas (i.e., not the central business district of Houston and not high-intensity residential) were summed and divided by subbasin area. The final subbasins chosen for this calculation are shown in Table 3.11. The average of the maintenance hole density per acre for these subbasins was used to calculate the number of maintenance holes within regions covered by MUDs. Using MUD and subbasin areas, the number of SSOs was calculated using the average failure rate of 0.0219 SSO/MH/yr presented earlier.



Legend

WWTP Municipal Utility Districts (MUDs)

To evaluate the error involved in these estimates, the number of SSOs per year was estimated for regions where observed data were available. As can be seen in Figure 3.6, the method used for SSO estimation generally underestimates higher numbers of SSOs and overestimates lower number of SSOs. This type of error indicates that there are factors controlling the number of SSOs that occur in a watershed that are not accounted for in this estimation method. Such factors could include construction materials, size of pipes, and types of maintenance performed on piping. However, for the purposes of the BLEST, this method was considered adequate.

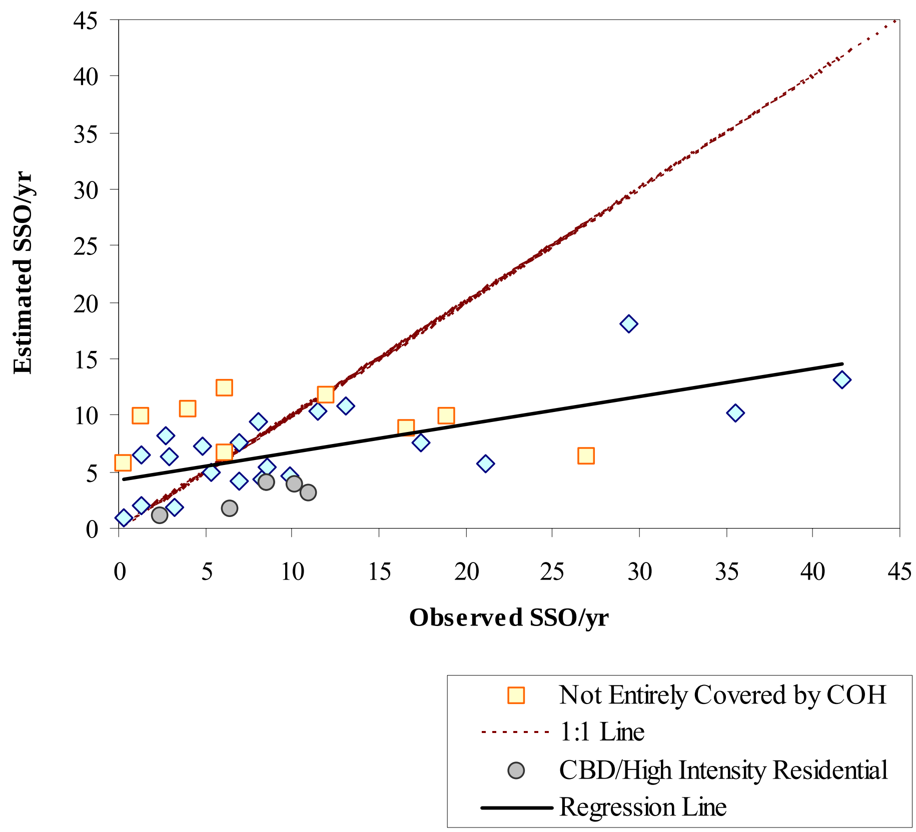


Figure 3.6. Comparison of Estimated and Observed SSO/yr

DETERMINATION OF LOAD AND FLOW FROM SSOs

SSO flows were estimated using the number of SSOs calculated in the previous section, along with volume estimates obtained from the US EPA SSO Report (2004). Volumes for each type of SSO event are shown in Table 3.12. Both average and median volumes were reported by US EPA; the median volume was used in the SSO calculations as it best represents the central tendency of the generally skewed volume data. Wet weather and inflow/infiltration sanitary sewer overflows produce the highest volume of discharge per event, at an average of 14,400 gallons per event. Blockages in the sanitary sewer system account for the largest percentage of SSO events, yet they produce the smallest volumes of discharge per event, with an average of 500 gallons per event (US EPA 2004).

An effort was undertaken to characterize SSO discharges in and around the Buffalo and Whiteoak Bayou watersheds as described in Chapter 7 of the Final Report for Work Order 6 (2004) and Chapter 6 of the Final Report for Work Order 8 (2005). As described in these chapters, SSOs were difficult to locate and sample and thus WWTP influent was sampled during both wet and dry (Table 3.13). One 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 on the table. The geometric mean of the dry weather concentrations was found to be 4.70×10^6 MPN/dL, while the wet weather concentrations were 3.50×10^6 MPN/dL.

Table 3.12 Summary of Estimated Volumes by US EPA (2004)

Table 3.13 Measured concentrations of *E. coli* in wastewater

The concentration and volume for each type of SSO event were used in conjunction with the number of SSO events estimated or reported to determine a daily load from these discharges into the bayous. Based upon data from the US EPA SSO Report to Congress (US EPA 2004), it was assumed that 72% of the volume and load from the SSO event reached the stream

FINAL SSO LOADS

The final calculated loads are presented in Table 3.14 for both dry and wet weather. The largest dry weather SSO *E. coli* load is found in Subbasin 5, with 1.09×10^{10} MPN/day delivered to the stream, while the largest wet weather SSO load is found in Subbasin 37, with 9.87×10^{9} MPN/day being delivered to Buffalo Bayou.

Table 3.14 Final Estimates of SSO Occurrences, Flow and Loads

Table 3.14 continued

Table 3.14 continued

3.2.2.4 SEGMENT LOADING FOR MS4 DISCHARGES

The three sources of loading from the MS4s are summarized in Table 3.15. Overall, segment 1014 has the largest loading from SSOs, both dry and wet. In addition, segment 1014 also has the largest loading from DWSS discharges. The largest wet weather and intermediate flow MS4 discharges were found at the mouth of the reservoirs. Wet condition *E. coli* loads at the mouth of the reservoirs were estimated to be 531,253.65 billion MPN/day. Segment 1017 was found to have the second highest loading under wet and intermediate conditions.

Table 3.15 Loading and Flow from MS4 Pipes in BLEST on Segment Basis

3.3 LOAD ALLOCATION

The load allocation of a total maximum daily load (TMDL) includes all sources of bacteria that are not regulated through environmental permitting. In the Buffalo and Whiteoak Bayou bacteria TMDLs, this includes on-site sewage facilities, bed sediment resuspension and direct deposition into the bayou. The load estimation methods for these sources will be described in the next section.

3.3.1 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.

To determine the loads associated with septic system facilities, data from the Harris County Engineer's office were obtained. Septic system data were obtained for the period of July 1991 through August 2004. These data were logged into an Access database and the number of septic systems per zip code within in Harris County was determined, as shown in Table 3.16. The areas of zip code coverages within Harris County were determined and used to determine

Table 3.16 Summary of Number of Septic Systems by Zip Codes in Harris County the number of septic systems per acre within each zip code. Regions covered by WWTP municipal utility districts (MUDs) were excluded from the subwatershed totals. To determine the number of septic systems in each subbasin, the coverage of each zip code per subbasin (excluding MUDs) was calculated and used to determine the total number of septic systems per zip code.

Because the database was only for Harris County, septic system density had to be estimated outside the county. For subbasins more than 50% within Harris County, the density of septic systems was used to calculate the total number of septic systems in the subbasin. For those subbasins with less than 50% of their area in Harris County and those that were entirely outside of Harris County, the average of septic systems in the nearby regions was used to calculate loads instead. For subbasins primarily in Fort Bend County, the number of septic systems was estimated using the average density of subbasin 132, 147, 151, 152, 153, 154, 155, and 156 to obtain an average septic density of 0.012 septic systems/acre. For those subbasins primarily in Waller County, the average septic density of subbasin 128, 138, and 139 (0.005 septic systems/acre) was used to determine the number of septic systems.

The flows and loads associated with failing septic systems were estimated using the assumptions presented in Table 3.17. The values in the table were determined from literature values. There is a wide variation in reported failure rates, with rates between 1-5% reported by De Walle (1981), 10-15% reported by the US EPA (US EPA 2002), 15% reported by Moyer and Hyer (2003) and 5-35% reported by Schueler (2000). For this study, a conservative value of 25% was chosen. The number of individuals per household was determined based upon Harris County Census data (2000), which reported 2.79 individuals per household. The average amount

Table 3.17 Assumptions made for OSSF Loading Determination of wastewater produced by an individual per day of 70 gallons was obtained from literature Values reported in Metcalf and Eddy (1997). In addition, a very conservative assumption was made that all failing OSSF flow and bacteria load reached the bayou, resulting in a delivery rate of 100%.

E. coli concentrations associated with wastewater were calculated using data collected by the project in Work Order 6 (2004) and Work Order 8 (2005). The geometric mean concentration of *E. coli* was determined to be 4.78 x 10^6 MPN/dL. This value differs slightly from the concentration used in SSOs calculations because the OSSF geometric mean excludes the SSO sample.

The final numbers of OSSFs, along with their flow and bacteria loads, are presented in Table 3.18. The watershed with the highest overall septic load is in Subbasin 12 located in Whiteoak Bayou with 1.02 x 10^{12} MPN/day. A summary of septic system loading on a segment basis is presented in Table 3.19. The mouth of the reservoir watersheds had the highest loading from septic systems, while the mouth of segment 1013 has the lowest.

Table 3.18 Estimate of Septic System Totals, Flow and Loading

Table 3.18 continued

Table 3.18 continued

Table 3.19 Loading and Flow from OSSF in BLEST on Segment Basis

3.3.2 SEDIMENT CONTRIBUTIONS FROM STREAM BED

The load allocation portion of BLEST is comprised of *E. coli* sources that are, to some extent, non-controllable. One such nonpoint source is sediment resuspension. Sediment is resuspended in the bayous when shear stress on the bottom of 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 (Yang 2003). Storm water conveyances are often designed to maintain high velocities during runoff events and thus this critical velocity may be exceeded during multiple rain events throughout the year.

The BLEST approach used to determine sediment contributions focuses only on wet weather conditions, as that would be when resuspension would likely be expected. Streams in urban areas are typically designed to maintain high velocities during runoff events to quickly move water out of the area, which results in scour of stream beds (Walsh et al. 2005). Scouring results in stream sediment being resuspended and thus contributing to the overlying water concentrations of *E. coli*.

Site specific scour rate data are not available for the Houston area. Therefore, the experimentally determined resuspension rates of *E. coli* in a small stream determined by Jamieson et al. (2005) were used. In their study, *E. coli* resistant to nalidixic acid (*E. coli* NAR) were inoculated into the stream bed. Sediment bed and overlying water *E. coli* concentrations were measured during several small storms and *E. coli* resuspension rates were found to be between 8,200 and 15,000 cfu/m^2/s. A resuspension rate of 8,200 cfu/m^2/s was used in BLEST.

Estimates of bayou width and stream lengths were obtained from GIS shapefiles of the bayou stream network and LiDAR (Light Detection and Ranging) elevation data. Average widths were estimated for Whiteoak Bayou and upper Buffalo Bayou to be 10 ft, while in lower Buffalo Bayou the stream width was found to be wider, about 20 ft. NOAA data suggest that the typical storm length in the Houston area is around 8 hours. It was assumed that during the peak conditions, which was assumed to occur during only 5% of the storm, would sediment resuspension occur. The portions of Whiteoak Bayou that were concrete lined were assumed to add no additional *E. coli* loading from sediment resuspension but did transmiit suspended sediments from the upper watershed downstream.

The calculated bed sediment contribution to wet weather loading of bacteria using the above listed assumption is presented in Table 3.20. 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 subbasin with the lowest non-zero contribution is subbasin 105, with a contribution of 1.06×10^{10} MPN/day while the subbasin with the largest contribution is subbasin 45, with a loading of 4.78×10^{11} MPN/day.

As can be seen in Table 3.21, sediment resuspension was assumed to occur during wet weather conditions in all watersheds. The mouth of the reservoir watersheds has the highest loading from sediment resuspension, for an overall load of 9,536 billion MPN/day. The segment with the lowest loading from sediment resuspension is segment 1013.

Table 3.20 Sediment Resuspension Variables and Loading

Table 3.20 continued

Table 3.20 continued

Table 3.21 Loading and Flow from Sediment Resuspension in BLEST on Segment Basis

3.3.3 NONPOINT SOURCE DIRECT DEPOSITION INTO BAYOU

The bayou and its surrounding area provide a good habitat for many different types of wild life, such as birds, water fowl, raccoon, deer and other mammals. In addition, dogs and other animals use the bayou for recreation and drinking water. The numbers and potential loads associated with direct deposition into the bayou will be discussed in this section.

Southeastern Texas is the year-round home to many types of water fowl, including the White Ibis (Kushlan and Bildstein 1992), White-Faced Ibis (Ryder and Manry 1994), Roseate Spoonbill (Dumas 2000), Reddish Egret (Lowther and Paul 2002), Great Blue Heron (Butler 1992), Great Egret (McCrimmon et al. 2001), Snowy Egret (Parsons and Master 2000), Cattle Egret (Telfair 1994), and Neotropic Cormorant (Telfair and Morrison 2005). Reported estimates from the *Birds of North America* publication are provided in Table 3.22, along with estimated population densities and percentage contribution of the particular bird species to the stream. The percent contribution to the stream was based upon bird behavior. Birds present in the Houston area only in the fall were assumed to have a 25% contribution throughout the year, while birds present in the water only a portion of the day were assumed to have a contribution of 50%. Neotropic cormorants prefer water that is deeper, and, thus, they were assumed to be present only in the reservoirs. Finally, the remaining birds were assumed to have 100% contribution, since there were no data to indicate other birds were present.

In addition, other animals were also included in this assessment. The number of dogs swimming and defecating into the bayou were estimated based upon density estimates proposed in the 4 Mile Run TMDL completed in Virginia. These estimates proposed that in open space

Table 3.22 Waterfowl Population and Population Density for Buffalo and Whiteoak Bayou Watersheds

Waterfowl Name	Population	Region	Population Density (pairs/acre)[1]	% Contribution[2]	Final Density (pair/acre)
White Ibis	Small population in Texas	Texas Gulf Coast	2.81E-05	25%	7.01E-06
White-faced Ibis	2300 pairs along Texas coast, in decline	Texas Gulf Coast	2.15E-04	50%	1.08E-04
Roseate Spoonbill	686 in 1998 for Gal Bay	Galveston Bay	1.79E-03	100%	1.79E-03
Reddish Egret	1500 Pairs in Texas	Texas Gulf Coast	1.40E-04	50%	7.01E-05
Great Blue Heron	40% of breeding population (36,248) in Texas and Louisiana	Texas/Louisiana Gulf Coast	8.27E-04	50%	4.13E-04
Great Egret	6500 pairs in 1969 in Texas	Texas Gulf Coast	6.08E-04	100%	6.08E-04
Snowy Egret	Not found in Buffalo and Whiteoak Bayou watersheds	N/A	0.00E+00	0%	0.00E+00
Cattle Egret	Present in Texas, not generally near water	N/A	0.00E+00	0%	0.00E+00
Neotropic Cormorant	608 pairs on average in Texas	Texas Gulf Coast	5.69E-05	100%	5.69E-05

Notes:
1. Population density estimates made using the following areas for each habitat range:
Gulf coast is 1.07×10^{17} acres (based upon Level 3 Texas Parks and Wildlife Ecoregion shapefile), Galveston Bay is 3.8×10^{5} acres (based upon data from http://wwww.gbep.state.tx.us/about-galveston-bay/geography.asp), and Louisiana Gulf Coast (based upon data from http://www.nature.org/wherewework/northamerica/states/louisiana/ /preservers/art6866.html) is 6.7×10^{6} acres.
2. Percent contribution determined using waterfowl behavior.
Those waterfowl that migrate only to Texas in the fall were assumed to have a 25% contribution, while those that are present year round and feed in the water only during a portion day were assumed to have 50% contribution. Cormorants prefer deeper waters, and thus were assumed to be present only in the reservoirs. The remaining waterfowl were assumed to have 100% contribution as there were not data to suggest otherwise.

and park areas, the density of dogs would be 0.12 dogs/acre. In addition, the 4 Mile Run TMDL also developed density estimates for "other" animals, basically any animal that was not included explicitly in the study, such as raccoons, nutria, rodents, bats and birds under bridges. The density of animals was noted in the 4 Mile Run TMDL to be 8 animals/acre.

A small buffer area around the bayou was estimated for each subbasin based upon the length of the stream and width, as previously described in the sediment resuspension load calculations. This buffer could basically be considered as direct deposition into the bayou, as feces in this area might also potentially get knocked in or washed into the bayou during high flow events. The width of the buffer used was 10 feet on either side of the bayou. In addition, a delivery ratio of 100% for birds and 5% for dogs and other animals was used to describe the percentage of the waste that actually would be deposited in the water at any given time.

Bacteria loads associated with direct deposition are not well studied in the literature and loads that are reported often differ by many orders of magnitude. Loads from the birds were estimated from loading rates provided by the US EPA Bacteria Indicator Tool (US EPA 2000) and from loads reported by Zeckoski et al (2005), Northern Virginia Regional Commission (2002), and MapTech Inch (2000), shown in Table 3.23. The geometric mean of loading from birds, 1.0×10^{8} MPN/day, was used to calculate loading from birds while the values of *E. coli* associated with dogs and other organisms were 2.0×10^{9} MPN/day and 8.6×10^{8} MPN/day, respectively.

Table 3.23 Estimate of *E. coli* loading from Animals on a daily basis

Animal Type	Fecal Coliform Deposition Rate (MPNday)	E. coli Deposition Rate (MPN/day)[1]	Source
Goose	8.00E+08	5.04E+08	Zeckoski, 2005
Duck	2.40E+09	1.51E+09	Zeckoski, 2005
Duck	2.43E+09	1.53E+09	US EPA Bacteria Indicator Tool
Goose	4.90E+10	3.09E+10	US EPA Bacteria Indicator Tool
Duck	7.35E+04	4.63E+04	Upper Blackwater River, 2000
Goose	7.04E+04	4.44E+04	Upper Blackwater River, 2000
Dog	4.09E+09	2.58E+09	4 Mile Run TMDL, May 2002
Dog	9.90E+08	6.24E+08	Upper Blackwater River, 2000
Racoon	5.90E+09	3.71E+09	Upper Blackwater River, 2000
Muskrat	1.90E+08	1.20E+08	Upper Blackwater River, 2000
Deer	2.55E+09	1.60E+09	Upper Blackwater River, 2000
Other	1.88E+08	1.18E+08	4 Mile Run TMDL, May 2002

[1] Fecal coliform converted to E. coli using ratio of standards (126/200).

Abbreviations: MPN - most probable number

The calculated loads are presented in Table 3.24. Loads are assumed to be constant during all weather conditions. Subbasin 127 had the highest loading from direct deposition, with loads of 6.26×10^9 MPN/day while subbasin 105 had the lowest loading from direct deposition, with 1.54×10^8 MPN/day.

A summary of segment loadings is presented in Table 3.25. The largest load from direct deposition is found at the mouth of the reservoir watershed with a load of 139 billion MPN/day while the lowest loading was 36 billion MPN/day at the mouth of Segment 1013. In Segment 1017, Whiteoak Bayou, the loading was 16 billion MPN/day.

Table 3.24 Summary of Loading from Direct Deposition

Table 3.24 continued

Table 3.24. continued

Table 3.25 Loading and Flow from Direct Deposition in BLEST on Segment Basis

3.4 UPSTREAM LOADS

In BLEST, the upstream loads are included in the analysis. The upstream loads are calculated using the flow from each upstream segment and multiplying it by the contact recreation standard minus the margin of safety. This is the load that is allowed from the upstream watershed.

3.5 MARGIN OF SAFETY AND TARGET LOADS

All of the waste load and load calculations contain conservative assumptions that include an implicit margin of safety (MOS). An explicit MOS of 5% is included in the allocations to provide for changes in the watershed due to continuing expansion of developed areas. The contact recreation target is calculated as the contact recreation standard of 126 MPN/dL multiplied by the flow estimated by BLEST for each flow condition. For comparison purposes, a target load is also calculated for the non-contact recreation target of 605 MPN/dL. The target loads can be compared to the estimated current load, which is the sum of all loads occurring in each flow condition, to observe that under almost all conditions the targets are not met.

3.6 CALCULATION OF WASTE LOAD AND LOAD ALLOCATIONS

Using the loads predicted by BLEST, it was possible to determine waste load and load allocations for Buffalo and Whiteoak Bayous. The first step is establishing the load allocation. To determine the load allocation, the sum of the upstream inputs and margin of safety were subtracted from the contact recreation target load. The difference was the load allocation. The load allocation for intermediate and wet weather conditions were equivalent to the dry condition load allocation. There was one exception to this, however. If the dry weather condition load allocation was basically equivalent to zero, then the difference between the contact recreation target and estimated load was used as intermediate and wet condition load allocation instead (this exception was used at the mouth of Segment 1013).

Next the waste load allocation was set. The waste load allocation was always zero under the dry weather condition. The waste load allocation for intermediate and wet conditions was determined by taking the difference between the contact recreation target and the sum of the load allocation, margin of safety and upstream input. The difference was assigned to the waste load allocation.

The final TMDL target was computed as the sum of the waste load allocation, load allocation, upstream inputs, and margin of safety. The TMDL target was always equal to the contact recreation standard target. Percent reductions are calculated by comparing the waste load or load allocation to the estimated current load.

3.7 FINAL BACTERIA LOAD SPREADSHEET ESTIMATES

The load estimates for *E. coli* using BLEST discussed in this chapter are shown in Table 3.26(A)-(D), for contact and non-contact *E. coli* standards. Loads that have been estimated from all the sources are totaled and compared to the in-stream target load.

The primary sources of loading across the segments under dry weather conditions appear to be OSSFs and direct deposition at the mouth of segment 1014 and the mouth of the reservoir watersheds. It is estimated that the mouth of segment 1013 has the highest loading from upstream sources followed by direct deposition in dry conditions. Finally, segment 1017 exhibits the highest loading from OSSFs and dry weather storm sewer discharges.

Under intermediate and wet conditions, the greatest source of loading in all segments is from wet weather storm water conveyance discharges. In intermediate conditions, BLEST estimates the second highest source to be OSSFs in all segments except for the mouth of segment 1013 where the second highest source is estimated to be SSOs. Finally, under wet weather conditions, the source that contributes the most *E. coli* loading after wet weather storm water conveyance discharges is bed sediment resuspension.

As can be seen from the spreadsheets, in general, very large reductions are required in the bacteria loads to meet contact recreation standards under dry weather conditions, with percent reductions for waste load allocation sources greater than 99% for all segments. Required reductions for load allocation sources range from 87% at the mouth of Segment 1014 under dry conditions to almost 100% at the mouth of Segment 1013. Under intermediate conditions, BLEST predicts that reductions of between 99% to 100% are required for waste load sources while load allocation sources require between 87% and 100% reductions. Under wet conditions, reductions for both waste load and load allocation sources are greater than 98% in all segments.

For purposes of comparison, the non-contact recreation target was calculated and percent reductions for the segments to meet the target were calculated. Under dry conditions, a wide range of load reductions are required, between 0% and 91%. For intermediate conditions, 0% reduction is required for the mouth of Segment 1014 while other segments require reductions of between 82% and 97%. Wet weather conditions all require greater than 92% reduction.

Table 3.26(A) Load Analysis for Mouth of Segment 1014

Table 3.26 (B) Load Analysis for Mouth of Segment 1013

Table 3.26(C) Load Analysis for the Mouth of Reservoir Watersheds

Table 3.26 (D) Load Analysis for Segment 1017

3.8 SUMMARY

Bacteria load and flows from sources were estimated for three different flow conditions: dry, intermediate and wet. Initial results using BLEST (a load estimation tool) indicated that the major sources of bacteria in the two watersheds appear to be wet weather MS4 discharges, bed sediment resuspension and OSSFs. Waste load and load allocations have been calculated and demonstrate that reductions in bacteria loads can be achieved via a combination of waste load and load allocation reductions.

CHAPTER 4 : FUTURE WORK

During the coming fiscal year (September 1, 2006 through August 31, 2007), the project team will focus on the following activities:

- Complete WWTP Sampling, data gathering and analysis;
- Refine allocations; and
- Write the TMDL.

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Appendix A

Slides from February 7, 2006 Stakeholder Meeting