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

**Contract No. 582-6-70860**
**Work Order No. 582-6-70860-01**

**FINAL REPORT**

Prepared by
*University of Houston*

Principal Investigator
Hanadi Rifai

Prepared for
Total Maximum Daily Load Program
Texas Commission on Environmental Quality
P.O. Box 13087, MC - 150
Austin, Texas 78711-3087

TCEQ Contact:
Ronald Stein
TMDL Team (MC-203)
P.O. Box 13087, MC - 203
Austin, Texas 78711-3087
RStein@tceq.state.tx.us

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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

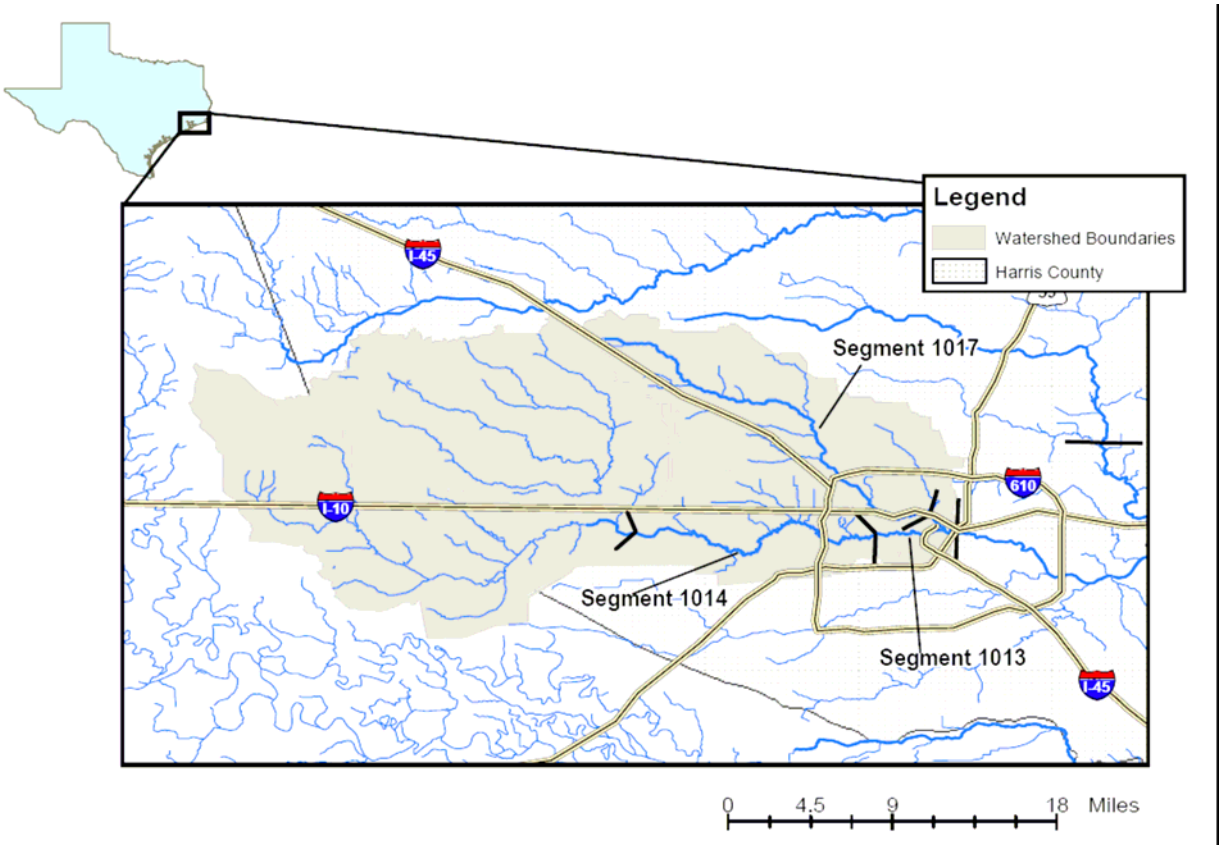


Figure 3.1. Locations of Segments in the Buffalo and Whiteoak Bayou Watersheds

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

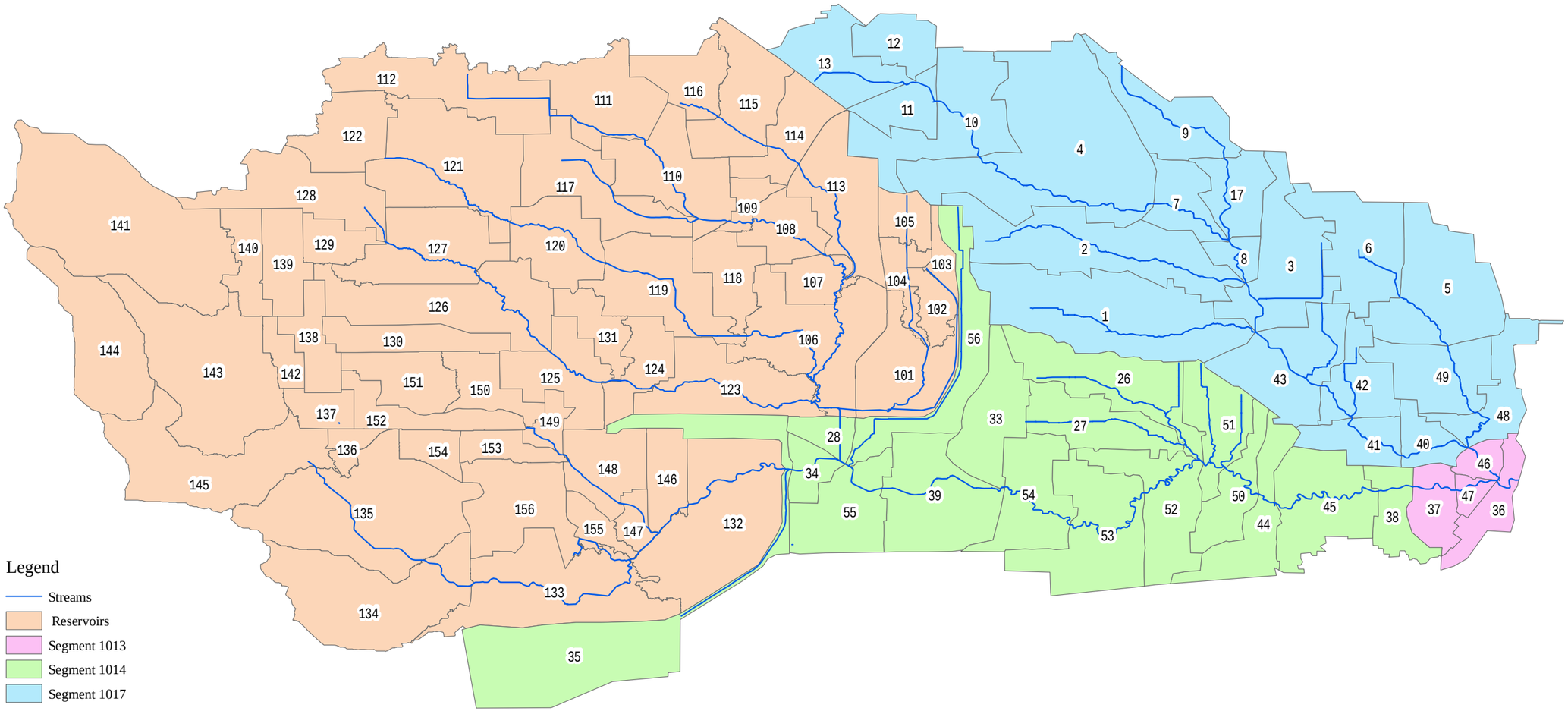


Figure 3.2: Subbasins Used in the Bacteria Loading Estimator Spreadsheet tool

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 $2.22 \times 10^{11}$ MPN/day. The smallest non-zero load was found to be $7.44 \times 10^{5}$ 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 $3.45 \times 10^{12}$ MPN/day. The smallest load was in Subbasin 142 with a load of $6.95 \times 10^{9}$ 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.

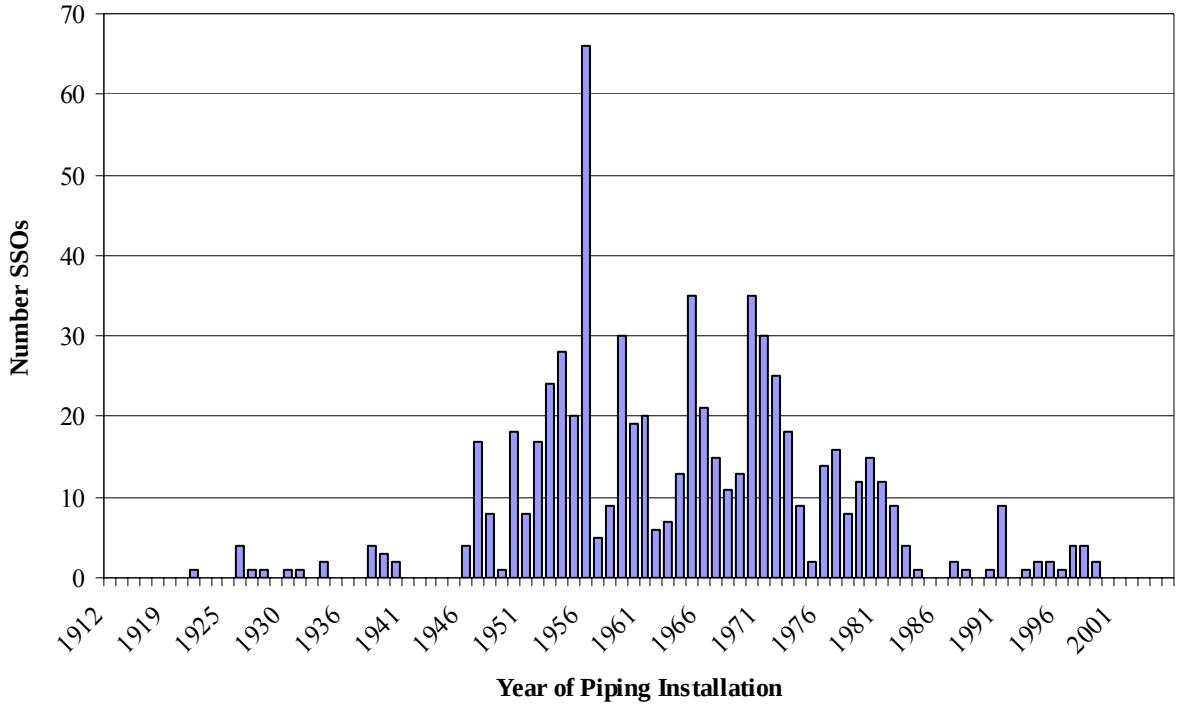


Figure 3.3. Influence of Age on SSOs in Buffalo and Whiteoak Bayous

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

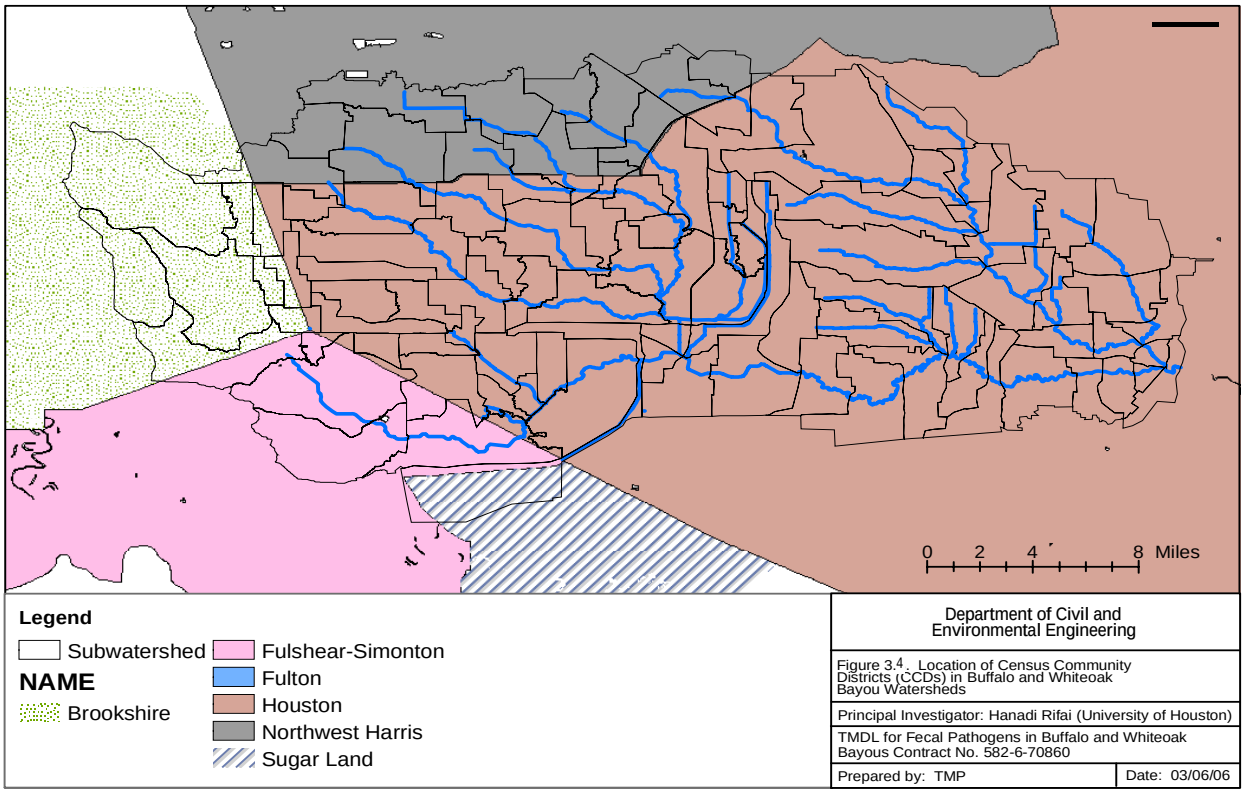


Figure 3.4. Location of Census Community Districts (CCDs) in Buffalo and Whiteoak Bayou

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.

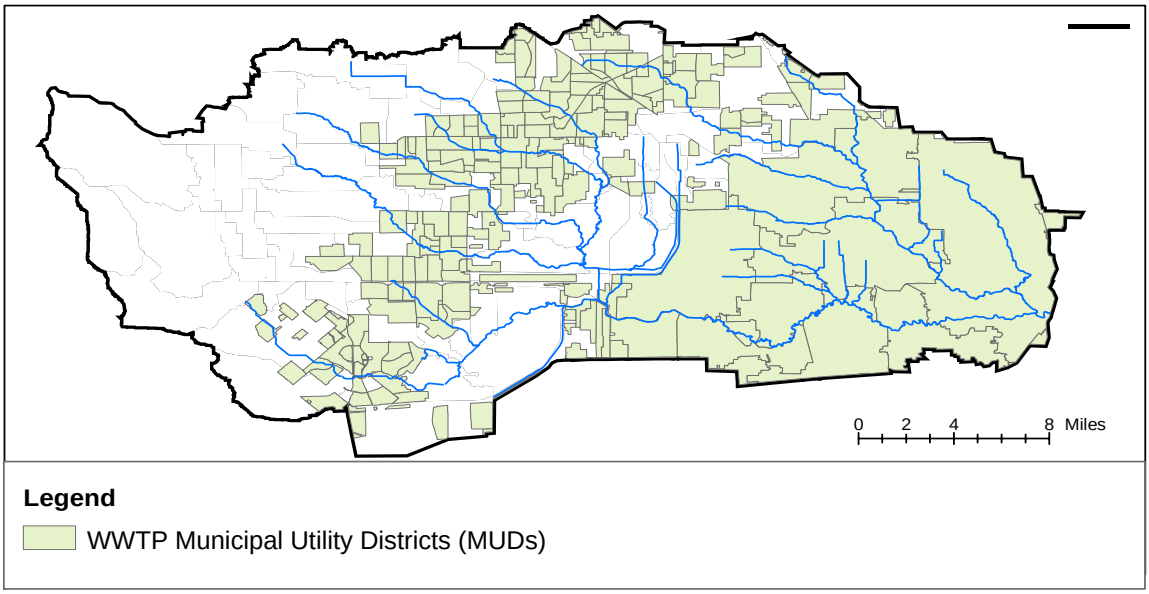


Figure 3.5. Location of Municipal Utility Districts (MUDs) in Buffalo and Whiteaok Bayous

Table 3.11. Calculation of Maintenance Hole Density in Residential areas

| Subbasin | Number Maintenance Holes (MH) | Acres | MH per acre |
|---|---|---|---|
| 1 | 2653 | 7680.3 | 0.345 |
| 3 | 1735 | 4411.4 | 0.393 |
| 5 | 2212 | 5263.8 | 0.420 |
| 6 | 1665 | 3848.1 | 0.433 |
| 7 | 903 | 1814.8 | 0.498 |
| 8 | 199 | 760.3 | 0.262 |
| 17 | 952 | 1999.6 | 0.476 |
| 26 | 1853 | 4088.1 | 0.453 |
| 27 | 806 | 2870.7 | 0.281 |
| 28 | 258 | 887.3 | 0.291 |
| 33 | 1176 | 3001.4 | 0.392 |
| 34 | 767 | 1037.7 | 0.739 |
| 41 | 703 | 1693.4 | 0.415 |
| 42 | 985 | 2175.6 | 0.453 |
| 43 | 1672 | 4150.2 | 0.403 |
| 48 | 1241 | 2271.9 | 0.546 |
| 49 | 1610 | 3018.0 | 0.533 |
| 50 | 948 | 2001.6 | 0.474 |
| 54 | 1612 | 3262.4 | 0.494 |
| 55 | 1523 | 3174.3 | 0.480 |
| 56 | 854 | 3613.6 | 0.236 |
| | | Average | 0.429 |

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.

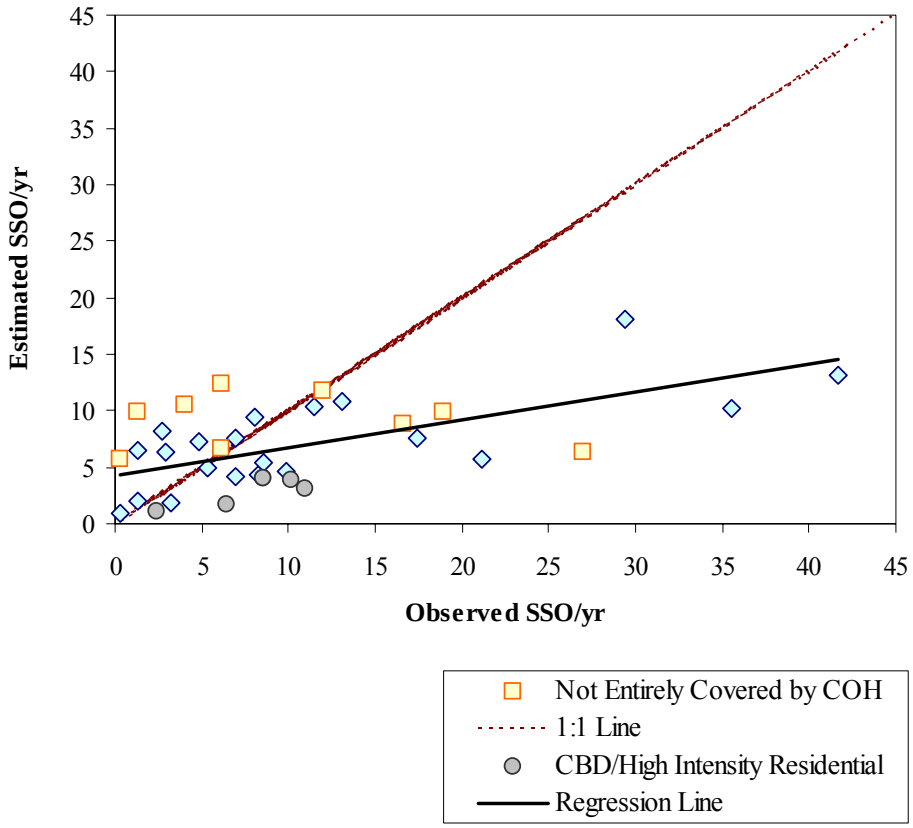


Figure 3.6. Comparison of Estimated and Observed SSO/yr

## *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 $4.70 \times 10^6$ MPN/dL, while the wet weather concentrations were $3.50 \times 10^6$ MPN/dL.

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

| Type of SSO Event | Average Volume (gallons) | Median Volume (gallons) | Percent Occurrence |
|---|---|---|---|
| Blockage | 5,900 | 500 | 90% |
| Wet Weather – Inflow/Infiltration | 360,000 | 14,400 | 0.60% |
| Mechanical or Power | 63,000 | 2,000 | 1.40% |
| Line Break | 172,000 | 1,500 | 7% |
| Miscellaneous | 260,000 | 1,200 | 0.20% |

Abbreviations: SSO - sanitary sewer overflow

Table 3.13. Measured concentrations of E. coli in wastewater

| Sample ID | Date | EC Concentration (MPN/dL) | Dry or Wet? |
|---|---|---|---|
| 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

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 $1.09 \times 10^{10}$ MPN/day delivered to the stream, while the largest wet weather SSO load is found in Subbasin 37, with $9.87 \times 10^{9}$ MPN/day being delivered to Buffalo Bayou.

Table 3.14 Final Estimates of SSO Occurrences, Flow and Loads

| Sbsn | Dry SSO/yr | Flow on dry day to stream (MGD) | Load on dry day to stream (MPN/day) | Wet SSO/yr | Flow on wet day to stream (MGD) | Load on wet day to stream (MPN/day) |
|---|---|---|---|---|---|---|
| 1 | 29 | 4.30E-05 | 7.65E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 2 | 4 | 5.86E-06 | 1.04E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 3 | 13 | 1.92E-05 | 3.41E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 4 | 1 | 1.95E-06 | 3.48E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 5 | 42 | 6.10E-05 | 1.09E+10 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 6 | 8 | 1.17E-05 | 2.09E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 7 | 8 | 1.21E-05 | 2.16E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 8 | 3 | 4.69E-06 | 8.35E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 9 | 3 | 4.20E-06 | 7.47E+08 | 2.23E-02 | 3.1E-06 | 4.12E+08 |
| 10 | 6 | 8.97E-06 | 1.60E+09 | 4.76E-02 | 6.6E-06 | 8.80E+08 |
| 11 | 3 | 4.34E-06 | 7.72E+08 | 2.30E-02 | 3.2E-06 | 4.26E+08 |
| 12 | 1 | 1.41E-06 | 2.51E+08 | 7.47E-03 | 1.0E-06 | 1.38E+08 |
| 13 | 4 | 5.83E-06 | 1.04E+09 | 3.09E-02 | 4.3E-06 | 5.72E+08 |
| 17 | 10 | 1.45E-05 | 2.57E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 26 | 36 | 5.20E-05 | 9.25E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 27 | 5 | 7.04E-06 | 1.25E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 28 | 0.3 | 3.91E-07 | 6.96E+07 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 33 | 7 | 1.02E-05 | 1.81E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 34 | 1 | 1.95E-06 | 3.48E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 35 | 0.3 | 3.91E-07 | 6.96E+07 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 36 | 9 | 1.25E-05 | 2.23E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 37 | 10 | 1.49E-05 | 2.64E+09 | 5.34E-01 | 7.4E-05 | 9.87E+09 |
| 38 | 9 | 1.25E-05 | 2.23E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 39 | 12 | 1.76E-05 | 3.13E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 40 | 11 | 1.60E-05 | 2.85E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 41 | 7 | 1.02E-05 | 1.81E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 42 | 9 | 1.25E-05 | 2.23E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 43 | 11 | 1.68E-05 | 2.99E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 44 | 6 | 8.99E-06 | 1.60E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 45 | 19 | 2.78E-05 | 4.94E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 46 | 6 | 9.38E-06 | 1.67E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 47 | 2 | 3.52E-06 | 6.26E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 48 | 21 | 3.09E-05 | 5.50E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 49 | 17 | 2.54E-05 | 4.52E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 50 | 5 | 7.82E-06 | 1.39E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 51 | 27 | 3.95E-05 | 7.03E+09 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 52 | 17 | 2.42E-05 | 4.31E+09 | 5.34E-01 | 7.4E-05 | 9.87E+09 |
| 53 | 6 | 8.99E-06 | 1.60E+09 | 2.67E-01 | 3.7E-05 | 4.94E+09 |
| 54 | 3 | 3.91E-06 | 6.96E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 55 | 3 | 4.30E-06 | 7.65E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 56 | 1 | 1.95E-06 | 3.48E+08 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 101 | 0.001 | 1.36E-09 | 2.42E+05 | 7.21E-06 | 1.0E-09 | 1.33E+05 |
| 102 | 0.2 | 3.21E-07 | 5.71E+07 | 1.70E-03 | 2.4E-07 | 3.14E+07 |
| 103 | 0.1 | 8.02E-08 | 1.43E+07 | 4.26E-04 | 5.9E-08 | 7.86E+06 |
| 104 | 0.4 | 5.18E-07 | 9.22E+07 | 2.75E-03 | 3.8E-07 | 5.08E+07 |
| 105 | 0.3 | 3.68E-07 | 6.55E+07 | 1.95E-03 | 2.7E-07 | 3.61E+07 |
| 106 | 0.5 | 6.66E-07 | 1.18E+08 | 3.53E-03 | 4.9E-07 | 6.53E+07 |
| 107 | 2 | 2.59E-06 | 4.61E+08 | 1.37E-02 | 1.9E-06 | 2.54E+08 |

Table 3.14 Final Estimates of SSO Occurrences, Flow and Loads, continued

| Sbsn | Dry SSO/yr | Flow on dry day to stream (MGD) | Load on dry day to stream (MPN/day) | Wet SSO/yr | Flow on wet day to stream (MGD) | Load on wet day to stream (MPN/day) |
|---|---|---|---|---|---|---|
| 108 | 2 | 3.19E-06 | 5.67E+08 | 1.69E-02 | 2.4E-06 | 3.12E+08 |
| 109 | 2 | 2.79E-06 | 4.97E+08 | 1.48E-02 | 2.1E-06 | 2.74E+08 |
| 110 | 4 | 6.52E-06 | 1.16E+09 | 3.46E-02 | 4.8E-06 | 6.40E+08 |
| 111 | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 112 | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 113 | 7 | 9.76E-06 | 1.74E+09 | 5.18E-02 | 7.2E-06 | 9.57E+08 |
| 114 | 4 | 6.06E-06 | 1.08E+09 | 3.22E-02 | 4.5E-06 | 5.95E+08 |
| 115 | 4 | 5.91E-06 | 1.05E+09 | 3.14E-02 | 4.4E-06 | 5.80E+08 |
| 116 | 1 | 7.71E-07 | 1.37E+08 | 4.09E-03 | 5.7E-07 | 7.56E+07 |
| 117 | 2 | 3.65E-06 | 6.49E+08 | 1.94E-02 | 2.7E-06 | 3.58E+08 |
| 118 | 3 | 4.15E-06 | 7.38E+08 | 2.20E-02 | 3.1E-06 | 4.07E+08 |
| 119 | 6 | 8.47E-06 | 1.51E+09 | 4.50E-02 | 6.3E-06 | 8.31E+08 |
| 120 | 4 | 5.91E-06 | 1.05E+09 | 3.14E-02 | 4.4E-06 | 5.79E+08 |
| 121 | 1 | 1.11E-06 | 1.97E+08 | 5.88E-03 | 8.2E-07 | 1.09E+08 |
| 122 | 0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 123 | 2 | 2.47E-06 | 4.40E+08 | 1.31E-02 | 1.8E-06 | 2.42E+08 |
| 124 | 0 | 6.07E-07 | 1.08E+08 | 3.22E-03 | 4.5E-07 | 5.95E+07 |
| 125 | 1 | 1.64E-06 | 2.91E+08 | 8.69E-03 | 1.2E-06 | 1.61E+08 |
| 126 | 0.1 | 1.24E-07 | 2.22E+07 | 6.61E-04 | 9.2E-08 | 1.22E+07 |
| 127 | 0.0002 | 2.46E-10 | 4.38E+04 | 1.31E-06 | 1.8E-10 | 2.42E+04 |
| 128 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 129 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 130 | 0.0 | 6.59E-08 | 1.17E+07 | 3.50E-04 | 4.9E-08 | 6.47E+06 |
| 131 | 2 | 2.55E-06 | 4.54E+08 | 1.35E-02 | 1.9E-06 | 2.50E+08 |
| 132 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 133 | 3 | 4.32E-06 | 7.69E+08 | 2.29E-02 | 3.2E-06 | 4.24E+08 |
| 134 | 1 | 1.50E-06 | 2.67E+08 | 7.98E-03 | 1.1E-06 | 1.47E+08 |
| 135 | 1 | 9.30E-07 | 1.66E+08 | 4.94E-03 | 6.9E-07 | 9.12E+07 |
| 136 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 137 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 138 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 139 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 140 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 141 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 142 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 143 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 144 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 145 | 0.1 | 9.83E-08 | 1.75E+07 | 5.22E-04 | 7.3E-08 | 9.64E+06 |
| 146 | 0.5 | 7.27E-07 | 1.29E+08 | 3.86E-03 | 5.4E-07 | 7.13E+07 |
| 147 | 0.0 | 3.78E-08 | 6.72E+06 | 2.00E-04 | 2.8E-08 | 3.70E+06 |
| 148 | 4 | 5.91E-06 | 1.05E+09 | 3.14E-02 | 4.4E-06 | 5.80E+08 |
| 149 | 1 | 2.01E-06 | 3.58E+08 | 1.07E-02 | 1.5E-06 | 1.97E+08 |
| 150 | 3 | 4.54E-06 | 8.07E+08 | 2.41E-02 | 3.4E-06 | 4.45E+08 |
| 151 | 2 | 2.70E-06 | 4.81E+08 | 1.44E-02 | 2.0E-06 | 2.65E+08 |
| 152 | 1 | 1.29E-06 | 2.30E+08 | 6.86E-03 | 9.6E-07 | 1.27E+08 |
| 153 | 1 | 2.18E-06 | 3.88E+08 | 1.16E-02 | 1.6E-06 | 2.14E+08 |
| 154 | 0.02 | 2.25E-08 | 4.00E+06 | 1.19E-04 | 1.7E-08 | 2.20E+06 |
| 155 | 1 | 7.46E-07 | 1.33E+08 | 3.96E-03 | 5.5E-07 | 7.32E+07 |

Table 3.14 Final Estimates of SSO Occurrences, Flow and Loads, continued

| Sbsn | Dry SSO/yr | Flow on dry day to stream (MGD) | Load on dry day to stream (MPN/day) | Wet SSO/yr | Flow on wet day to stream (MGD) | Load on wet day to stream (MPN/day) |
|---|---|---|---|---|---|---|
| 156 | 3 | 3.74E-06 | 6.66E+08 | 1.99E-02 | 2.8E-06 | 3.67E+08 |
| 171 | 2 | 2.84E-06 | 5.06E+08 | 1.51E-02 | 2.1E-06 | 2.79E+08 |
| 172 | 0.3 | 4.46E-07 | 7.93E+07 | 2.37E-03 | 3.3E-07 | 4.37E+07 |
| 173 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 174 | 0.002 | 3.26E-09 | 5.80E+05 | 1.73E-05 | 2.4E-09 | 3.20E+05 |
| 175 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 176 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 177 | 0.1 | 1.48E-07 | 2.64E+07 | 7.86E-04 | 1.1E-07 | 1.45E+07 |
| 178 | 0.0 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.0E+00 | 0.00E+00 |
| 180 | 0.3 | 4.54E-07 | 8.09E+07 | 2.41E-03 | 3.4E-07 | 4.46E+07 |
| 181 | 2 | 3.35E-06 | 5.96E+08 | 1.78E-02 | 2.5E-06 | 3.28E+08 |
| 182 | 0.4 | 6.02E-07 | 1.07E+08 | 3.20E-03 | 4.5E-07 | 5.91E+07 |
| 183 | 2 | 3.56E-06 | 6.34E+08 | 1.89E-02 | 2.6E-06 | 3.50E+08 |
| 184 | 1 | 9.01E-07 | 1.60E+08 | 4.78E-03 | 6.7E-07 | 8.84E+07 |
| 185 | 0.5 | 7.21E-07 | 1.28E+08 | 3.83E-03 | 5.3E-07 | 7.07E+07 |
| 186 | 0.3 | 3.85E-07 | 6.84E+07 | 2.04E-03 | 2.8E-07 | 3.77E+07 |
| 187 | 0.1 | 1.50E-07 | 2.67E+07 | 7.96E-04 | 1.1E-07 | 1.47E+07 |
| 188 | 0.01 | 8.08E-09 | 1.44E+06 | 4.29E-05 | 6.0E-09 | 7.92E+05 |

Abbreviations: dL - deciliter, MPN - most probable number, SSO - sanitary sewer overflow, yr - year

#### 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

| *E. coli* Sources | Dry | | Intermediate | | Wet | |
|---|---|---|---|---|---|---|
| | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) |
| Mouth of Reservoir Watersheds | | | | | | |
| Dry Weather Storm Sewer Discharges | 0.00 | 0.00 | 0.00 | 0.00 | - | - |
| Wet Weather Discharges | - | - | 44.36 | 50673.93 | 465.03 | 531,253.65 |
| SSOs - All conditions | 1.15E-04 | 20.40 | 1.15E-04 | 20.40 | 1.99E-04 | 31.64 |
| Mouth of Segment 1014 | | | | | | |
| Dry Weather Storm Sewer Discharges | 0.62 | 272.84 | 0.62 | 272.84 | - | - |
| Wet Weather Discharges | - | - | 0.50 | 805.42 | 333.18 | 539,159.82 |
| SSOs - All conditions | 2.17E-04 | 38.62 | 2.17E-04 | 38.62 | 3.29E-04 | 53.43 |
| Mouth of Segment 1013 | | | | | | |
| Dry Weather Storm Sewer Discharges | 5.36E-04 | 1.47E-02 | 5.36E-04 | 1.47E-02 | - | - |
| Wet Weather Discharges | - | - | 6.84 | 11377.44 | 175.48 | 291,700.00 |
| SSOs - All conditions | 1.82E-04 | 32.31 | 1.82E-04 | 32.31 | 2.56E-04 | 42.18 |
| Mouth of Segment 1017 | | | | | | |
| Dry Weather Storm Sewer Discharges | 0.76 | 250.09 | 0.76 | 250.09 | - | - |
| Wet Weather Discharges | - | - | 12.44 | 19928.55 | 362.34 | 580,640.16 |
| SSOs - All conditions | 1.82E-04 | 32.31 | 1.82E-04 | 32.31 | 2.00E-04 | 34.73 |

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

Abbreviations: BLEST - Bacteria Load Estimator Spreadsheet Tool, MGD - million gallon per day, MPN - most probable number, MS4 - municipal separate storm sewer system, SSO - sanitary sewer overflow

## 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 Coun

| Zip Code | Number of Septic Systems per Zip Code |
|---|---|
| 77002 | 1 |
| 77004 | 1 |
| 77007 | 1 |
| 77018 | 1 |
| 77019 | 1 |
| 77022 | 1 |
| 77023 | 1 |
| 77024 | 4 |
| 77032 | 77 |
| 77037 | 120 |
| 77038 | 132 |
| 77039 | 246 |
| 77040 | 53 |
| 77041 | 149 |
| 77042 | 2 |
| 77043 | 2 |
| 77055 | 1 |
| 77056 | 2 |
| 77057 | 1 |
| 77060 | 124 |
| 77064 | 147 |
| 77065 | 212 |
| 77070 | 47 |
| 77076 | 1 |
| 77077 | 3 |
| 77079 | 3 |
| 77082 | 4 |
| 77084 | 70 |
| 77086 | 132 |
| 77088 | 27 |
| 77092 | 3 |
| 77093 | 264 |
| 77094 | 14 |
| 77095 | 15 |
| 77401 | 1 |
| 77429 | 1454 |
| 77433 | 124 |
| 77447 | 642 |
| 77449 | 102 |
| 77450 | 9 |
| 77484 | 201 |
| 77493 | 128 |
| 77494 | 6 |

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

| Assumption | Value | Units |
|---|---|---|
| Failure Rate | 25% | |
| Number People per Household | 2.79 | |
| Wastewater Production | 70 | gallons/person/day |
| *E. coli* in Wastewater | 4.78E+06 | cfu/dL |
| Delivery rate | 100% | |

Abbreviations: cfu - colony forming unit, dL - deciliter
OSSF - on-site sewage facility

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

| Subwatershed | # Septic Systems | # Failing Septic Systems | EC (MPN/day) | Flow (MGD) |
|---|---|---|---|---|
| 1 | 9 | 2.25 | 5.01E+10 | 4.39E-04 |
| 2 | 38 | 9.5 | 2.11E+11 | 1.86E-03 |
| 3 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 4 | 167 | 41.75 | 9.29E+11 | 8.15E-03 |
| 5 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 6 | 3 | 0.75 | 1.67E+10 | 1.46E-04 |
| 7 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 8 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 9 | 105 | 26.25 | 5.84E+11 | 5.13E-03 |
| 10 | 25 | 6.25 | 1.39E+11 | 1.22E-03 |
| 11 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 12 | 184 | 46 | 1.02E+12 | 8.98E-03 |
| 13 | 35 | 8.75 | 1.95E+11 | 1.71E-03 |
| 17 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 26 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 27 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 28 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 33 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 34 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 35 | 53 | 13.25 | 2.95E+11 | 2.59E-03 |
| 36 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 37 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 38 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 39 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 40 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 41 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 42 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 43 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 44 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 45 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 46 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 47 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 48 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 49 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 50 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 51 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 52 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 53 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 54 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 55 | 3 | 0.75 | 1.67E+10 | 1.46E-04 |
| 56 | 20 | 5 | 1.11E+11 | 9.77E-04 |
| 101 | 19 | 4.75 | 1.06E+11 | 9.28E-04 |
| 102 | 11 | 2.75 | 6.12E+10 | 5.37E-04 |
| 103 | 12 | 3 | 6.67E+10 | 5.86E-04 |
| 104 | 13 | 3.25 | 7.23E+10 | 6.35E-04 |
| 105 | 22 | 5.5 | 1.22E+11 | 1.07E-03 |
| 106 | 22 | 5.5 | 1.22E+11 | 1.07E-03 |
| 107 | 3 | 0.75 | 1.67E+10 | 1.46E-04 |
| 108 | 3 | 0.75 | 1.67E+10 | 1.46E-04 |

Table 3.18. Estimate of Septic System Totals, Flow and Loading , continued

| Subwatershed | # Septic Systems | # Failing Septic Systems | EC (MPN/day) | Flow (MGD) |
|---|---|---|---|---|
| 109 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 110 | 8 | 2 | 4.45E+10 | 3.91E-04 |
| 111 | 25 | 6.25 | 1.39E+11 | 1.22E-03 |
| 112 | 39 | 9.75 | 2.17E+11 | 1.90E-03 |
| 113 | 15 | 3.75 | 8.34E+10 | 7.32E-04 |
| 114 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 115 | 11 | 2.75 | 6.12E+10 | 5.37E-04 |
| 116 | 11 | 2.75 | 6.12E+10 | 5.37E-04 |
| 117 | 13 | 3.25 | 7.23E+10 | 6.35E-04 |
| 118 | 3 | 0.75 | 1.67E+10 | 1.46E-04 |
| 119 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 120 | 15 | 3.75 | 8.34E+10 | 7.32E-04 |
| 121 | 49 | 12.25 | 2.73E+11 | 2.39E-03 |
| 122 | 22 | 5.5 | 1.22E+11 | 1.07E-03 |
| 123 | 27 | 6.75 | 1.50E+11 | 1.32E-03 |
| 124 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 125 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 126 | 5 | 1.25 | 2.78E+10 | 2.44E-04 |
| 127 | 46 | 11.5 | 2.56E+11 | 2.25E-03 |
| 128 | 20 | 5 | 1.11E+11 | 9.77E-04 |
| 129 | 6 | 1.5 | 3.34E+10 | 2.93E-04 |
| 130 | 9 | 2.25 | 5.01E+10 | 4.39E-04 |
| 131 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 132 | 9 | 2.25 | 5.01E+10 | 4.39E-04 |
| 133 | 46 | 11.5 | 2.56E+11 | 2.25E-03 |
| 134 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 135 | 42 | 10.5 | 2.34E+11 | 2.05E-03 |
| 136 | 8 | 2 | 4.45E+10 | 3.91E-04 |
| 137 | 8 | 2 | 4.45E+10 | 3.91E-04 |
| 138 | 9 | 2.25 | 5.01E+10 | 4.39E-04 |
| 139 | 10 | 2.5 | 5.56E+10 | 4.88E-04 |
| 140 | 7 | 1.75 | 3.89E+10 | 3.42E-04 |
| 141 | 51 | 12.75 | 2.84E+11 | 2.49E-03 |
| 142 | 4 | 1 | 2.22E+10 | 1.95E-04 |
| 143 | 23 | 5.75 | 1.28E+11 | 1.12E-03 |
| 144 | 23 | 5.75 | 1.28E+11 | 1.12E-03 |
| 145 | 25 | 6.25 | 1.39E+11 | 1.22E-03 |
| 146 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 147 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 148 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 149 | 2 | 0.5 | 1.11E+10 | 9.77E-05 |
| 150 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 151 | 8 | 2 | 4.45E+10 | 3.91E-04 |
| 152 | 7 | 1.75 | 3.89E+10 | 3.42E-04 |
| 153 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 154 | 5 | 1.25 | 2.78E+10 | 2.44E-04 |
| 155 | 7 | 1.75 | 3.89E+10 | 3.42E-04 |
| 156 | 3 | 0.75 | 1.67E+10 | 1.46E-04 |
| 171 | 7 | 1.75 | 3.89E+10 | 3.42E-04 |

Table 3.18. Estimate of Septic System Totals, Flow and Loading , continued

| Subwatershed | # Septic Systems | # Failing Septic Systems | EC (MPN/day) | Flow (MGD) |
|---|---|---|---|---|
| 172 | 10 | 2.5 | 5.56E+10 | 4.88E-04 |
| 173 | 11 | 2.75 | 6.12E+10 | 5.37E-04 |
| 174 | 8 | 2 | 4.45E+10 | 3.91E-04 |
| 175 | 9 | 2.25 | 5.01E+10 | 4.39E-04 |
| 176 | 14 | 3.5 | 7.79E+10 | 6.84E-04 |
| 177 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 178 | 38 | 9.5 | 2.11E+11 | 1.86E-03 |
| 180 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 181 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 182 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 183 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 184 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 185 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 186 | 0 | 0 | 0.00E+00 | 0.00E+00 |
| 187 | 1 | 0.25 | 5.56E+09 | 4.88E-05 |
| 188 | 49 | 12.25 | 2.73E+11 | 2.39E-03 |

Abbreviations: cfu - colony forming unit, dL - deciliter, EC - *E. coli* , MGD - million gallon per day
MPN - most probable number

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

| *E. coli* Sources | Dry | | Intermediate | | Wet | |
|---|---|---|---|---|---|---|
| | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) |
| Mouth of Reservoir Watersheds | | | | | | |
| OSSF | 4.3E-02 | 4,922.75 | 4.3E-02 | 4,922.75 | 4.3E-02 | 4,922.75 |
| Mouth of Segment 1014 | | | | | | |
| OSSF | 3.9E-03 | 439.43 | 3.9E-03 | 439.43 | 3.9E-03 | 439.43 |
| Mouth of Segment 1013 | | | | | | |
| OSSF | 2.4E-04 | 27.81 | 2.4E-04 | 27.81 | 2.4E-04 | 27.81 |
| Mouth of Segment 1017 | | | | | | |
| OSSF | 2.8E-02 | 3,153.90 | 2.8E-02 | 3,153.90 | 2.8E-02 | 3,153.90 |

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

Abbreviations: BLEST - Bacteria Load Estimator Spreadsheet Tool, MGD - million gallon per day, MPN - most probable number, OSSF - on-site sewage facility

### 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 $1.06 \times 10^{10}$ MPN/day while the subbasin with the largest contribution is subbasin 45, with a loading of $4.78 \times 10^{11}$ 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

| Subbasin | Stream Length (ft) | Width (Ft) | Majority Concrete Lined? | MPN/wet day |
|---|---|---|---|---|
| 1 | 30529 | 10 | N | 3.21E+11 |
| 2 | 35392 | 10 | N | 3.73E+11 |
| 3 | 7704 | 10 | Y | 0.00E+00 |
| 4 | 27113 | 10 | N | 2.85E+11 |
| 5 | 10782 | 10 | N | 1.13E+11 |
| 6 | 12123 | 10 | N | 1.28E+11 |
| 7 | 13137 | 10 | N | 1.38E+11 |
| 8 | 8559 | 10 | N | 9.01E+10 |
| 9 | 21363 | 10 | N | 2.25E+11 |
| 10 | 11669 | 10 | N | 1.23E+11 |
| 11 | 5982 | 10 | N | 6.30E+10 |
| 12 | 8226 | 10 | N | 8.66E+10 |
| 13 | 10486 | 10 | N | 1.10E+11 |
| 17 | 12698 | 10 | N | 1.34E+11 |
| 26 | 21701 | 20 | N | 4.57E+11 |
| 27 | 17846 | 20 | N | 3.76E+11 |
| 28 | 6600 | 20 | N | 1.39E+11 |
| 33 | 17899 | 20 | N | 3.77E+11 |
| 34 | 7603 | 20 | N | 1.60E+11 |
| 35 | 792 | 20 | N | 1.67E+10 |
| 36 | 5491 | 20 | N | 1.16E+11 |
| 37 | 5491 | 20 | N | 1.16E+11 |
| 38 | 4752 | 20 | N | 1.00E+11 |
| 39 | 17952 | 20 | N | 3.78E+11 |
| 40 | 10681 | 10 | Y | 0.00E+00 |
| 41 | 10322 | 10 | Y | 0.00E+00 |
| 42 | 6864 | 10 | Y | 0.00E+00 |
| 43 | 12403 | 10 | Y | 0.00E+00 |
| 44 | 3274 | 20 | N | 6.89E+10 |
| 45 | 22704 | 20 | N | 4.78E+11 |
| 46 | 7371 | 20 | N | 1.55E+11 |
| 47 | 5227 | 20 | N | 1.10E+11 |
| 48 | 9573 | 20 | N | 2.02E+11 |
| 49 | 11025 | 20 | N | 2.32E+11 |
| 50 | 9187 | 20 | N | 1.93E+11 |
| 51 | 4118 | 20 | N | 8.67E+10 |
| 52 | 16368 | 20 | N | 3.45E+11 |
| 53 | 21542 | 20 | N | 4.54E+11 |
| 54 | 14678 | 20 | N | 3.09E+11 |
| 55 | 8131 | 20 | N | 1.71E+11 |
| 56 | 1320 | 20 | N | 2.78E+10 |
| 101 | 16632 | 10 | N | 1.75E+11 |
| 102 | 6019 | 10 | N | 6.34E+10 |
| 103 | 6917 | 10 | N | 7.28E+10 |
| 104 | 16157 | 10 | N | 1.70E+11 |
| 105 | 1003 | 10 | N | 1.06E+10 |
| 106 | 24922 | 10 | N | 2.62E+11 |
| 107 | 19642 | 10 | N | 2.07E+11 |
| 108 | 18322 | 10 | N | 1.93E+11 |

Table 3.20. Sediment Resuspension Variables and Loading, continued

| Subbasin | Stream Length (ft) | Width (Ft) | Majority Concrete Lined? | MPN/wet day |
|---|---|---|---|---|
| 109 | 3590 | 10 | N | 3.78E+10 |
| 110 | 19536 | 10 | N | 2.06E+11 |
| 111 | 15523 | 10 | N | 1.63E+11 |
| 112 | 11405 | 10 | N | 1.20E+11 |
| 113 | 22757 | 10 | N | 2.40E+11 |
| 114 | 5122 | 10 | N | 5.39E+10 |
| 115 | 7973 | 10 | N | 8.39E+10 |
| 116 | 1426 | 10 | N | 1.50E+10 |
| 117 | 18638 | 10 | N | 1.96E+11 |
| 118 | 19800 | 10 | N | 2.08E+11 |
| 119 | 25661 | 10 | N | 2.70E+11 |
| 120 | 15998 | 10 | N | 1.68E+11 |
| 121 | 18691 | 10 | N | 1.97E+11 |
| 122 | 2798 | 10 | N | 2.95E+10 |
| 123 | 3274 | 10 | N | 3.45E+10 |
| 124 | 7022 | 10 | N | 7.39E+10 |
| 125 | 10085 | 10 | N | 1.06E+11 |
| 126 | 2851 | 10 | N | 3.00E+10 |
| 127 | 40656 | 10 | N | 4.28E+11 |
| 128 | 14150 | 10 | N | 1.49E+11 |
| 129 | 10138 | 10 | N | 1.07E+11 |
| 130 | 21120 | 10 | N | 2.22E+11 |
| 131 | 13253 | 10 | N | 1.40E+11 |
| 132 | 19378 | 10 | N | 2.04E+11 |
| 133 | 1531 | 10 | N | 1.61E+10 |
| 134 | 6389 | 10 | N | 6.73E+10 |
| 135 | 17054 | 10 | N | 1.80E+11 |
| 136 | 7128 | 10 | N | 7.50E+10 |
| 137 | 6442 | 10 | N | 6.78E+10 |
| 138 | 15259 | 10 | N | 1.61E+11 |
| 139 | 6811 | 10 | N | 7.17E+10 |
| 140 | 3326 | 10 | N | 3.50E+10 |
| 141 | 19378 | 10 | N | 2.04E+11 |
| 142 | 15365 | 10 | N | 1.62E+11 |
| 143 | 38333 | 10 | N | 4.04E+11 |
| 144 | 31627 | 10 | N | 3.33E+11 |
| 145 | 19325 | 10 | N | 2.03E+11 |
| 146 | 6653 | 10 | N | 7.00E+10 |
| 147 | 3907 | 10 | N | 4.11E+10 |
| 148 | 10296 | 10 | N | 1.08E+11 |
| 149 | 8290 | 10 | N | 8.73E+10 |
| 150 | 10718 | 10 | N | 1.13E+11 |
| 151 | 3485 | 10 | N | 3.67E+10 |
| 152 | 15259 | 10 | N | 1.61E+11 |
| 153 | 12883 | 10 | N | 1.36E+11 |
| 154 | 24130 | 10 | N | 2.54E+11 |
| 155 | 7867 | 10 | N | 8.28E+10 |
| 156 | 4594 | 10 | N | 4.84E+10 |
| 171 | 18058 | 10 | N | 1.90E+11 |

Table 3.20. Sediment Resuspension Variables and Loading, continued

| Subbasin | Stream Length (ft) | Width (Ft) | Majority Concrete Lined? | MPN/wet day |
|---|---|---|---|---|
| 172 | 7550 | 10 | N | 7.95E+10 |
| 173 | 11405 | 10 | N | 1.20E+11 |
| 174 | 9293 | 10 | N | 9.78E+10 |
| 175 | 7709 | 10 | N | 8.11E+10 |
| 176 | 18374 | 10 | N | 1.93E+11 |
| 177 | 5438 | 10 | N | 5.72E+10 |
| 178 | 28248 | 10 | N | 2.97E+11 |
| 180 | 1795 | 10 | N | 1.89E+10 |
| 181 | 11458 | 10 | N | 1.21E+11 |
| 182 | 2851 | 10 | N | 3.00E+10 |
| 183 | 2323 | 10 | N | 2.45E+10 |
| 184 | 1954 | 10 | N | 2.06E+10 |
| 185 | 7234 | 10 | N | 7.61E+10 |
| 186 | 1320 | 10 | N | 1.39E+10 |
| 187 | 1056 | 10 | N | 1.11E+10 |
| 188 | 33264 | 10 | N | 3.50E+11 |

Abbreviations: MPN - most probable number

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

| *E. coli* Sources | Dry | | Intermediate | | Wet | |
|---|---|---|---|---|---|---|
| | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) |
| Mouth of Reservoir Watersheds | | | | | | |
| Sediment Resuspension | - | - | - | - | - | 9,536 |
| Mouth of Segment 1014 | | | | | | |
| Sediment Resuspension | - | - | - | - | - | 4,036 |
| Mouth of Segment 1013 | | | | | | |
| Sediment Resuspension | - | - | - | - | - | 1,271 |
| Mouth of Segment 1017 | | | | | | |
| Sediment Resuspension | - | - | - | - | - | 1,949 |

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

Abbreviations: BLEST - Bacteria Load Estimator Spreadsheet Tool, MGD - million gallon per day, MPN - most probable number, OSSF - on-site sewage facility

### 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 $1.07 \times 10^{17}$ acres (based upon Level 3 Texas Parks and Wildlife Ecoregion shapefile), Galveston Bay is $3.8 \times 10^{5}$ 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 $6.7 \times 10^{6}$ 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, $1.0 \times 10^8$ MPN/day, was used to calculate loading from birds while the values of *E. coli* associated with dogs and other organisms were $2.0 \times 10^9$ MPN/day and $8.6 \times 10^8$ 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 x $10^9$ MPN/day while subbasin 105 had the lowest loading from direct deposition, with 1.54 x $10^8$ 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

| Subbasin | EC Load (MPN/day) |
|---|---|
| 1 | 4.70E+09 |
| 2 | 5.45E+09 |
| 3 | 1.19E+09 |
| 4 | 4.17E+09 |
| 5 | 1.66E+09 |
| 6 | 1.87E+09 |
| 7 | 2.02E+09 |
| 8 | 1.32E+09 |
| 9 | 3.29E+09 |
| 10 | 1.80E+09 |
| 11 | 9.21E+08 |
| 12 | 1.27E+09 |
| 13 | 1.61E+09 |
| 17 | 1.95E+09 |
| 26 | 5.57E+09 |
| 27 | 4.58E+09 |
| 28 | 1.69E+09 |
| 33 | 4.59E+09 |
| 34 | 1.95E+09 |
| 35 | 2.03E+08 |
| 36 | 1.41E+09 |
| 37 | 1.41E+09 |
| 38 | 1.22E+09 |
| 39 | 4.60E+09 |
| 40 | 1.64E+09 |
| 41 | 1.59E+09 |
| 42 | 1.06E+09 |
| 43 | 1.91E+09 |
| 44 | 8.40E+08 |
| 45 | 5.82E+09 |
| 46 | 1.89E+09 |
| 47 | 1.34E+09 |
| 48 | 2.46E+09 |
| 49 | 2.83E+09 |
| 50 | 2.36E+09 |
| 51 | 1.06E+09 |
| 52 | 4.20E+09 |
| 53 | 5.52E+09 |
| 54 | 3.76E+09 |
| 55 | 2.09E+09 |
| 56 | 3.39E+08 |
| 101 | 2.56E+09 |
| 102 | 9.26E+08 |
| 103 | 1.06E+09 |
| 104 | 2.49E+09 |
| 105 | 1.54E+08 |
| 106 | 3.83E+09 |
| 107 | 3.02E+09 |
| 108 | 2.82E+09 |

Table 3.24 Summary of Loading from Direct Deposition, continued

| Subbasin | EC Load (MPN/day) |
|---|---|
| 109 | 5.52E+08 |
| 110 | 3.01E+09 |
| 111 | 2.39E+09 |
| 112 | 1.75E+09 |
| 113 | 3.50E+09 |
| 114 | 7.88E+08 |
| 115 | 1.23E+09 |
| 116 | 2.19E+08 |
| 117 | 2.87E+09 |
| 118 | 3.05E+09 |
| 119 | 3.95E+09 |
| 120 | 2.46E+09 |
| 121 | 2.88E+09 |
| 122 | 4.31E+08 |
| 123 | 5.04E+08 |
| 124 | 1.08E+09 |
| 125 | 1.55E+09 |
| 126 | 4.39E+08 |
| 127 | 6.26E+09 |
| 128 | 2.18E+09 |
| 129 | 1.56E+09 |
| 130 | 3.25E+09 |
| 131 | 2.04E+09 |
| 132 | 2.98E+09 |
| 133 | 2.36E+08 |
| 134 | 9.83E+08 |
| 135 | 2.62E+09 |
| 136 | 1.10E+09 |
| 137 | 9.91E+08 |
| 138 | 2.35E+09 |
| 139 | 1.05E+09 |
| 140 | 5.12E+08 |
| 141 | 2.98E+09 |
| 142 | 2.36E+09 |
| 143 | 5.90E+09 |
| 144 | 4.87E+09 |
| 145 | 2.97E+09 |
| 146 | 1.02E+09 |
| 147 | 6.01E+08 |
| 148 | 1.58E+09 |
| 149 | 1.28E+09 |
| 150 | 1.65E+09 |
| 151 | 5.36E+08 |
| 152 | 2.35E+09 |
| 153 | 1.98E+09 |
| 154 | 3.71E+09 |
| 155 | 1.21E+09 |
| 156 | 7.07E+08 |
| 171 | 2.78E+09 |

Table 3.24 Summary of Loading from Direct Deposition, continued

| Subbasin | EC Load (MPN/day) |
|---|---|
| 172 | 1.16E+09 |
| 173 | 1.75E+09 |
| 174 | 1.43E+09 |
| 175 | 1.19E+09 |
| 176 | 2.83E+09 |
| 177 | 8.37E+08 |
| 178 | 4.35E+09 |
| 180 | 2.76E+08 |
| 181 | 1.76E+09 |
| 182 | 4.39E+08 |
| 183 | 3.57E+08 |
| 184 | 3.01E+08 |
| 185 | 1.11E+09 |
| 186 | 2.03E+08 |
| 187 | 1.62E+08 |
| 188 | 5.12E+09 |

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

| *E. coli* Sources | Dry | | Intermediate | | Wet | |
|---|---|---|---|---|---|---|
| | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) | Flow (MGD) | Load (billion MPN/day) |
| Mouth of Reservoir Watersheds | | | | | | |
| Direct Deposition | - | 139 | - | 139 | - | 139 |
| Mouth of Segment 1014 | | | | | | |
| Direct Deposition | - | 49 | - | 49 | - | 49 |
| Mouth of Segment 1013 | | | | | | |
| Direct Deposition | - | 16 | - | 16 | - | 16 |
| Mouth of Segment 1017 | | | | | | |
| Direct Deposition | - | 36 | - | 36 | - | 36 |

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

## 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

| *E. coli* Sources | Dry Condition | | Intermediate Condition | | Wet Condition | |
|---|---|---|---|---|---|---|
| | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) |
| Waste Load Allocation | | 0.00 | | 6.46 | | 1,516.22 |
| WWTPs | | | | | | |
| WWTP Discharges | 18.00 | 1.35 | 18.93 | 1.42 | 18.93 | 1.42 |
| WWTP Biosolid Releases | - | - | - | - | 1.13 | 111.55 |
| MS4s | | | | | | |
| Dry Weather Storm Sewer Discharges | 0.62 | 272.84 | 0.62 | 272.84 | - | - |
| Wet Weather Storm Sewer Discharges | | | 0.50 | 805.42 | 333.18 | 539,159.82 |
| SSO | | | | | | |
| SSO - All Conditions | 2.17E-04 | 38.62 | 2.17E-04 | 38.62 | 3.29E-04 | 53.43 |
| Load Allocation | | 84.36 | | 84.36 | | 84.36 |
| OSSF | 3.86E-03 | 439.43 | 3.86E-03 | 439.43 | 3.86E-03 | 439.43 |
| Bed Sediment | - | - | - | - | - | 4,036.32 |
| Direct Deposition | - | 49.17 | - | 49.17 | - | 49.17 |
| Upstream Input | | 93.44 | | 299.23 | | 2211.19 |
| Upstream of Segment 1014 | 20.62 | 93.44 | 66.04 | 299.23 | 488.00 | 2,211.19 |
| Margin of Safety (MOS) | | 9.36 | | 20.53 | | 200.62 |
| Margin of Safety (5% of Target Load) | | 9.36 | | 20.53 | | 200.62 |
| Final Load Calculation | | | | | | |
| Estimated Current Load | 39.24 | 904.20 | 86.08 | 1,926.66 | 841.24 | 546,262.96 |
| Contact Recreation Target (126 MPN/dL) | 39.24 | 187.16 | 86.08 | 410.58 | 841.24 | 4,012.39 |
| Non-contact Recreation Target (605 MPN/dL) | 39.24 | 898.67 | 86.08 | 1,971.43 | 841.24 | 19,265.86 |
| TMDL Target | | 187.16 | | 410.58 | | 4,012.39 |
| Percent Reduction (Contact Recreation) | WLA | 100% | | 99% | | 100% |
| | LA | 83% | | 83% | | 98% |
| Percent Reduction (Non-contact Recreation) | All | 1% | | 0% | | 96% |

Abbreviations: MGD = million gallons per day, MOS = margin of safety, 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

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

| *E. coli* Sources | Dry Condition | | Intermediate Condition | | Wet Condition | |
|---|---|---|---|---|---|---|
| | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) |
| Waste Load Allocation | | 0.00 | | 0.00 | | 764.10 |
| WWTPs | | | | | | |
| WWTP Discharges | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WWTP Biosolid Releases | - | - | - | - | 0.00 | 0.00 |
| MS4s | | | | | | |
| Dry Weather Storm Sewer Discharges | 5.36E-04 | 0.01 | 5.36E-04 | 0.01 | - | - |
| Wet Weather Storm Sewer Discharges | | | 6.84 | 11,377.44 | 175.48 | 291,700.00 |
| SSO | | | | | | |
| SSO - All Conditions | 1.82E-04 | 32.31 | 1.82E-04 | 32.31 | 2.56E-04 | 42.18 |
| Load Allocation | | 0.00 | | 31.02 | | 31.02 |
| OSSF | 2.44E-04 | 27.81 | 2.44E-04 | 27.81 | 2.44E-04 | 27.81 |
| Bed Sediment | - | - | - | - | - | 1,271.26 |
| Direct Deposition | - | 16.07 | - | 16.07 | - | 16.07 |
| Upstream Input | | 177.80 | | 390.05 | | 3811.78 |
| Upstream of Segment 1014 | 20.62 | 93.44 | 66.04 | 299.23 | 488.00 | 2,211.19 |
| Segment 1014 | 18.62 | 84.36 | 20.04 | 90.82 | 353.24 | 1,600.59 |
| Margin of Safety (MOS) | | 9.36 | | 22.16 | | 242.47 |
| Margin of Safety (5% of Target Load) | | 9.36 | | 22.16 | | 242.47 |
| Final Load Calculation | | | | | | |
| Estimated Current Load | 39.24 | 263.37 | 92.93 | 11,865.86 | 1016.72 | 297,111.57 |
| Contact Recreation Target (126 MPN/dL) | 39.24 | 187.16 | 92.93 | 443.23 | 1016.72 | 4,849.36 |
| Non-contact Recreation Target (605 MPN/dL) | 39.24 | 898.69 | 92.93 | 2,128.20 | 1016.72 | 23,284.62 |
| TMDL Target | | 187.16 | | 443.23 | | 4,849.36 |
| Percent Reduction (Contact Recreation) | WLA | 100% | | 100% | | 100% |
| | LA | 100% | | 29% | | 98% |
| Percent Reduction (Non-contact Recreation) | All | 0% | | 82% | | 92% |

Abbreviations: MGD = million gallons per day, MOS = margin of safety, 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

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

| *E. coli* Sources | Dry Condition | | Intermediate Condition | | Wet Condition | |
|---|---|---|---|---|---|---|
| | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) |
| Waste Load Allocation | | 0.00 | | 205.79 | | 2,117.75 |
| WWTPs | | | | | | |
| WWTP Discharges | 20.58 | 6.46 | 21.64 | 6.80 | 21.64 | 6.80 |
| WWTP Biosolid Releases | - | - | - | - | 1.29 | 127.55 |
| MS4s | | | | | | |
| Dry Weather Storm Sewer Discharges | 0.00 | 0.00 | 0.00 | 0.00 | - | - |
| Wet Weather Storm Sewer Discharges | | | 44.36 | 50,673.93 | 465.03 | 531,253.65 |
| SSO | | | | | | |
| SSO - All Conditions | 1.15E-04 | 20.40 | 1.15E-04 | 20.40 | 1.99E-04 | 31.64 |
| Load Allocation | | 93.44 | | 93.44 | | 93.44 |
| OSSF | 4.32E-02 | 4,922.75 | 4.32E-02 | 4,922.75 | 4.32E-02 | 4,922.75 |
| Bed Sediment | - | - | - | - | - | 9,535.55 |
| Direct Deposition | - | 139.39 | - | 139.39 | - | 139.39 |
| Upstream Input | | 0.00 | | 0.00 | | 0.00 |
| None | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Margin of Safety (MOS) | | 4.92 | | 15.75 | | 116.38 |
| Margin of Safety (5% of Target Load) | | 4.92 | | 15.75 | | 116.38 |
| Final Load Calculation | | | | | | |
| Estimated Current Load | 20.62 | 5,093.93 | 66.04 | 55,779.02 | 488.00 | 546,133.71 |
| Contact Recreation Target (126 MPN/dL) | 20.62 | 98.36 | 66.04 | 314.98 | 488.00 | 2,327.57 |
| Non-contact Recreation Target (605 MPN/dL) | 20.62 | 472.27 | 66.04 | 1,512.40 | 488.00 | 11,176.02 |
| TMDL Target | | 98.36 | | 314.98 | | 2,327.57 |
| Percent Reduction (Contact Recreation) | WLA | 100% | | 100% | | 100% |
| | LA | 98% | | 98% | | 99% |
| Percent Reduction (Non-contact Recreation) | All | 91% | | 97% | | 98% |

Abbreviations: MGD = million gallons per day, MOS = margin of safety, 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

Table 3.26 (D) Load Analysis for Mouth of Segment 1017

| *E. coli* Sources | Dry Condition | | Intermediate Condition | | Wet Condition | |
|---|---|---|---|---|---|---|
| | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) | Q (MGD) | Load (billion MPN/day) |
| Waste Load Allocation | | 0.00 | | 61.03 | | 1,648.74 |
| WWTPs | | | | | | |
| WWTP Discharges | 20.03 | 59.39 | 21.06 | 62.45 | 21.06 | 62.45 |
| WWTP Biosolid Releases | - | - | - | - | 1.26 | 124.16 |
| MS4s | | | | | | |
| Dry Weather Storm Sewer Discharges | 0.76 | 250.09 | 0.76 | 250.09 | - | - |
| Wet Weather Storm Sewer Discharges | | | 12.44 | 19,928.55 | 362.34 | 580,640.16 |
| SSO | | | | | | |
| SSO - All Conditions | 1.82E-04 | 32.31 | 1.82E-04 | 32.31 | 2.00E-04 | 34.73 |
| Load Allocation | | 94.32 | | 94.32 | | 94.32 |
| OSSF | 2.77E-02 | 3,153.90 | 2.77E-02 | 3,153.90 | 2.77E-02 | 3,153.90 |
| Bed Sediment | - | - | - | - | - | 1,949.07 |
| Direct Deposition | - | 35.87 | - | 35.87 | - | 35.87 |
| Upstream Input | | 0.00 | | 0.00 | | 0.00 |
| None | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Margin of Safety (MOS) | | 4.96 | | 8.18 | | 91.74 |
| Margin of Safety (5% of Target Load) | | 4.96 | | 8.18 | | 91.74 |
| Final Load Calculation | | | | | | |
| Estimated Current Load | 20.82 | 3,536.53 | 34.28 | 23,471.35 | 384.69 | 586,019.58 |
| Contact Recreation Target (126 MPN/dL) | 20.82 | 99.29 | 34.28 | 163.53 | 384.69 | 1,834.81 |
| Non-contact Recreation Target (605 MPN/dL) | 20.82 | 476.74 | 34.28 | 785.18 | 384.69 | 8,809.98 |
| TMDL Target | | 99.29 | | 163.53 | | 1,834.81 |
| Percent Reduction (Contact Recreation) | WLA | 100% | | 100% | | 100% |
| | LA | 97% | | 97% | | 98% |
| Percent Reduction (Non-contact Recreation) | All | 87% | | 97% | | 98% |

Abbreviations: MGD = million gallons per day, MOS = margin of safety, 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

## 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

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

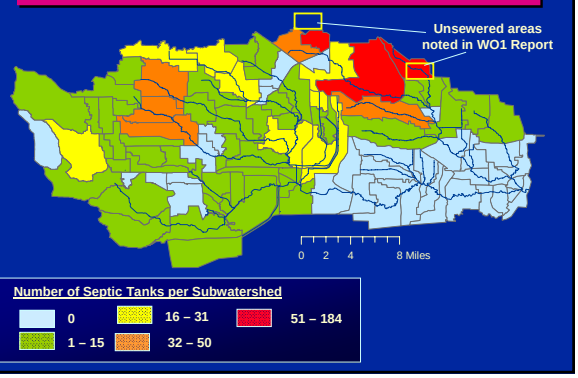
*University of Houston*
*Texas A&M University – Corpus Christi*

## Progress since last Stakeholder Meeting

- Evaluation of septic systems on a sub-watershed basis
- Spreadsheet modeling
- HSPF Load Allocation Modeling
- BST Results

*Abbreviations: HSPF = hydrologic simulation program – Fortran; BST = bacteria source tracking*

## Septic system distribution




## Wildlife in Buffalo and Whiteoak Bayous

## Population and Loads from EC Sources

| Source | Estimated Population | EC Load (MPN/day) |
|---|---|---|
| Cow | 6,307 | 3.4E+09 – 6.3E+10 |
| Horse | 14,406 | 2.6E+08 |
| Bird | Unknown ~250 species | 6.0E+07 – 3.1E+10 |
| Dog | 93,000 | 3.2E+09 |
| Bat | 600,000 | Unknown |
| Human | 1,040,000 | 1.3E+09 |

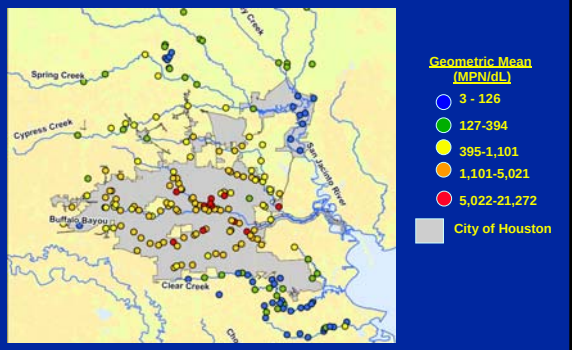
*Sources: Loads taken from US EPA (2000). Protocol for Developing Pathogen TMDLs. Populations estimates from Work Order 5 Report or estimated from other reports. Bat and Bird estimates from WO5 Report. Cow estimates calculated using data from http://www.texascattleraisers.org/mediaKit05/images/BeefByCounty05.jpg, Horse estimates calculated using data from http://animalscience.tamu.edu/ansc/publications/horsepubs/hrg014-industry.pdf, dog estimates from http://www.cdc.gov/ncidod/EID/vol10no1/02-0616.htm and WO5 Report, Human estimates from http://www.hcfcd.org/.*

## Population and Loads from EC Sources

| Bayou | Estimated Background Load (MPN/day) | Estimated Bayou Load (MPN/day) |
|---|---|---|
| Buffalo | 7.67E+12 – 4.11E+14 | 3.41E+13 |
| Whiteoak | 2.33E+12 – 1.25E+14 | 2.69E+14 |

*Assumptions:*
- *Bird and bat loads assumed to be the equal and animals present in watersheds only 50% of the year due to migration patterns*
- *Bayou loads were determined from regression between daily flow and EC concentrations*
- *Animal loads assumed to be evenly distributed across bayou. Loads calculated only for areas within 20-m buffer along streams. This accounts only for those animals within vicinity to potentially make "direct" contribution*

## EC Geomeans Across Houston Area




*Abbreviations: EC = E. coli, MPN = most probable number*

## Bacteria Source Tracking

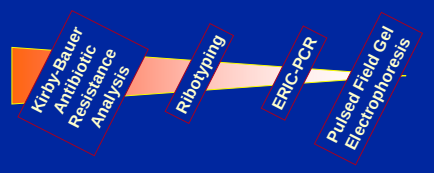
The determination of the animal source(s) of fecal contamination using characteristics of fecal bacteria (*E. coli*)

## Bacteria Source Tracking Techniques

- Microbiological
  - Identify actual pathogens in water
- Genotypic – DNA fingerprinting
  - Ribotyping
  - Repetitive PCR (rep PCR)
  - Pulse Field Gel Electrophoresis (PFGE)
- Phenotypic – Bacterial response
  - Antibiotic Resistance Analysis (ARP)
- Chemical
  - Fecal sterols

*Abbreviations: PCR = polymerase chain reaction*

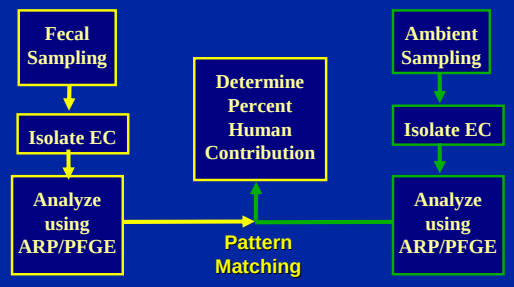
## Ability of Methods to Resolve Differences Between Bacterial Strains




**Which method or combination is best?**

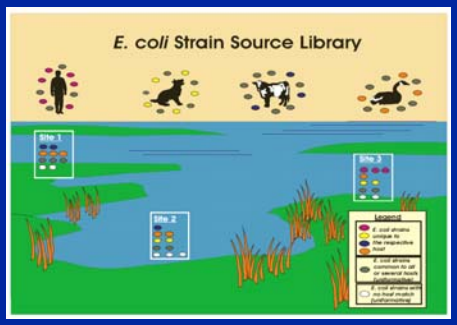
*Abbreviations: ERIC-PCR - Enterobacterial Repetitive Intergenic Consensus Polymerase Chain Reaction*

## How Bacteria Source Tracking Works




*Abbreviations: ARP = antibiotic resistance profiling, BST = bacteria source tracking, PFGE = pulse gel electrophoresis, EC = E. coli*

## How Bacteria Source Tracking Works



## Overview of BST Studies in Texas

| BST Studies | Method/ # of Isolates | Sources Evaluated | Dominant Sources |
|---|---|---|---|
| Sources of *E.coli* in Coastal Waters of Texas, Texas A&M Corpus | ARP Samples –83 Animal -236 | Deer, cattle, horses, and birds | Not identified due to narrow database |
| Copano Bay TMDL Project (ongoing), Texas A&M Corpus | ARP & PFGE Library – 1067 | Human/Sewage, Cow, Horse, Duck, Wildlife, and Gull | Livestock (cow/horse), human sewage and duck |
| Trinity River TMDL Project, (TIAER) | Ribotyping | Industrial discharges, agricultural run off | Not examined |
| Elm & Sandies Creeks TMDL project, (ongoing) (TEES) | DNA finger printing | Ongoing study | Ongoing study |

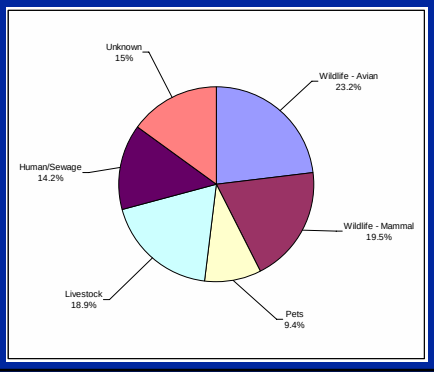
*Abbreviations: ARP = antibiotic resistance profiling, BST = bacteria source tracking, PFGE = pulse gel electrophoresis, TIAER = Texas Institute for Applied Environmental Research, TEES = Texas Engineering Experimental Station*

## Overview of BST Studies in Texas

| BST Studies | Method/ # of Isolates | Sources Evaluated | Dominant Sources |
|---|---|---|---|
| San Antonio River Basin, Leon River, and Peach Creek, Ag. Research & Ext. Center, TAMU El Paso | Ribotyping -- 3000 isolates from 750 known sources -- 3000 isolates from 850 water samples | Cattle, domestic sewage, pets, zoo | Further study to examine key sources |
| Oyster Creek TMDL, Parsons | Ribotyping # of fecal samples-400 Isolates - 800 | Cattle, Dogs, wildlife | Wildlife – 40% Human/sewage- 15% |
| Lakes Waco and Belton, Parsons, Ag. Research & Ext. Center, TAMU El Paso | ARP, PFGE, ERIC-PCR, Ribotyping | Livestock (cow/horse), human, avian | Ongoing study |

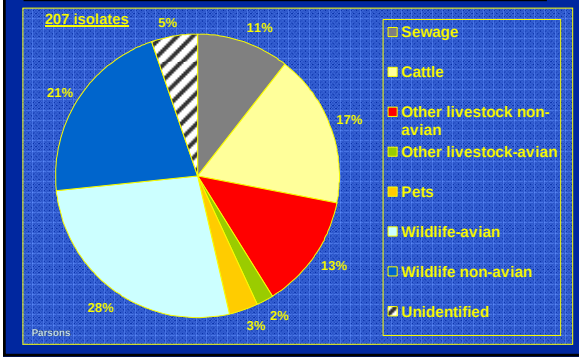
*Abbreviations: ARP = antibiotic resistance profiling, BST = bacteria source tracking, PFGE = pulse gel electrophoresis, ERIC-PCR = Enterobacterial Repetitive Intergenic Consensus Polymerase Chain Reaction*

## All Upper Oyster Creek Ambient Sites




Parsons

## All Belton Lake & Leon River Sites Ambient Water




## Factors Affecting BST Results

- Size of library or host origin database
  - Greater than 300 isolates is best
- Type of statistical approach adopted
  - Discriminant analyses better than cluster analysis
- Number of isolates analyzed from ambient water/sediment samples
  - 48 – 96 best for ARA, 5 – 10 for DNA finger printing
- Size and complexity of watershed
  - 10,000 to 40,000 acres is ideal
  - Buffalo and Whiteoak Bayous cover over 227,000 acres

*References: Harwood (2005), US EPA (2005) Microbial Source Tracking Guide; Rose et al. (2000); Johnson et al. (2004); Lasalde et al. (2005); Abbreviations: BST = bacteria source tracking, ARA = antibiotic resistance analysis*

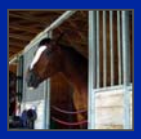
## BST Findings for BB and WOBs

Based upon limited data, findings show that:

- Human sources found in every sample
- Human contribution high even in watersheds without wastewater treatment plants
- Residential land use had lowest human contribution

*Abbreviations: BST = bacterial source tracking, BB = Buffalo Bayou, WOB = Whiteoak Bayou*

## EC Sources Sampled


Horse

Cow

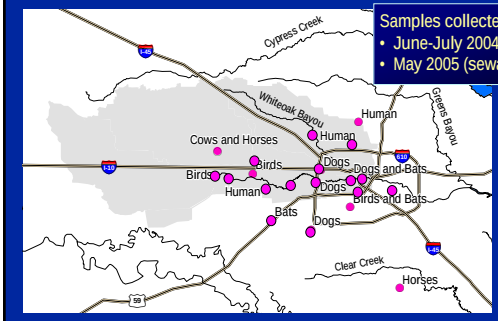
Bats

Humans

Dog

Birds

## BST Sampling Locations




*Abbreviations: BST – bacteria source tracking*

## Sample Collection

- Fecal samples collected June-July 2004 , May 2005 (sewage only)
- Locations within the watershed – identified by UH personnel
- Animals included based on UH sanitary survey
- Samples transported to Texas A&M University-Corpus Christi for analysis

## *E. coli* isolation

- Swabbed onto mTEC Agar
- Transferred to Rainbow Agar
- Verified as *E. coli* using the Biolog MicroLog™ or MicroStation™ Microbial Identification System – carbon source utilization (CSU)
- Temporary storage on Tryptic Soy Agar slants
- Storage at –70 C

## Antibiotic Resistance Profiling

- ARP utilizes patterns of resistance among indicator bacteria
- Bacteria from GI tracts of a range of animals should exhibit different profiles of resistance due to:
  - environmental factors
  - exposure or lack of exposure to antibiotics
  - variation in food source (diet)

*Abbreviations: ARP = antibiotic resistance profiling, GI = gastrointestinal*

## Antibiotic Resistance Profiles

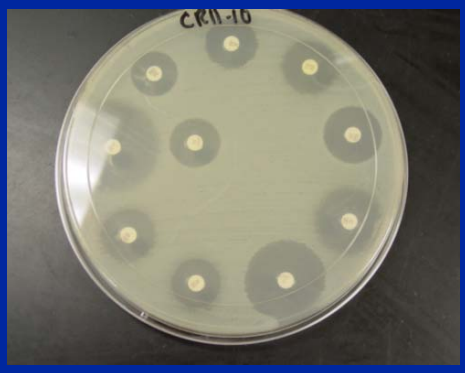
- ARP was performed using the Kirby Bauer Disk Diffusion Test, a clinically approved, standard method
- Commercial disks, each containing an antibiotic are placed on a plate, pre-inoculated with the *E. coli* isolate
- After incubation, plates are read using a BIOMIC Microbiology Analyzer System with a digital camera

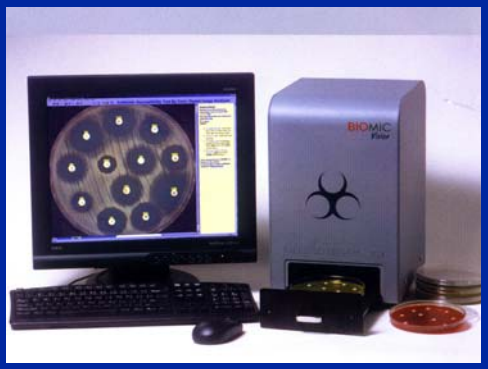
*Abbreviations: ARP = antibiotic resistance profiling*

## Antibiotic Resistance Analysis

- Plates assessed for zones of inhibition (no growth) around the disks i.e. susceptible to the antibiotic or reduced zones indicating resistance to the antibiotic
- The information is compared with NCCLS tables of standard zones for *E. coli* included in the computer software

*Abbreviations: NCCLS = National Committee for Clinical Laboratory Standards*






## Antibiotic Resistance Analysis

- A printout is generated which includes zones of inhibition and resistance classification
- The information for each isolate is entered into a database, converted to SPSS and analyzed to determine whether isolates from different animals have different ARPs.
- This "library" can then be used to identify sources of *E. coli* from water/sediment samples by comparing the profiles

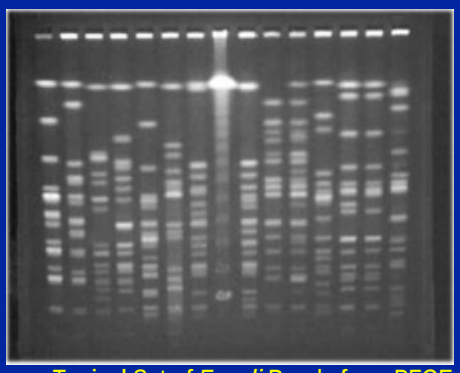
*Abbreviations: ARP = antibiotic resistance profile*

## Pulse Field Gel Electrophoresis

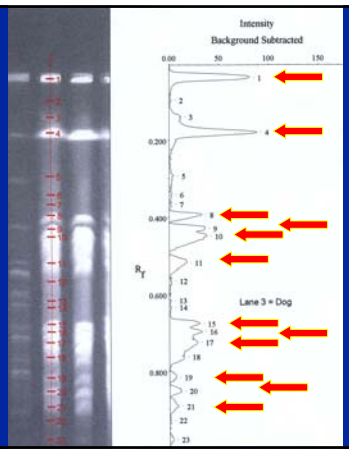
- A molecular technique which generates a DNA "fingerprint" specific for different strains of the bacteria
- The confirmed *E. coli* isolates were batch cultured for DNA analysis
- The total DNA was extracted from the cultures and fingerprinted

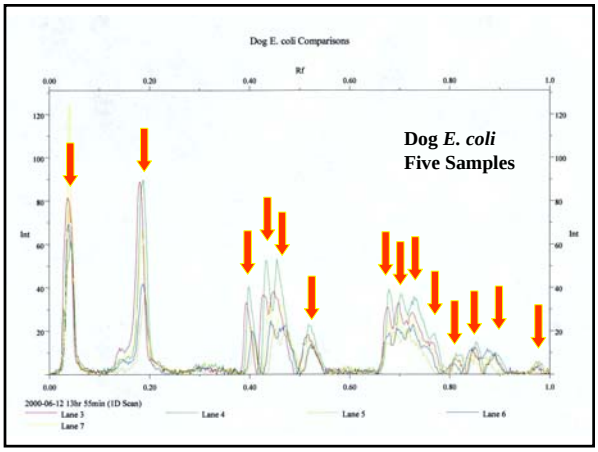
## Pulse Field Gel Electrophoresis

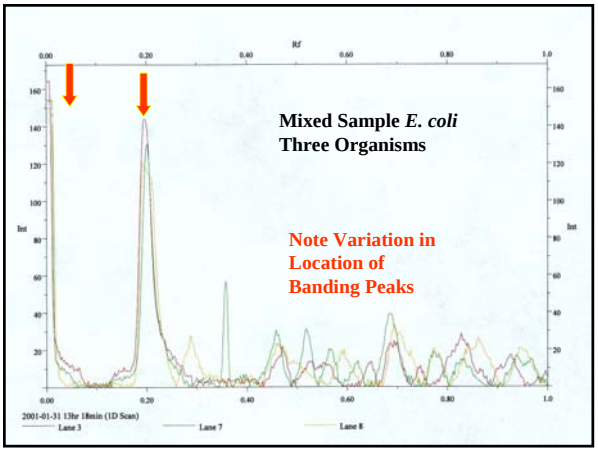
- A comparative analysis was performed against the database using Diversity Database©.
- Similarity searches of all bands using the Jaccard Coefficient Method were completed.
- The Diversity Database© report displays all the members of the population, sorted in order of decreasing similarity from the reference sample.



Typical Set of *E. coli* Bands from PFGE.




## Fecal Sample Isolates Analyzed

| Animal Source | # Isolates | ARA | PFGE |
|---|---|---|---|
| Bird | 365 | 171 | 63 |
| Cow | 426 | 219 | 58 |
| Dog | 306 | 182 | 59 |
| Horse | 348 | 200 | 53 |
| Bat | 389 | 204 | 59 |
| H/Sewage '04 | 449 | 207 | 52 |
| H/Sewage '05 | 456 | 171 | 0 |
| TOTAL | 2458 | 1354 | 344 |

*Abbreviations: ARA = antibiotic resistance analysis, PFGE = pulse gel electrophoresis*

## Library development

- Known source isolates from each animal source
- Concern regarding original sewage samples – resample year 2 at 2 WWTP – statistics improved
- Addition of CSU profiles (statistics consultation) improved analysis
- Isolates could not be added to PFGE library due to time/money constraints

*Abbreviations: WWTP = wastewater treatment plants, CSU = carbon source utilization, PFGE = pulse gel electrophoresis*

## Library Development – ARP/CSU

| % Correct classific-ation | ARP only | | CSU only | | ARP+CSU | |
|---|---|---|---|---|---|---|
| | HS 2005 only | HS 2004 and 2005 | HS 2005 only | HS 2004 and 2005 | HS 2005 only | HS 2004 and 2005 |
| ARCC | 83.5 | 73.6 | 96.0 | 83.4 | 97.5 | 86.7 |
| Human | 87.2 | 80.0 | 96.3 | 84.4 | 98.0 | 88.3 |
| Non human | 63.7 | 57.9 | 94.7 | 81.0 | 94.7 | 82.5 |
| Cross-val. ARCC | 82.6 | 72.8 | 93.9 | 79.5 | 95.3 | 82.4 |

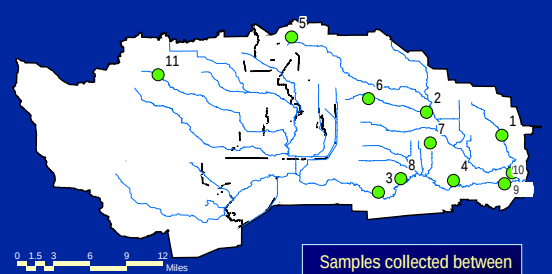
*Abbreviations: ARCC = average rate of correct classification, HS = human sewage, CSU = carbon source utilization, ARP = antibiotic resistance profiling*

## Analysis - # isolates in libraries

| Animal Source | ARA + CSU | PFGE |
|---|---|---|
| Bird | 167 | 52 |
| Cow | 213 | 51 |
| Dog | 170 | 51 |
| Horse | 193 | 51 |
| Bat | 191 | 49 |
| H/Sewage '04 | 207 | 52 |
| H/Sewage '05 | 171 | 0 |
| TOTAL | 1312 | 306 |

*Abbreviations: CSU = carbon source utilization, ARP = antibiotic resistance profiling, PFGE = pulse gel electrophoresis*

## Ambient BST Sampling Locations




Samples collected between Aug. 2004-July 2005

*Abbreviations: BST – bacteria source tracking*

## BST Sampling Site Descriptions

| BST ID | Sampled | Description |
|---|---|---|
| 1 | Wet, Dry, Sediment | No WWTPs upstrm |
| 2 | Dry, Sediment | WWTP upstream |
| 3 | Wet, Dry, Sediment | Residential |
| 4 | Dry | Open |
| 5 | Wet, Dry, Sediment | Agricultural |
| 7 | Wet, Dry, Sediment | Commercial |
| 9 | Wet, Dry | Mouth of BB |
| 10 | Wet, Dry | Mouth of WOB |
| 11 | Wet, Sediment | Open |

*Abbreviations: BST – bacteria source tracking, WWTP - wastewater treatment plants, WOB = Whiteoak Bayou, BB = Buffalo Bayou, upstrm = upstream*

## Water and Sediment Samples

- Collected by UH personnel Aug. 2004-July 2005
- 14 water, 6 sediment samples. 50-78 *E. coli* isolated per sample
- Isolation and analysis for *E. coli* followed fecal sample procedures. 30-60 per sample analyzed by ARA, 11-30 by PFGE
- Total analyzed:
  - 910 ARA
  - 396 PFGE

*Abbreviations: ARP = antibiotic resistance profiling, PFGE = pulse gel electrophoresis, UH = University of Houston*

## % Human Contributions in Ambient Water

| BST ID | Dry Weather | Wet Weather | Sediment (Dry weather) |
|---|---|---|---|
| 1 | 23.9% | | 31.0% |
| 2 | 35.0% | | 21.9% |
| 3 | 7.9% | 50.9% | 24.5% |
| 4 | 46.7% | | |
| 5 | 44.7% | 51.9% | 36.4% |
| 7 | 18.2% | 53.6% | 27.6% |
| 9 | 64.7% | 89.8% | |
| 10 | 67.3% | 63.2% | |
| 11 | | 71.1% | 80.9% |
| *Average:* | 39% | 63% | 37% |

*Abbreviations: BST – bacteria source tracking*

## Results: Water and Sediment

- Approx. 8-90% isolates identified as HSewage in samples from the various sites
- Higher proportions of HSewage isolates at Sites 9, 10 and 11 (mouths of each Bayou and 'open land')
- Limited #s of isolates but appears to be human source isolates in all samples
- 'Open land' numbers may indicate survival in soil – only 2 samples

## Results: ARP/CSU vs. PFGE

- Comparison of isolates analyzed by ARP/CSU and PFGE were limited by size of PFGE library and use of different HSewage isolates
- Relatively high proportion of isolates identified as non-human by both methods in 2004
- Overall confirmation approx. 50%

*Abbreviations: ARP = antibiotic resistance profiling, CSU = carbons source utilization, PFGE = pulse gel electrophoresis*

## Summary

- Bacteria source tracking results suggest higher proportion of non-human isolates in dry weather, with increase in human source after rainfall
- Difference marked for the mouth of Buffalo Bayou
- Human sewage source contamination appears widespread, although sometimes only as a small proportion, varying with site and rainfall