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

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Final Report
Revision 1

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CHAPTER 1

INTRODUCTION

Portions of Buffalo Bayou (Segments 1013 and 1014) and Whiteoak Bayou (Segment 1017) in Houston, Texas are on the 1998 Texas' Clean Water Act §303(d) List for pathogen impairments. Stream segments are typically included on the 303(d) list due to violations of a given water standard. Buffalo and Whiteoak Bayous are among the most fecal-contaminated water bodies in Texas as indicated by the frequency and magnitude of exceedances of the fecal coliform water quality criteria for contact recreation. The purpose of this project 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. In addition, the project will result in the preparation of several allocation scenarios, including potential costs and sources of funding that the TCEQ will use to formulate an implementation plan. The TMDL and the implementation plan will be incorporated into a Watershed Action Plan (WAP) that will address violations of water quality criteria for contact recreation in these Houston bayous.

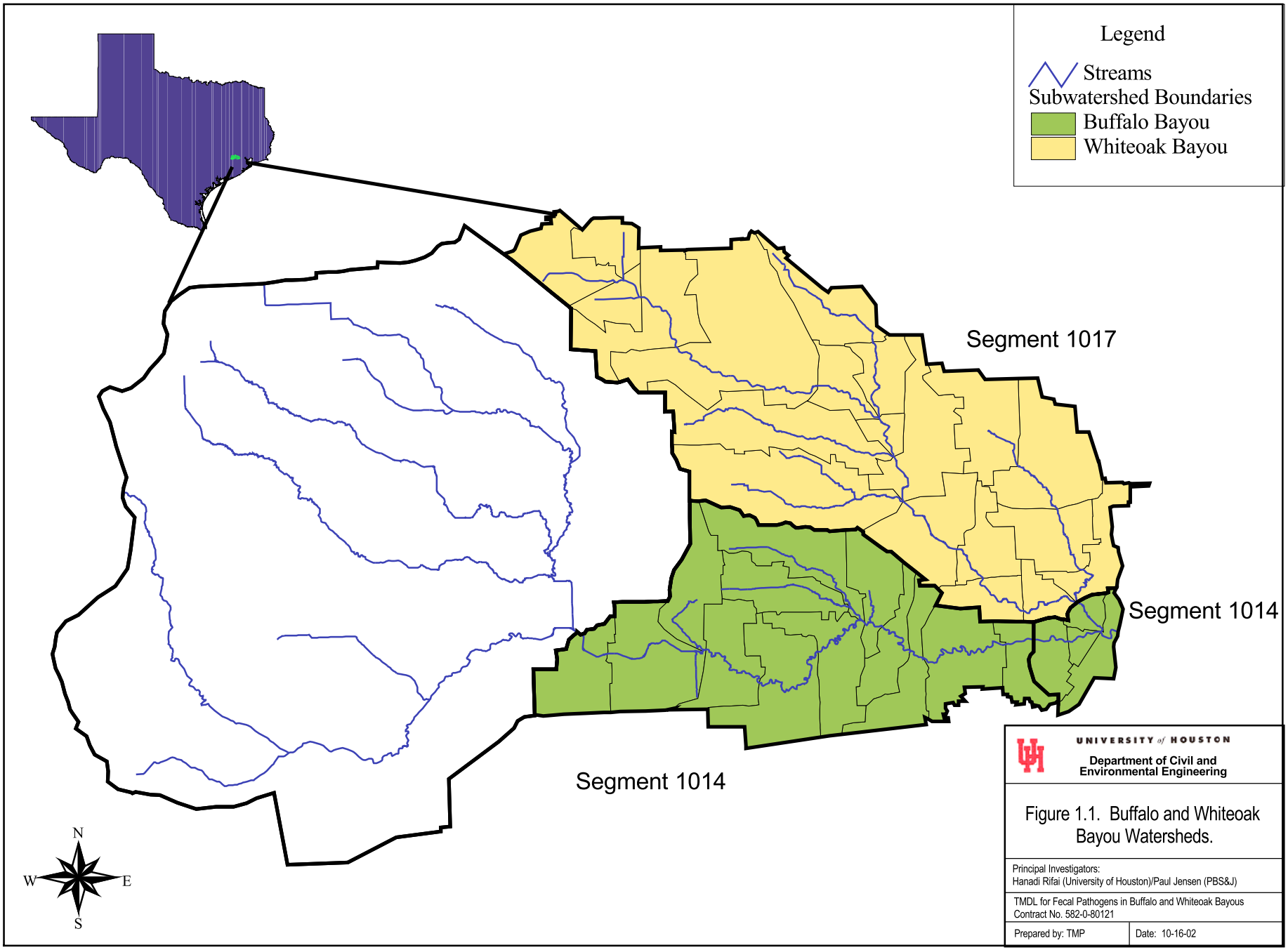
1.1 PROBLEM STATEMENT

The two bayous that are the subject of this TMDL Study, Buffalo Bayou and Whiteoak Bayous, are designated for contact recreation. Until recently, the water pathogen quality standard for contact recreation was based on the fecal coliform indicator bacteria. For

fecal coliform, no sample should exceed 400 colony-forming units (cfu) per 100 mL for contact recreation. In addition, the geometric mean over a 30-day period should be less than 200 cfu/100 mL to meet contact recreation criteria. However, the State of Texas adopted new standards based upon *Escherichia coli* (*E. coli* or EC) rather than the fecal coliform indicator bacteria. For *E. coli*, no sample should exceed 394 cfu/ 100 mL and the 30-day geometric mean should be less than 126 cfu/100 mL (30 Texas Administrative Code 307.7(b)(A)). Both bayous have frequently exceeded the fecal coliform standard in the past. Phase 1 of this study (University of Houston and PBS&J, 2001) demonstrated the regularity and magnitude of these violations and evaluated the trends in the FC historical data. In both bayous, Phase 1 also identified the data gaps in available FC information and evaluated data needs for model development.

1.2 DESCRIPTION OF THE STUDY AREA

Buffalo Bayou (Figure 1.1) meanders from the outlying, less-developed portions of Harris County joining Whiteoak Bayou in the highly urbanized central part of the Houston business district. All three segments (1013, 1014 and 1017) lie within the San Jacinto River Basin and eventually discharge to Galveston Bay. Segment 1013, Buffalo Bayou tidal watershed, has a drainage area of 7 square miles and is about 4 miles long. Buffalo Bayou above tidal, segment 1014, is 24 mile long and has a watershed of 358 square miles. The Whiteoak Bayou watershed has an area of 105 square miles and the stream segment is 23 miles long (H-GAC, 2001).


Legend
Streams
Subwatershed Boundaries
Buffalo Bayou
Whiteoak Bayou
Segment 1017
Segment 1014
Segment 1014
N
W
E
S
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 1.1. Buffalo and Whiteoak Bayou Watersheds.
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121
Prepared by: TMP
Date: 10-16-02

1.3 SCOPE OF THE PROJECT

There have been two work orders associated with this TMDL. The scope of work performed under Work Order #1(June 1, 2000 through May 31, 2001) included:

- An assessment of current fecal pathogen levels and trends in Buffalo and Whiteoak Bayous;
- A survey of the current knowledge of major sources, and fate and transport of fecal pathogen contamination in surface waters;
- Selection of a fate and transport model for the scope area;
- Development of a quality assurance project plan for the project;
- Development of a work plan for additional sampling and modeling activities; and
- Participation in the Buffalo and Whiteaok Bayous stakeholder participation/communication process.

The results from Work Order 1 were detailed in a final report (University of Houston and PBS&J, 2001). In summary, Work Order 1 demonstrated that for both Buffalo and Whiteoak Bayous, the average concentrations generally increase from upstream to downstream by a factor of 2. Overall, long-term FC geometric means for Whiteoak Bayou appear to be higher than those of Buffalo Bayou, also by a factor of 2. Data acquisition and analysis of nine potential sources of high indicator bacteria levels indicated that point sources, illegal discharges, sediments, runoff, and upstream sources are relatively significant contributors of bacteria in the bayous. Finally, a review of suitable models to quantify the fate and transport of the indicator bacteria suggested that HSPF was the most appropriate model for the purposes of this TMDL

study.

Work Order No. 2 (July 5, 2001 through August 31, 2002) encompassed the following tasks:

1. Project administration;
2. Stakeholder/public education and involvement;
3. Assessment of current levels and trends of bacterial indicators of fecal pathogens in Buffalo and Whiteoak Bayous;
4. Assessment of major sources of bacterial indicators of fecal contamination;
5. Application of models to elucidate the sources and major processes controlling observed levels of bacterial indicators of fecal contamination; and
6. TMDL allocation analysis

1.4 DESCRIPTION OF THE REPORT

This document constitutes the final report of the TMDL Bacteria Project for Work Order No. 582-0-80121-02 and summarizes the activities undertaken by the University of Houston and PBS&J during the period July 5, 2001 to August 31, 2002.

This report compiles the four quarterly reports submitted to TCEQ in compliance with the Work Order and reflects the changes made to respond to stakeholders and TCEQ comments. The topics in the report are organized according to the tasks specified in Work Order 582-0-80121-02.

Chapter 2 summarizes the support activities conducted by the project team as part of the

stakeholder involvement. This chapter includes presentations given by members of the team at stakeholder meetings and a summary of questions and answers.

Chapter 3 presents a summary of the activities completed to assess current levels of indicator bacteria in Buffalo and Whiteoak Bayous.

A summary of the activities completed between July 5, 2001 and May 31, 2002 to assess the sources of bacteria to these two bayous as well as an analysis of the collected data are included in Chapter 4.

Chapter 5 reports the methods and the technical approach followed to develop a quality model for indicator bacteria in the two bayous.

A summary of preliminary load allocation scenarios in the study bayous is presented in Chapter 6 of this report.

Finally, Chapter 7 presents the conclusions obtained from the project activities conducted under Work Order No. 2.

CHAPTER 2

STAKEHOLDER/PUBLIC EDUCATION AND INVOLVEMENT

2.1 SUMMARY OF SUPPORT ACTIVITIES

The project team supported the stakeholder process facilitated by the Houston Galveston Area Council (HGAC) and the Environmental Institute of Houston (EIH). The following support tasks were undertaken:

- Development of informational materials summarizing the technical aspects of the project for electronic and hardcopy distribution at stakeholder meetings including documents, maps, and quarterly reports;
- Preparation of web based project informational briefs;
- Participation in two stakeholder meetings (March 7, 2002 and June 26, 2002);
- Preparation and presentation of technical information at stakeholder meetings;
- Preparation of responses to questions and information requests from stakeholders and providing rationale for whether or not certain requests by stakeholders for refinement in technical analysis can or cannot be achieved; and
- Providing technical expertise on issues related to microbiological public health, urban wastewater infrastructure and water quality.

2.2 TECHNICAL PRESENTATIONS AT STAKEHOLDER MEETINGS

Copies of the technical presentations given at the stakeholder meetings are included in Appendix A. Other informational materials prepared by the project team can be found at http://www.hgac.cog.tx/intro/introtmdl.html.

2.3 RESPONSE TO STAKEHOLDERS' COMMENTS/QUESTIONS

The project team addressed the comments and questions received from stakeholders during the stakeholder meetings. Below is a list of meeting comments and their respective responses.

1. Relationship of fertilizers and levels of bacteria in the bayous - is there one?

The primary concern is manure-based fertilizers that may contain animal bacteria. Manure based fertilizers can contribute bacteria to the bayous by wash-off during rains or during irrigation into the stormwater system and into the bayous. The fertilizers may be applied to agricultural land or used in landscaping for commercial and residential land. This is a component of the non-point sources that may be significant because of the large number of people and facilities within the watershed and the large percentage of impervious area that allows runoff to directly enter the stormwater system and then the bayous. Chemical fertilizers that provide nutrients are unlikely to contribute to the bacteria load in the bayous.

For the stakeholder meeting on June 23, 2002, the project team invited Mr. Theo Glanton from the City of Houston to present the results of an experiment conducted to evaluate whether or not sediments are a major source of *E. coli*, and to assess the impact that fertilizers might have

on the bacterial concentrations. Samples were collected in an attempt to quantify typical sediment and organic fertilizer contributions.

A local nursery selling various types of enhanced soils was sampled. These samples are shown in Table 2.1 below under the heading of "Nursery Samples." In addition to typical regional mulch samples, the data from typical City of Houston processed sludge are included. This material is sold as a fertilizer enhancement product in the local market. Also, a typical bagged commercial product was tested. The results of this analysis are shown in Table 2.1. As can be seen, EC bacteria were found in fertilizers (concentrations ranged from less than 3 to around 12,000 MPN/g dry weight). Therefore, fertilizers could be a potential source of bacteria if carried by runoff into the bayous.

Table 2.1 FC Concentrations in Fertilizer Samples

Commercial Products	**Classification**	**MPN/g Dry Weight**
Nursery Samples	Mushroom Mulch	1,100
	Garden Mulch/soil	5,600
	Rose Bed Mulch/soil	11,000
City of Houston	Dry Product – Almeda Sims	2.8
City of Houston	Dry Product – 69th Street	33.2 *
Home Depot bag	Bag Mulch	12,000

* Mean value from City of Houston reporting data for 2002 - note: the data for 69th St were skewed by a result on 1/3/02 of 130 MPN/g. Excluding that data point reduces the value to 4.5 MPN/g.
MPN = most probable number; g = gram

2. Does the bacteria source tracking data really show that the pathogen indicators detected in the bayous are NOT human related?

The bacteria source data that were presented in the Urban Bayou Bacteria Source Identification Study (PBS&J, 2001) are still in a research phase and are not a definitive characterization of the sources of the bacteria found in the bayous. Although there were sensitivity problems due to various factors that affect the results, the results do show that it is likely that sources other than human waste are also contributing to the bacteria impairments in the bayous. This reinforces the idea that there are numerous contributors to the impairments and that the approach to solving the problem must be a multi-faceted approach that calls for a reduction in loading from all point and non-point sources in the watershed.

3. Contribution of non-human species to the load?

Non-human contributions to the bacteria in the bayous may come from wildlife, livestock, and domestic pets either through direct deposition in the bayous or by being carried into the bayous by runoff from the watershed. There is some evidence (Table 2.2 below) that a portion of the bacteria existing in soil and on the surface of plants can show positive on the indicator bacteria tests and this can also be a source of bacteria.

Table 2.2 shows the results of a second set of samples collected by PBS&J to look at background soil levels. The samples were collected from two locations. The first set of samples was collected outside the Houston PBS&J office and the second set of samples was collected from the bank of Buffalo Bayou at West Belt.

Table 2.2 FC Concentrations in Soil and Sediment Samples

Commercial products	Classification	MPN/g Dry Weight
Outside PBS&J office on Dairy Ashford	Grass Area	22
Outside PBS&J office on dairy Ashford	Flower Bed	42
Buffalo Bayou at West Belt	Dry bank soil away from the bridge	820
Buffalo Bayou at West Belt	Dry bank soil under the bridge	760

MPN = most probable number
g = gram

The soil samples were diluted in water at a predetermined ratio (in the samples above the ratio was one to one-thousand). Then three sample sets of five tubes each were made up. A 0.1 ml, a 1.0 ml and 10 ml sample was added to a medium and enclosed in a glass tube. The samples were incubated for a period of twenty-four hours and the numbers of gas producing tubes were then counted i.e. the tubes that float up in the water bath. The number of positive gas tubes was then compared to a chart and the MPN value was read from the table. The data were then converted to MPN per unit dry weight of the sediment sample. It is noted that the soil bacteria analysis differs from that for water. A water sample is drawn through a 0.45 micron membrane filter pad by a vacuum and the filter pad is then place on a medium. The sample is incubated for twenty-four hours at 44.5 degree Celsius and the colonies are individually counted and reported as coliform forming unit per deci-liter (cfu/dL).

Since these are two different methods on two different matrices (water and sediment), one cannot make a direct correlation between MPN/g and cfu/dL. Thus, it is difficult to draw a direct comparison between the bayou fecal concentrations and the soil derived values.

The entire trash collection system also has the potential of contributing bacteria of non-human origin through spills, leaks, and improper disposal. The source identification studies conducted in the bayous also indicate that insects may contribute to bacteria in the bayous. There are very few studies that have quantified non-human loads as of this writing.

4. Contribution of sediments on the banks?

As shown in Table 2.2, a portion of the bacteria existing in soil and on the surface of plants can show positive on the indicator bacteria tests. The soils/sediments on the banks of the bayous do not typically contribute indicator bacteria to the bayous during dry weather but the soils/sediments may contribute indicator bacteria to the bayous during runoff events. Wildlife, livestock, domestic pet, and even human waste deposited on the banks of the bayous can contribute to the bacteria in the bayous by runoff in the same manner as other sources in the watershed.

Heat-tolerant bacteria exist in the natural environment, including soils, vegetation, etc. Two soil samples were collected on 6/13/02 from Buffalo Bayou at the West Belt from under and away from the bridge. The samples were analyzed by the City of Houston Public Works and Engineering (PW&E) Wastewater Operation QC lab. The under bridge sample resulted in 760 MPN/g dry weight FC level and the away from bridge sample resulted in an 820 MPN/g dry

weight FC level. Assuming 80% moisture content and 2.63 g/cm3 soil density, 800 MPN/g dry weight = 42,080 MPN/dL wet weight. These numbers are within the range of results obtained last summer using bottom sediments (24,192 to 77,000 MPN/dL wet weight). It is noted that pigeons live under the Beltway 8 bridge where the samples were collected. Additionally, the EPA has a limit on dry sludge which equals 1,000 MPN/g dry weight and the 800 MPN/g dry weight is approaching that limit, thus, dry sediments represent background soils that contribute to bacteria loads. Whether this load is controllable or not is a stakeholder issue.

5. Contribution of the watershed above the Barker and Addicks dams to Buffalo Bayou?

The Piney Point gage controls the operation of the Barker and Addicks dams but there is not much historical FC data upstream or downstream of the dams. The data shown in Table 2.3 correspond to 1980's data collected by the USGS from 1978 through 1981. The mean FC (cfu/dL) at the Addicks tributaries (going into the dam) was 6,307 while the reservoir mean was 1,090 and the discharge was 737. The mean FC (cfu/dL) at the Barker tributaries (going into the dam) was 3,220, while the reservoir mean was 763 and the discharge was 663. These numbers exceed the standard in general. From 1981-1996, the time series for FC data at Barker Dam (Figure 2.1) shows that about half of the time what is coming out of the dam is higher than the water quality standard. Likewise at the Highway 6 location (Figure 2.2). The time series of FC data at Dairy Ashford indicates that the input from Addicks Reservoir exceeds limits coming into the area. Overall there is a 60% exceedance from the reservoirs coming into both bayous.

Table 2.3 Reservoir Historical Bacteria Data

Reservoir	Location	Mean FC (cfu/100 mL)
Addicks	Tributaries	6307
	Reservoir	1090
	Discharge	737
Barker	Tributaries	3220
	Reservoir	763
	Discharge	663

Source: USGS WRI 86-4356, 1987. Samples collected from 1978-1981.
cfu = colony froming units
mL = milliliter

To conclude, there are historically high levels of fecal coliform observed within and downstream of the reservoirs, the reservoirs are attenuating the bacteria levels but they are not completely eliminated. During dry weather conditions, most of the upstream bayou flow originates from the reservoirs. Due to the high percent of flow actually released from the dams during dry weather conditions, the discharge will be treated as a point source input for this TMDL study.

6. Possibility of setting new and less stringent standards for urban areas?

The adjustment of water quality standards in the bayous is not being considered in this TMDL. However, it is important to recognize that the contact recreation standards are currently being studied to determine if the standards are appropriate in all circumstances and guidance since the EPA may change the water quality target. One approach being discussed is to define the conditions under which contact recreation may be feasible and make the standard apply only

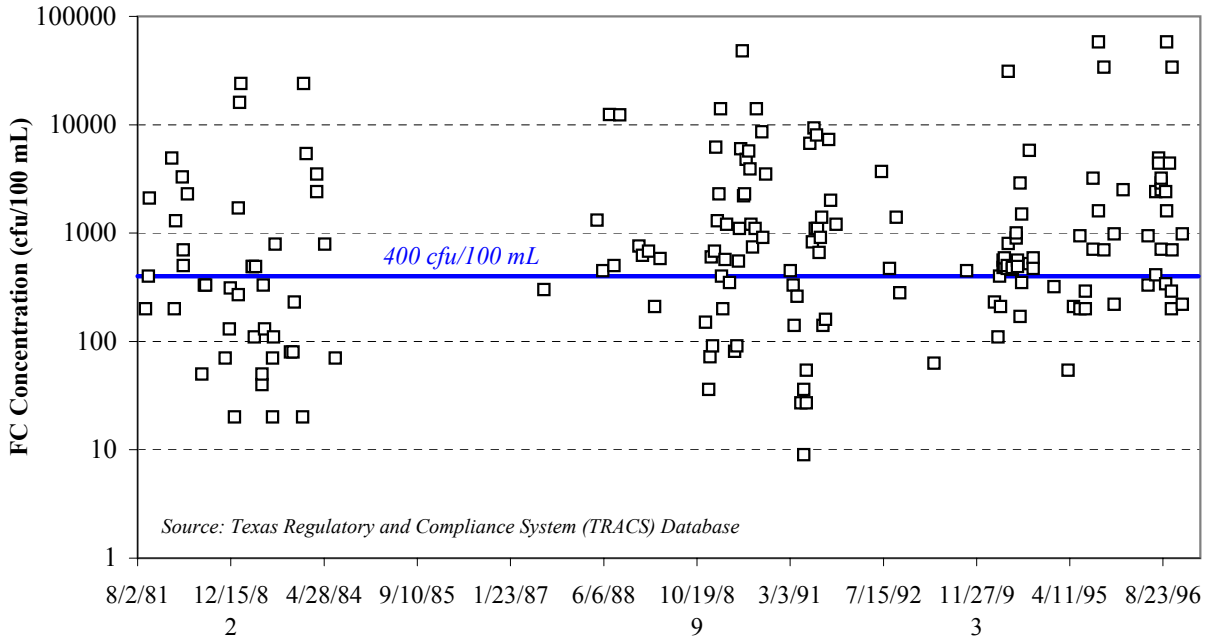


Figure 2.1 Fecal Coliform Concentrations at Barker Dam

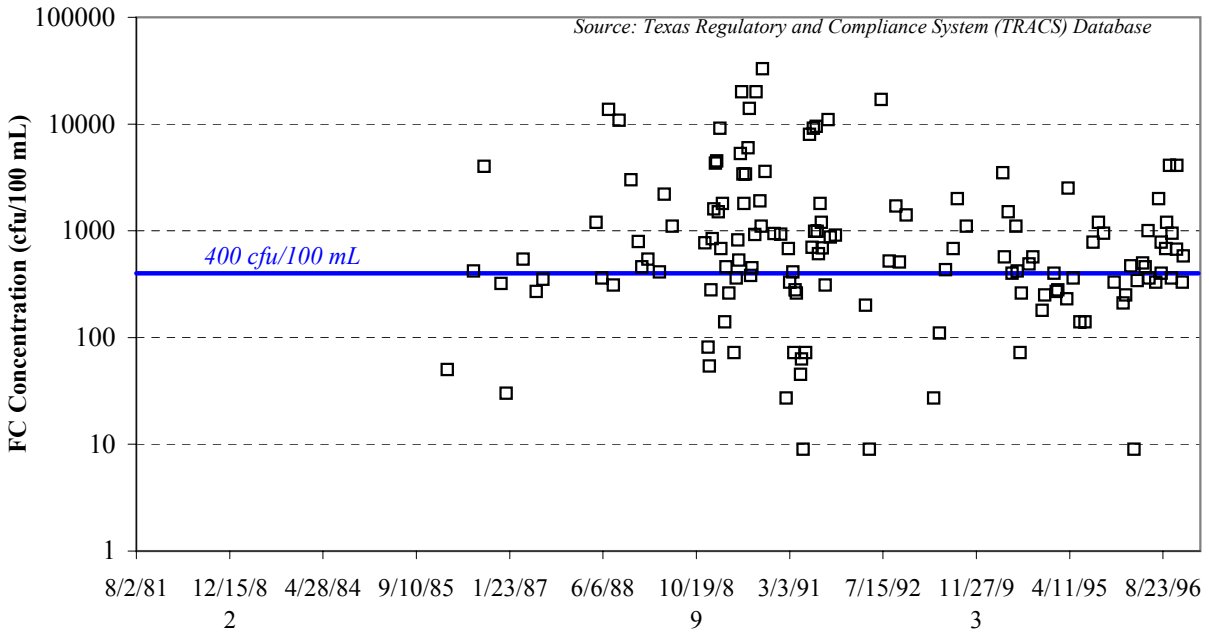


Figure 2.2 Fecal Coliform Concentrations at Highway 6

to the flow conditions suitable for such use. In this case, the project team would concentrate on the bacteria levels under low flow conditions.

7. Is it possible that the 45 WWTPs that were not confirmed or sampled are the source of the bacteria in the Bayous?

There were several different reasons that some WWTP were not sampled during summer 2001. Table 2.4 presents a summary of the reasons for not sampling. Approximately 31% (14) were no longer operating; they either connected to the City of Houston or were not yet built. Some plants also declined the request to take samples at their plant; these comprised approximately 13% (6) of the plants that could not be sampled. The last group of plants were those that either the facility or operator could not be located due to various reasons (e.g., incorrect contact information).

Table 2.4 Reasons that WWTPs were not sampled

Reason	Number of plants
Facility no longer in operation	14
Request to collect samples was declined	6
Information from TCEQ database regarding location and/or operator incorrect or operator non-responsive.	25

Overall, the EC concentrations at the sampled WWTPs were small (i.e., geometric mean of E. coli at WWTPs is 3.4 MPN/100 mL) and therefore it is not expected that these few plants are major contributors of bacteria into the bayous. These non-sampled plants were incorporated

in the model by assigning an EC value based on the flow-weighted geometric mean for the subwatershed.

CHAPTER 3

ASSESSMENT OF CURRENT LEVELS AND TRENDS OF BACTERIAL INDICATORS OF FECAL PATHOGENS IN BUFFALO BAYOU AND WHITEOAK BAYOU

One of the main reasons for establishing current levels and trends of bacterial indicators in the bayous is to provide insight to background levels of bacterial indicators as well as to provide the necessary tools for model calibration. A second reason is to better understand the processes affecting bacteria concentrations in the bayous, such as survival in the water and sediment, possible regrowth/reactivation, and bacterial inputs from sediments. This task encompassed two main activities: (i) conducting studies and monitoring to assess physical and biological dynamics of bacterial contamination within the bayous, and (ii) conducting monitoring and data collection to assess bacterial levels resulting from moderate rainfall events.

3.1 ANALYSIS OF DYNAMICS OF BACTERIA IN BUFFALO AND WHITEOAK BAYOUS

Three major tasks were completed to provide data for better understanding of the processes affecting bacteria concentrations in the bayou waters. These include survival rates of bacteria in water and sediment, possible regrowth or reactivation of bacteria after treatment and

discharge into the bayous, and resupply of bacteria from bayou sediments. The following sections provide an analysis of the results obtained from such studies.

3.1.1 Equipment and Methods

The method used for measuring EC in this task was the IDEXX Colilert. The equipment involved a sealer, incubator and an ultraviolet (UV) lamp case. Other items involved included 100-milliliter (mL) sample bottles, Colilert reagent and Colilert Quanti-Tray 2000 units. Initial method test results were encouraging. A set of six tests were conducted using both undiluted bayou water and water with a 1:10 dilution. Replicate results are shown in Table 3.1 below, with variation between duplicates of less than 10%.

Table 3.1 Initial IDEXX Test Results

Sample Type	Total Coliform (MPN/dL)*	*E. Coli* (MPN/dL)*
Date	7/5/01	7/5/01
Time	13:55	13:55
100% Bayou Water	>2,419	>2,419
100% Bayou Water	>2,419	>2,419
100% Bayou Water	>2,419	>2,419
10% Bayou Water	>24,192	5,172
10% Bayou Water	>24,192	4,884
10% Bayou Water	>24,192	5,794

Note: Water samples collected from Buffalo Bayou at Beltway 8.
** MPN = Most Probable Number, dL = deciliter*

Based on these results and historical fecal coliform (FC) data, it was determined that a 1:5 dilution with laboratory deionized (DI) water would be appropriate for most routine bayou testing. This yields a maximum quantifiable concentration of 12,096 MPN/dL (most probable number per deciliter), and somewhat better resolution than would be obtained with a 1:10 dilution such as the one used above. However, due to high bacteria counts in runoff samples, some stormwater analysis was conducted using 1:10 or 1:20 dilutions.

The equipment was used for a range of studies involving die-off and regrowth in controlled test chambers, measurements of sediment concentrations and possible bacteria resupply from the sediments, and measurements of bayou levels under moderate runoff conditions. During the testing process, samples were also sent to two contract laboratories: North Water District Laboratory Services (NWDLS) and Anacon Laboratories, Inc. (Anacon). These samples were tested for conventional parameters and sediment physical and chemical characteristics, respectively.

Initial tests were aimed at studying the effect of isolating water samples in the experimental test chambers under both normal and reduced light conditions and at addressing regrowth of bacteria from point sources. All of these tests were conducted in special test chambers built to float in the bayou and, thus, experience truly ambient levels of temperature and light (Figure 3.1). Experiments were performed in-situ, rather than in the lab, to account for ambient conditions. Performing experiments in the field, however, introduced its own set of limitations and challenges. For example, the experimental floating test chambers were disturbed

Figure 3.1 Floating Test Chambers

by strong changes in bayou flow and construction activities. Also, the environmental variability that exists naturally is carried into the experiments (e.g., insects getting into the test chambers).

Each floating container was built from a 5-gallon cubitainer with the top cut off and held to the float frame with fasteners. With each test a new plastic bag was placed inside the cubitainer frame and clipped in place as shown in Figure 3.2. Water samples were placed in the fresh bag containers by either pouring a sample collected directly from the bayou with a pre-cleaned bucket or from new cubitainers where samples were obtained from a remote location. Field blank samples were routinely collected and analyzed to insure that sterile conditions were maintained.

As is the case with most fieldwork, rain and bayou flows played a major role in these experiments. The rainfall measurements recorded at a number of west Houston rain gages are tabulated in Table 3.2, and the locations of the gages are shown in Figure 3.3. Also shown in Figure 3.3 are the major road crossings of Buffalo and Whiteoak bayous where samples were collected, and the locations of the main stream flow gages. Bayou flows at several gages are listed in Table 3.3. The locations of the gages are shown in Figure 3.3.

Figure 3.2 Test chambers covered with black plastic cover (top picture) and clear plastic cover (bottom picture)

TABLE 3.2
RAINFALL DATA FOR BUFFALO AND WHITE OAK WATERSHEDS

Date	RG14 Upper WO	RG15 Upper WO	RG21 Upper BB	RG23 Middle WO	RG30 Upper BB	RG31 Upper BB	RG32 Middle BB	RG34 Confluence BB & WO	RG35 Below confluence
07/01/01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.27	0.07
07/02/01	0.04	0.06	0.58	1.18	1.17	0.18	0.21	0.15	0.16
07/03/01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.29
07/04/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
07/05/01	0.36	0.63	0.12	0.07	0.00	0.00	0.00	0.49	0.02
07/06/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/07/01	0.04	0.00	0.22	0.00	0.22	0.12	0.96	0.00	0.00
07/08/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/09/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/10/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/11/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00
07/12/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/13/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/14/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/15/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/16/01	0.05	0.44	0.02	0.14	0.58	0.00	0.00	0.44	0.00
07/17/01	0.00	0.00	0.01	0.35	0.31	0.02	0.00	0.34	0.26
07/18/01	0.00	0.00	0.01	0.00	0.00	0.01	0.15	0.00	0.00
07/19/01	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00
07/20/01	0.22	0.06	0.10	0.23	0.00	0.00	0.00	0.00	0.02
07/21/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/22/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/23/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/24/01	0.00	0.00	0.20	0.00	0.08	0.00	0.23	0.00	0.00
07/25/01	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
07/26/01	0.01	0.21	0.05	0.98	0.02	0.84	1.37	0.04	0.45
07/27/01	0.44	0.13	0.13	0.40	0.12	0.11	0.26	0.75	1.42
07/28/01	0.02	0.14	0.03	0.01	0.01	0.00	0.00	0.00	0.06
07/29/01	0.02	0.02	0.01	0.12	0.00	0.02	0.17	0.17	0.00
07/30/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07/31/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/01/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/02/01	0.00	0.00	0.00	0.04	0.03	0.00	0.17	0.51	0.54
08/03/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/04/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/05/01	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.04
08/06/01	2.68	0.84	1.38	0.00	1.28	0.65	0.19	0.00	0.00
08/07/01	0.14	0.11	0.03	0.13	0.00	0.02	0.63	0.28	0.00
08/08/01	0.20	0.13	0.04	0.00	0.00	0.00	0.00	0.35	0.00
08/09/01	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/10/01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
08/11/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/12/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/13/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/14/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
08/15/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/16/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/17/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

BB = Buffalo Bayou, WO = Whiteoak Bayou

TABLE 3.2 (CONCLUDED)
RAINFALL DATA FOR BUFFALO AND WHITE OAK WATERSHEDS

Date	RG14 Upper WO	RG15 Upper WO	RG21 Upper BB	RG23 Middle WO	RG30 Upper BB	RG31 Upper BB	RG32 Middle BB	RG34 Confluence BB & WO	RG35 Below confluence
08/18/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/19/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/20/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/21/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/22/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/23/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/24/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/25/01	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
08/26/01	0.06	0.88	0.29	0.02	0.01	0.00	0.00	0.47	0.50
08/27/01	0.29	0.12	1.03	0.10	0.59	0.34	0.34	0.63	0.12
08/28/01	0.26	0.16	0.08	0.51	1.74	0.39	0.48	0.51	0.13
08/29/01	0.70	1.00	0.42	0.50	1.00	1.12	1.19	0.75	0.47
08/30/01	0.95	1.36	2.05	0.77	1.12	1.09	2.18	1.76	1.73
08/31/01	2.17	2.15	1.99	1.66	2.00	2.37	2.06	2.29	1.81

BB = Buffalo Bayou, WO = Whiteoak Bayou

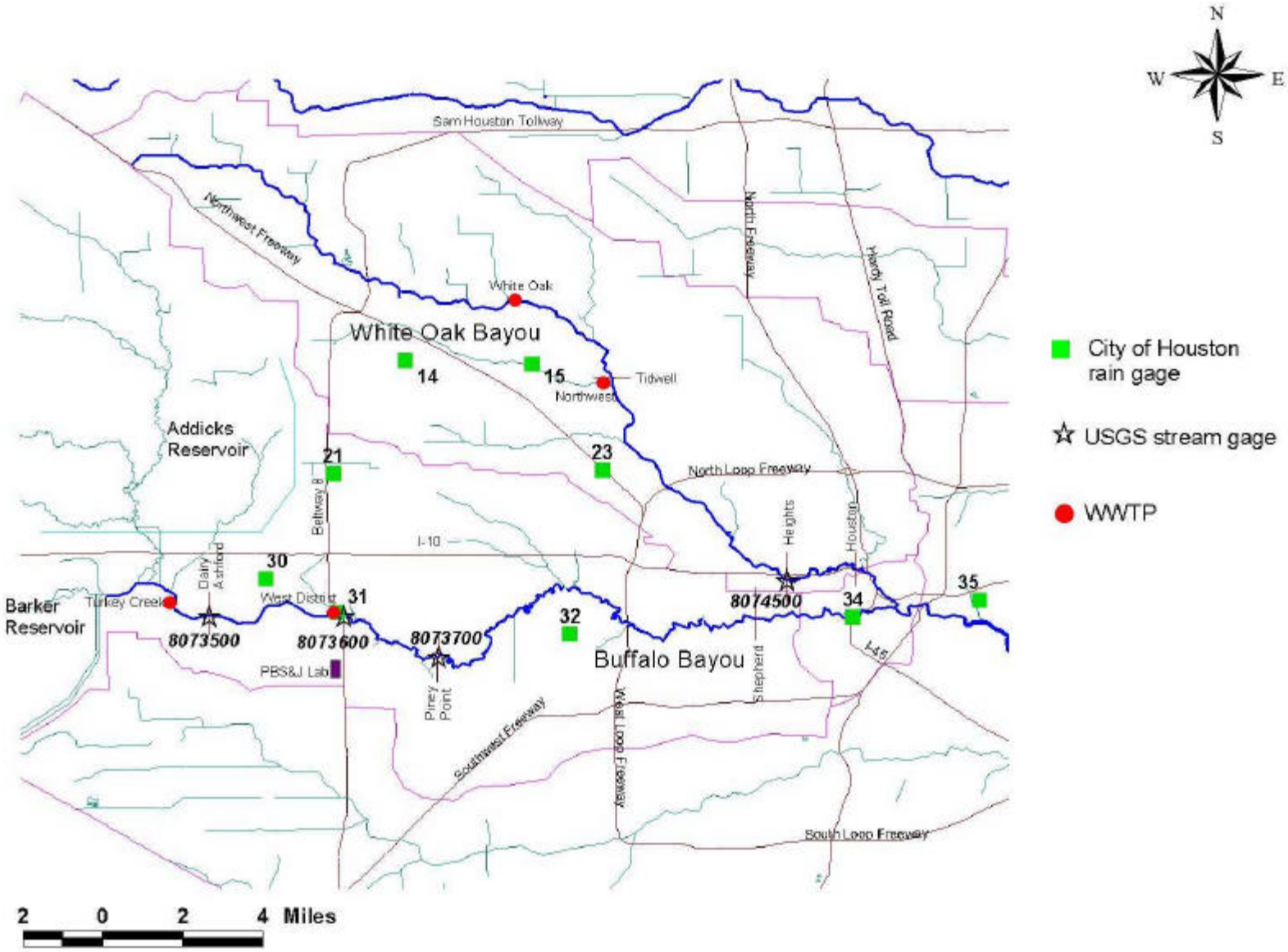


Figure 3.3 Location Map

TABLE 3.3
USGS FLOW DATA (CFS) FOR BUFFALO AND WHITE OAK BAYOUS

Date	08073500 BB Dairy Ashford	08073600 BB West Belt	08073700 BB Piney Point	08074500 WO Heights
07/01/01	111	132	139	126
07/02/01	411	484	389	222
07/03/01	61	118	190	101
07/04/01	27	54	49	59
07/05/01	276	239	194	125
07/06/01	575	551	547	126
07/07/01	409	477	529	56
07/08/01	167	193	218	51
07/09/01	93	101	105	51
07/10/01	68	81	78	48
07/11/01	56	75	69	48
07/12/01	54	73	66	50
07/13/01	51	69	62	51
07/14/01	49	68	62	52
07/15/01	49	67	61	54
07/16/01	76	97	86	215
07/17/01	186	191	181	196
07/18/01	198	202	193	72
07/19/01	148	155	163	54
07/20/01	104	101	110	86
07/21/01	85	83	89	49
07/22/01	62	70	69	44
07/23/01	54	64	65	43
07/24/01	52	68	69	41
07/25/01	65	72	75	40
07/26/01	94	153	197	405
07/27/01	170	190	212	351
07/28/01	35	57	57	139
07/29/01	24	48	44	64
07/30/01	437	372	292	53
07/31/01	134	178	237	40
08/01/01	89	87	89	37
08/02/01	85	83	87	37
08/03/01	82	82	83	39
08/04/01	86	82	83	38
08/05/01	88	85	86	38
08/06/01	167	221	135	199
08/07/01	388	474	533	462
08/08/01	212	248	262	126
08/09/01	128	139	141	74
08/10/01	94	101	102	47
08/11/01	71	83	80	43
08/12/01	58	73	69	41
08/13/01	54	73	67	38
08/14/01	52	71	66	40
08/15/01	50	70	64	35
08/16/01	48	66	60	35
08/17/01	44	64	58	34
08/18/01	46	65	59	36
08/19/01	44	65	58	35
08/20/01	43	64	58	36
08/21/01	46	64	57	35
08/22/01	48	64	NA	35
08/23/01	50	64	NA	33
08/24/01	48	61	55	32
08/25/01	46	63	54	83
08/26/01	54	66	58	290
08/27/01	129	163	173	362
08/28/01	331	439	445	230
08/29/01	149	307	345	414
08/30/01	207	317	346	883
08/31/01	749	1,490	1,780	2,160

NA = not available

3.1.2 Dynamics of Bacteria Population Change (Light/Dark Test Chambers)

The objective of the tests described in this section was to obtain data on the rates of change in bacteria concentration when water samples are isolated from new sources, and also to examine the effects of different light levels. A series of four test chamber experiments was completed. All of the test chambers were located in Buffalo Bayou near the Beltway 8 crossing, but some of the water samples came from Whiteoak Bayou. This section describes these four tests and the major findings.

3.1.2.1 Test Started on July 11, 2001

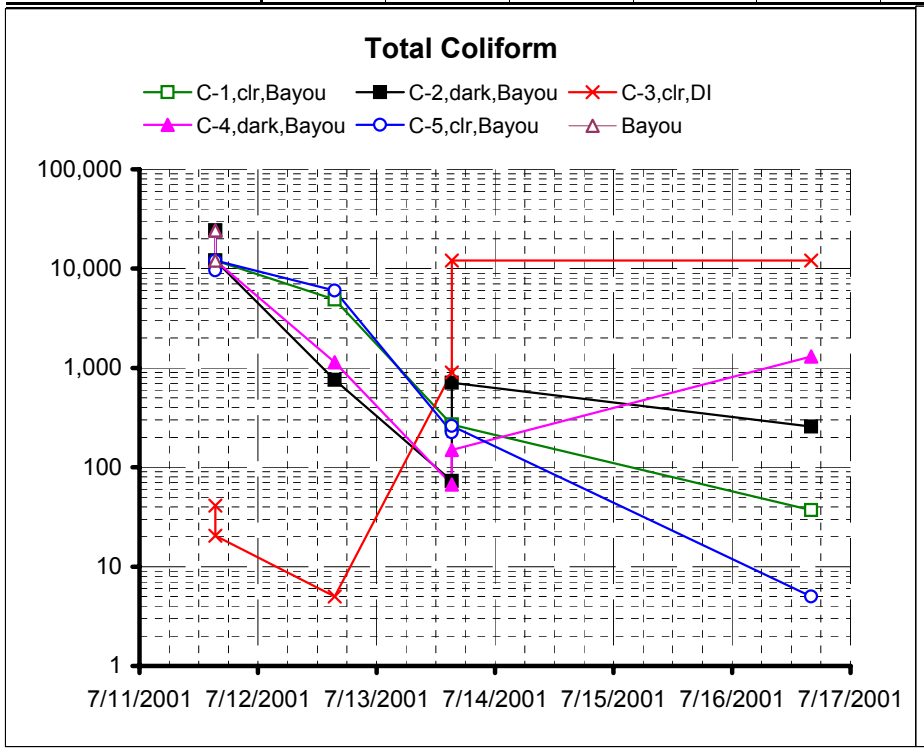
The first test was performed with Buffalo Bayou water between July 11 and July 16. The main factor being tested was the effect of clear versus dark covers over the test chambers on EC concentrations in samples that were isolated from new sources. Table 3.4 shows the results for both TC (total coliform) and EC along with plots of the data over time.

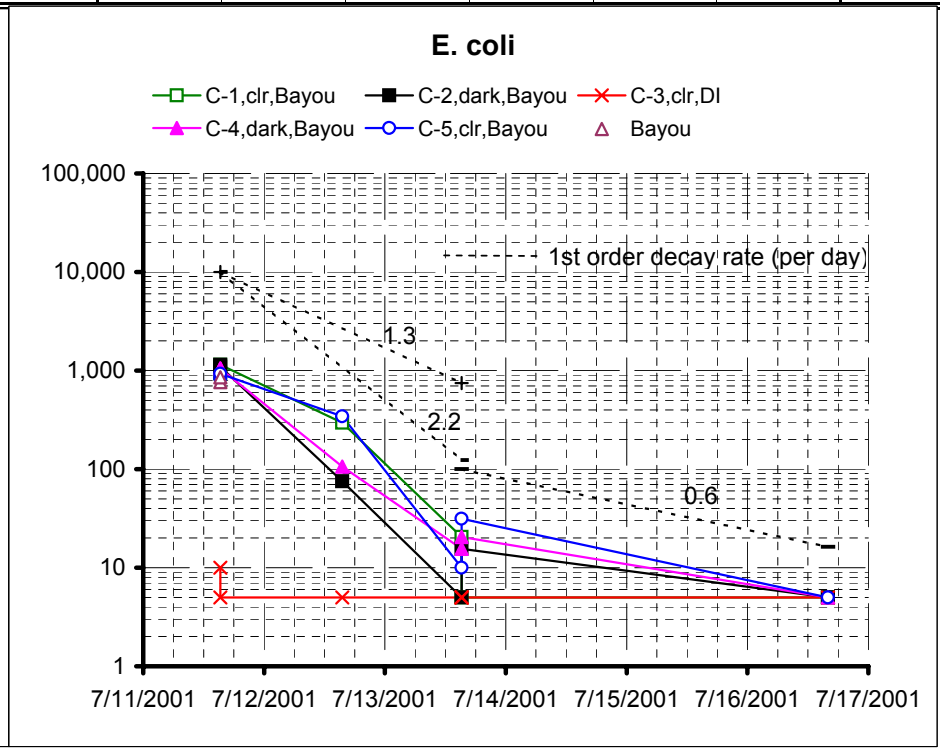
The first point to note is that there are very different results with the IDEXX TC and EC results. The TC values were initially beyond the measurement limit with the dilutions employed, while the EC levels were within range, at approximately 1,000 MPN/dL.

For the test chambers with clear covers, both the TC and EC declined quickly for the first two days, with the dark covered test chambers showing a more rapid decline in both cases. However, on the second day the dark TC test chambers stopped declining and in some cases rebounded. Similarly, the deionized (DI) lab water control with a clear cover spiked in TC

TABLE 3.4
LIGHT/DARK EFFECTS, BUFFALO BAYOU, TEST 1

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)						DO
Date	7/11/2001	7/11/2001	7/12/2001	7/13/2001	7/13/2001	7/16/2001	7/11/2001	7/11/2001	7/12/2001	7/13/2001	7/13/2001	7/16/2001	#######
Time	15:20	15:20	15:30	15:15	15:15	16:00	15:20	15:20	15:30	15:15	15:15	16:00	16:00
C-1,clr,Bayou	> 24,192	> 12,096	4,902	269	269	37	933	1,141	296	21	5	< 5	11.2
C-2,dark,Bayou	> 24,192	> 12,096	758	73	711	256	1,145	1,094	75	5	16	< 5	6.6
C-3,clr,DI	41	21	< 5	901	> 12,096	> 12,096	< 10	< 5	< 5	< 5	< 5	< 5	6.5
C-4,dark,Bayou	24,192	> 12,096	1,141	67	150	1,301	1,054	1,049	107	16	21	5	6.3
C-5,clr,Bayou	9,606	> 12,096	6,017	224	260	< 5	836	925	345	10	32	< 5	8.8
Bayou	> 12,096	> 24,192					765	857					
Remarks		Duplicate			Duplicate			Duplicate			Duplicate		





Note: A dead fly was found in DI chamber on 7/13/01.

concentration. However, the EC test of the same water (same test) did not show any increase in concentration. Note that all the test chambers were open under the covers for air exchange. The chambers were built using two longitudinal wooden side boards and six lateral boards placed in between the side boards. The longitudinal ones were shorter in height than the lateral ones and all of them were lined up on the bottom, resulting in the lateral boards being about one inch higher than the longitudinal side boards. A flat lid/cover was attached to the top of the lateral boards, forming open spaces under the lid and above the top of the longitudinal side boards. The lid prevented bird droppings from entering the chambers while the open spaces allowed air, insects, and dust to enter the chambers. It is noted that a dead fly was found in the DI water test chamber on July 13.

The EC test results for both light and dark chambers showed strong bacterial die-off while the DI water control remained at the non-detect level. Of interest is that for both EC and TC, the rate of initial (first 2 days) die-off was higher with the dark test chambers than with the clear plastic covered chambers. The EC plots on the bottom of Table 3.4 include as dashed lines the approximate first-order decay rate, plotted above or below the actual data for clarity. The decay rate for EC in the clear test chambers was approximately 1.3/day while it was 2.2/day in the dark test chambers. After two days, the EC levels became so low that the decay rate dropped to approximately 0.6/day, probably limited by the lower concentration limit of the test.

Another point of interest was the dissolved oxygen levels at the end of the experiment. They were above saturation for the light test chambers and below saturation for the dark and DI water clear test chambers. A related observation was that at the end of the 5-day experiment,

there was noticeable periphyton accumulation on the clear bayou water test chambers but not on the DI water or the bayou water test chambers with dark covers.

3.1.2.2 Test started on July 30, 2001

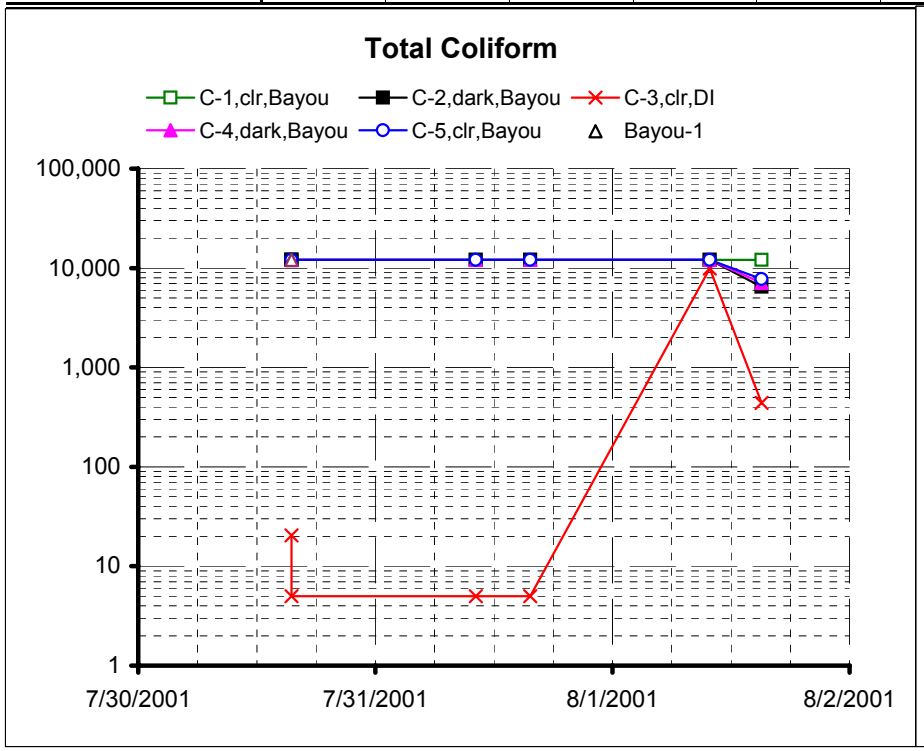
From July 30 to August 1, similar experiments were conducted using Buffalo Bayou water with light and dark covers and also open test chambers. Results are shown in Table 3.5a for covered and Table 3.5b for open test chambers. Both tests were performed near the Beltway 8 bridge on Buffalo Bayou. It is noted that when water samples were taken to fill the test chambers in this test, there had been no recent rainfall events but the Barker and Addicks flood reservoirs were releasing water from previous rains. Therefore, water samples for this test contained more than the typical dry-weather flow.

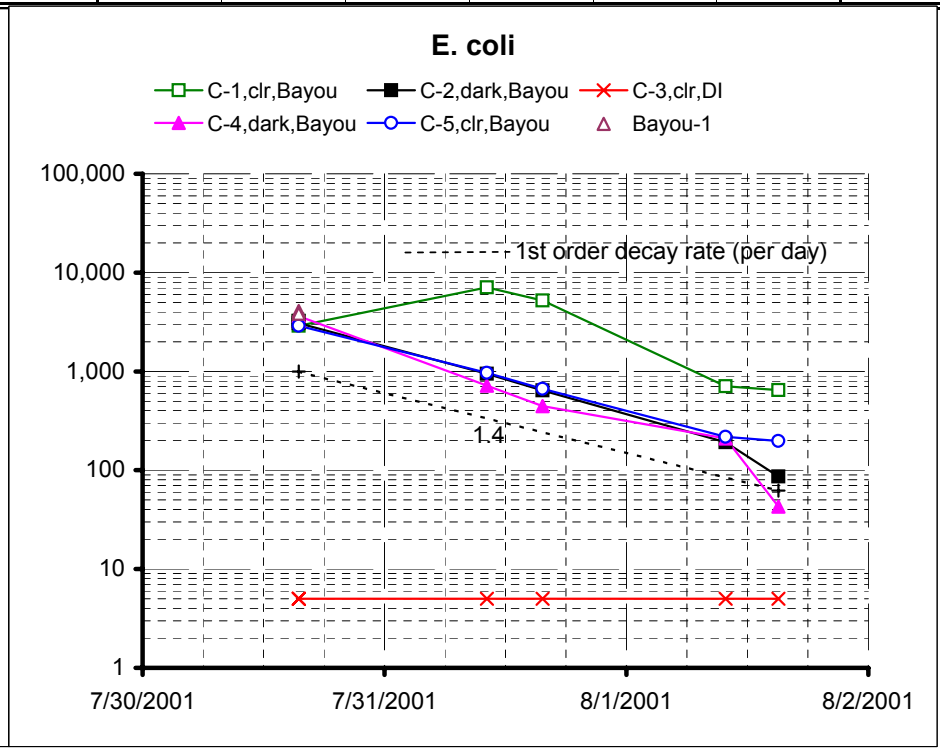
For both the covered and open test chambers, the Buffalo Bayou TC results were too high to quantify. The main difference between the covered and open test chambers is that the DI control showed more of an increase with the clear cover than with the open test chamber. However, all the EC control results were negative. Apparently, airborne inputs of TC (bacteria that grow on the media provided but do not fluoresce under UV light) are fairly common but airborne inputs of EC bacteria (bacteria that grow and do fluoresce) are more rare.

Both the covered (clear and dark) and open test chambers showed very consistent and monotonic die-off of EC bacteria. The first order die-off rates were in the 1.4 to 1.5/day range. An exception was one clear covered test chamber that showed an increase in concentration on the

TABLE 3.5a
LIGHT/DARK EFFECTS, BUFFALO BAYOU, TEST 2, COVERED TEST CHAMBERS

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)						DO
Date	7/30/2001	7/30/2001	7/31/2001	7/31/2001	8/1/2001	8/1/2001	7/30/2001	7/30/2001	7/31/2001	7/31/2001	8/1/2001	8/1/2001	
Time	15:30	15:30	10:10	15:40	9:50	15:05	15:30	15:30	10:10	15:40	9:50	15:05	
C-1,clr,Bayou	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	3,244	2,897	7,068	5,231	710	648	
C-2,dark,Bayou	> 12,096	> 12,096	> 12,096	> 12,096	12,096	6,498	3,244	3,066	946	644	192	87	
C-3,clr,DI	21	5	< 5	< 5	9,931	440	< 5	< 5	< 5	< 5	5	< 5	
C-4,dark,Bayou	> 12,096	> 12,096	> 12,096	> 12,096	12,096	7,068	3,244	3,630	720	445	210	43	
C-5,clr,Bayou		> 12,096	> 12,096	> 12,096	> 12,096	7,765		2,897	968	667	218	198	
Bayou-1	> 12,096	> 12,096					4,082	3,851					
Remarks		Duplicate						Duplicate					

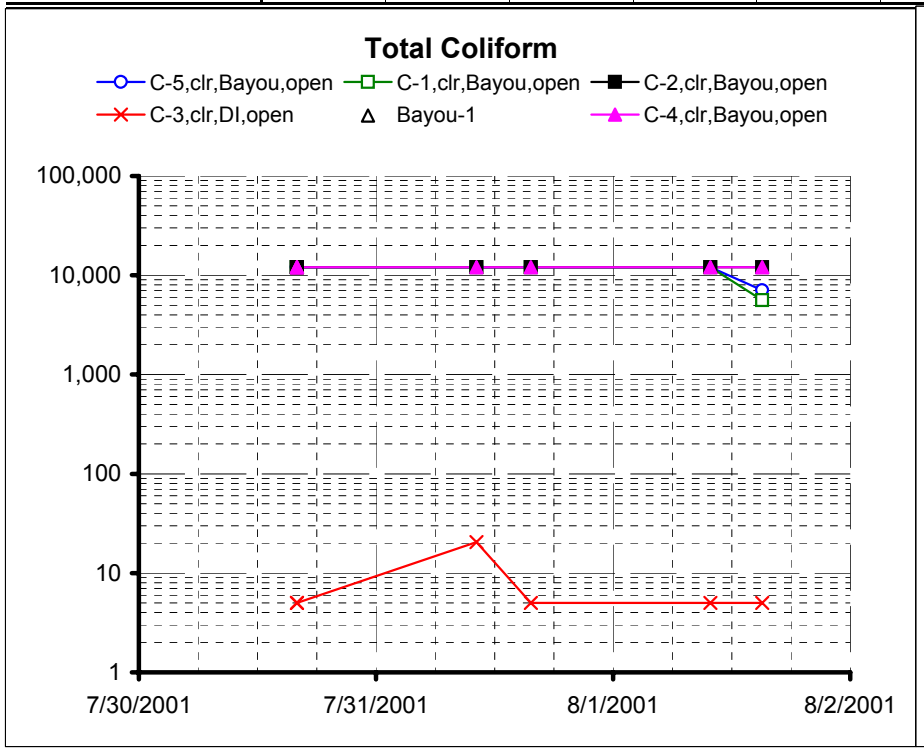


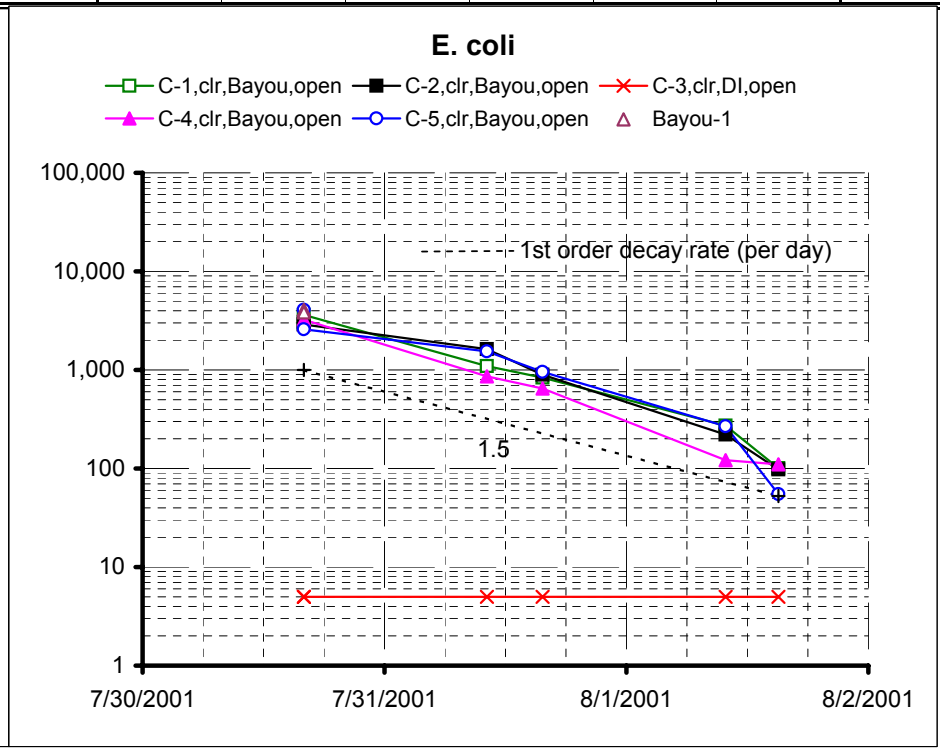


Note: Water samples collected from BB @ Beltway 8.

TABLE 3.5b
LIGHT/DARK EFFECTS, BUFFALO BAYOU, TEST 2, OPEN TEST CHAMBERS

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)						DO
Date	7/30/2001	7/30/2001	7/31/2001	7/31/2001	8/1/2001	8/1/2001	7/30/2001	7/30/2001	7/31/2001	7/31/2001	8/1/2001	8/1/2001	
Time	16:00	16:00	10:10	15:40	9:50	15:05	16:00	16:00	10:10	15:40	9:50	15:05	
C-1,clr,Bayou,open	> 12,096	> 12,096	> 12,096	> 12,096	12,096	5,599	2,897	3,630	1,094	835	273	101	
C-2,clr,Bayou,open	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	3,066	2,897	1,628	893	222	98	
C-3,clr,DI,open	< 5	< 5	21	< 5	5	5	< 5	< 5	5	< 5	< 5	5	
C-4,clr,Bayou,open	> 12,096	> 12,096	> 12,096	> 12,096	12,096	12,096	2,897	3,244	863	648	122	111	
C-5,clr,Bayou,open	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	7,068	4,082	2,586	1,538	959	269	55	
Bayou-1	> 12,096	> 12,096					4,082	3,851					
Remarks		Duplicate						Duplicate					





Note: Water samples collected from BB @ Beltway 8.

second day, and then resumed the monotonic decline typical of the other results. The cause for the observed increase remains unknown.

3.1.2.3 Test started August 1, 2001

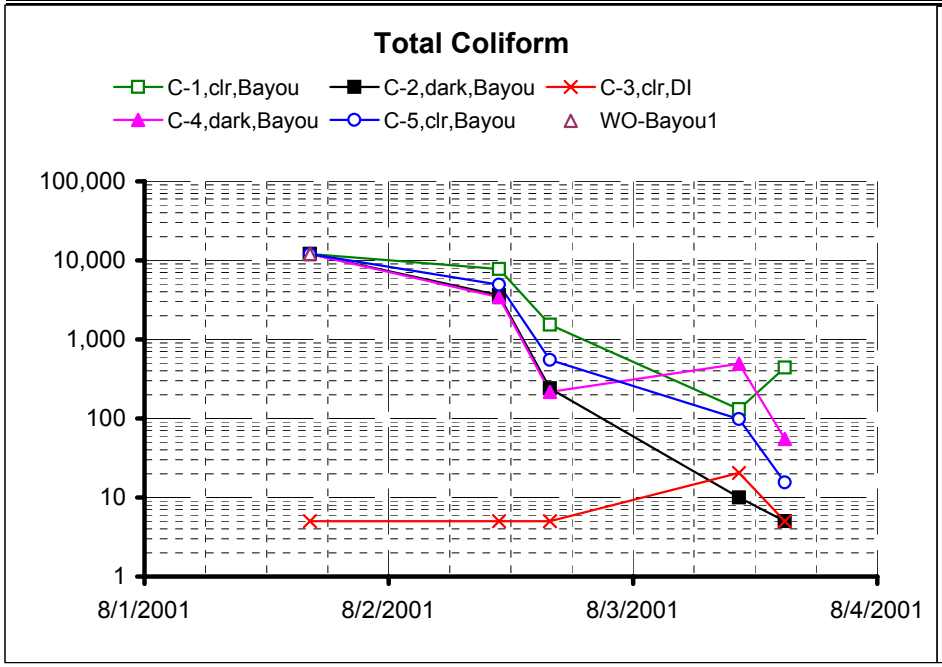
From August 1 to 3, light-dark test chambers were set up using Whiteoak Bayou water collected at IH-610 (West Loop). Two sets of test chambers were set up, one with both clear and opaque plastic covers and the other with the surface open. Both racks of test chambers were deployed at the Beltway 8 bridge on Buffalo Bayou. Results of the two series are shown in Tables 3.6a (covered) and 3.6b (open). Two water samples were collected from Whiteoak Bayou for EC analysis at the same time as a large volume of water was collected in new 5-gallon cubitainers for transport to the Buffalo Bayou test site. The analytical results for the two samples plus the large volume samples were markedly lower than the readings obtained from Buffalo Bayou during the earlier tests. This reflected a period of stable flow in Whiteoak bayou compared to flow impacted by reservoir releases in Buffalo Bayou. By the time the test chambers were set up and the water placed in the new bags, the initial samples taken from the test chambers were lower in EC than when the water was first collected. The average of the initial values was 282 MPN/dL for the open test chambers and 253 MPN/dL for the covered test chambers versus approximately 450 MPN/dL for the samples taken directly from the bayou.

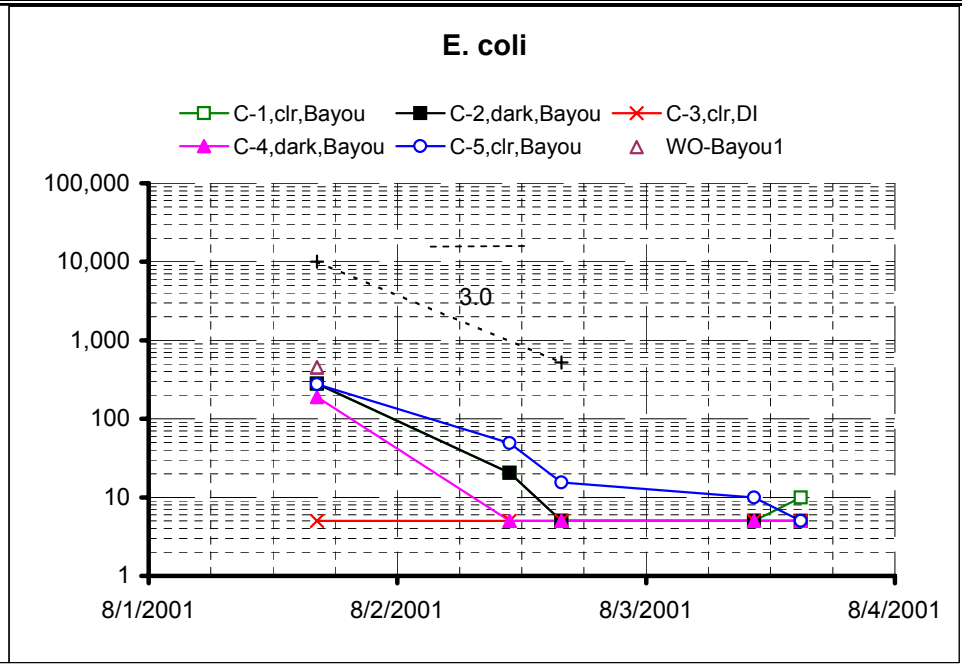
By the next morning the EC level in most of the test chambers had declined further. One open test chamber showed a sharp increase but the other three and all the closed test chambers showed strong decreases in EC levels. The rapid decline continued that afternoon and both sets

TABLE 3.6a
LIGHT/DARK EFFECTS, WHITE OAK BAYOU, TEST 3, COVERED TEST CHAMBERS

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)						DO
Date	8/1/2001	8/1/2001	8/2/2001	8/2/2001	8/3/2001	8/3/2001	8/1/2001	8/1/2001	8/2/2001	8/2/2001	8/3/2001	8/3/2001	8/3/2001
Time	16:15	16:15	10:50	15:50	10:25	14:55	16:15	16:15	10:50	15:50	10:25	14:55	14:55
C-1,clr,Bayou	> 12,096		7,765	1,538	131	441	278		21	< 5	< 5	10	11.3
C-2,dark,Bayou	> 12,096		3,630	241	10	5	282		21	< 5	< 5	< 5	8.2
C-3,clr,DI	< 5		< 5	< 5	21	< 5	< 5		< 5	< 5	< 5	< 5	7.6
C-4,dark,Bayou	> 12,096		3,434	216	492	55	190		5	5	< 5	< 5	7.8
C-5,clr,Bayou	> 12,096		4,902	553	99	16	277		49	16	10	< 5	11.2
WO-Bayou1	> 12,096	> 12,096					450	455					
Remarks		Duplicate						Duplicate					

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
WO-Bayou1	8/1/2001	16:15	18.4				220	120	WO @ 610; NWDLS picked up samples on 8/7/01.



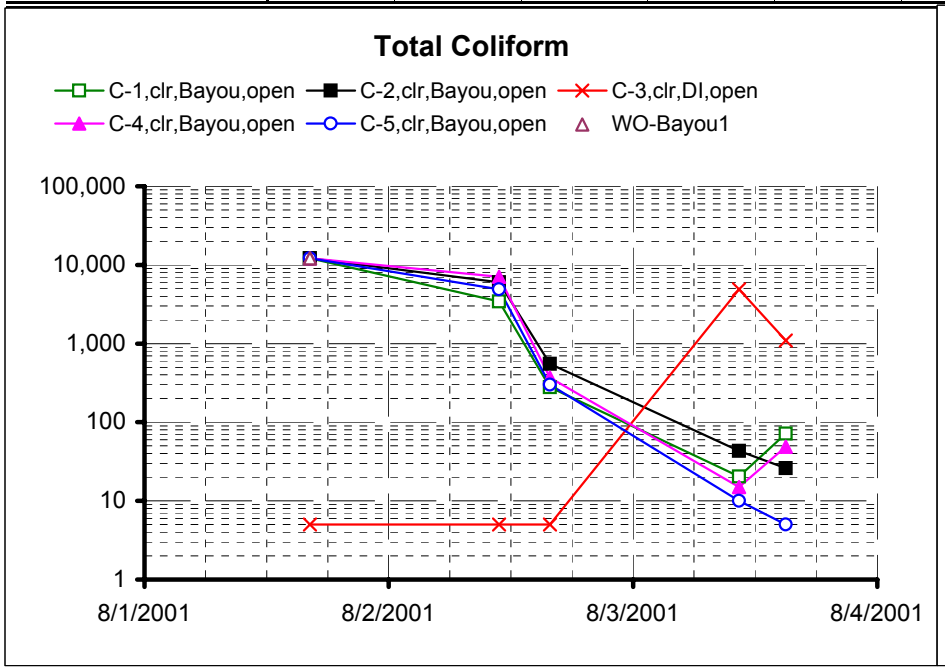


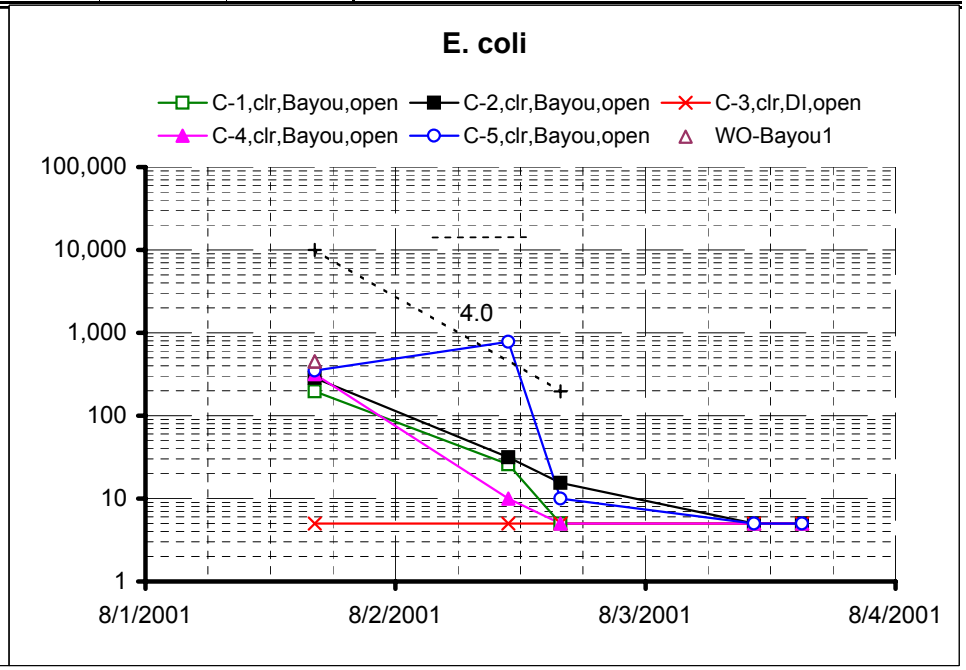
Note: Water samples collected from WO @ 610.

TABLE 3.6b
LIGHT/DARK EFFECTS, WHITE OAK BAYOU, TEST 3, OPEN TEST CHAMBERS

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)						DO
Date	8/1/2001	8/1/2001	8/2/2001	8/2/2001	8/3/2001	8/3/2001	8/1/2001	8/1/2001	8/2/2001	8/2/2001	8/3/2001	8/3/2001	8/3/2001
Time	16:15	16:15	10:50	15:50	10:25	15:01	16:15	16:15	10:50	15:50	10:25	15:01	15:01
C-1,clr,Bayou,open	> 12,096		3,434	279	21	72	197		26	< 5	< 5	5	11.1
C-2,clr,Bayou,open	> 12,096		6,017	553	43	26	287		32	16	< 5	< 5	10.5
C-3,clr,DI,open	< 5		5	< 5	4,902	1,094	< 5		5	< 5	< 5	< 5	8.0
C-4,clr,Bayou,open	12,096		7,068	369	15	49	319		10	< 5	< 5	< 5	11.3
C-5,clr,Bayou,open	> 12,096		4,902	301	10	< 5	352		783	10	< 5	< 5	10.9
WO-Bayou1	> 12,096	> 12,096					450	455					
Remarks		Duplicate						Duplicate					

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
WO-Bayou1	8/1/2001	16:15	18.4				220	120	WO @ 610; NWDLS picked up samples on 8/7/01.





Note: Water samples collected from WO @ 610.

of test chambers were at the non-detect level at that time and also on the following morning when the test chamber experiments were ended. The first-order die-off rate for both sets of experiments was very high, in the range of 3-4/day.

The DI water controls for both experiments were at non-detect the entire time for EC, but showed TC growth in the open control test chamber but not the covered one. All of the samples had high TC levels initially and TC die-off rates were also fairly high.

Dissolved oxygen (DO) levels were measured when the test chamber experiments were ended. The levels for the DI water controls, both open and covered, were essentially at saturation and there was no indication of attached algal growth on the inside of the plastic cubitainers. The bayou water samples were supersaturated (10.5 to 11.3 where saturation was 7.6 milligrams per liter [mg/L]) when there was either no cover or a clear cover. These test chambers showed attached algal growth on the inside walls of the plastic container. For the two test chambers with a dark cover, the DO levels were 7.8 and 8.2 mg/L, and there was no algal growth.

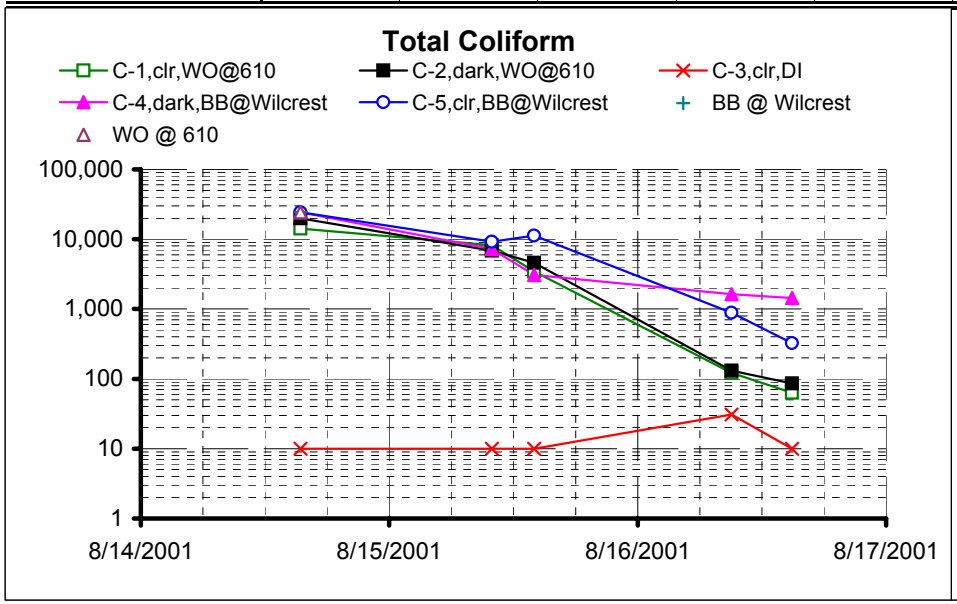
3.1.2.4 Test started August 14, 2001

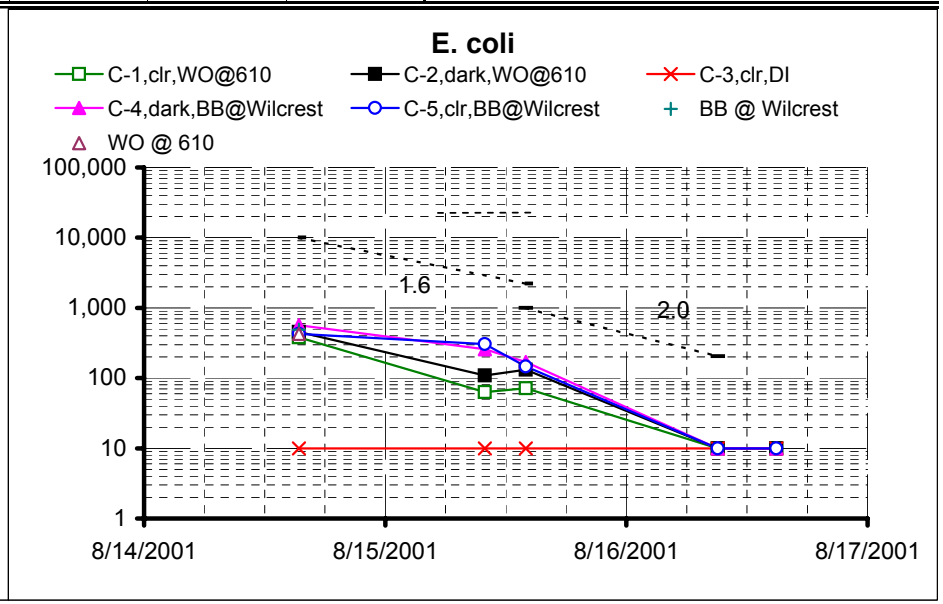
A final set of light/dark test chamber tests was conducted during August 14-16 using water samples collected from Buffalo Bayou at Wilcrest and Whiteoak Bayou at IH-610. These test chambers were covered and the results are shown in Table 3.7. Similar fast die-off rates to those from earlier tests were observed and the first-order rates were in the range of 1.6/day.

TABLE 3.7
LIGHT/DARK EFFECTS, TEST 4, COVERED TEST CHAMBERS

SampleType	Total Coliform (MPN/dL)					E coli (MPN/dL)					DO
Date	8/14/2001	8/15/2001	8/15/2001	8/16/2001	8/16/2001	8/14/2001	8/15/2001	8/15/2001	8/16/2001	8/16/2001	8/16/2001
Time	15:25	9:55	14:00	9:05	14:55	15:25	9:55	14:00	9:05	14:55	14:55
C-1,clr,WO@610	14,136	8,164	3,448	122	63	379	63	72	10	< 10	6.6
C-2,dark,WO@610	19,863	6,867	4,611	131	86	452	109	132	< 10	< 10	4.9
C-3,clr,DI	< 10	< 10	< 10	31	< 10	< 10	< 10	10	< 10	< 10	5.0
C-4,dark,BB@Wilcrest	> 24,192	7,260	3,076	1,631	1,440	565	259	169	10	10	5.3
C-5,clr,BB@Wilcrest	> 24,192	9,208	11,199	882	323	426	305	146	10	10	5.8
BB @ Wilcrest	> 24,192					487					
WO @ 610	24,192					428					
Remarks											Hydrolab mulfunction.

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
BB @ Wilcrest	8/14/2001	11:00	45.0	1.03	< 0.10	11.0			Buffalo Bayou @ Wilcrest
WO @ 610	8/14/2001	11:40	9.0	0.92	1.61	9.9			White Oak Bayou @ 610





Note: Water samples collected from BB @ Wilcrest and WO @ 610.

3.1.2.5 Discussion of Light/Dark Test Chamber Results

The studies of light and dark effects gave us insight to dieoff rates under light and dark conditions The test chambers were designed to replicate as many aspects of bayou water conditions as possible while still allowing parcels of water to be isolated from new sources. One unavoidable consequence of the isolation was that the level of water turbulence in the test chamber was considerably less than that in the flowing stream. A lower level of turbulence allows particulate matter to settle much more readily than would be the case in the bayous.

These studies consistently demonstrated that bacteria levels decay rapidly in volumes of water that are isolated from turbulence and external resupply. The overall rate varied in these tests from over 1 to as high as 4/day. Table 3.8 presents a summary of the light/dark test chamber test results. One general finding is that bacteria levels in the test chambers tended to follow first-order kinetics and drop off rapidly. If ambient bacteria concentrations in the bayous dropped at the first-order rates observed in the test chamber tests, it is likely that ambient concentrations would be much lower than actually observed. It follows that either the concentrations in the test chambers are reducing more rapidly than in the bayous or there are major external sources to the bayous that maintain the high concentrations despite rapid die-off. Of these two explanations, the first seems more likely. Major efforts have been made to find and correct significant sewage sources. While leaks have been found and corrected, and very high concentrations reduced, the overall high background levels have not been affected. On the other hand, the relatively quiescent conditions in the test chambers would seem to allow more settling of particulate matter than

TABLE 3.8
LIGHT/DARK EFFECTS SUMMARY

TABLE	INITIAL EC (MPN/dL)	TSS (mg/L)	FLOW at Collection (cfs)	K Rates for EC (/day)		
				Covered Clear	Covered Dark	Open
2.3	1022		75	1.3	2.2	
2.4a	3112		372	1.4	1.4	
2.4b	3122		372			1.5
2.5a	257	18.4	37	3	4	
2.5b	273	18.4	37			4
2.6BB	496	45	71	1.6	1.6	
2.6WO	416	9	40	1.6	1.6	

would be the case in the bayous. Since bacteria are settleable particulate matter, this could account for the high die-off rates observed.

Another finding from these data is that there appear to be slightly higher decay rates in some of the dark covered test chambers relative to the clear covered test chambers. In other cases there was no difference between the clear and covered test chambers. The expected result was that the clear test chambers would produce higher die-off because of the disinfection effect of sunlight. It is possible that the clear plastic covers functioned as filters for uv light, effectively eliminating the bactericidal effect. If that were the case, no strong pattern of difference would be expected. There is still the difference in photosynthetic activity between light and dark test chambers. The DO levels at the end of the tests were clearly higher in the light test chambers and there was noticeably more attached algae in the clear and open test chambers than in the dark test chambers. It is not clear how differences in DO and attached algae would have affected the die-off rates.

One fairly dramatic difference was observed between the Buffalo and White Oak bayou results. The White Oak tests (Table 3.6a&b) have die-off rates that are almost twice those observed in Buffalo Bayou (see Tables 3.4 and 3.5). This might be caused by the fact that during dry weather Whiteoak Bayou contains mostly wastewater effluent while Buffalo Bayou includes upstream reservoir discharge that is mostly stormwater. However, the side-by-side covered test chamber experiments using Buffalo and Whiteoak water (Table 3.7) showed similar results.

The test chamber experiments provided useful information, but few definitive answers. While the causes of the observed high decay rates are not certain, it is very likely that settling

probably is one of the major ones. This conclusion is supported by the findings of the sediment resupply study discussed in the following section that indicate high levels of bacteria in the sediment. Understanding the settling process and its impacts on bacteria concentrations is important for developing implementation strategies for the TMDL.

3.1.3 In-stream Dynamics - Post Treatment Bacteria Regrowth

One of the areas of interest for the study is the extent to which bacteria levels in wastewater effluent, which constitutes the bulk of bayou flows in dry weather, can affect bayou bacteria concentrations. Data gathering in this study (Chapter 4) generally confirmed that wastewater treatment plant (WWTP) effluent has low indicator bacteria concentrations after normal disinfection. Effluent from the smaller plants in the area contains a chlorine residual that acts to insure low levels in the receiving stream until that residual is consumed. A consideration is that dechlorination is now required for all domestic WWTPs with permitted flows over 1 million gallons per day (MGD). Although it is not considered likely, this could allow the possibility of regrowth in the stream. To assess this possibility, a series of experiments was performed in the test chambers.

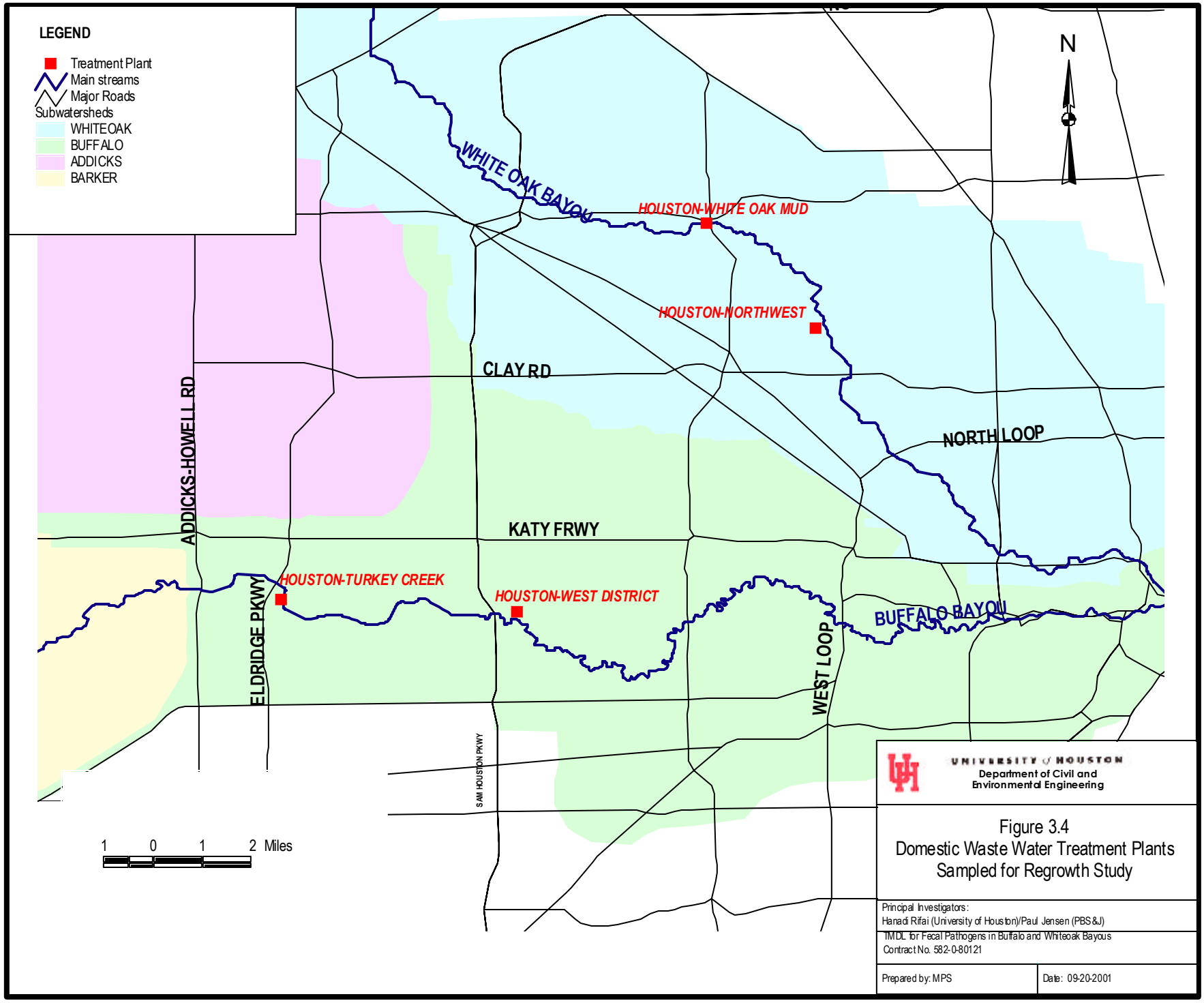
Water samples were collected under dry weather conditions from upstream and downstream of large domestic wastewater treatment plants. The samples were collected in new 2.5-gallon cubitainers and brought to the BB at Beltway 8 site where the test chambers were located. A pre-calculated quantity of sodium bisulfite (assuming 1 mg/L of residual chlorine)

was added to the cubitainers containing effluent samples to prevent any effects that residual chlorine may have on bacterial regrowth.

Four major domestic treatment plants were selected for this study (Figure 3.4):

1. West District Wastewater Treatment Plant in Buffalo Bayou,
2. Turkey Creek Wastewater Treatment Plant in Buffalo Bayou,
3. White Oak Wastewater Treatment Plant in Whiteoak Bayou, and
4. Northwest Wastewater Treatment Plant in Cole Creek (Whiteoak)

For West District WWTP, the upstream and downstream locations were Buffalo Bayou at Wilcrest and Beltway 8, respectively. For Turkey Creek WWTP, the locations were Buffalo Bayou at Eldridge and Dairy Ashford. For White Oak WWTP, the upstream and downstream locations were Whiteoak Bayou downstream of confluence with E122 drainage ditch and Whiteoak Bayou at N. Houston Rosslyn, respectively. Finally, for Northwest WWTP, the locations were Cole Creek at Antoine and Whiteoak Bayou at Creekmont.


LEGEND
Treatment Plant
Main streams
Major Roads
Subwatersheds
WHITEOAK
BUFFALO
ADDICKS
BARKER
N
WHITE OAK BAYOU
HOUSTON-WHITE OAK MUD
HOUSTON-NORTHWEST
CLAY RD
NORTH LOOP
ADDICKS-HOWELL RD
KATY FRWY
HOUSTON-TURKEY CREEK
HOUSTON-WEST DISTRICT
ELDRIDGE PKWY
BUFFALO BAYOU
WEST LOOP
SAM HOUSTON PKWY
1 0 1 2 Miles
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 3.4
Domestic Waste Water Treatment Plants Sampled for Regrowth Study
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121
Prepared by: MPS
Date: 09-20-2001

3.1.3.1 Test Conducted on July 16, 2001

The first test was performed with the City of Houston's West District and Turkey Creek WWTP effluents and results are shown in Tables 3.9a and 3.9b. On the day prior to this test, a relatively significant rain (0.58 and 0.31 inch at Turkey Creek WWTP on July 16 and 17) had occurred and the EC levels in Buffalo Bayou were relatively high after the events, >12k MPN/dL. The flow in the bayou at West Belt was about 190 cubic feet per second (cfs) on July 17. This is much larger than the roughly 15 cfs (10 MGD) flow typically reported by the West District plant nearby.

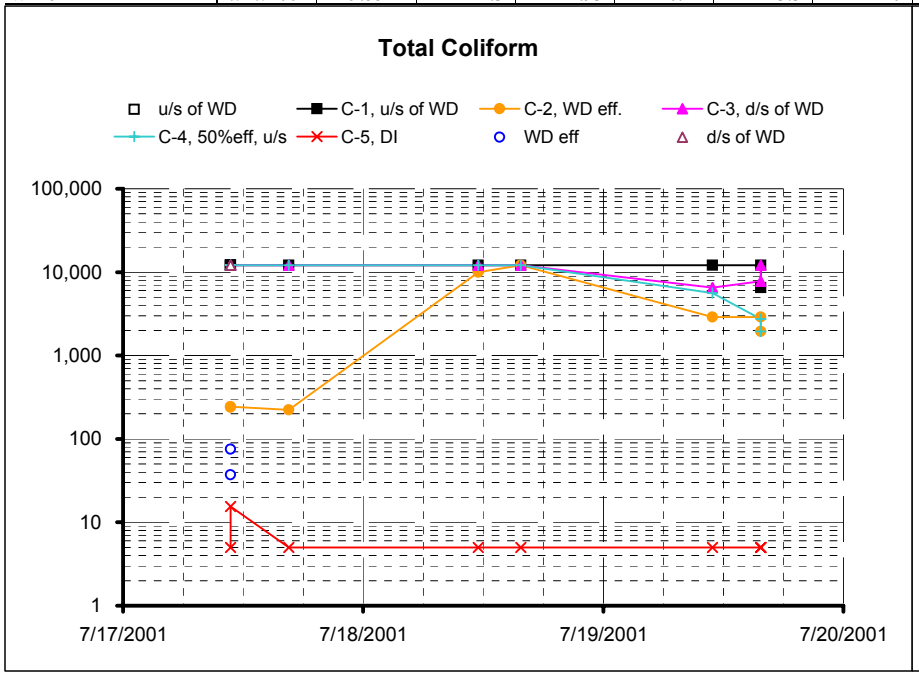
The West District effluent and the DI control had <5 MPN/dL EC levels. The duplicate samples of a 50:50 mixture of upstream water and West District effluent averaged 8,848 MPN/dL. From this and the daily average flows from the bayou and plant, we can infer an upstream concentration of about 17,500 MPN/dL. However, the results of the duplicate samples sent to North Water District Laboratory Services (NWDLS) confirmed low levels in the West District effluent, but only 1,800 MPN/dL for waters upstream of West District. The total suspended solids (TSS) level in the West District sample was high, 205 mg/L, possibly explaining the discrepancy.

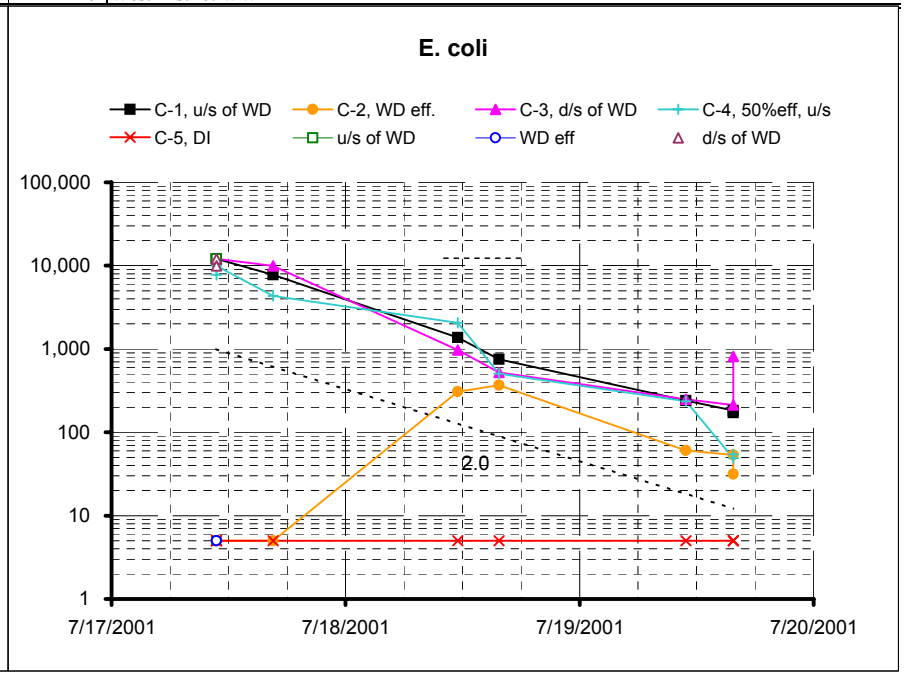
Bacteria levels upstream of Turkey Creek WWTP on the 16th were much lower than at West District, averaging 244 MPN/dL, with the NWDLS results providing confirmation. The

TABLE 3.9a
REGROWTH - WEST DISTRICT WWTP

SampleType	Total Coliform (MPN/dL)								E coli (MPN/dL)							
Date	7/17/2001	7/17/2001	7/17/2001	7/18/2001	7/18/2001	7/19/2001	7/19/2001	7/19/2001	7/17/2001	7/17/2001	7/17/2001	7/18/2001	7/18/2001	7/19/2001	7/19/2001	7/19/2001
Time	10:45	10:45	16:35	11:30	15:45	10:55	15:45	15:45	10:45	10:45	16:35	11:30	15:45	10:55	15:45	15:45
C-1, u/s of WD	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	12,096	12,096	6,498	> 12,096	> 12,096	7,765	1,378	750	241	182	173
C-2, WD eff.	240	244	224	9,931	12,096	2,897	2,897	1,937	< 5	< 5	5	308	367	61	54	32
C-3, d/s of WD	> 12,096	> 12,096	> 12,096	> 12,096	12,096	6,498	7,765	> 12,096	> 12,096	12,096	9,931	976	523	248	213	812
C-4, 50%eff, u/s	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096	5,599	2,738	1,937	7,765	9,931	4,332	2,053	507	236	49	55
C-5, DI	5	16	5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
u/s of WD	> 12,096	> 12,096							> 12,096	> 12,096						
WD eff	75	37							< 5	5						
d/s of WD	> 12,096	> 12,096							12,096	9,931						
Remarks		Duplicate						Duplicate		Duplicate						Duplicate

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
u/s of WD	7/17/2001	8:50	204.8				3,400	1,800	u/s: Buffalo Bayou @ Wilcrest; d/s: Buffalo Bayou @ Beltway 8.
WD eff	7/17/2001	9:55	1.3	1.93	0.12	23.3	0	0	West District WWTP



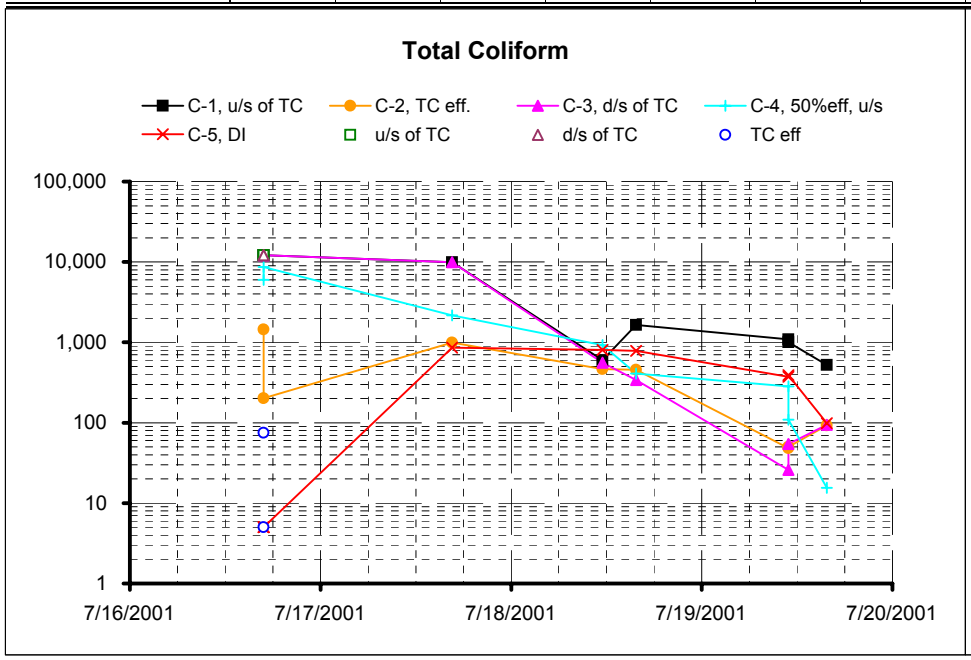


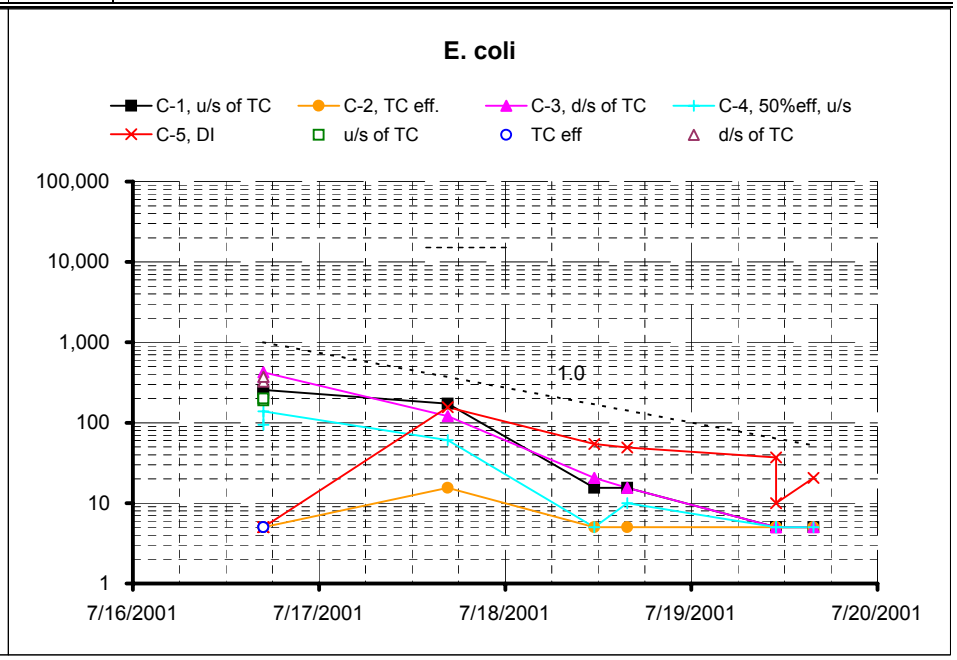
Note: Storm event occurred the day before sampling.

TABLE 3.9b
REGROWTH - TURKEY CREEK WWTP

SampleType	Total Coliform (MPN/dL)								E coli (MPN/dL)							
Date	7/16/2001	7/16/2001	7/17/2001	7/18/2001	7/18/2001	7/19/2001	7/19/2001	7/19/2001	7/16/2001	7/16/2001	7/17/2001	7/18/2001	7/18/2001	7/19/2001	7/19/2001	7/19/2001
Time	16:50	16:50	16:35	11:30	15:45	10:55	10:55	15:45	16:50	16:50	16:35	11:30	15:45	10:55	10:55	15:45
C-1, u/s of TC	> 12,096	> 12,096	9,931	601	1,641	1,094	1,007	522	232	256	173	16	16	< 5	5	5
C-2, TC eff.	1,455	203	995	467	455	49	50	93	< 5	< 5	16	5	< 5	< 5	< 5	5
C-3, d/s of TC	> 12,096	12,096	9,931	556	342	26	55	95	369	425	121	21	16	5	5	5
C-4, 50%eff, u/s	6,017	8,664	2,176	925	408	283	109	16	95	139	61	5	10	< 5	< 5	< 5
C-5, DI	< 5	5	862	804	783	372	390	99	< 5	< 5	156	55	49	37	10	21
u/s of TC	> 12,096	12,096							190	200						
TC eff	< 5	75							< 5	5						
d/s of TC	> 12,096	> 12,096							325	375						
Remarks		Duplicate					Duplicate			Duplicate					Duplicate	

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
u/s of TC	7/16/2001	14:30	23.3				460	340	u/s: Buffalo Bayou @ Eldridge; d/s: Buffalo Bayou @ Dairy Ashford.
TC eff	7/16/2001	14:05	< 1.0	1.18	< 0.10	20.8	18	11	Turkey Creek WWTP





WWTP effluent annual average flow is 4.8 MGD or 7.4 cfs. The effluent concentration was low so the concentration of the 50% effluent-upstream mixture averaged 117 MPN/dL.

Chamber tests were set up for samples from both plants with all test chambers having clear plastic covers but open on the sides for air passage. The samples of upstream, downstream, 50% effluent, pure effluent, and DI control water were then tracked for over two days. For the West District test starting on the 17th, the EC and TC level of the DI water controls stayed low with very little changing concentrations. The bayou water and mixture samples exhibited a sharp die-off of EC concentrations, with a first order rate of about 2.0/day while the TC data showed little reduction over time.

The Turkey Creek test started on the 16th, before the rain and flow increased. This test showed an increase in the DI control on the second day that affected both the TC and EC results. The 50% mixture, upstream water, and downstream water samples all showed a monotonic die-off but at a first order rate that was markedly lower, about 1/day.

The EC level in the 100% West District effluent sample increased from near zero on the first day to over 300 MPN/dL on the second. After the second day the levels declined at a rate similar to the bayou water samples. While not a large increase, this suggests that regrowth may be occurring. Similarly, the TC concentration of the West District effluent increased overnight from about 240 to nearly 10,000 MPN/dL, again suggesting regrowth. Less significant but similar results occurred with the Turkey Creek effluent TC, growing from about 200 to 1,000 MPN/dL in one day.

3.1.3.2 Test Conducted on July 24, 2001

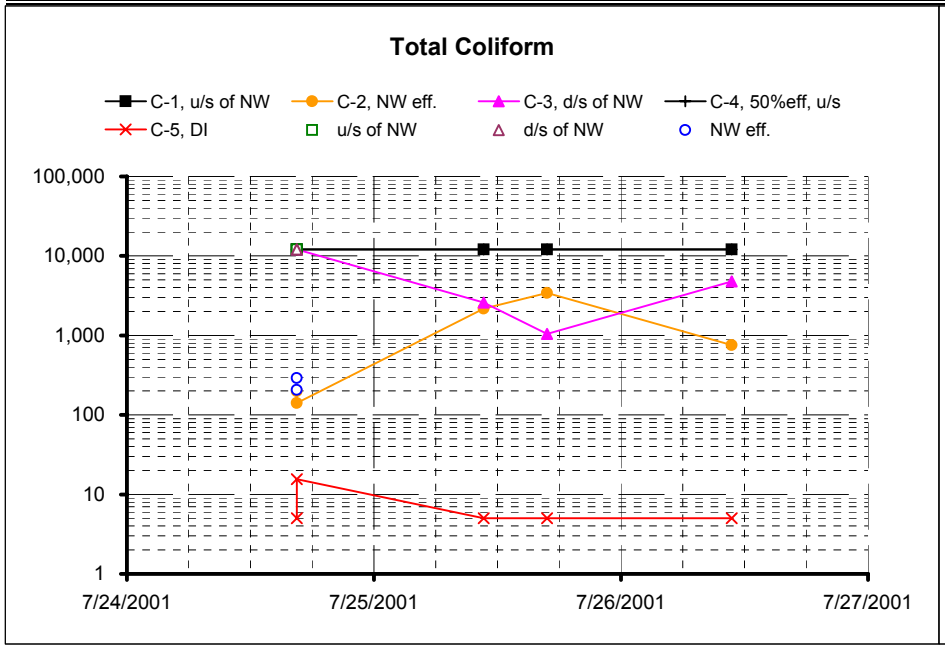
The next set of regrowth experiments was focused on Whiteoak Bayou treatment plants and began on July 24. Effluent samples from two plants, the City of Houston's Northwest WWTP and White Oak WWTPs, along with water samples from upstream and downstream of each outfall were collected in new 5-gallon cubitainers and taken to the Buffalo Bayou at Beltway 8 location for test chamber setup. Table 3.10a shows the data for Northwest and Table 3.10b shows the White Oak plant results.

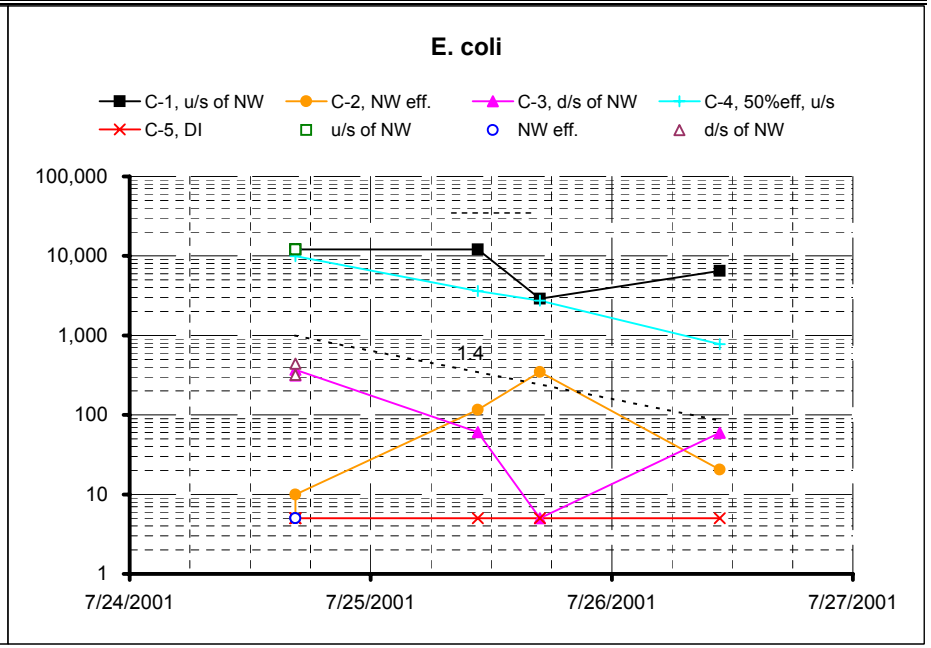
For the Northwest plant, water samples upstream of the plant showed EC concentrations higher than 12,000 MPN/dL, while the effluent itself showed <5 MPN/dL. The flow upstream of the plant was not measured, but was substantially less than the 41 cfs measured downstream at the Heights gage. The Northwest plant effluent typically averages 14 cfs (9.2 MGD). The downstream sample had substantially lower concentrations of bacteria than the upstream sample (i.e. 342 MPN/dL versus > 12,000 MPN/dL). On the other hand a 50% effluent-upstream mixture only reduced the value to 11,014 MPN/dL. Based on the ratio of quantified EC levels, the upstream EC concentration was probably about 20,000 MPN/dL and the flow could have been less than the wastewater discharge. However, samples sent to the NWDLS showed that upstream of the plant the FC level was 8,000 while the EC level, measured by Standard Method 9213D, was 2,000 MPN/dL. This difference may be due to the difference in analytical methods (membrane filtration versus IDEXX).

TABLE 3.10a
REGROWTH - NORTHWEST WWTP

SampleType	Total Coliform (MPN/dL)								E coli (MPN/dL)							
Date	7/24/2001	7/24/2001	7/25/2001	7/25/2001	7/26/2001				7/24/2001	7/24/2001	7/25/2001	7/25/2001	7/26/2001			
Time	16:30	16:30	10:40	16:50	10:45				16:30	16:30	10:40	16:50	10:45			
C-1, u/s of NW	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096				> 12,096	12,096	> 12,096	2,897	6,498			
C-2, NW eff.	200	141	2,176	3,434	758				5	10	117	348	21			
C-3, d/s of NW	> 12,096	> 12,096	2,586	1,049	4,803				312	372	61	5	60			
C-4, 50%eff, u/s	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096				> 12,096	9,931	3,630	2,738	777			
C-5, DI	5	16	< 5	< 5	5				< 5	< 5	< 5	< 5	< 5			
u/s of NW	> 12,096	> 12,096							> 12,096	> 12,096						
NW eff.	291	207							< 5	5						
d/s of NW	> 12,096	> 12,096							443	319						
Remarks		Duplicate			Vessel sunk by stormwater in 7/26 pm.					Duplicate			Vessel sunk by stormwater in 7/26 pm.			

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
u/s of NW	7/24/2001	10:45	28.7				8,000	2,000	u/s: Cole Ck @Antoine (lots of trash was present); d/s: WO Bayou @ Creekmont.
NW eff.	7/24/2001	11:20	1.6	0.18	0.44	3.4	4	3	NW WWTP



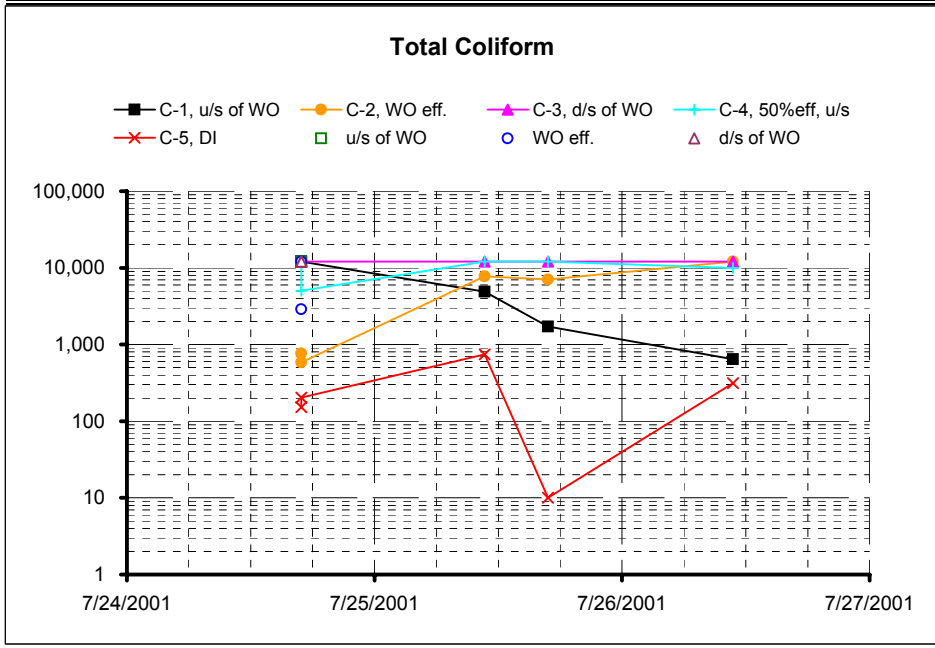


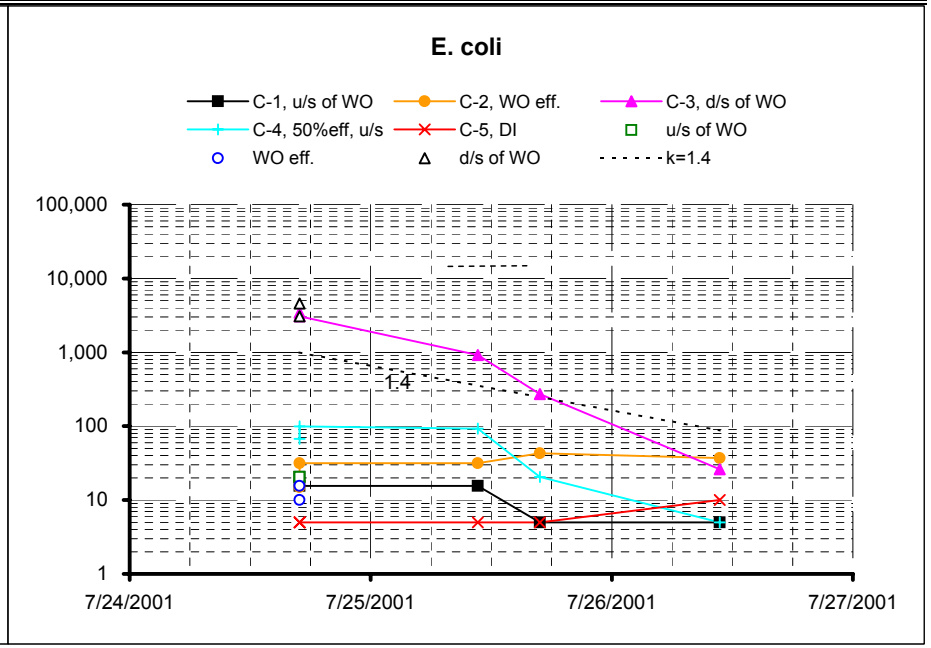
Note: C-1 samples after 7/24/01 might be contaminated with bayou water due to storm conditions during experiment.

TABLE 3.10b
REGROWTH - WHITE OAK WWTP

SampleType	Total Coliform (MPN/dL)								E coli (MPN/dL)							
Date	7/24/2001	7/24/2001	7/25/2001	7/25/2001	7/26/2001				7/24/2001	7/24/2001	7/25/2001	7/25/2001	7/26/2001			
Time	16:55	16:55	10:40	16:50	10:45				16:55	16:55	10:40	16:50	10:45			
C-1, u/s of WO	> 12,096	> 12,096	4,902	1,724	646				21	16	16	< 5	< 5			
C-2, WO eff.	765	585	7,765	7,068	12,096				15	32	32	43	37			
C-3, d/s of WO	> 12,096	> 12,096	> 12,096	> 12,096	> 12,096				3,434	3,066	921	273	26			
C-4, 50%eff, u/s	12,096	5,056	> 12,096	> 12,096	9,931				68	100	93	21	< 5			
C-5, DI	153	204	742	10	312				< 5	< 5	5	< 5	10			
u/s of WO	> 12,096	> 12,096							21	21						
WO eff.	2,897	> 12,096							16	10						
d/s of WO	> 12,096	> 12,096							4,604	3,066						
Remarks		Duplicate			Vessel sunk by stormwater in 7/26 pm.					Duplicate			Vessel sunk by stormwater in 7/26 pm.			

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
u/s of WO	7/24/2001	13:30	26.0				180	100	u/s: WO Bayou d/s of jnct. w/ E122; d/s: WO Bayou @ N. Houston Rosslyn.
WO eff.	7/24/2001	13:10	1.8	2.83	0.06	25.1	19	16	WO WWTP





Note: Effluent samples were collected from the outfall pipe right before the flow enters the bayou.

The test chambers were monitored for two days before high flows in Buffalo Bayou capsized the test chambers and ended the tests. During that time the upstream and 50% effluent samples declined much more slowly than had the other samples, with an average die-off rate of about 1.4/day. The Northwest effluent showed a strong increase on the first day and then dropped on the second. The control DI water sample remained at non-detect. These results also demonstrate some regrowth and show considerably different die-off rates.

The samples from the White Oak WWTP in Table 3.10b are quite different. The upstream sample had fairly low EC levels (<20 MPN/dL) but still high TC levels. Also, the effluent had low but non- zero EC concentrations and substantial TC levels. Note that, due to access limitations, the effluent sample was collected from the outfall pipe at the bayou instead of from within the WWTP before the outfall pipe. The average flow for this plant is 1.7 MGD or 2.6 cfs. The 50% mixture of upstream and effluent was somewhat higher than either measured individually, but not by a large margin (i.e. 68 MPN/dL). The first order decay rate for this mixture was 1.4/day. A more striking difference was the sample measured downstream of the discharge. This sample had much higher EC concentration (3,434 MPN/dL) than any of the other samples, suggesting a significant bacteria source between the WWTP outfall and the downstream sampling location. The downstream concentration was confirmed using four samples, the arithmetic average of which was 3,543 MPN/dL. The companion NWDLS analyses of the upstream and effluent samples were in general agreement with the IDEXX results.

Over the two-day sample period, there was no strong evidence of regrowth in EC, and the test chambers exhibited modest reductions in the concentrations. In most cases there was little

reduction in the first day. The TC levels showed some reduction for the upstream sample, and an increase for the effluent sample.

The pure effluent test chambers again indicated significant TC regrowth. The Northwest effluent showed a regrowth from about 200 to 3,500 MPN/dL in one day. Similarly, the White Oak effluent TC concentration increased from about 700 to 7,800 MPN/dL.

3.1.3.3 Tests Conducted on August 14, 2001

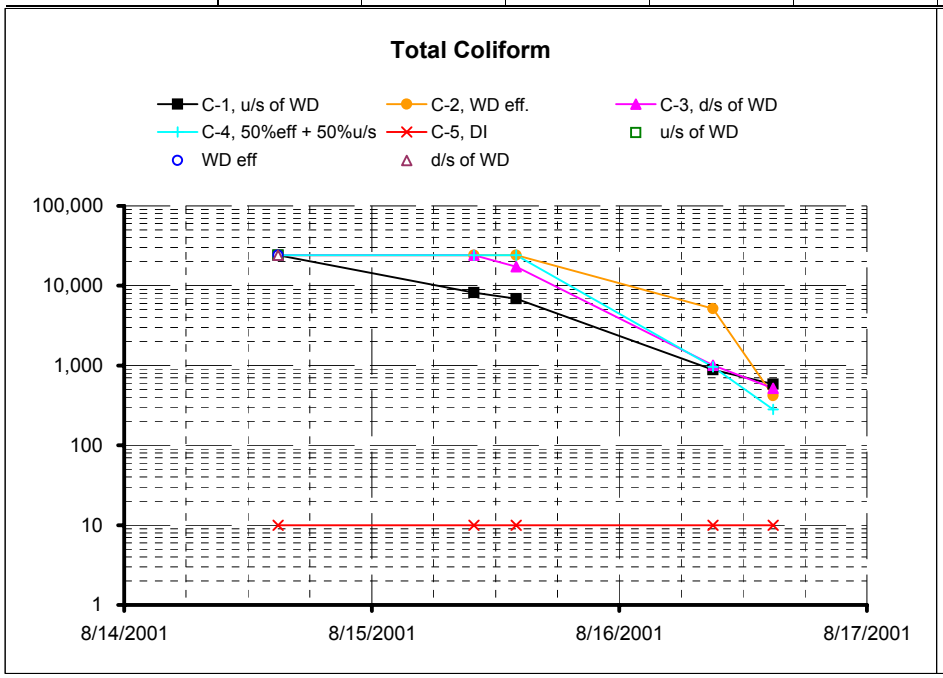
The final regrowth test was initiated on August 14 using West District effluent and Buffalo Bayou water. Results are shown in Table 3.11. Prior to and during the test there was no rain and bayou flows remained constant at about 70 cfs. This test was unusual in that the West District effluent had an EC level of about 20,000 MPN/dL, while the upstream water EC level was unusually low, at about 400 MPN/dL.

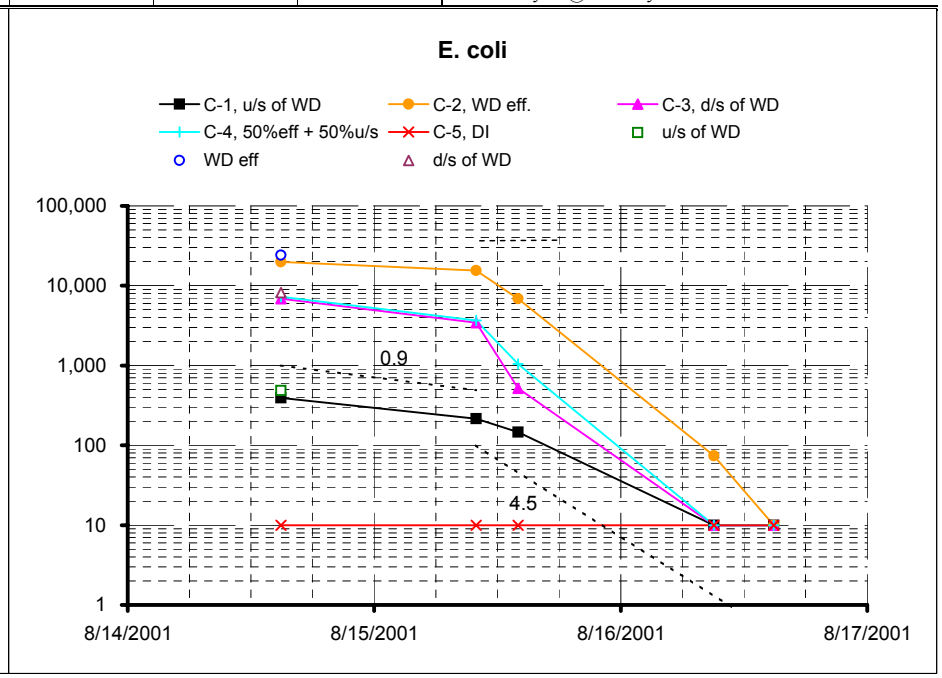
Most test chambers had relatively high bacteria concentrations. Reductions in the levels of these test chambers seemed to follow two distinct patterns, with a low decay rate on the first evening followed by a more rapid decay rate for the remainder of the tests. The TC levels appeared to follow a similar pattern. However, the TC regrowth effect cannot be seen due to most of the TC levels being >12,000 MPN/dL.

TABLE 3.11
REGROWTH - WEST DISTRICT WWTP 2nd STUDY

SampleType	Total Coliform (MPN/dL)					E coli (MPN/dL)					DO
Date	8/14/2001	8/15/2001	8/15/2001	8/16/2001	8/16/2001	8/14/2001	8/15/2001	8/15/2001	8/16/2001	8/16/2001	8/16/2001
Time	14:55	9:55	14:00	9:05	14:55	14:55	9:55	14:00	9:05	14:55	14:55
C-1, u/s of WD	> 24,192	8,164	6,867	884	583	393	216	146	10	< 10	5.4
C-2, WD eff.	> 24,192	> 24,192	> 24,192	5,172	419	19,863	15,531	6,867	74	10	5.2
C-3, d/s of WD	> 24,192	24,192	17,329	1,010	520	6,867	3,448	520	< 10	< 10	5.9
C-4, 50%eff + 50%u/s	> 24,192	> 24,192	24,192	960	282	7,260	3,654	1,043	10	< 10	6.0
C-5, DI	< 10	< 10	< 10	< 10	10	< 10	< 10	< 10	< 10	< 10	6.6
u/s of WD	> 24,192					487					7.3
WD eff	> 24,192					24,192					
d/s of WD	> 24,192					8,164					
Remarks											Hydrolab mulfunction.

NWDLS Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	FC	EC	Remarks
u/s of WD	8/14/2001	11:00	45.0	1.03	< 0.10	11.0			Buffalo Bayou @ Wilcrest
WD eff	8/14/2001	10:25	< 1.0	1.23	2.73	10.3			West District WWTP
d/s of WD	8/14/2001	14:10	126.0	1.13	0.70	12.7			Buffalo Bayou @ Beltway 8





3.1.3.4 Analysis and Discussion

Table 3.12 presents a summary of the regrowth results obtained. In general, there was no strong and systematic indication of regrowth in the 50% effluent EC samples. About half of the tests showed some evidence of regrowth, such as an increase in effluent concentrations for a time or the values holding steady for a day. Also, the decay rates observed tended to be lower than those using bayou water in the light/dark tests described in the previous section. Overall, there appears to be some indication that fresh effluent has the potential to increase in concentration after disinfection, but not to the levels that would explain the overall high concentrations in the bayous. The data provide little support to the idea that bacteria regrowth from wastewater effluent could be a significant source of EC bacteria in the bayous.

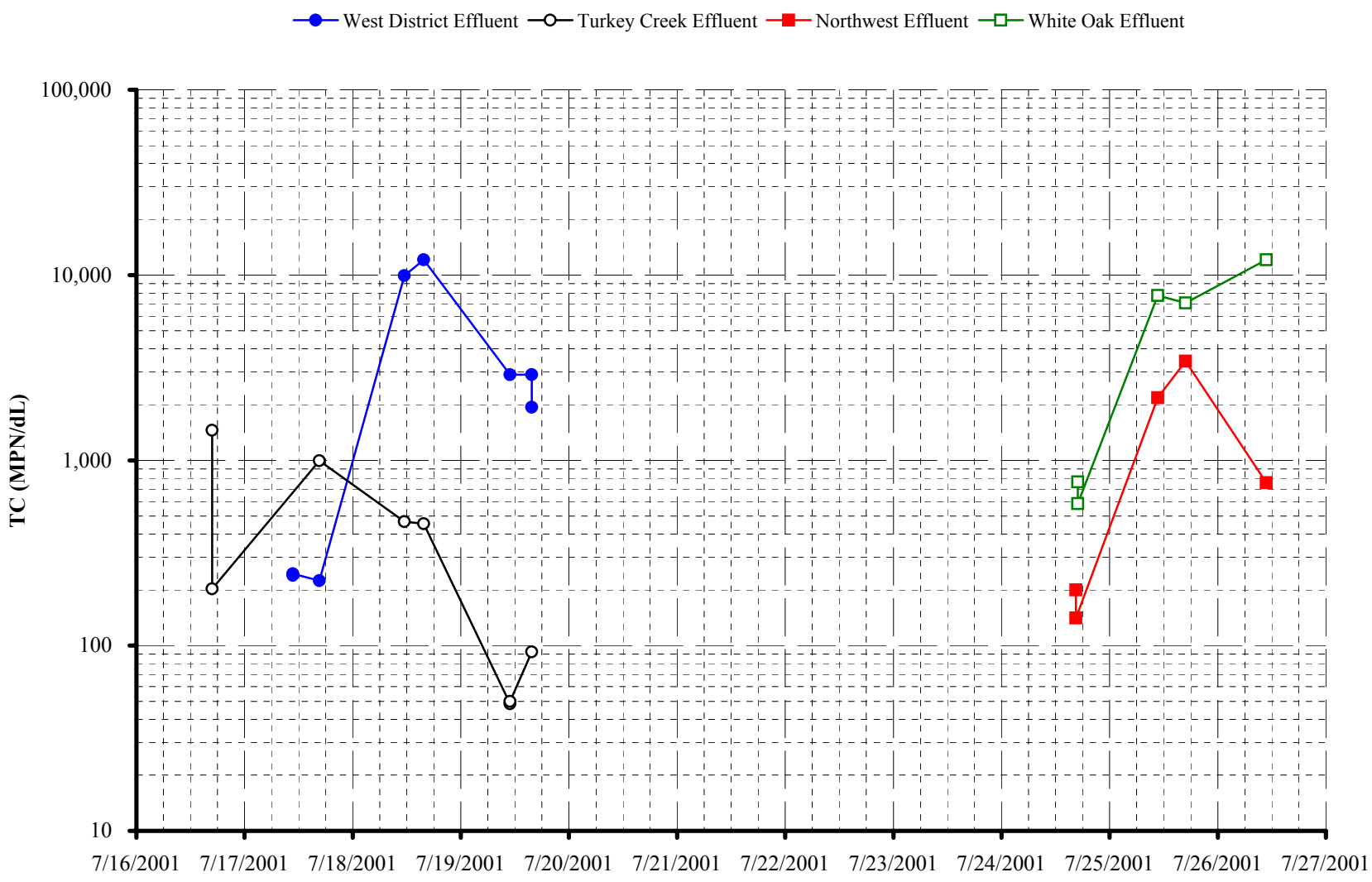
However, as shown in Figure 3.5, substantial regrowth of TC bacteria in the effluent test chambers can be seen consistently. Given that FC is a subset of TC, classically defined by a higher incubation temperature, this raises the question of whether the regrowth potential for FC may not be higher. The chamber tests results indicate that regrowth cannot be entirely ruled out as a significant factor affecting FC levels in the bayous.

TABLE 3.12
SUMMARY OF REGROWTH STUDIES

TABLE	PLANT	BAYOU Q (cfs)	BAYOU TSS (mg/L)	EC in 50% Effluent (MPN/dL)	K (1/day)	EC REGROWTH	TC EFF. REGROWTH
3.9a	WD	191	204.8	8,848	2.0	yes	yes
3.9b	TC	76	23.3	117	1.0	slight	slight
3.10a	NW	41 (1)	28.7	11,000	1.4	yes	yes
3.10b	WO	41 (1)	26.0	84	1.4	neutral	yes
3.11	WD	71	126.0	7,260	0.9 4.5	no	no

(1) Flow at Heights, downstream of WWTP locations

FIGURE 3.5
REGROWTH OF TOTAL COLIFORM IN EFFLUENT TEST CHAMBERS



The treatment plant flows during the time of sampling for the regrowth study were retrieved. They are:

- West District 7/17/01 09:55 7.654 MGD
- Turkey Creek 7/16/01 14:05 5.287 MGD
- Northwest 7/24/01 11:20 7.531 MGD
- White Oak 7/24/01 13:10 1.731 MGD
- West District 8/14/01 10:25 8.4585 MGD

The 8/14/01 high bacteria levels in the West District effluent were also investigated by checking the records of residual chlorine levels. It was found that the residual chlorine levels before dechlorination were down to almost zero during the time of sample collection. This finding is consistent with the high bacteria levels found in the effluent by the sampling team.

3.1.4 Bacteria Resupply from Sediments

Both Buffalo and Whiteoak bayous are small systems with mean depths varying from 5 to 11 ft for Buffalo and around 3-4 feet (ft) for Whiteoak. The low-flow widths for these bayous are always less than 30 ft and often less than 10 ft. This small size means that water is in frequent contact with the stream bottom. Presumably the particulate matter of the sediment exchanges frequently with the suspended particulate matter in the water. It follows that the sediment in the bayou bottom can act as a reservoir, supplying particulate matter to the water column when the bayou flows increase enough to resuspend the sediment, and accepting

particulate matter when the flow declines enough to allow settling to occur. This may be significant in the case of Buffalo Bayou and the upper part of Whiteaok Bayou which is unpaved. However, this does not appear to be significant for the lower part of Whiteoak Bayou due to the fact that it is a concrete-lined channel designed to prevent sediment accumulation.

3.1.4.1 Bacteria Concentrations in Sediment

To better understand and quantify the role of sediments in the bacterial balance, sediment sampling was undertaken. The basic procedure was to employ a suitable dredge (Ponar or Ekman, depending on sediment characteristics) to collect a small portion of sediment from the bayou at a number of stations. At each station, the soft unconsolidated sediment collected from the top of the sediment grab was transferred with a sterilized stainless spatula into a sterile wide mouth jar. The jar was then iced prior to analysis. Difficulties in sample collection were encountered at several stations because there was little soft sediment available. Stations on the concrete portion of White Oak Bayou (Pinemont, W. 43rd, W 34th, IH-610, and Heights) proved impossible to sample.

A portion of the soft sediment was removed from the wide mouth jar with a pipette and transferred to a sterilized beaker. Three different dilutions of sediment were analyzed for each sediment test. First both a 1-mL and 0.5 mL portions of the soft sediment were transferred to the 100 mL sample jars after first passing the sediment through a sterilized screen to reject large pieces that could cause problems in the analysis. The rest of the water for the samples came from bayou water that had been boiled for 20 minutes to kill bacteria, and then cooled to room

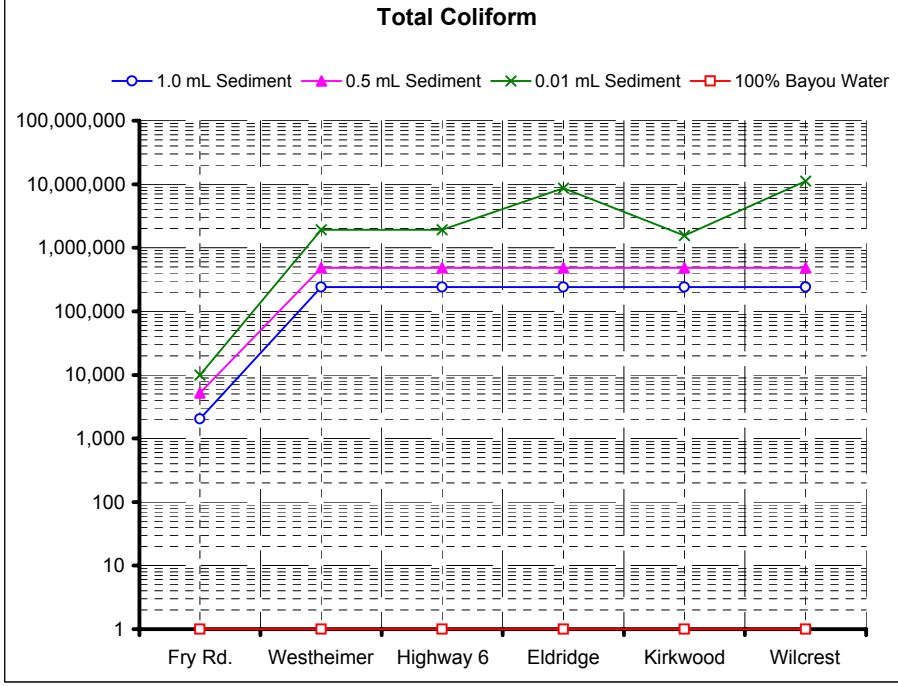
temperature. The third dilution was obtained by first transferring 1 mL of sediment to a jar with 99 mL of sterilized bayou water, and mixing thoroughly. Then a 1 mL portion of this mixture was added to another 99 mL volume of bayou water, yielding a total of 10,000:1 dilution. The three mixtures of soft stream sediment and sterilized bayou water were then treated as normal bacteria water samples and analyzed for TC and EC with the Colilert procedure. For each set of sediment samples, a blank sample using boiled bayou water only was first prepared by running the water through the screen and beaker to verify that sterile conditions were being maintained.

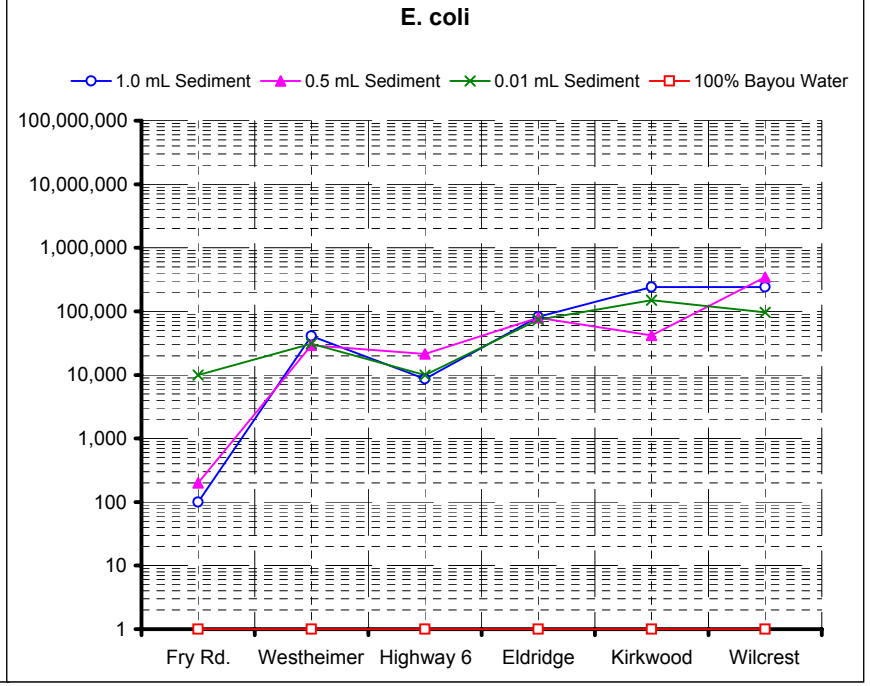
Tables 3.13a and b show the results for stations on Buffalo Bayou and Table 3.14 shows the results for Whiteoak Bayou and Cole Creek. Each sample had a total of three concentration measurements expressed as a number of colony forming units per deciliter of in-situ sediment, along with a geometric mean value for the station. While there was often considerable variation between individual measurements/dilutions, the general patterns seem reasonably consistent. The most upstream station at Fry Road on Buffalo Bayou had sediment bacteria levels that were markedly lower than the rest. There appears to be a steady increase going downstream towards Beltway 8. Downstream of Beltway 8 the values appear to be similar. On Whiteoak Bayou the most downstream station, Houston Avenue, had markedly higher concentration than the rest. The Cole Creek station at Deihl Road had also relatively high bacteria levels.

TABLE 3.13a
BUFFALO BAYOU SEDIMENTS UPSTREAM OF BELTWAY 8

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)					
Sediment Collection Sites	Wilcrest	Kirkwood	Eldridge	Highway 6	Westheimer	Fry Rd.	Wilcrest	Kirkwood	Eldridge	Highway 6	Westheimer	Fry Rd.
Date	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001	8/15/2001
1.0 mL Sediment	> 241,920	> 241,920	> 241,920	> 241,920	> 241,920	2,040	> 241,920	241,917	81,640	8,620	41,060	< 100
0.5 mL Sediment	> 483,840	> 483,840	> 483,840	> 483,840	> 483,840	5,180	346,574	41,960	79,360	21,340	29,100	< 200
0.01 mL Sediment	11,198,500	1,550,700	8,664,000	1,918,000	1,918,000	10,000	97,000	150,000	74,000	10,000	31,000	< 10,000
Geometric Means	1,094,404	566,196	1,004,687	607,772	607,772	4,728	201,101	115,044	78,267	12,253	33,334	585
100% Boiled Bayou Water	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

ANACON Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	TOC	Remarks
Beltway 8 - Boiled Water	8/6/2001	9:40	28.0	1.63	< 0.20	4.7	8	BB@ Beltway 8.



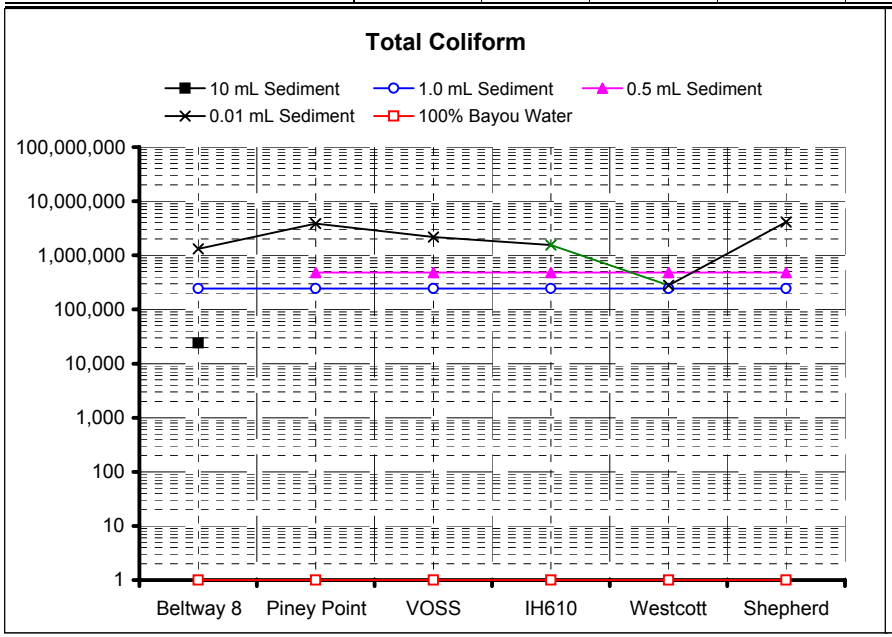


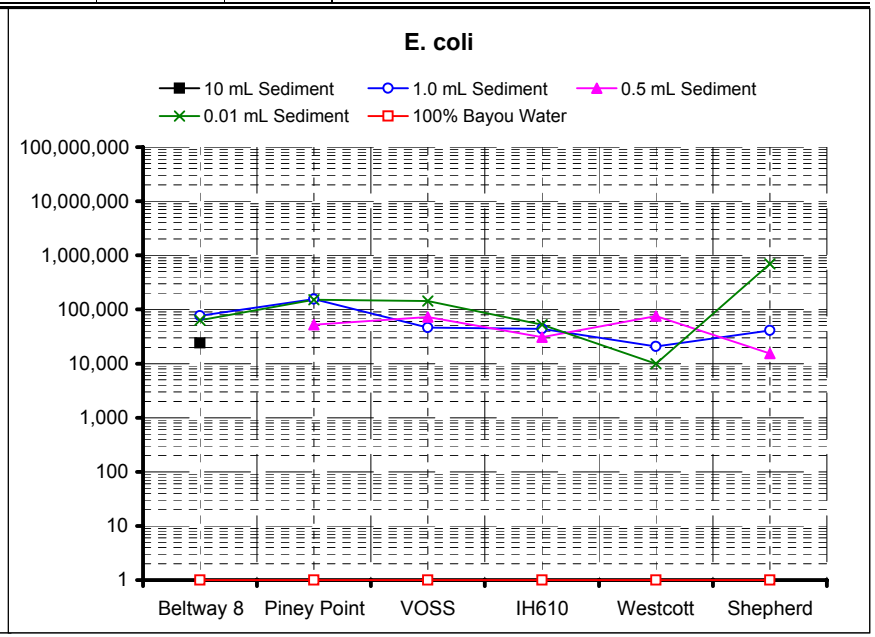
Note: Water samples collected from BB @ Beltway 8, boiled then cooled for flushing sediment samples through sterilized solar screen.

TABLE 3.13b
BUFFALO BAYOU SEDIMENTS DOWNSTREAM OF BELTWAY 8

SampleType	Total Coliform (MPN/dL)						E coli (MPNdL)					
Sediment Collection Sites	Shepherd	Westcott	IH610	VOSS	Piney Point	Beltway 8	Shepherd	Westcott	IH610	VOSS	Piney Point	Beltway 8
Date	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001	8/6/2001
10 mL Sediment						> 24,192						24,192
1.0 mL Sediment	> 241,920	> 241,920	> 241,920	> 241,920	> 241,920	> 241,920	41,060	20,750	43,520	46,110	155,307	77,010
0.5 mL Sediment	> 483,840	> 483,840	> 483,840	> 483,840	> 483,840		15,360	75,680	30,820	72,180	52,040	
0.01 mL Sediment	4,160,000	278,000	1,553,000	2,178,000	3,873,000	1,313,000	697,000	< 10,000	52,000	143,000	152,000	63,000
Geometric Means	786,724	319,256	566,476	634,080	768,199	197,334	76,035	25,042	41,163	78,076	107,100	48,961
100% Boiled Bayou Water	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

ANACON Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	TOC	Remarks
Beltway 8 - Boiled Water	8/6/2001	9:40	28.0	1.63	< 0.20	4.7	8	BB@ Beltway 8.



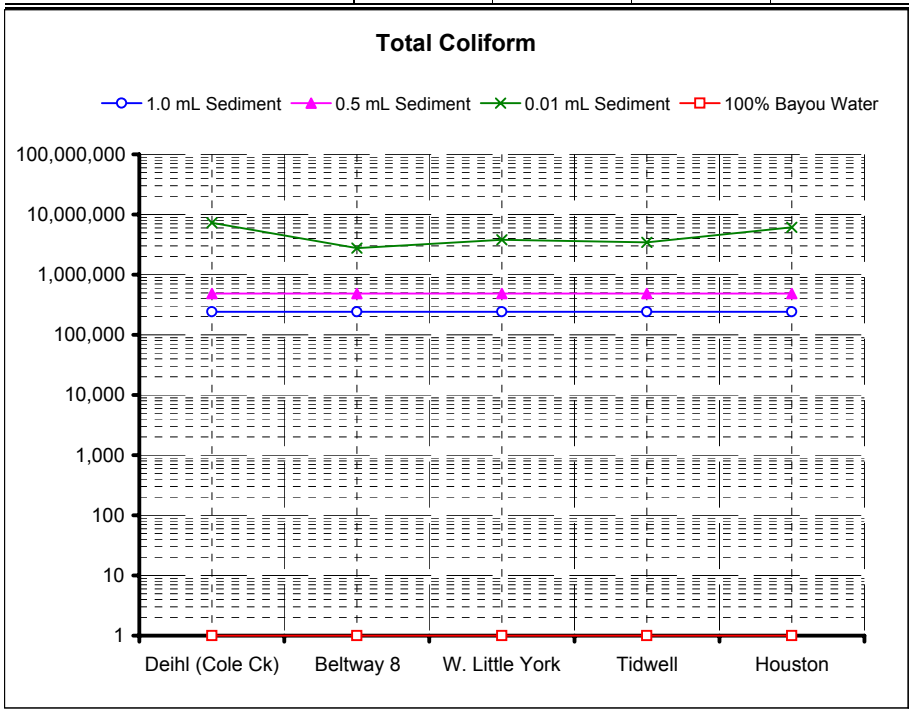


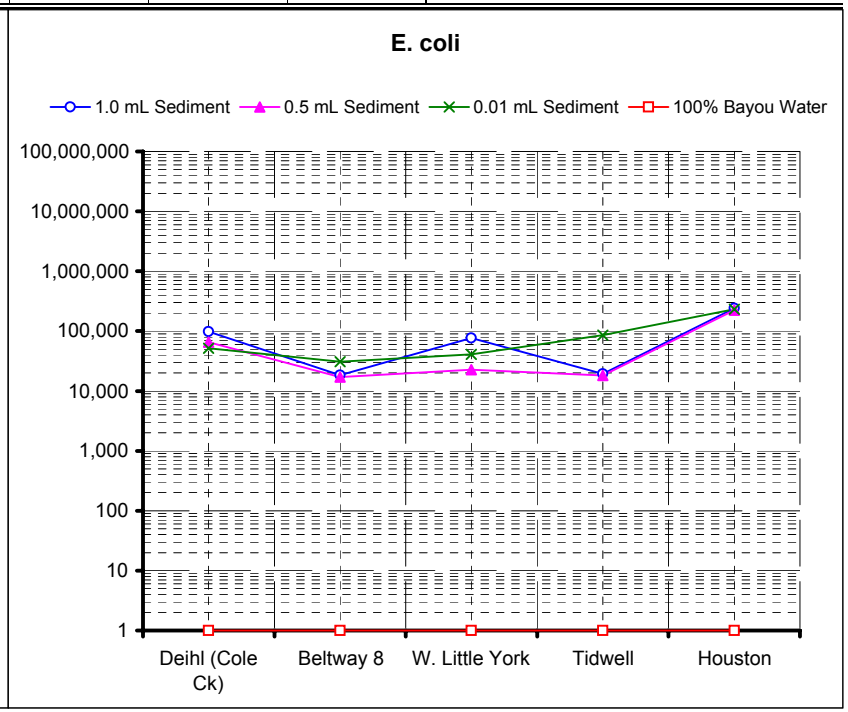
Note: Water samples collected from BB @ Beltway 8, boiled then cooled for flushing sediment samples through sterilized solar screen.

TABLE 3.14
WHITE OAK BAYOU SEDIMENTS

SampleType	Total Coliform (MPN/dL)					E coli (MPN/dL)				
Sediment Collection Sites	Houston	Tidwell	W. Little York	Beltway 8	Deihl (Cole Ck)	Houston	Tidwell	W. Little York	Beltway 8	Deihl (Cole Ck)
Date	8/13/2001	8/13/2001	8/13/2001	8/13/2001	8/13/2001	8/13/2001	8/13/2001	8/13/2001	8/13/2001	8/13/2001
1.0 mL Sediment	> 241,920	> 241,920	> 241,920	> 241,920	> 241,920	241,917	19,350	77,010	18,500	98,040
0.5 mL Sediment	> 483,840	> 483,840	> 483,840	> 483,840	> 483,840	223,970	18,140	22,600	17,100	65,640
0.01 mL Sediment	6,131,000	3,448,000	3,784,000	2,755,000	7,260,000	231,000	86,000	41,000	31,000	52,000
Geometric Means	895,299	739,004	762,269	685,749	947,189	232,179	31,137	41,478	21,405	69,426
100% Boiled Bayou Water	< 1	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

ANACON Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	TOC	Remarks
Beltway 8 - Boiled Water	8/6/2001	9:40	28.0	1.63	< 0.20	4.7	8	BB@ Beltway 8.





Note: Water samples collected from BB @ Beltway 8, boiled then cooled for flushing sediment samples through sterilized solar screen.

3.1.4.2 Sediment Resupply

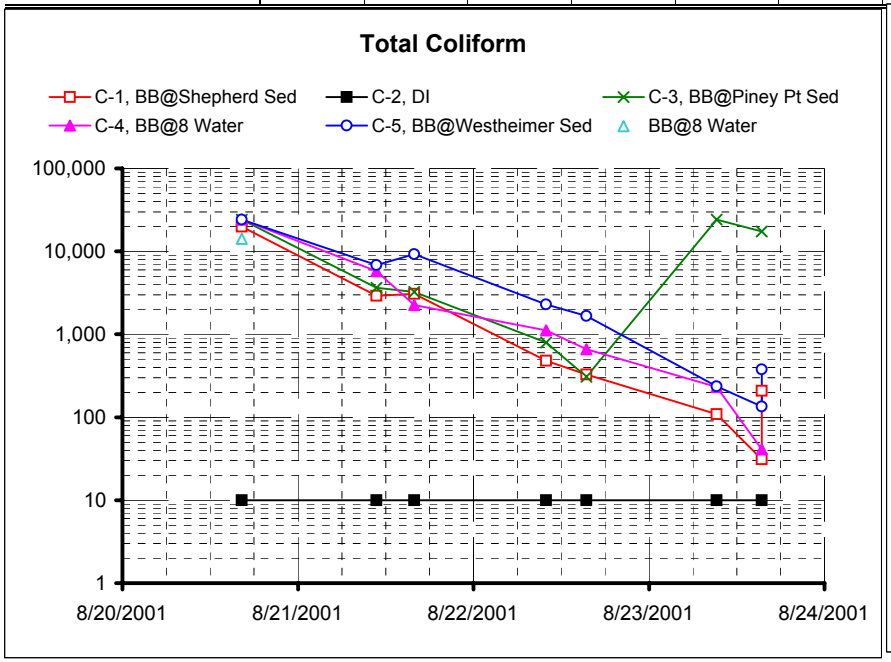
To assess the role of bacteria resupply from sediments, three of the sediment samples collected on both Buffalo and Whiteoak bayous were transferred to test chambers and fresh bayou water was added with minimal disturbance of the sediment in the bottom of the test chambers. The bacteria concentrations were monitored at the start of the test and also on a daily basis during the period August 20 to August 24. Also monitored was a water sample collected from the same location but without sediment and a DI control (field blank) water source.

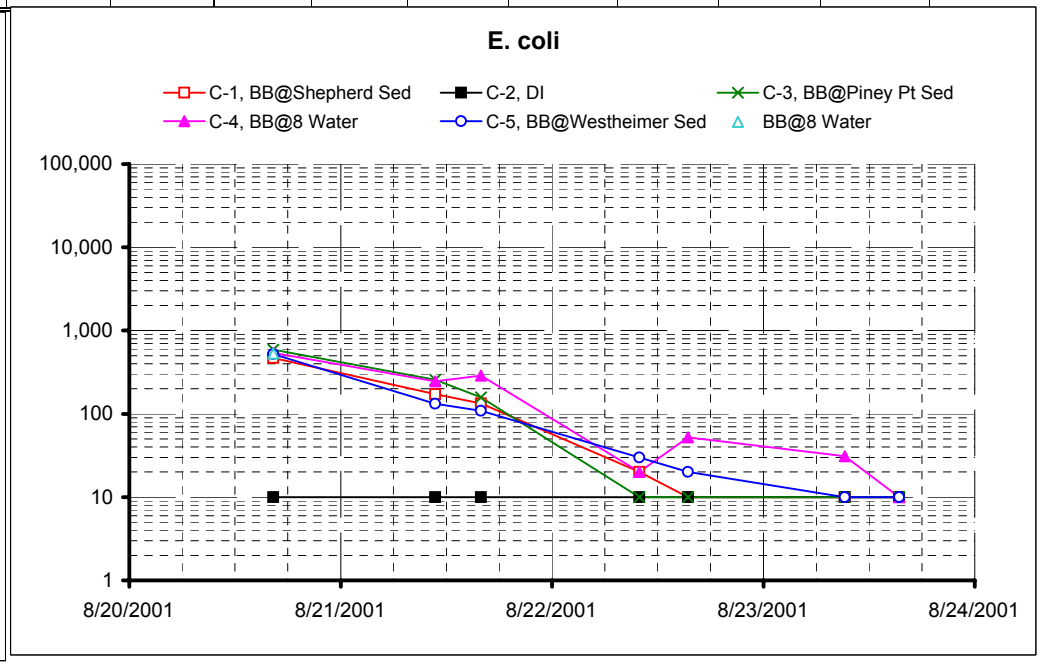
Tables 3.15 and 3.16 show the time series for the test chambers with sediment added from Buffalo and Whiteoak bayous, respectively. The major observation from these resupply tests was that the rate of decay of the bacteria in the test chambers with sediment was not significantly different from the rate of decay of the water without sediment. A mild stirring of the water in the chambers was conducted and a second set of samples was collected. Analysis of these samples did not show an increase in EC bacteria , but did show a significant increase in TC. This result suggests some potential for higher bacteria levels in the water column due to sediment re-suspension by turbulence.

A limitation of this resupply analysis is that there was little water motion in the test chambers like there would be in the bayous. With no current movement and associated turbulence, there is much greater settling of suspended matter and very little resuspension.

TABLE 3.15
BUFFALO BAYOU SEDIMENT RESUPPLY TEST CHAMBER STUDY

SampleType	Total Coliform (MPN/dL)								E coli (MPN/dL)							
Date	8/20/2001	8/21/2001	8/21/2001	8/22/2001	8/22/2001	8/23/2001	8/23/2001	8/23/2001	8/20/2001	8/21/2001	8/21/2001	8/22/2001	8/22/2001	8/23/2001	8/23/2001	8/23/2001
Time	16:20	10:45	15:55	9:55	15:26	9:15	15:25	15:25	16:20	10:45	15:55	9:55	15:26	9:15	15:25	15:25
C-1, BB@Shepherd Sed	19,863	2,909	3,076	479	327	109	31	209	470	173	134	20	10	< 10	10	< 10
C-2, DI	< 10	< 10	< 10	< 10	< 10	< 10	< 10		< 10	< 10	< 10	< 10	< 10	< 10	< 10	
C-3, BB@Piney Pt Sed	24,192	3,654	3,255	794	309	> 24,192	17,329	19,863	591	256	158	10	10	< 10	< 10	< 10
C-4, BB@8 Water	> 24,192	5,794	2,247	1,112	663	231	41		538	246	288	20	52	31	< 10	
C-5, BB@Westheimer Sed	> 24,192	6,867	9,208	2,300	1,664	235	135	379	520	132	109	30	20	< 10	< 10	< 10
BB@8 Water	14,136								529							
Remarks								Stirred								Stirred

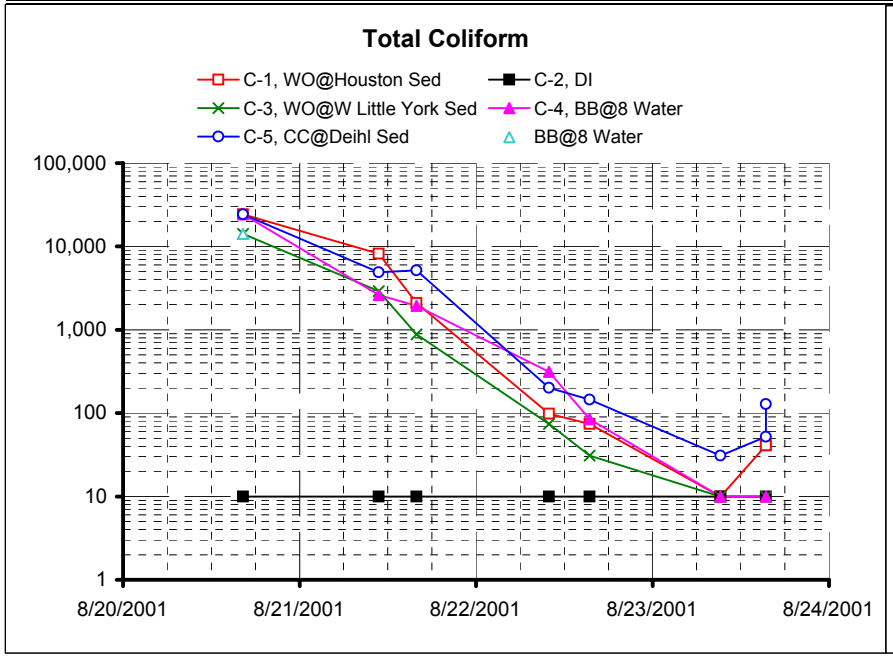


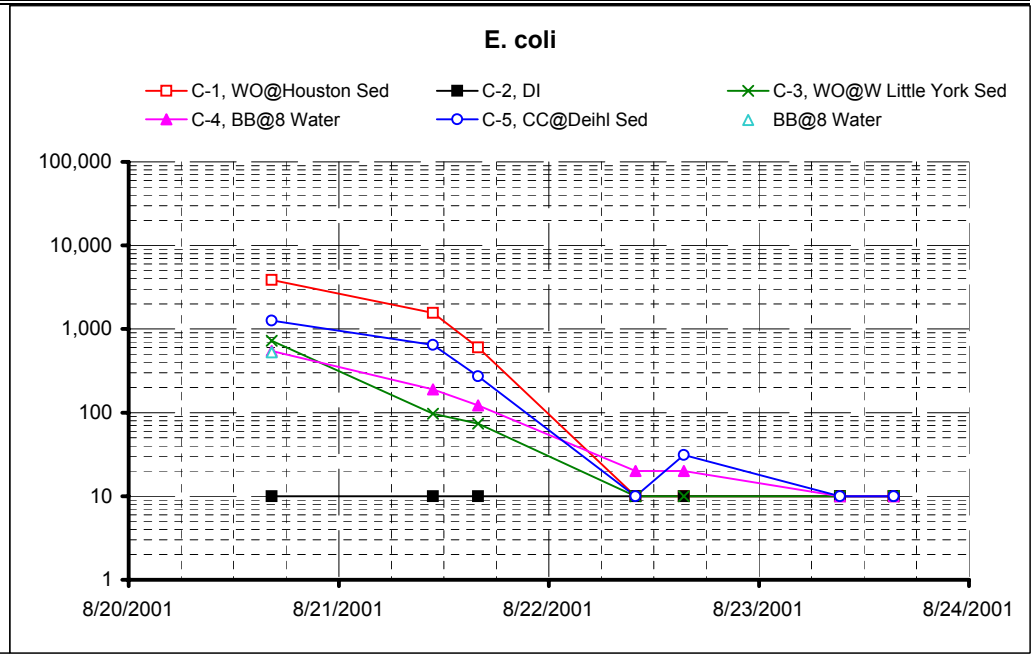


Note: 1. Water samples collected from BB @ Beltway 8. 2. The "stirred" data involve using a pipet to stir water in a chamber for 10 seconds before taking the water sample.

TABLE 3.16
WHITE OAK BAYOU SEDIMENT RESUPPLY TEST CHAMBER STUDY

SampleType	Total Coliform (MPN/dL)								E coli (MPN/dL)							
Date	8/20/2001	8/21/2001	8/21/2001	8/22/2001	8/22/2001	8/23/2001	8/23/2001	8/23/2001	8/20/2001	8/21/2001	8/21/2001	8/22/2001	8/22/2001	8/23/2001	8/23/2001	8/23/2001
Time	16:20	10:45	15:55	9:55	15:26	9:15	15:25	15:25	16:20	10:45	15:55	9:55	15:26	9:15	15:25	15:25
C-1, WO@Houston Sed	> 24,192	8,164	2,098	98	74	10	41	41	3,873	1,553	601	10	10	< 10	10	< 10
C-2, DI	< 10	< 10	< 10	< 10	< 10	< 10	< 10		< 10	< 10	< 10	< 10	< 10	< 10	< 10	
C-3, WO@W Little York Sed	14,136	2,909	880	74	31	10	< 10	402	723	97	74	10	< 10	10	< 10	< 10
C-4, BB@8 Water	24,192	2,613	1,935	314	85	< 10	10		546	189	122	20	20	< 10	< 10	
C-5, CC@Deihl Sed	> 24,192	4,884	5,172	201	145	31	52	128	1,259	645	272	10	31	< 10	< 10	< 10
BB@8 Water	14,136								529							
Remarks								Stirred								Stirred





Note: 1. Water samples collected from BB @ Beltway 8. 2. The "stirred" data involve using a pipet to stir water in a chamber for 10 seconds before taking the water sample.

3.1.4.3 Maintenance of Sediment Bacteria Levels

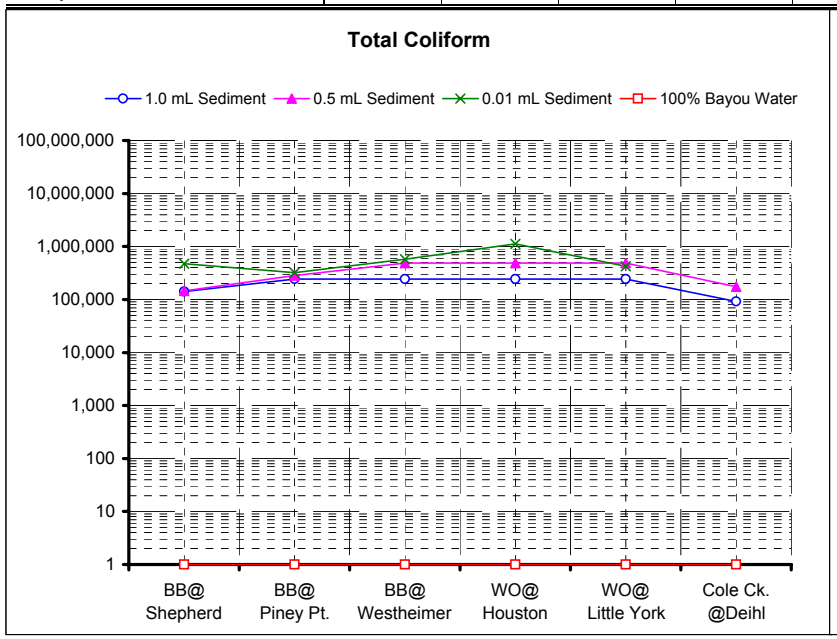
To evaluate the stability of bacteria concentrations in sediment, additional measurements using the same methods were taken after a week of refrigerated storage and a week of storage in the test chambers at ambient temperatures. Table 3.17 shows the results for each bayou for these aged samples, along with the geometric mean of the sediment concentrations originally measured. As listed in the table, the bacteria concentrations after collection, refrigerated storage for two weeks, and then maintained at ambient temperature for a week, were between 10,000 and 100,000 MPN/dL, or between 5% and 67% of the original values. This is very different from the water samples that would typically drop to non-detect levels in two days, suggesting that the sediments provide an environment that is conducive to supporting and maintaining high levels of both TC and EC bacteria.

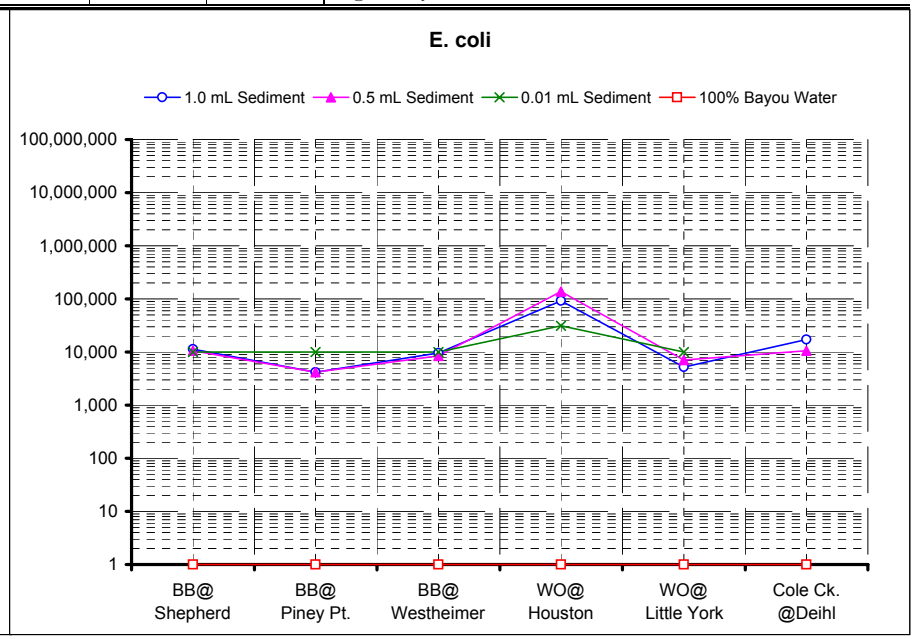
3.1.4.4 Relationship between Bacteria and Sediment Characteristics

As part of the sediment sampling process, a part of each sample was placed in a separate container and provided to ANACON, Inc. and NWDLS for analysis of physical characteristics and measures of organic content. These data are presented in Table 3.18. The sediment organic carbon content ranged from over 3,000 to over 50,000 milligrams per kilogram (mg/kg), expressed on a dry weight basis. The solids percentage tended to be fairly high, sometimes more than 80%. The sand content of the sediments was also high, in some cases exceeding 90%. The particle size distribution data gives the size in mm for different percentile values, and the EC concentration of the sediments shown is the geometric mean of the values measured.

TABLE 3.17
SEDIMENT RESUPPLY - SEDIMENTS FROM TEST CHAMBERS AFTER ONE WEEK IN STREAM

SampleType	Total Coliform (MPN/dL)						E coli (MPN/dL)					
Sediment Collection Sites	BB@ Shepherd	BB@ Piney Pt.	BB@ Westheimer	WO@ Houston	WO@ Little York	Cole Ck. @Deihl	BB@ Shepherd	BB@ Piney Pt.	BB@ Westheimer	WO@ Houston	WO@ Little York	Cole Ck. @Deihl
Date	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001
10 mL Sediment												
1.0 mL Sediment	141,360	> 241,920	> 241,920	> 241,920	> 241,920	92,080	11,300	4,160	9,590	92,080	5,200	17,230
0.5 mL Sediment	145,200	282,720	483,834	> 483,840	483,834	173,280	10,580	4,180	8,500	137,340	7,080	10,560
0.01 mL Sediment	471,000	323,000	576,000	1,124,000	426,000		< 10,000	10,000	10,000	31,000	10,000	
Geometric Mean after storage	213,029	280,593	407,002	508,604	368,066	173,280	10,613	5,582	9,341	73,188	7,167	13,489
% of Levels at Collection	27.1	36.5	67.0	56.8	48.3	18.3	14.0	5.2	28.0	31.5	17.3	19.4
100% Boiled Bayou Water	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Concentrations measured when samples were first obtained from the streams:												
Date	8/6/2001	8/6/2001	8/15/2001	8/13/2001	8/13/2001	8/13/2001	8/6/2001	8/6/2001	8/15/2001	8/13/2001	8/13/2001	8/13/2001
1.0 mL Sediment	> 241,920	> 241,920	> 241,920	> 241,920	> 241,920	> 241,920	41,060	155,307	41,060	241,917	77,010	98,040
0.5 mL Sediment	> 483,840	> 483,840	> 483,840	> 483,840	> 483,840	> 483,840	15,360	52,040	29,100	223,970	22,600	65,640
0.01 mL Sediment	4,160,000	3,873,000	1,918,000	6,131,000	3,784,000	7,260,000	697,000	152,000	31,000	231,000	41,000	52,000
Geometric Mean at collection	786,724	768,199	607,772	895,299	762,269	947,189	76,035	107,100	33,334	232,179	41,478	69,426
ANACON Results	Date	Time	TSS	TP	NH3-N	NO2+3-N	TOC	Remarks				
Beltway 8 - Boiled Water	8/6/2001	9:40	28.0	1.63	< 0.20	4.7	8	BB@ Beltway 8.				





Note: Water samples collected from BB @ Beltway 8, boiled then cooled for flushing sediment samples through sterilized solar screen.

TABLE 3.18
CHARACTERISTICS OF SEDIMENT SAMPLES FROM BUFFALO AND WHITE OAK BAYOUS

Station	Description	Date	TKN (mg/kg)	TOC (mg/kg)	% Solids	Size Distribution			Particle Size (mm)						EC[1] (MPN/dL)
						% Sand	% Silt	% Clay	D85	D60	D50	D30	D15	D10	
	BB @ Sheperd	8/06/01	421	9,700	80.8	77.2	21.6	1.2	0.220	0.160	0.140	0.091	0.058	0.046	76,035
	BB @ Westcott	8/06/01	108	3,100	79.9	87.7	13.6		0.170	0.140	0.130	0.108	0.083	0.068	25,042
	BB @ 610	8/06/01	109	4,110	81.2	93.1	8.2		0.300	0.240	0.230	0.198	0.150	0.116	41,163
	BB @ Voss	8/06/01	144	3,320	81.9	90.4	9.6		0.210	0.180	0.170	0.151	0.109	0.078	78,076
	BB @ Piney Point	8/06/01	558	16,800	80.8	76.0	23.6		0.200	0.160	0.130	0.089	0.058	0.049	107,100
	BB @ Beltway 8	8/06/01	156	9,640	77.2	85.4	13.4	0.2	0.260	0.230	0.220	0.167	0.083	0.057	48,961
	BB @ Wilcrest	8/06/01	130	20,500	82.6	81.6	13.6	1.1	1.350	0.340	0.250	0.212	0.077	0.053	201,101
	BB @ Kirkwood	8/15/01	420	9,500	71.9	61.6	36.9	1.5	0.210	0.100	0.090	0.067	0.049	0.040	115,044
	BB @ Eldridge	8/15/01	386	22,000	70.5	63.8	31.7	4.5	0.230	0.160	0.110	0.063	0.037	0.014	78,267
	BB @ Hwy. 6	8/15/01	206	5,650	81.2	91.5	8.6		0.210	0.180	0.170	0.141	0.110	0.088	12,253
	BB @ Westheimer	8/15/01	278	6,990	66.0	31.8	47.5	19.3	0.190		0.040	0.019	0.003	0.002	33,334
	BB @ Fry	8/15/01	267	13,600	53.1	9.4	55.7	34.9			0.010	0.004			< 585
	WO @ Houston	8/13/01	314	13,100	76.7	88.2	13.2		0.230	0.210	0.200	0.140	0.092	0.066	232,179
	WO @ Tidwell	8/13/01	190	51,700	80.8	77.4	5.5	0.9	4.750	1.420	1.050	0.626	0.360	0.207	31,137
	WO @ W. Little York	8/13/01	512	20,100	55.7	46.1	41.2	12.7	0.190	0.090	0.070	0.040	0.010	0.004	41,478
	WO @ Beltway 8	8/13/01	120	4,720	83.7	79.7	4.5	0.9	4.680	0.300	0.250	0.219	0.188	0.162	21,405
	Cole Ck @ Deihl	8/13/01	218	3,690	80.0	84.5	14.0	1.3	0.160	0.120	0.110	0.093	0.074	0.055	69,426

[1]Values listed represent geometric means of data obtained using various dilutions.

The sediment characteristics are illustrated using a correlation matrix (Table 3.19). First, it is noted that there is a 0.9 correlation coefficient between the % solids and % sand, with a similar negative coefficient between % solids and silt and clay indicating the sediments were mostly sandy. The EC concentration in the sediment is most strongly related to % clay (r = -0.48). The EC concentration was positively related to % sand, but not by as large of a correlation

coefficient (r = 0.29). It was weakly correlated to the total Kjeldahl nitrogen (TKN) and the total organic carbon (TOC). The EC is also weakly negatively correlated with the sizes of finer particles (D15 and D10) (r = -0.22 and -0.25, respectively). Not all correlations appear to make physical sense. For example, the TOC level shows a high degree of correlation with the sediment grain size at the higher percentile levels, but not with the % sand.

At the start of the work it was expected that the highest sediment bacteria levels would be associated with the smallest particles and most organic sediment. While there was some correlation with organic carbon and nitrogen, there was a bigger correlation factor (r) with % sand, and the strongest r was the negative one with the % clay. Possible factors include the relationship between bacteria colonies and different kinds of substrate, and ability to get separation and quantification of sand versus clay particles. Additionally, these results could be a function of the limited dataset generated.

3.1.4.5 Sediment Discussion

The series of sediment tests clearly demonstrate that unconsolidated sediments in the bayous are a reservoir of bacteria. This can be viewed as an expected result because at a basic

TABLE 3.19
CORRELATION MATRIX FOR SEDIMENT CHARACTERISTICS

	TKN	TOC	%Solids	% Sand	% Silt	% Clay	D85	D60	D50	D30	D15	D10	EC
TKN	1.00												
TOC	0.20	1.00											
%Solids	-0.44	-0.10	1.00										
% Sand	-0.39	-0.14	0.90	1.00									
% Silt	0.57	0.00	-0.90	-0.94	1.00								
% Clay	0.18	-0.11	-0.85	-0.96	0.83	1.00							
D85	-0.34	0.53	0.32	0.08	-0.44	-0.33	1.00						
D60	-0.26	0.83	0.24	0.07	-0.41	-0.27	0.76	1.00					
D50	-0.29	0.78	0.38	0.30	-0.51	-0.38	0.76	1.00	1.00				
D30	-0.41	0.68	0.49	0.41	-0.63	-0.45	0.79	0.98	0.98	1.00			
D15	-0.48	0.55	0.52	0.43	-0.70	-0.47	0.82	0.90	0.92	0.96	1.00		
D10	-0.55	0.35	0.62	0.52	-0.78	-0.52	0.82	0.77	0.80	0.87	0.97	1.00	
EC	0.19	0.09	0.25	0.29	-0.15	-0.48	-0.21	-0.15	-0.05	-0.02	-0.22	-0.25	1.00

level, bacteria themselves are suspended particulate matter, although that definition is not generally applied. These loose sediments and associated bacteria are continually getting exchanged between the water and streambed, settling during low flow periods and getting scoured during higher flows.

The test chamber studies described in section 3.2 demonstrate that in the absence of water turbulence and scour, bacteria concentrations drop off quickly, probably associated with the settling of suspended particulate matter. One immediate implication of this finding is that it may be possible to attain bacteria concentrations appropriate for contact recreation by providing areas where settling can occur during low flow periods.

3.2 BACTERIA FROM RAINFALL RUNOFF EVENTS

As is well recognized, both bacteria and suspended particulate matter (TSS) concentrations in runoff samples tend to be very high. The reasons for these high concentrations are not fully understood, but the empirical evidence is clear. Understanding this process is important because runoff from moderate rain events is a common phenomenon in Houston and it is reasonable to expect that these events make a significant contribution to the long-term average EC levels seen in the bayous. Accordingly, two runoff events were monitored during the month of August. The results are presented below, grouped by location. First, the results for Buffalo Bayou, then Whiteoak Bayou and then a smaller tributary, Cole Creek are presented for each runoff event.

3.2.1 Buffalo Bayou Runoff Monitoring

About an inch of rain occurred in the upper watershed on the 6th of August, resulting in a fairly clean spike in the flow records in the gages along Buffalo Bayou about 8 pm on the 6th (Table 3.2). A smaller event (0.6 inch) occurred on the 7th mostly near the mid-stream (Beltway 8 to IH-610) area. The sampling crew mobilized on the 7th and was able to sample the rain event twice at four U.S. Geological Survey (USGS) gage locations on the 7th, 8th, and 9th, resulting in a reasonably complete characterization of bacteria levels associated with the runoff event as the flows steadily declined.

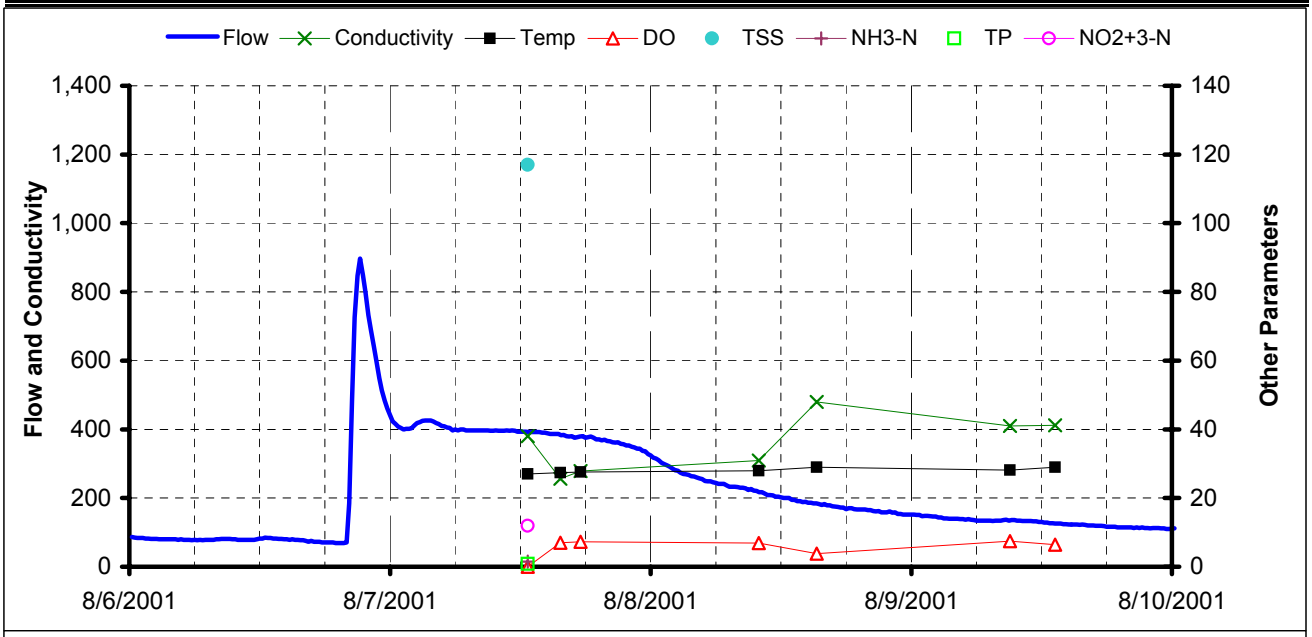
Tables 3.20a through 3.20d show the results from upstream to downstream at Dairy Ashford, Beltway 8, Piney Point, and Shepherd. With each location, the flow at the closest USGS gage is shown along with the other data collected.

Prior to the rain event, conditions in the bayou were low and stable, with little evidence of diurnal variations associated with wastewater discharges. The rain was intense enough to result in a very sharp increase in the flow rate. At the Dairy Ashford location, the flow increased from a base of about 75 cfs to the peak of about 900 cfs in a 2-hour period. The flow dropped to about 400 cfs in the next 6 hours, and then slowly declined until it was close to the original level on the third day after the rain.

Conventional parameters were sampled on the first day from upstream to downstream, following the flow. The results for TSS, TP, Nitrate-N and Ammonia-N are similar at each station. The crew could have been inadvertently tracking the same water at successive samplings.

TABLE 3.20a
RUNOFF STUDY - 7-9 August 2001 - Buffalo Bayou at Dairy Ashford

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/7/2001 12:41	27.0		380	117	0.812	1.45	11.9	> 24,192	> 24,192
8/7/2001 15:41	27.4	7.0	256					> 24,192	17,329
8/7/2001 17:32	27.6	7.3	279					> 24,192	17,329
8/8/2001 9:58	27.9	6.9	309					> 24,192	2,602
8/8/2001 15:17	29.0	3.8	480					> 24,192	3,255
8/9/2001 9:06	28.2	7.5	410					> 48,384	1,800
8/9/2001 13:15	29.0	6.4	412					> 48,384	1,724
Remarks	Flow data from **USGS** gage **08073500 - Buffalo Bayou near Addicks**								



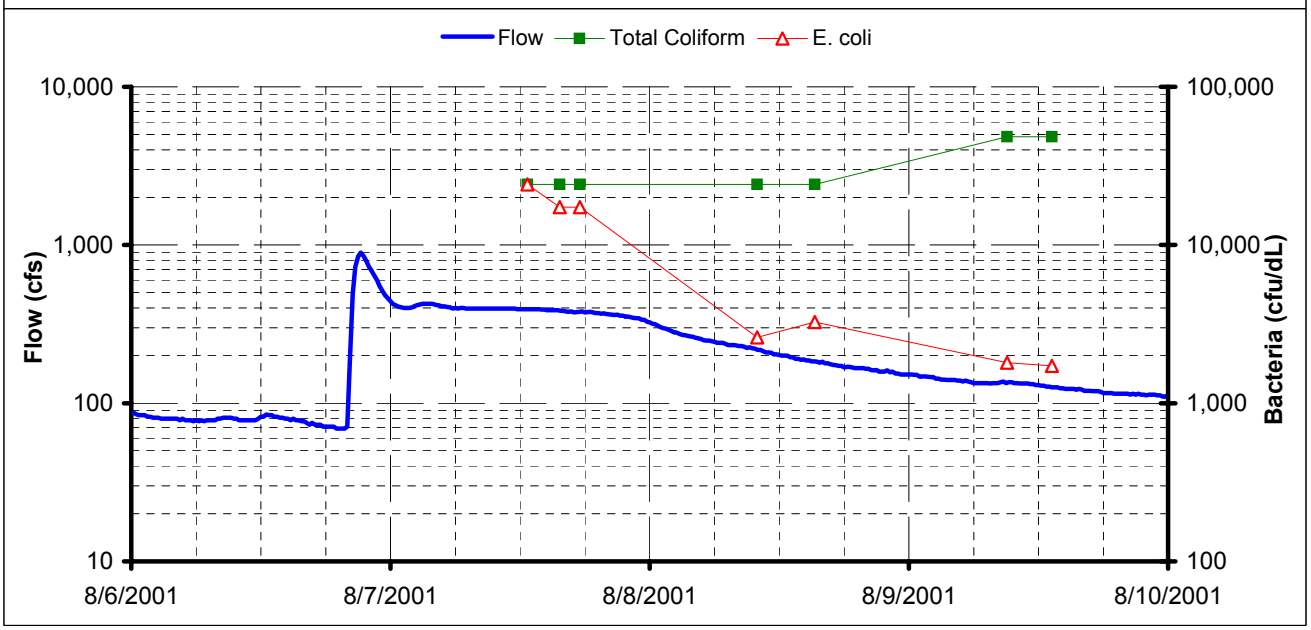
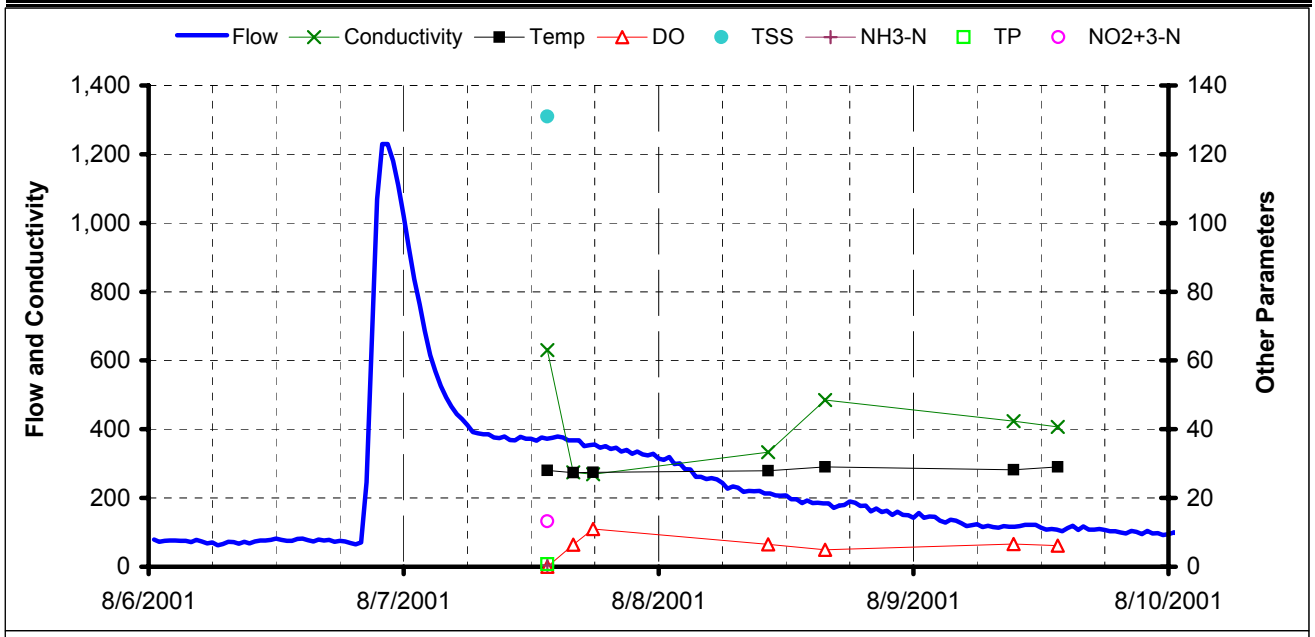


TABLE 3.20b
RUNOFF STUDY - 7-9 August 2001 - Buffalo Bayou at Beltway 8

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/7/2001 13:32	28.0		630	131	0.782	0.37	13.2	> 24,192	14,136
8/7/2001 15:59	27.3	6.5	275					> 24,192	14,136
8/7/2001 17:51	27.5	11.0	269					> 24,192	19,863
8/8/2001 10:19	28.0	6.5	333					> 24,192	1,850
8/8/2001 15:40	29.0	4.9	485					> 24,192	5,172
8/9/2001 9:26	28.2	6.6	424					> 48,384	3,232
8/9/2001 13:35	29.0	6.1	407					> 48,384	6,896
Remarks	Flow data from **USGS** gage **08073600 Buffalo Bayou at W Belt Dr at Houston, TX**								



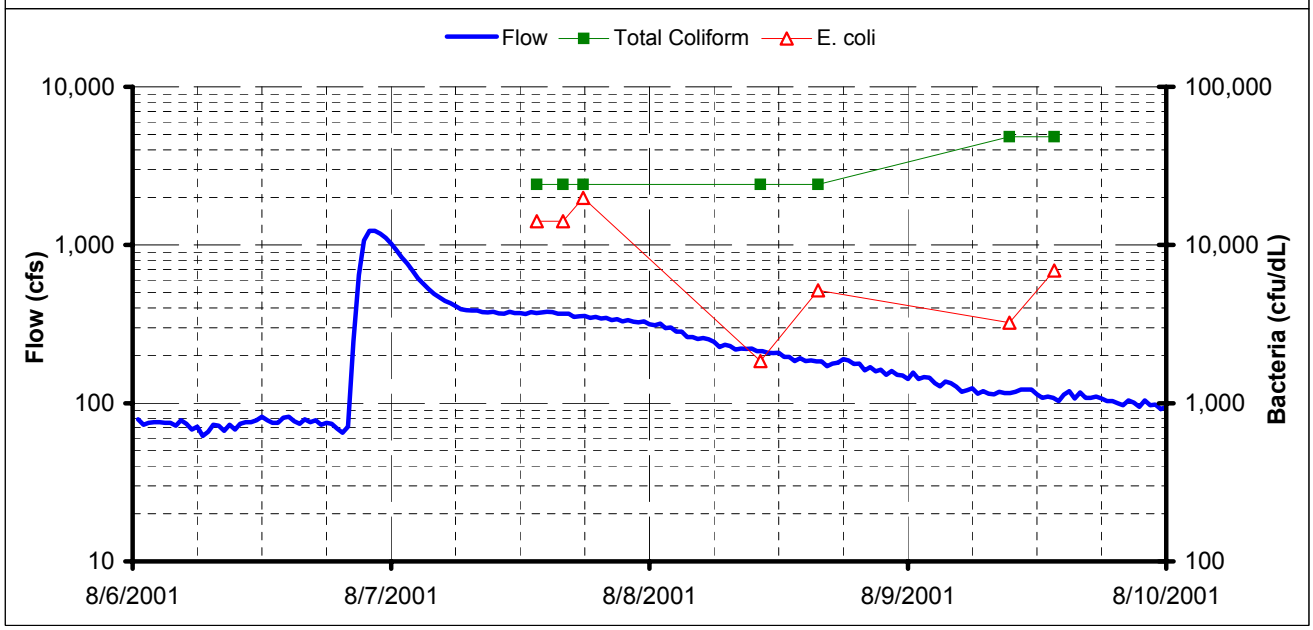
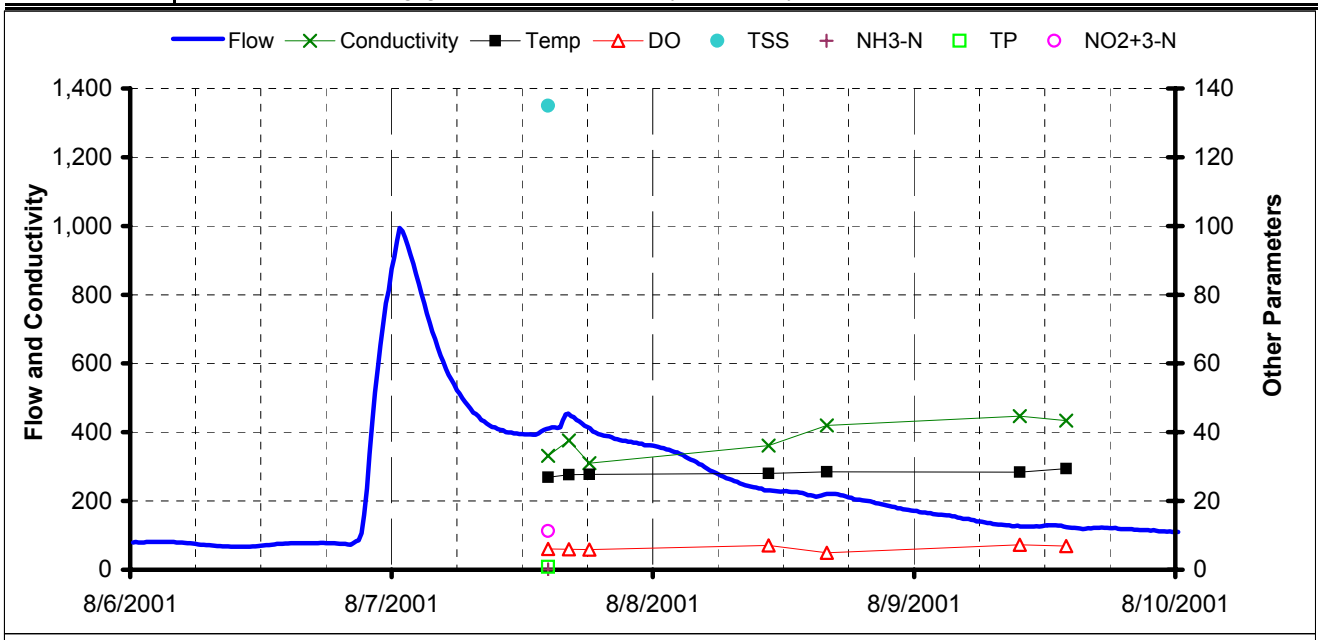


TABLE 3.20c
RUNOFF STUDY - 7-9 August 2001 - Buffalo Bayou at Piney Point

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/7/2001 14:24	26.9	6.0	332	135	0.803	< 0.1	11.3	> 24,192	> 24,192
8/7/2001 16:18	27.6	6.0	376					> 24,192	19,863
8/7/2001 18:10	27.7	5.9	310					> 24,192	15,531
8/8/2001 10:39	28.0	7.1	362					> 24,192	2,986
8/8/2001 16:00	28.5	4.9	420					> 24,192	4,611
8/9/2001 9:42	28.4	7.3	447					> 48,384	2,162
8/9/2001 13:58	29.4	6.9	434					> 48,384	2,626
Remarks	Flow data from **USGS** gage **08073700 Buffalo Bayou at Piney Point, TX**								



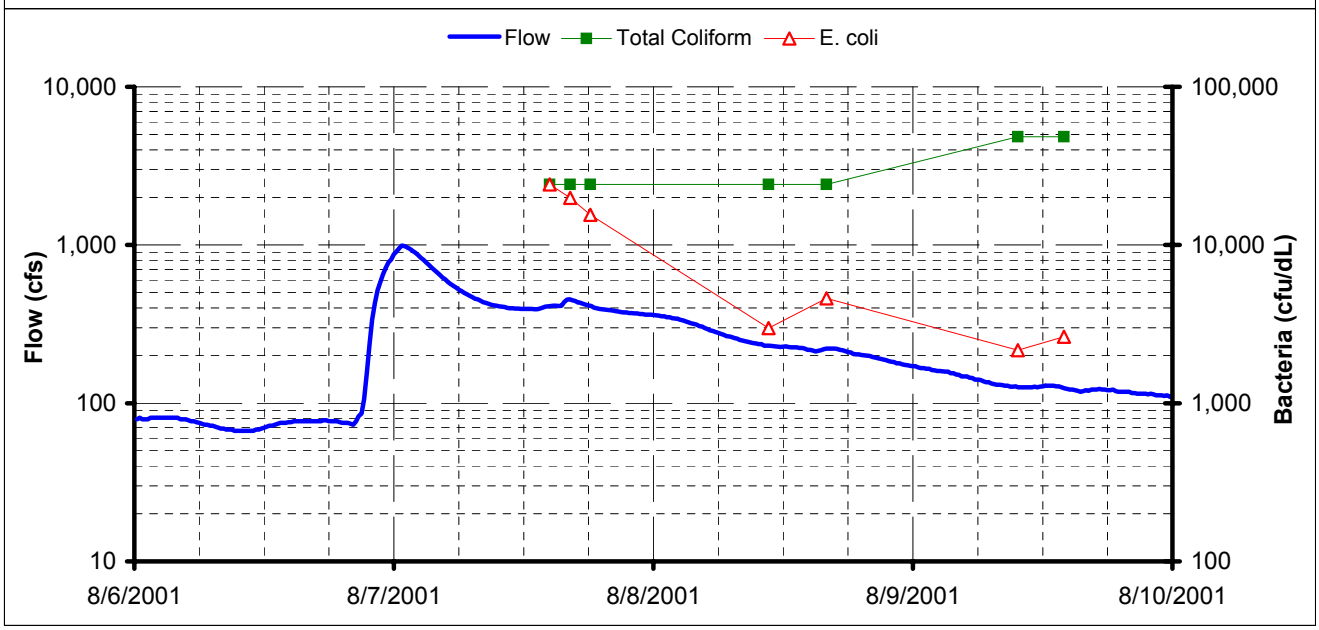
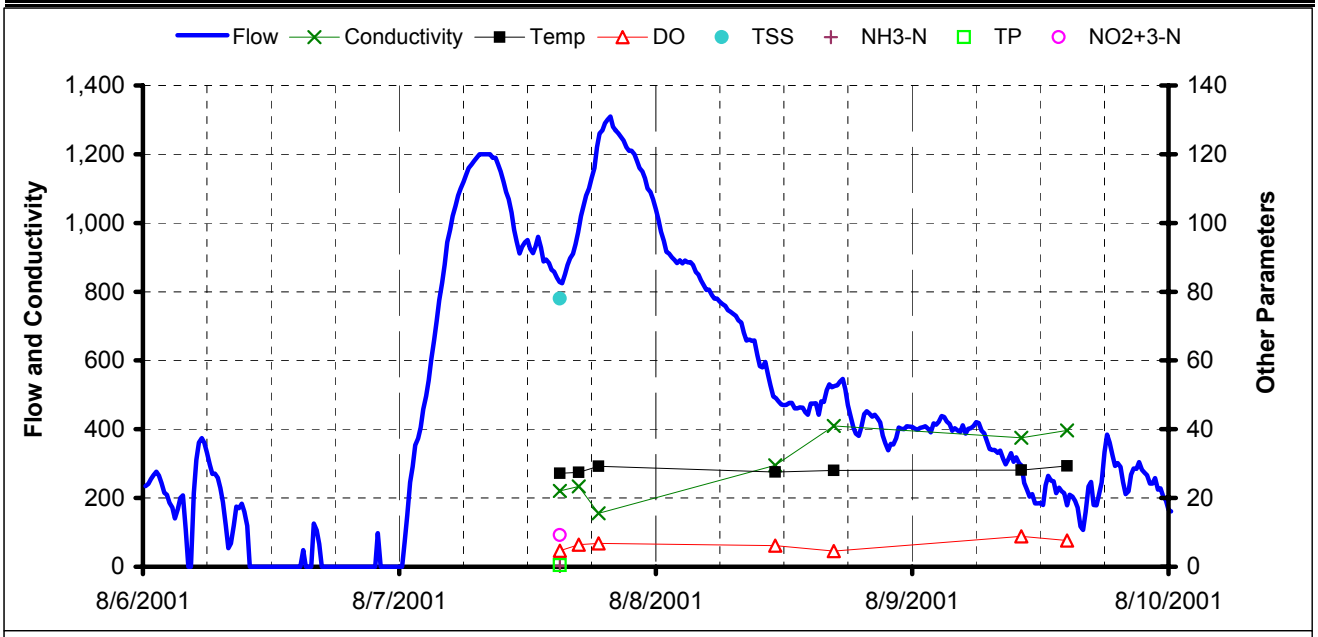
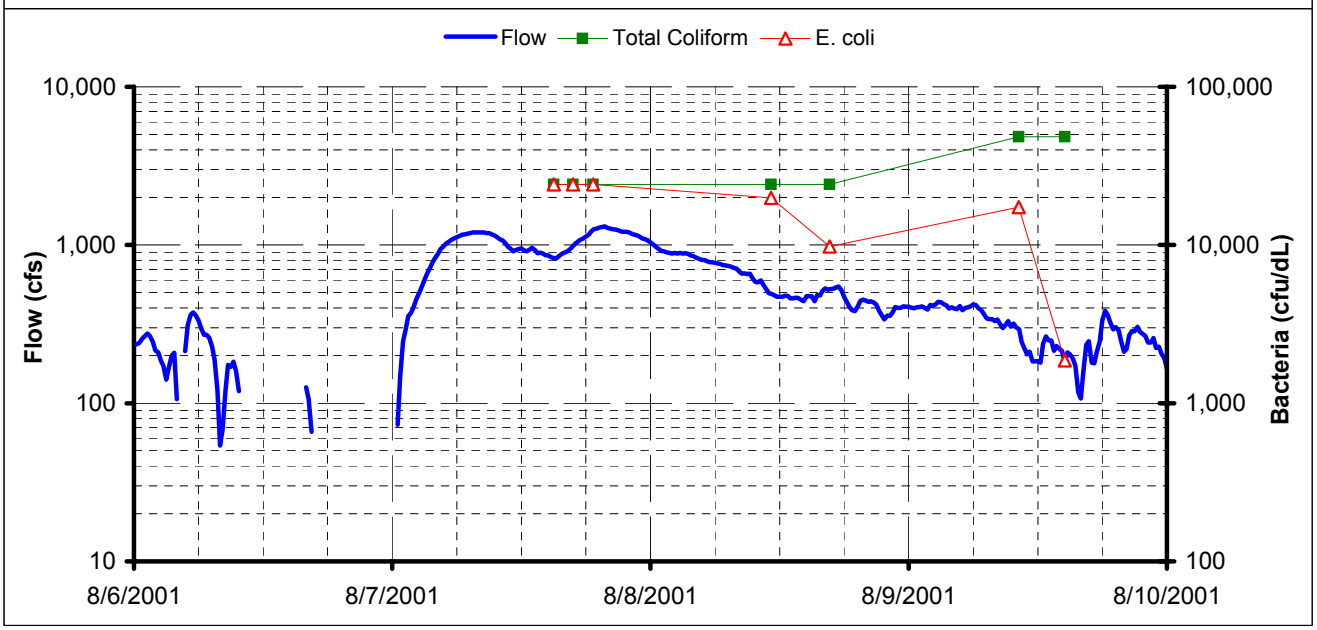


TABLE 3.20d
RUNOFF STUDY - 7-9 August 2001 - Buffalo Bayou at Shepherd

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/7/2001 15:01	27.1	4.7	220	78	0.492	0.22	9.2	> 24,192	> 24,192
8/7/2001 16:48	27.5	6.4	233					> 24,192	> 24,192
8/7/2001 18:40	29.2	6.8	156					> 24,192	> 24,192
8/8/2001 11:12	27.5	6.1	295					> 24,192	19,863
8/8/2001 16:40	28.0	4.6	410					> 24,192	9,804
8/9/2001 10:13	28.1	8.9	375					> 48,384	17,328
8/9/2001 14:31	29.4	7.6	397					> 48,384	1,866
Remarks	Flow data from **USGS** gage **08074000 Buffalo Bayou at Houston, TX (at Shepherd)**								





The conductivity showed a sharp decline between the first and second samplings. After that point, the conductivity data indicated a gradual rebound as the flows subsided.

The initial EC results tended to be above the quantification level. Over the monitoring period the EC results trended downwards in approximate coordination with the bayou flow. The TC results, in contrast, stayed above the quantification limit for the entire period.

A slight difference in the pattern can be seen in Table 3.20d, at Shepherd. The flow at this gage is influenced by tides during low flow periods. Being further downstream, the runoff spike did not arrive until early on the 7th. The flow exhibited a pronounced second spike late on the 7th triggered by more rainfall on the 7th and 8th occurring over the downstream area. This spike is not reflected in the other more-upstream gages.

The second monitored Buffalo Bayou event was between August 28 and August 30. Prior to this event there had been moderate rain events (about 0.6 inch on the 27th), and smaller rains continued during the monitoring period. At the start of the series the flow near Addicks Reservoir was about 250 cfs, much higher than the dry weather flows of about 50 cfs. On the late morning of the 28th the flow spiked to near 1,250 cfs, and then declined back to a lower level before 6 pm. At mid-day on the 29th the flow spiked again and then declined during the night of the 29th and morning of the 30th. Another spike in the flow occurred in the late morning of the 30th.

The field crew was able to sample during the leading edge of the first spike and then to continue monitoring during the entire event. As with the earlier event, monitoring runs were

made from upstream to downstream. Tables 3.21a through 3.21d show the monitoring results at Dairy Ashford, Beltway 8, Piney Point, and Shepherd, along with the flow measurements at the nearest USGS gage.

One observation is that with the higher flows during the initial sampling, the chemical concentrations were lower, with nitrate-N levels more typical of runoff water than wastewater. While the total coliform levels were above the quantification limits during the entire event, the EC levels were not and tended to follow the flow closely. Throughout most of the event the EC levels were often >10,000 MPN/dL.

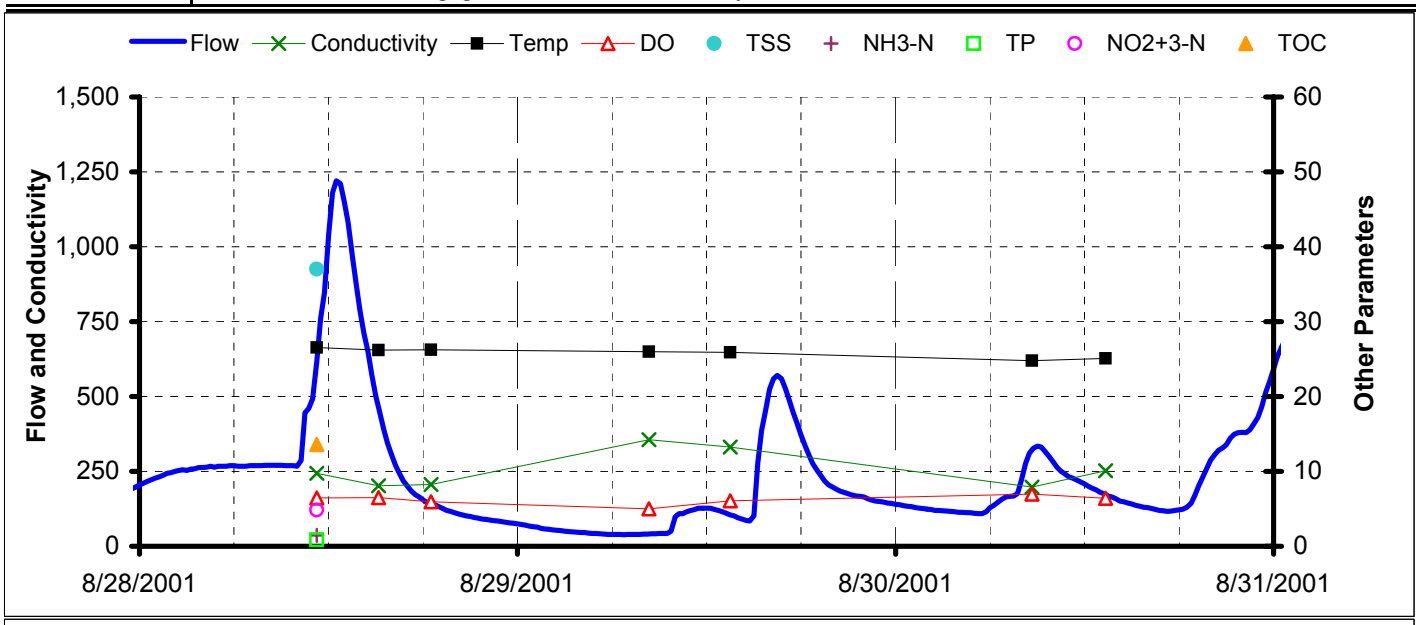
3.2.2 Whiteoak Bayou Runoff

Small (about 0.1 inch) rains occurred in upper Whiteoak bayou on the 7th and 8th, following a rain of more than 2 inches on the 6th. The sampling crew was able to sample the two USGS gages on Whiteoak bayou right before and during the middle of the runoff-related spike in the bayou flow. Tables 3.22a and 3.22b show the results at the two locations.

The flow at the Heights Street gage was about 100 cfs with and increased up to about 300 cfs after the rain. These values are higher than the base flow, but not by a significant amount. The conductivity declined by about a hundred units during the rain pulse and steadily rebounded to almost 600 micro ohms. The TC levels were almost always beyond the quantification limit, but the EC values were quantifiable. The first two EC samples at the Height Street gage were collected before the flow peak. The first was elevated and the second was not. The peak flow

TABLE 3.21a
RUNOFF STUDY - 28-30 August 2001 - Buffalo Bayou at Dairy Ashford

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 11:15	26.5	6.5	244	37	0.85	1.47	4.84	13.6	> 48,384	20,925
8/28/2001 15:10	26.2	6.5	202						> 48,384	34,657
8/28/2001 18:30	26.2	5.9	206						> 48,384	34,657
8/29/2001 8:20	26.0	5.0	356						> 48,384	2,338
8/29/2001 13:30	25.9	6.1	332						> 48,384	9,222
8/30/2001 8:40	24.8	7.0	198						> 48,384	16,328
8/30/2001 13:20	25.1	6.4	253						> 48,384	3,978
Remarks	Flow data from **USGS** gage **08073500 - Buffalo Bayou near Addicks**									



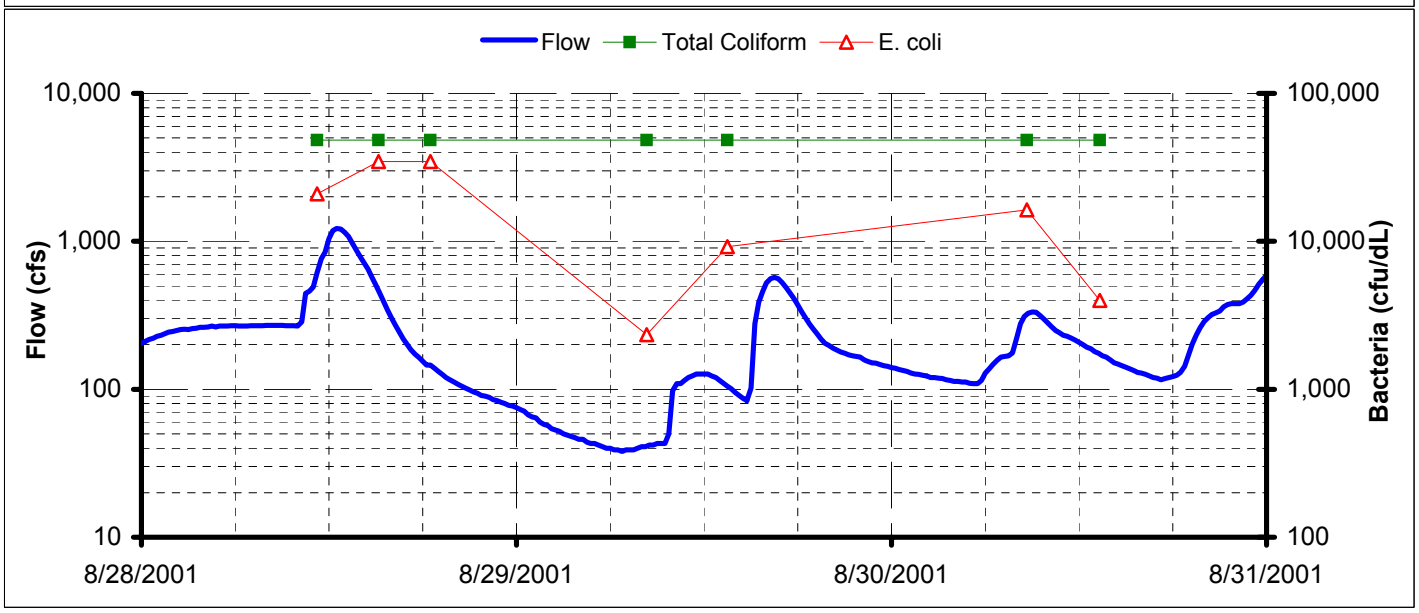
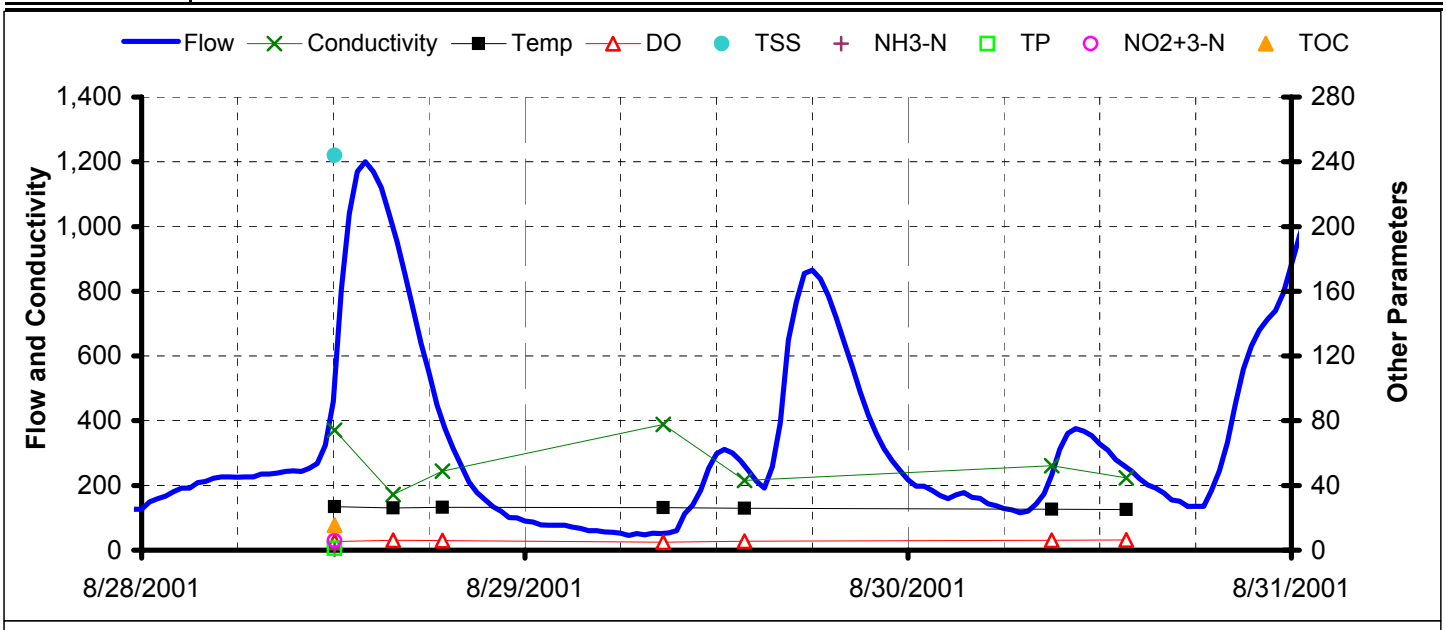


TABLE 3.21b
RUNOFF STUDY - 28-30 August 2001 - Buffalo Bayou at Beltway 8

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 12:05	27.0	5.4	371	244	1.18	0.55	5.96	15.4	> 48,384	20,925
8/28/2001 15:45	26.2	6.1	173						> 48,384	31,061
8/28/2001 18:50	26.4	5.9	244						> 48,384	25,993
8/29/2001 8:40	26.3	5.0	389						> 48,384	3,808
8/29/2001 13:45	25.8	5.5	216						> 48,384	34,657
8/30/2001 9:00	25.3	6.1	261						> 48,384	4,448
8/30/2001 13:40	25.2	6.4	223						> 48,384	10,950
Remarks	Flow data from **USGS** gage **08073600 - Buffalo Bayou at W Belt Dr at Houston, TX**									



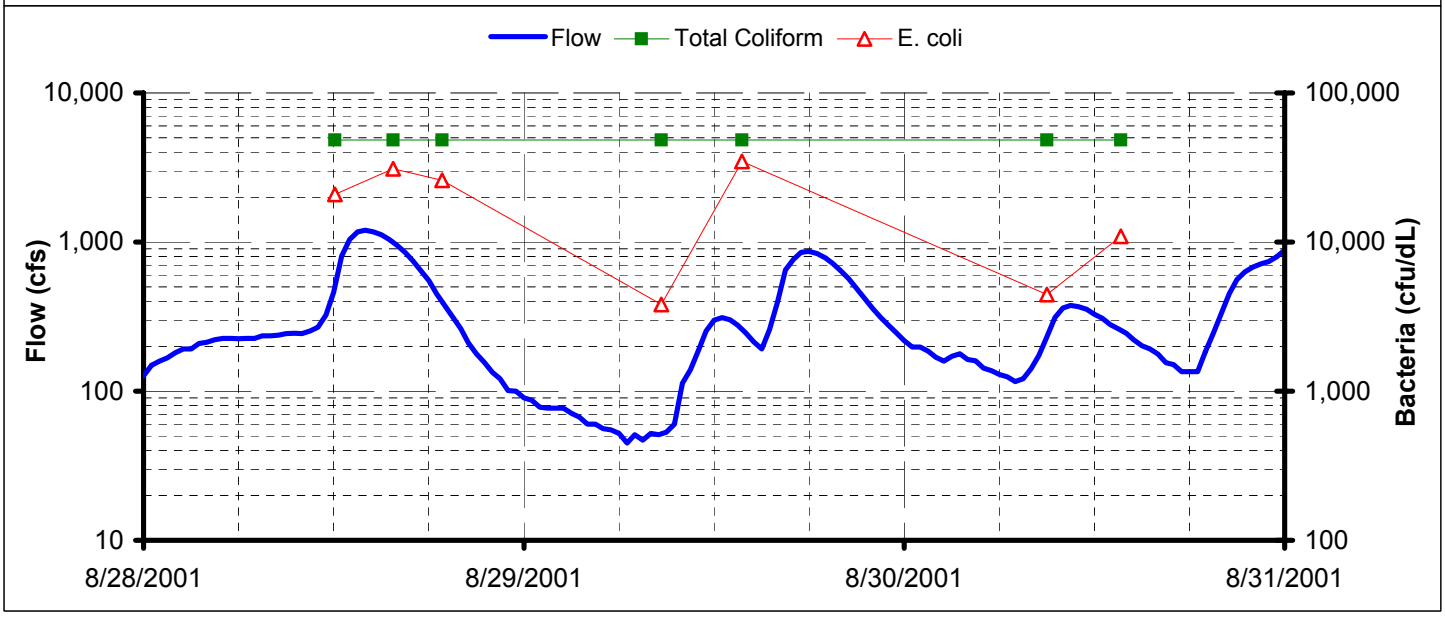
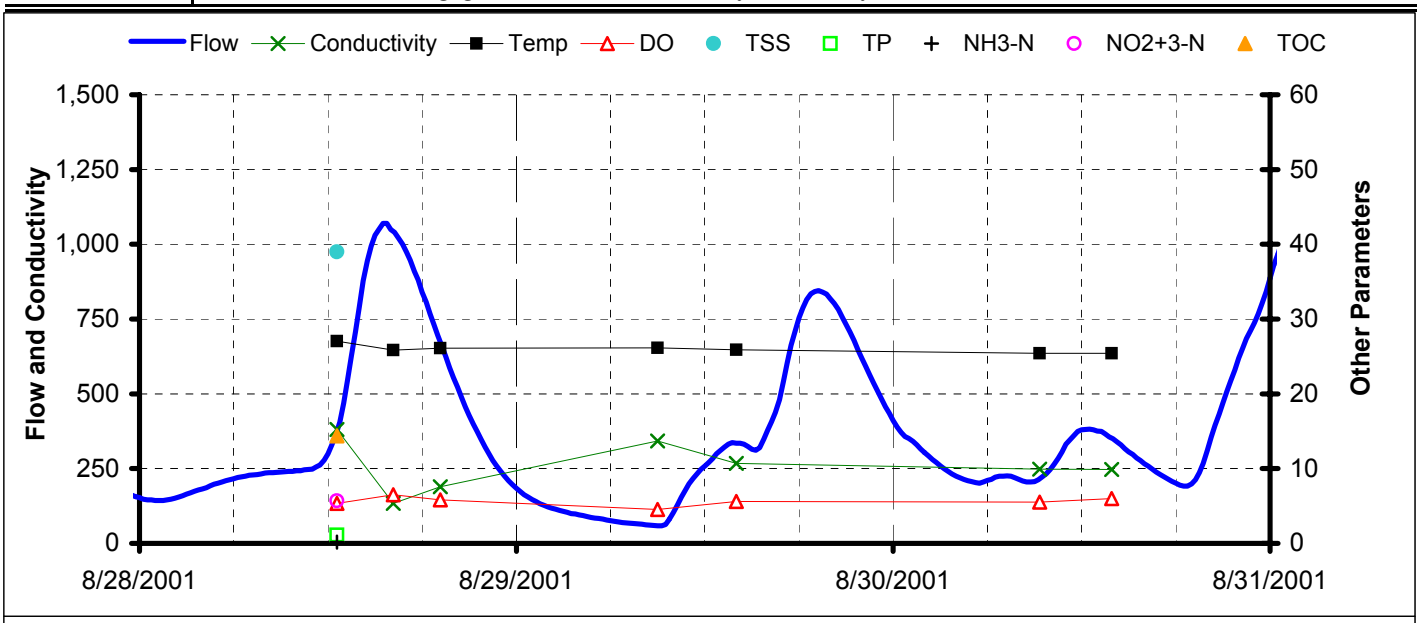


TABLE 3.21c
RUNOFF STUDY - 28-30 August 2001 - Buffalo Bayou at Piney Point

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 12:35	27.0	5.3	380	39	1.12	0.18	5.7	14.4	> 48,384	24,066
8/28/2001 16:10	25.9	6.5	134						> 48,384	48,383
8/28/2001 19:10	26.1	5.8	189						> 48,384	25,993
8/29/2001 9:00	26.2	4.6	342						> 48,384	3,452
8/29/2001 14:00	25.9	5.6	268						> 48,384	> 48,384
8/30/2001 9:20	25.4	5.5	248						> 48,384	8,212
8/30/2001 13:55	25.4	6.0	247						> 48,384	12,976
Remarks	Flow data from **USGS** gage **08073700 - Buffalo Bayou at Piney Point, TX**									



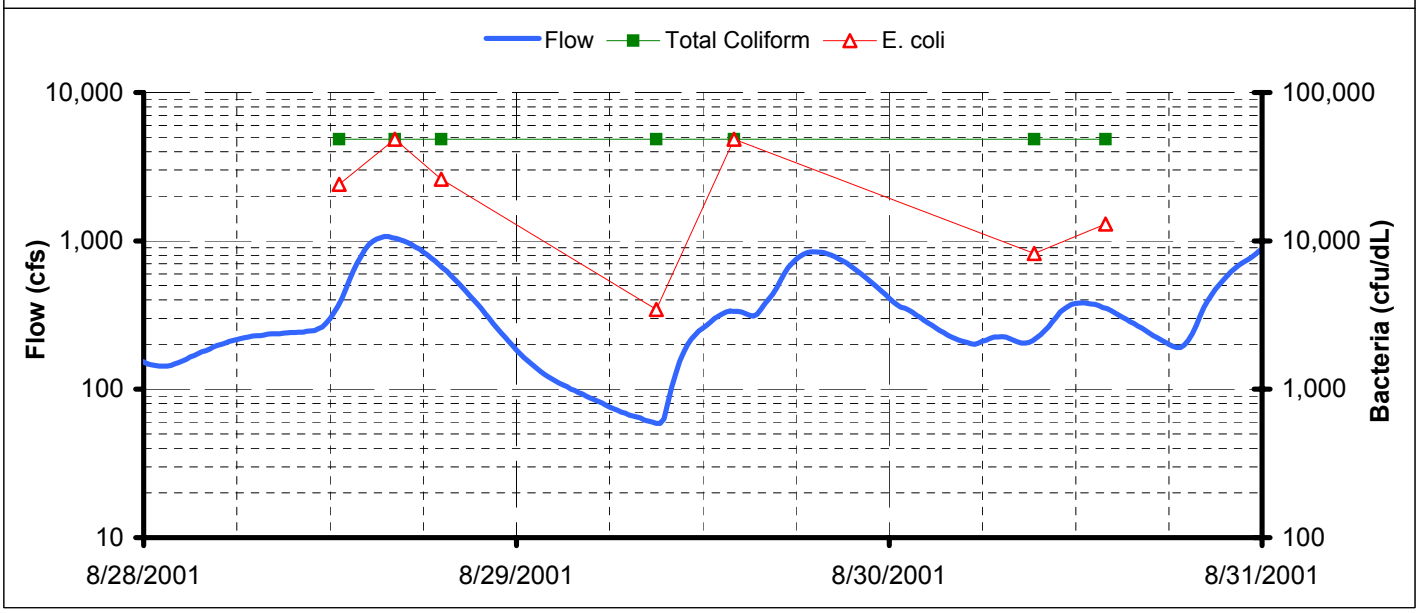
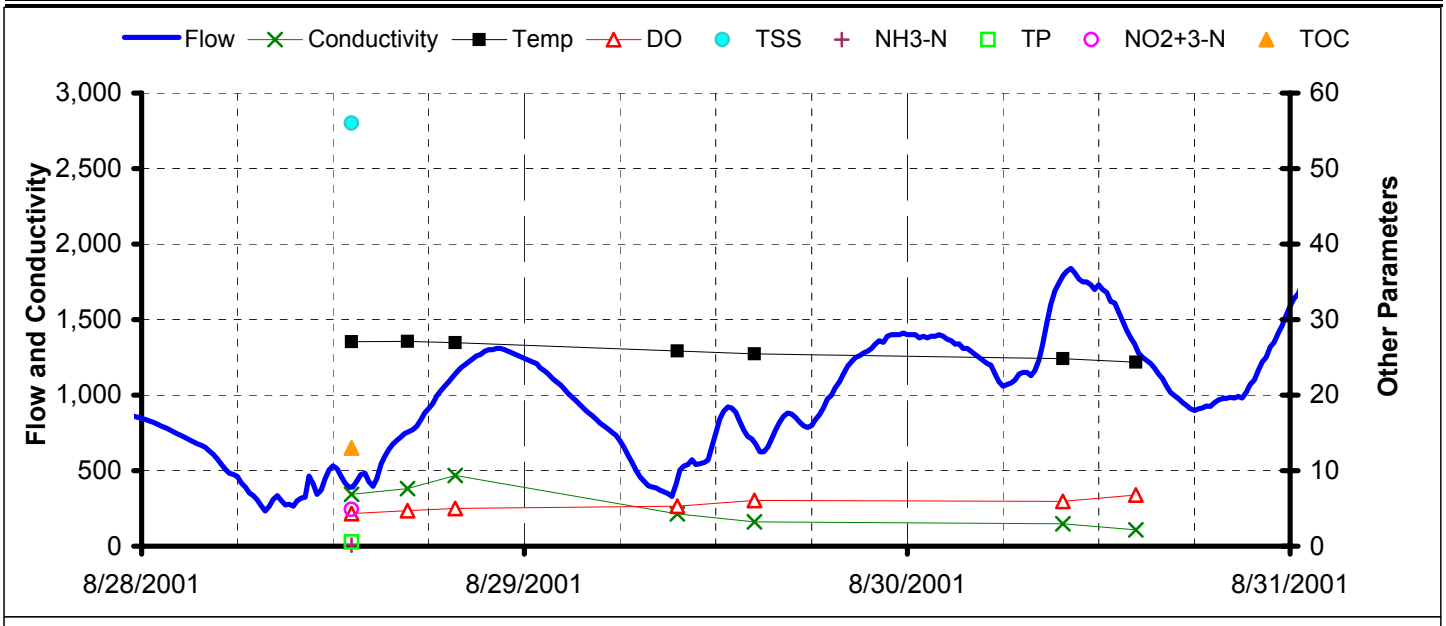


TABLE 3.21d
RUNOFF STUDY - 28-30 August 2001 - Buffalo Bayou at Shepherd

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 13:10	27.1	4.3	344	56	0.54	0.13	4.86	13	> 48,384	25,993
8/28/2001 16:40	27.1	4.7	381						> 48,384	19,608
8/28/2001 19:40	27.0	5.0	468						> 48,384	24,066
8/29/2001 9:35	25.8	5.3	215						> 48,384	15,402
8/29/2001 14:25	25.5	6.0	162						> 48,384	39,726
8/30/2001 9:45	24.8	6.0	149						> 48,384	25,993
8/30/2001 14:20	24.4	6.8	108						> 48,384	25,993
Remarks	Flow data from **USGS** gage **08074000 - Buffalo Bayou at Houston, TX (at Shepherd)**									



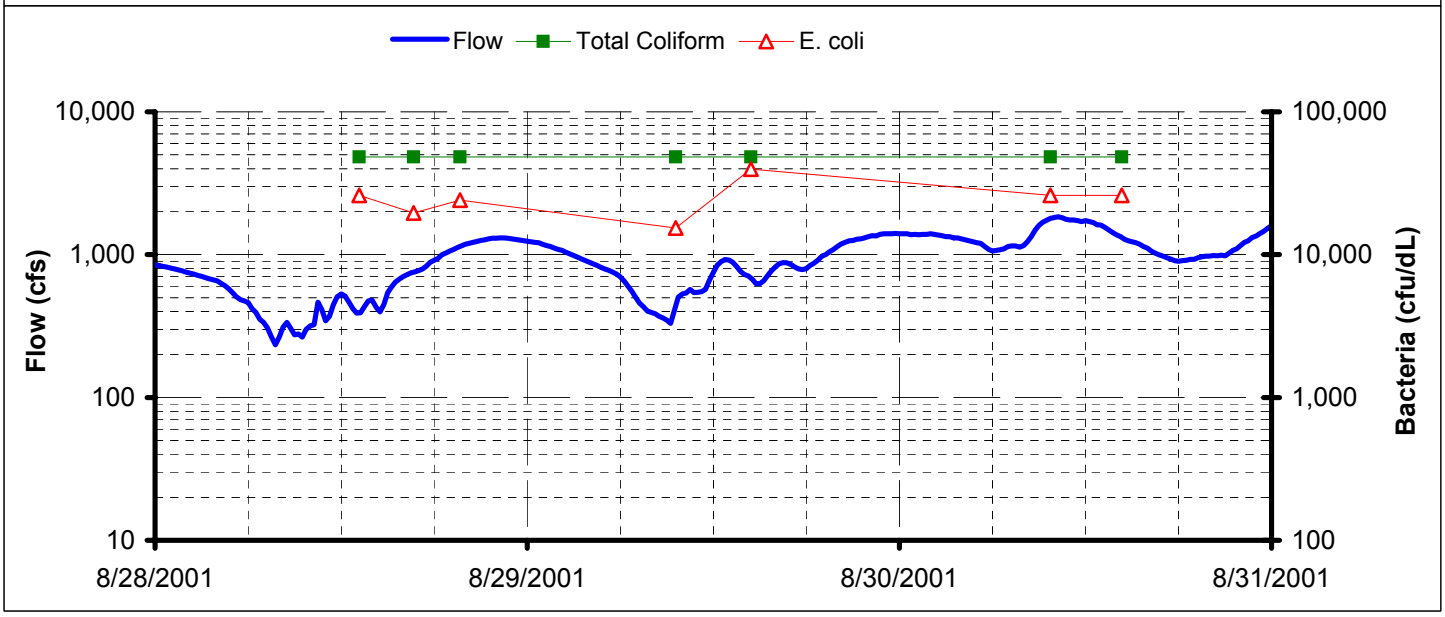
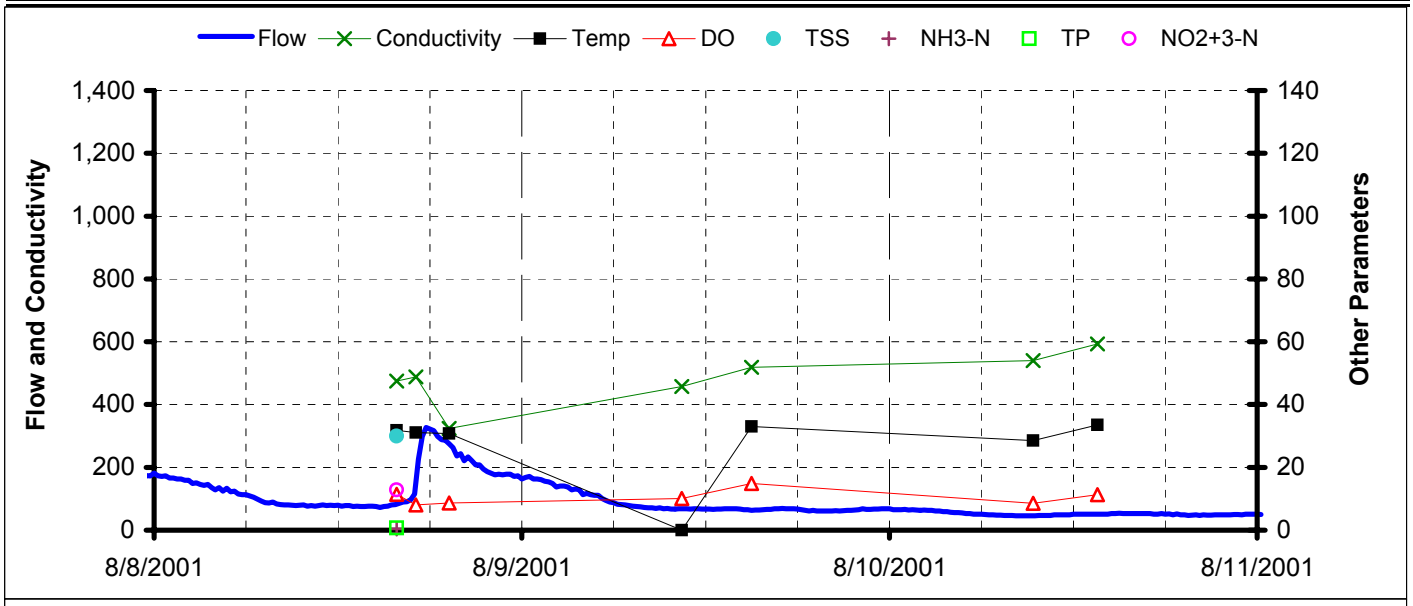


TABLE 3.22a
RUNOFF STUDY - 8-10 August 2001 - White Oak Bayou at Height

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/8/2001 15:50	31.8	11.4	475	30	0.736	0.39	12.8	> 48,384	39,726
8/8/2001 17:05	31.1	8.0	488					> 48,384	3,446
8/8/2001 19:15	30.7	8.7	324					> 48,384	20,925
8/9/2001 10:27		10.1	457					> 48,384	4,494
8/9/2001 15:00	33.1	14.9	519					28,272	1,588
8/10/2001 9:23	28.6	8.6	540					48,383	10,344
8/10/2001 13:35	33.5	11.3	593					48,383	1,366
Remarks	Flow data from **USGS** gage **08074500 Whiteoak Bayou at Houston, TX (at Height)**								



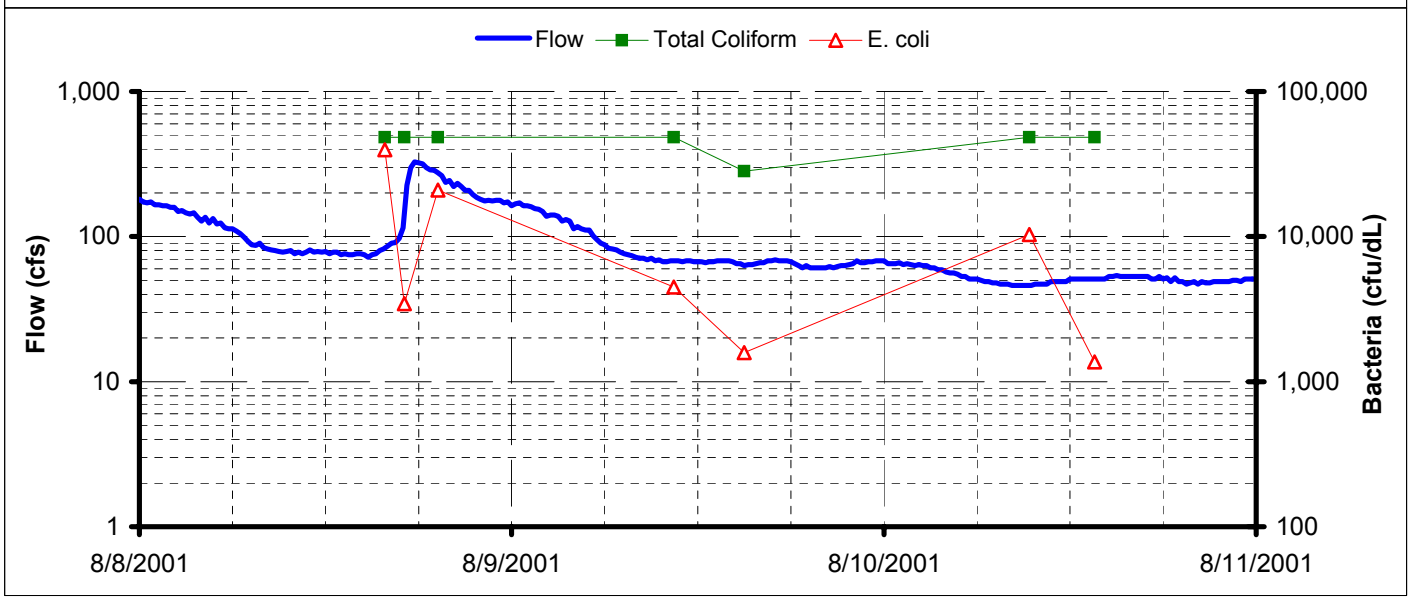
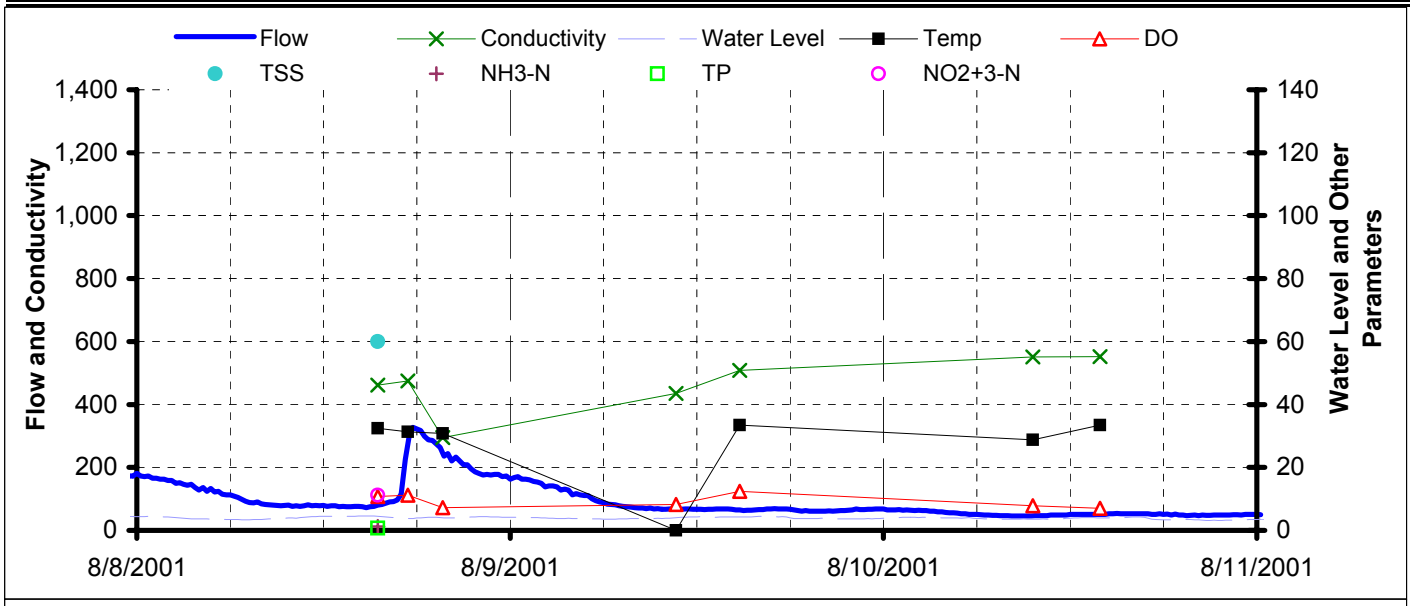
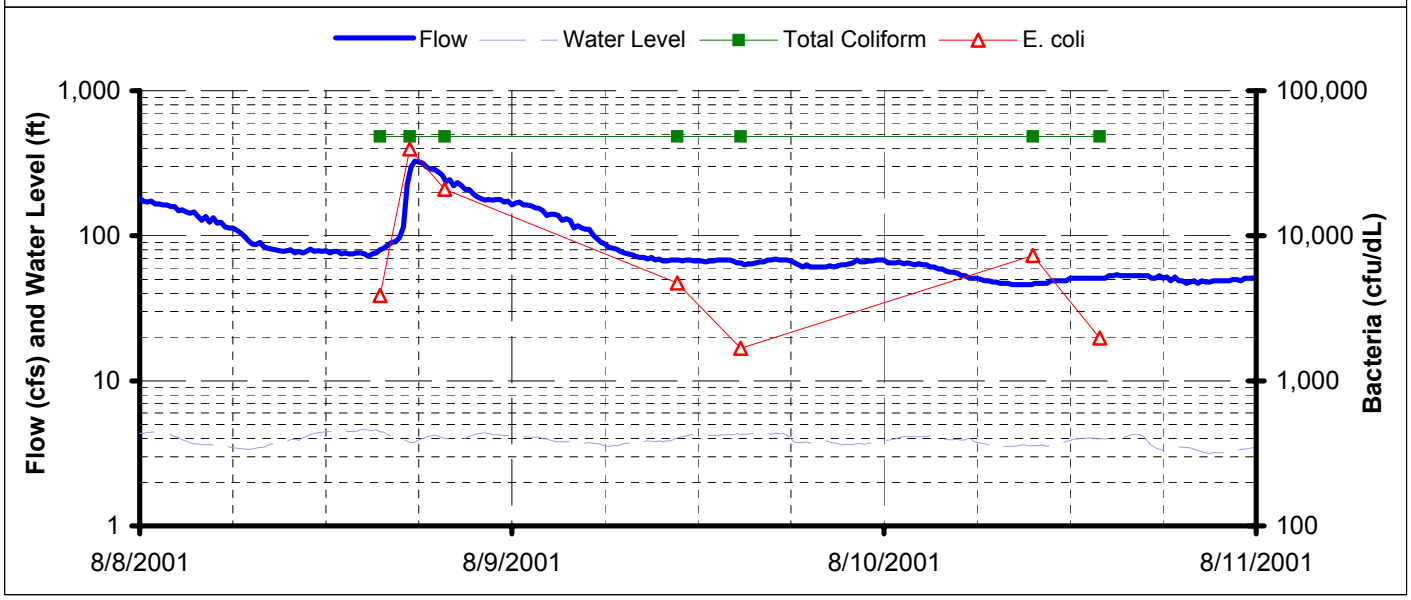


TABLE 3.22b
RUNOFF STUDY - 8-10 August 2001 - White Oak Bayou at Houston

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/8/2001 15:30	32.4	10.8	461	60	0.672	1.22	11.2	> 48,384	3,870
8/8/2001 17:25	31.3	11.2	475					> 48,384	39,726
8/8/2001 19:40	30.8	7.2	295					> 48,384	20,925
8/9/2001 10:40		8.3	435					> 48,384	4,718
8/9/2001 14:45	33.5	12.4	508					> 48,384	1,672
8/10/2001 9:36	28.7	7.8	551					> 48,384	7,308
8/10/2001 13:55	33.5	7.0	552					> 48,384	1,970
Remarks	Flow data from **USGS** gage **08074500 Whiteoak Bayou at Houston, TX (at Height)** Water level data from **USGS** gage **08074598 Whiteoak Bayou at Main St, Houston, TX**								





was sampled with the third sample and the EC level was elevated. Following that the EC levels declined over the next two days.

A similar pattern was exhibited by the EC levels at the Houston (Main Street) gage. One difference was that only the first sample was before the peak flow, and it was relatively low in EC as would be expected. The next samples during the peak flow had elevated EC levels. As the bayou flow declined, so did the EC concentrations.

A somewhat different runoff pattern was observed during the second event (August 28-30, 2001). In this event, moderate rains occurred on a daily basis (0.26, 0.70, and 0.95 inch on the 28th, 29th, and 30th) and the bayou flow oscillated between 100 and 2,000 cfs over the 3-day period. The field crew was able to sample initially at a lower point in the flow and then to sample several of the higher flow spikes that followed (Tables 3.23a and b). The chemical concentrations were more dilute than wastewater, and conductivity appeared to follow the reverse of the flow measurements. Tables 3.23a and b show the results from this sampling event.

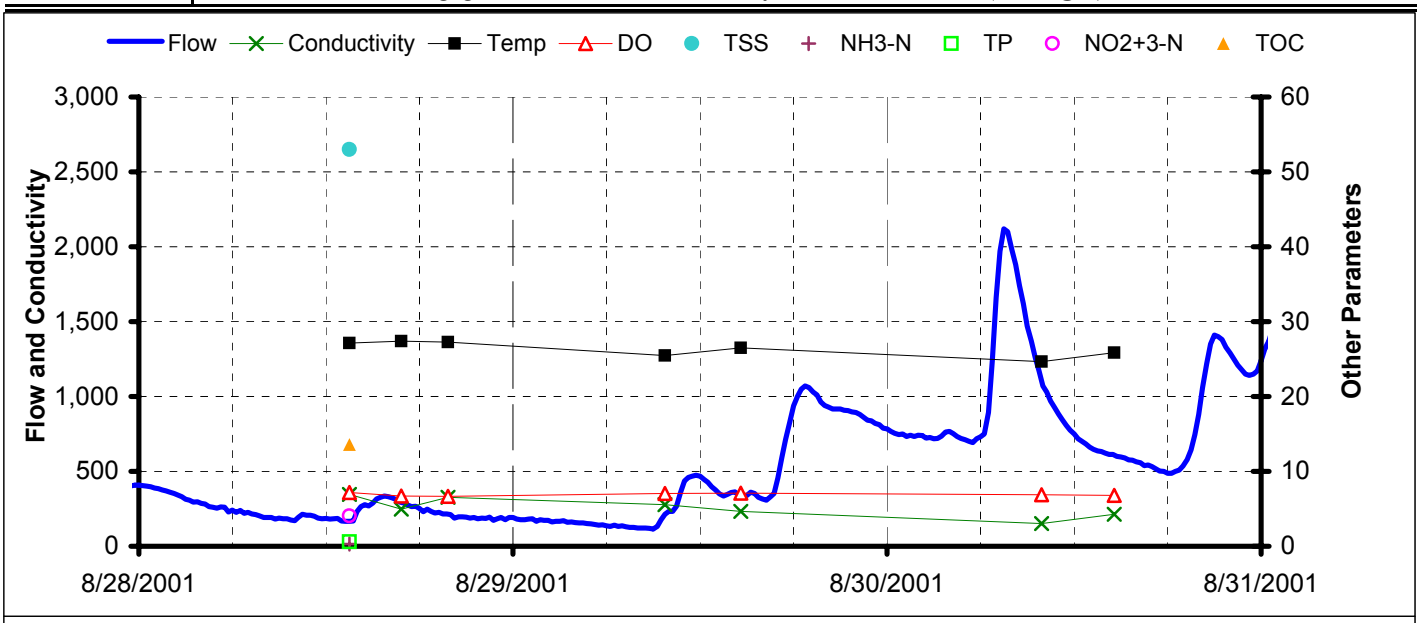
The EC concentrations were high throughout the event and appeared to track changes in the flow reasonably well. The TC concentrations were above their quantification level during the entire event.

3.2.3 Cole Creek Runoff

Cole Creek is a major tributary to Whiteoak Bayou with a USGS flow gage at the Deihl Road crossing. The watershed of Cole Creek is 4,800 acres at this point and is primarily urban.

TABLE 3.23a
RUNOFF STUDY - 28-30 August 2001 - White Oak Bayou at Height

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 13:30	27.2	7.2	347	53	0.58	0.29	4.04	13.6	> 48,384	5,974
8/28/2001 16:50	27.4	6.7	247						> 48,384	> 48,384
8/28/2001 19:50	27.3	6.7	326						> 48,384	18,416
8/29/2001 9:45	25.5	7.1	277						> 48,384	39,726
8/29/2001 14:37	26.5	7.1	233						> 48,384	48,383
8/30/2001 9:55	24.7	6.9	151						> 48,384	48,383
8/30/2001 14:35	25.9	6.8	213						> 48,384	20,925
Remarks	Flow data from **USGS** gage **08074500 - Whiteoak Bayou at Houston, TX (at Height)**									



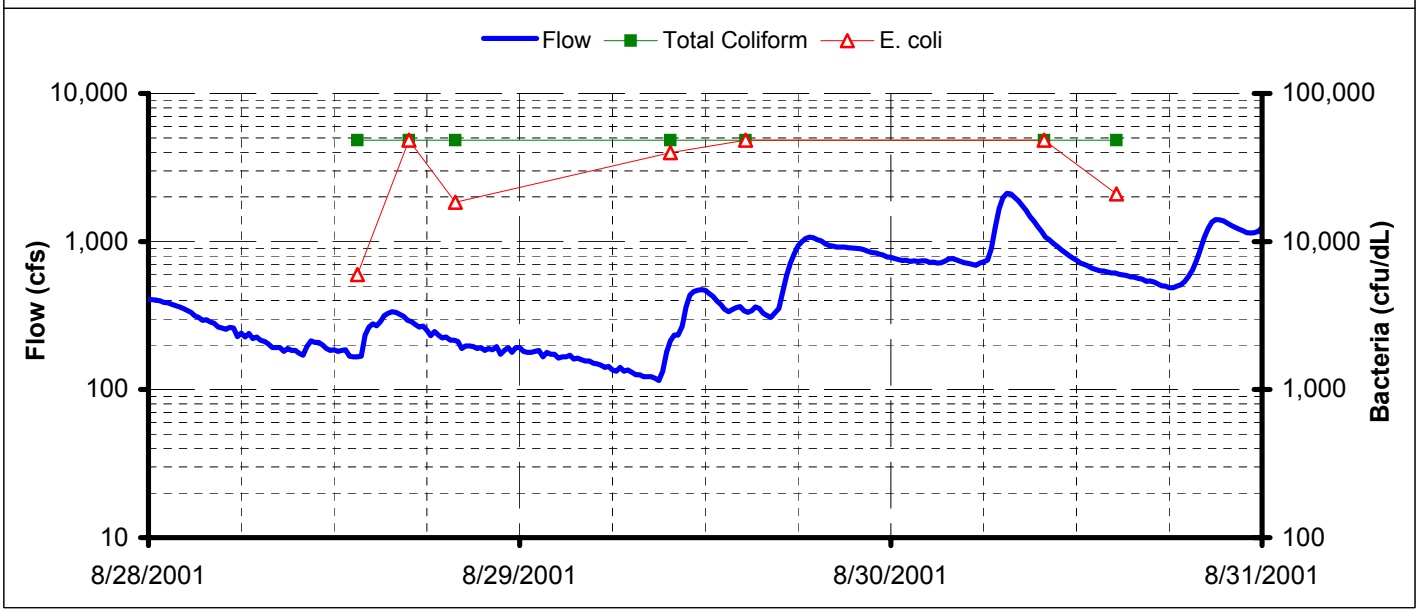
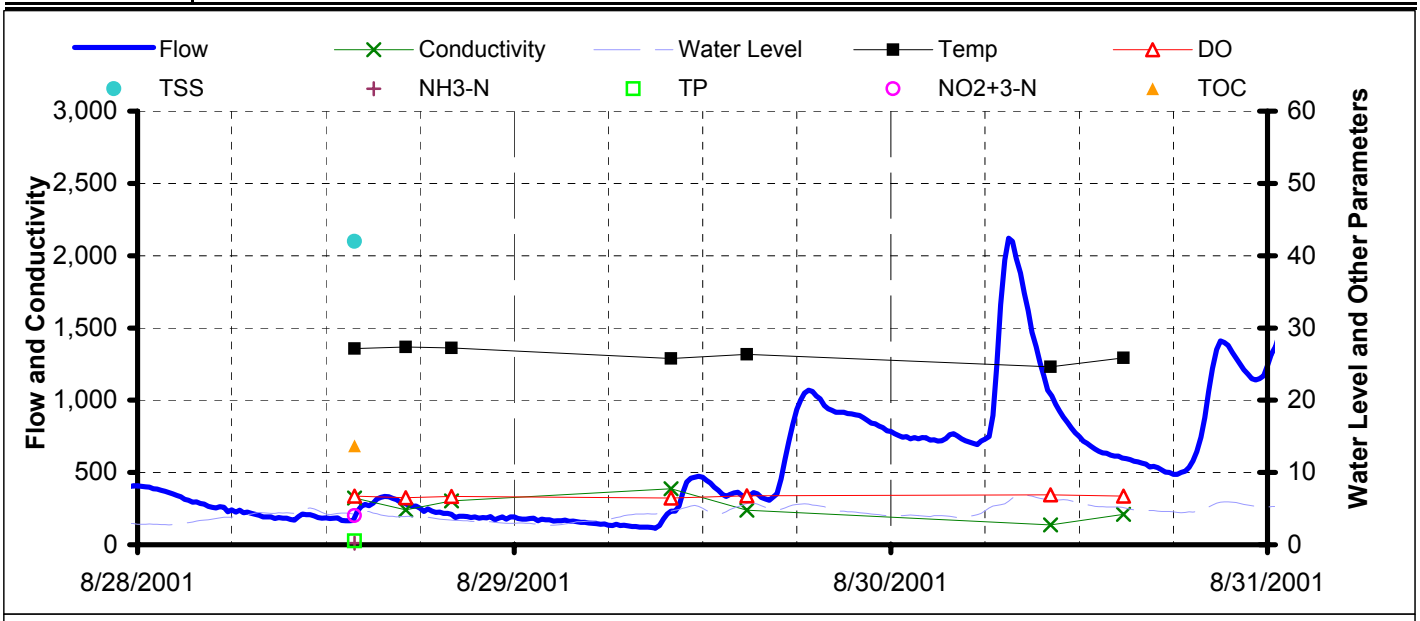
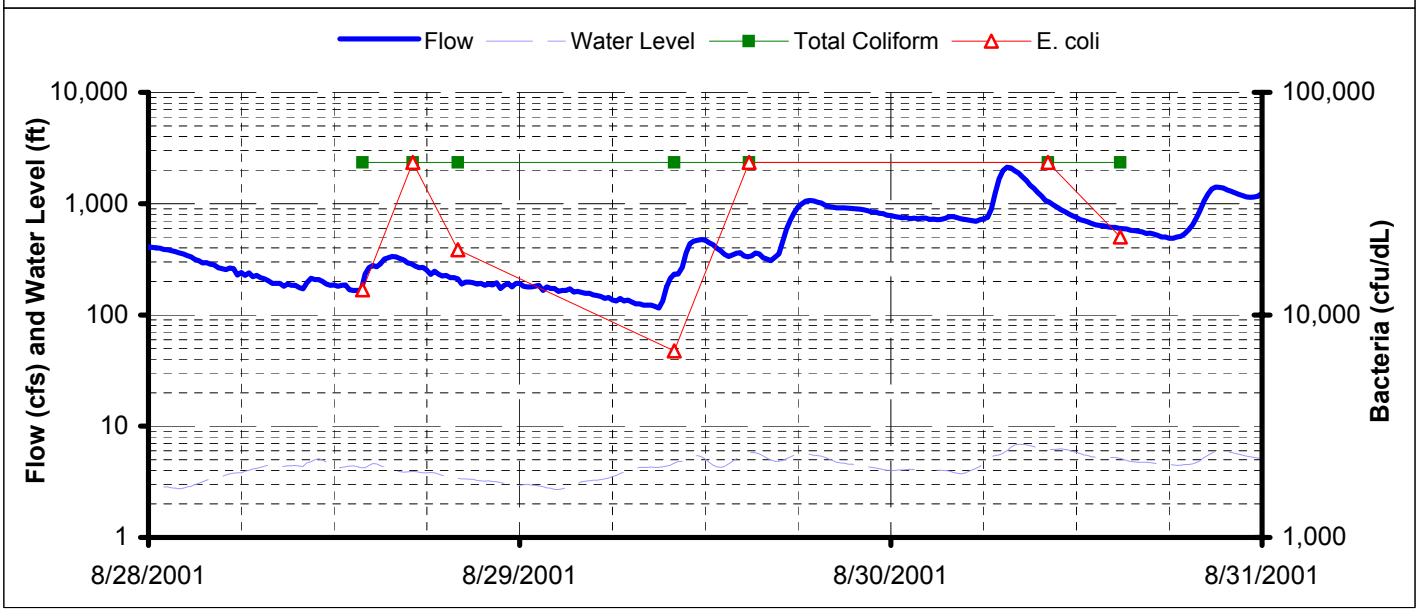


TABLE 3.23b
RUNOFF STUDY - 28-30 August 2001 - White Oak Bayou at Houston

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 13:50	27.2	6.7	324	42	0.54	0.22	4.05	13.7	> 48,384	12,976
8/28/2001 17:05	27.4	6.5	241						> 48,384	48,383
8/28/2001 20:00	27.2	6.7	304						> 48,384	19,608
8/29/2001 10:00	25.8	6.5	388						> 48,384	6,896
8/29/2001 14:50	26.4	6.8	238						> 48,384	> 48,384
8/30/2001 10:10	24.6	6.9	138						> 48,384	48,383
8/30/2001 14:50	25.9	6.8	210						> 48,384	22,397
Remarks	Flow data from **USGS** gage **08074500 - Whiteoak Bayou at Houston, TX (at Height)**□ Water level data from **USG**									





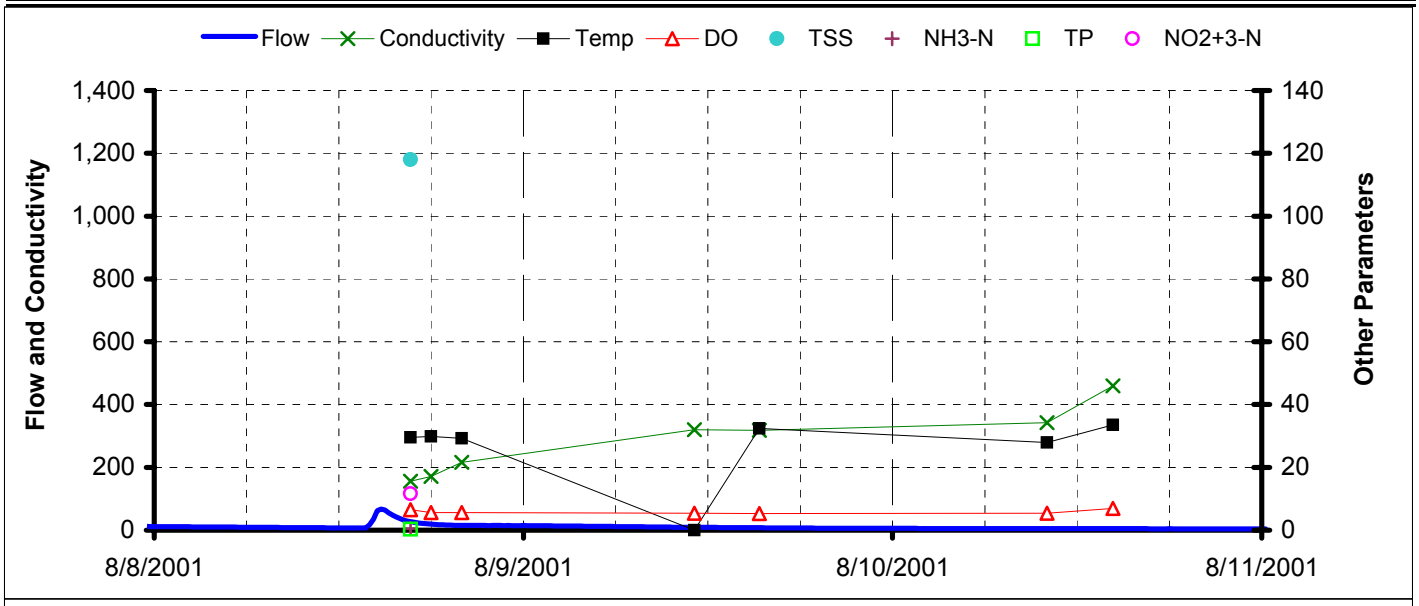
Runoff at this location was sampled during the August 8-10 rain event and again during the August 28-30 event.

With rainfall of only about 0.2 inch on the 8th, the first event produced a fairly clean spike in the flow from about 7 to nearly 70 cfs in less than 2 hours. Table 3.24a shows the data collected. The field crew was able to sample within about two hours of the flow peak, and TSS and bacteria concentrations were quite high, as would be expected. The flow then declined to about 4 cfs over the next two days, and the EC levels tracked the flow declines. The conductivity rose as the flow declined.

A somewhat different pattern was observed in the second Cole Creek sampling event during August 28-30, 2001. The rainfall exceeded the first event, about 0.16, 1.00, and 1.36 on the 28th, 29th, and 30th, respectively. Table 3.24b shows that the flow was initially low and then exhibited a moderate spike before the flow gage failed. The EC levels tracked the initial spike and then fluctuated. Referring to the flow data from other gages during this time it is apparent that a series of small rains was causing significant local fluctuations in flow and associated EC levels. There is also a sharp drop in the conductivity at the same time as there is a sharp rise in the EC on the 29th. Like most stations, the TC levels were higher than the quantification limit in all cases.

TABLE 3.24a
RUNOFF STUDY - 8-10 August 2001 - Cole Creek at Deihl

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/8/2001 16:40	29.6	6.6	156	118	0.327	0.56	11.6	> 48,384	48,384
8/8/2001 18:00	29.9	5.6	172					> 48,384	28,272
8/8/2001 20:00	29.3	5.6	216					> 48,384	22,397
8/9/2001 11:07		5.4	320					> 48,384	1,262
8/9/2001 15:20	32.4	5.3	318					> 48,384	2,634
8/10/2001 10:02	27.9	5.4	343					> 48,384	826
8/10/2001 14:20	33.5	6.9	460					> 48,384	718
Remarks	Flow data from **USGS** gage **08074150 Cole Ck at Deihl Rd, Houston, TX**								



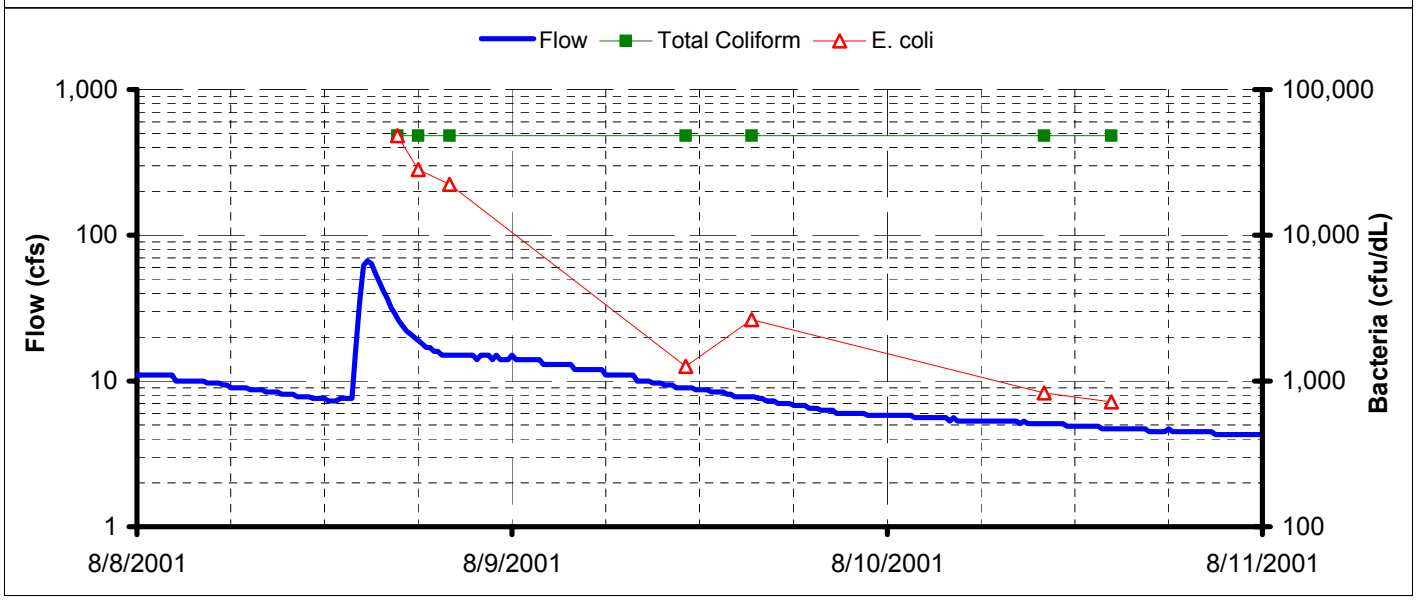
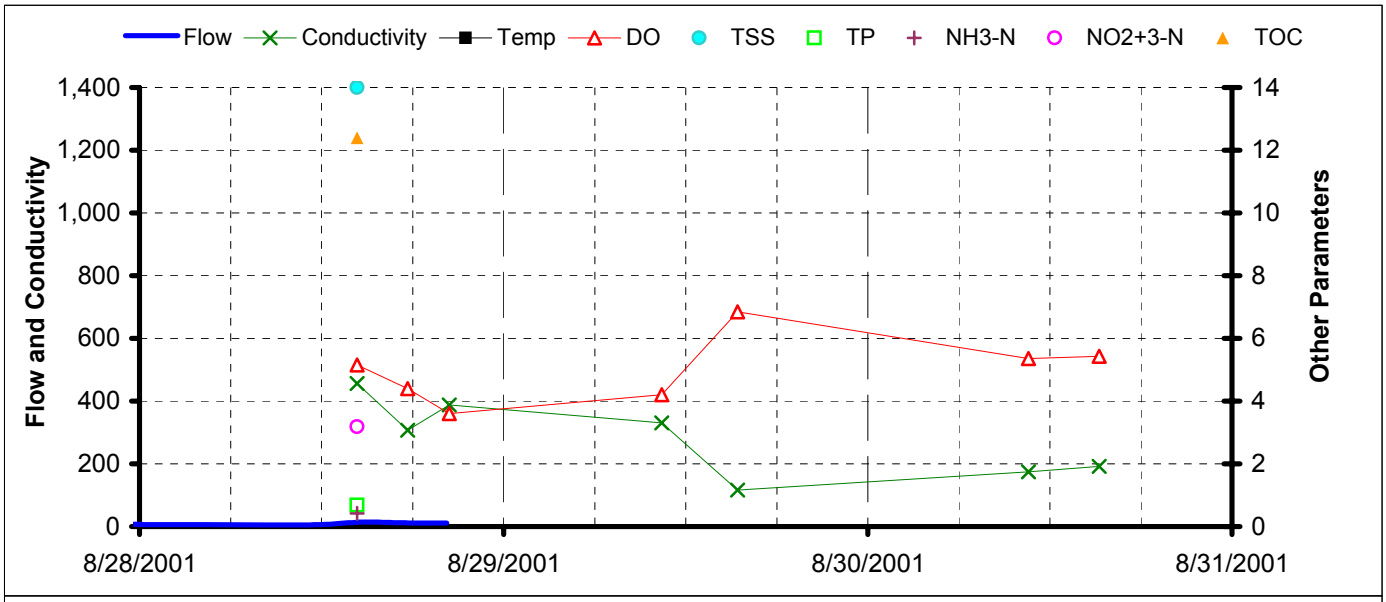
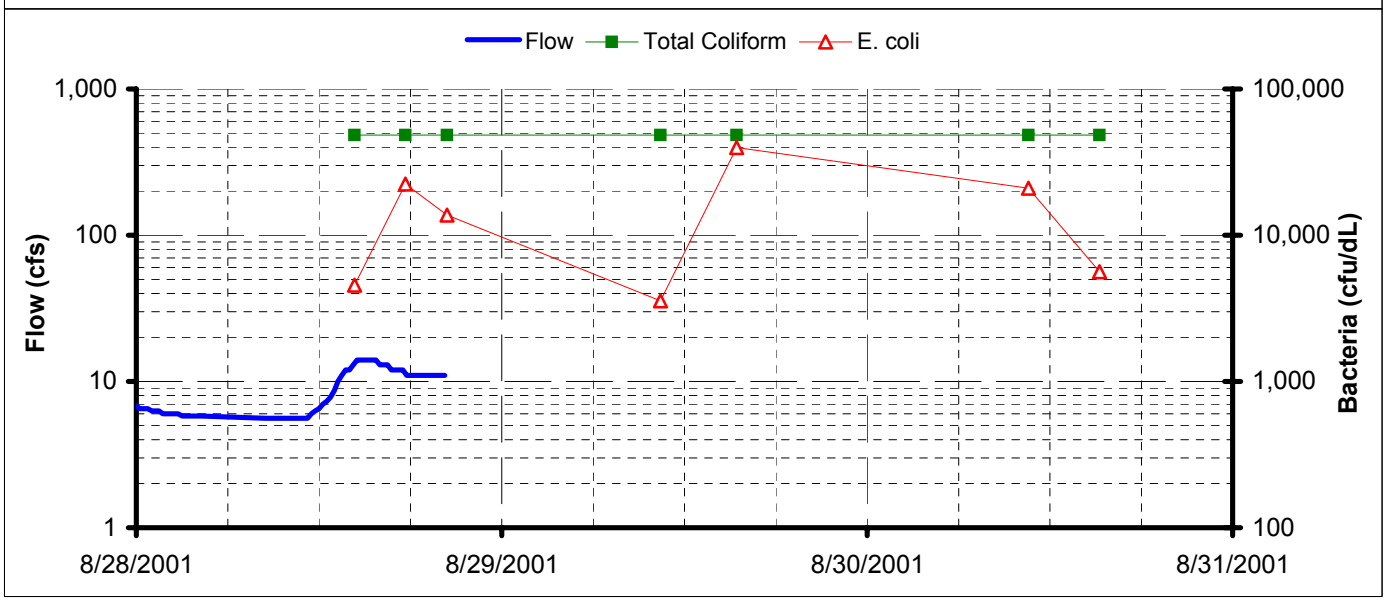


TABLE 3.24b
RUNOFF STUDY - 28-30 August 2001 - Cole Creek at Deihl

Time	Temp (°C)	DO (mg/L)	Cond (1/µΩ/cm)	TSS (mg/L)	TP (mg/L)	NH3-N (mg/L)	NO2+3-N (mg/L)	TOC (mg/L)	TC (MPN/dL)	EC (MPN/dL)
8/28/2001 14:20	27.2	5.2	456	14	0.68	0.42	3.18	12.4	> 48,384	4,564
8/28/2001 17:40	27.2	4.4	307						> 48,384	22,397
8/28/2001 20:25	26.9	3.6	388						> 48,384	13,734
8/29/2001 10:25	26.5	4.2	331						> 48,384	3,558
8/29/2001 15:25	25.4	6.9	116						> 48,384	39,726
8/30/2001 10:35	25.2	5.4	174						> 48,384	20,925
8/30/2001 15:15	25.9	5.4	192						> 48,384	5,618
Remarks	Flow data from **USGS** gage **08074150 - Cole Ck at Deihl Rd, Houston, TX** USGS gage malfunctioned from 8/28/2001 8:30 pm to 8/31/2001 12:30 am.									





3.2.4 Discussion of Runoff Results

As a whole, the runoff sampling results confirm expectations. That is, higher bacteria levels would be observed in bayou waters during storm events. At most stations there appears to be some tracking between bayou flow and EC levels. The causes of higher bacteria levels undoubtedly include wash-off of bacteria by stormwater runoff from land surfaces and possibly re-suspension from sediments.

CHAPTER 4

ASSESSMENT OF MAJOR SOURCES, TRANSPORT AND FATE OF BACTERIA IN BUFFALO AND WHITEOAK BAYOUS

This chapter presents an analysis of data obtained from sampling conducted between July 24 and November 30, 2001 for the point source assessment. A description of the methods and technical approach undertaken to accomplish this task is presented in Section 4.1. All the sampling and analysis procedures employed for this task follow the approved QAPP for the project (University of Houston and PBS&J, 2001). Results of the activities conducted between November 1, 2001 and May 31, 2002 as part of the dry-weather storm sewer discharges monitoring are summarized in Section 4.2.

4.1 POINT SOURCE SAMPLING

In dry weather essentially all of the flow in the urban Buffalo and Whiteoak Bayous is from point source discharges. Therefore, the TMDL team started the source assessment by sampling those water sources. The team targeted only the small WWTPs (flow below 1 MGD) because larger plants, such as the City of Houston (COH) plants in these stream segments, have a sophisticated system to regulate the dosage of disinfectant and the sodium bisulfite dechlorination agent, which ensures proper treatment of fecal pathogens.

To investigate and document the amount of FC and EC that are discharged to the bayous by point sources, the monitoring plan included early morning and mid-morning sampling of a

broad range of plants over the course of a 6-month period. This sampling effort covered all the minor domestic wastewater treatment plants discharging to Buffalo and Whiteoak Bayous that gave permission to field crews to sample their effluent. A total of 75 wastewater treatment plants were sampled (Figure 4.1), 41 of which discharge to Buffalo Bayou and the remaining 34 discharge to Whiteoak Bayou. Out of the 41 WWTPs in Buffalo Bayou, 28 discharge to the Addicks reservoir, 6 discharge to the Barker reservoir, and 7 discharge directly to the bayou.

Forty-five additional WWTPs that appear in the TCEQ database to be discharging to Buffalo and Whiteoak Bayous were not sampled. The reasons for not sampling those plants include: facility is no longer in operation (14 plants), the request to collect sample was declined (6 plants), and the information from TCEQ database regarding location and/or operator was incorrect or the operator was non-responsive (25 plants).

For the point source monitoring, a sampling crew (2 people) left early in the morning to sample two plants by 08:00 and 08:30 and again at 10:00 and 10:30. These two rounds of samples characterize the discharge at what is generally considered the high and low points in the diurnal flow cycle. Samples were collected at a point following the chlorine contact chamber as it is flowing over the weir. The sampling included field measurements of residual chlorine, flow, conventional field chemical parameters (see Table 4.1), and collecting water samples for laboratory analyses. Each of the samples was analyzed for EC at the University of Houston laboratory and for FC and TSS at the North Water District Laboratory Services (NWDLS) laboratory. The methods employed are shown in Table 4.2.

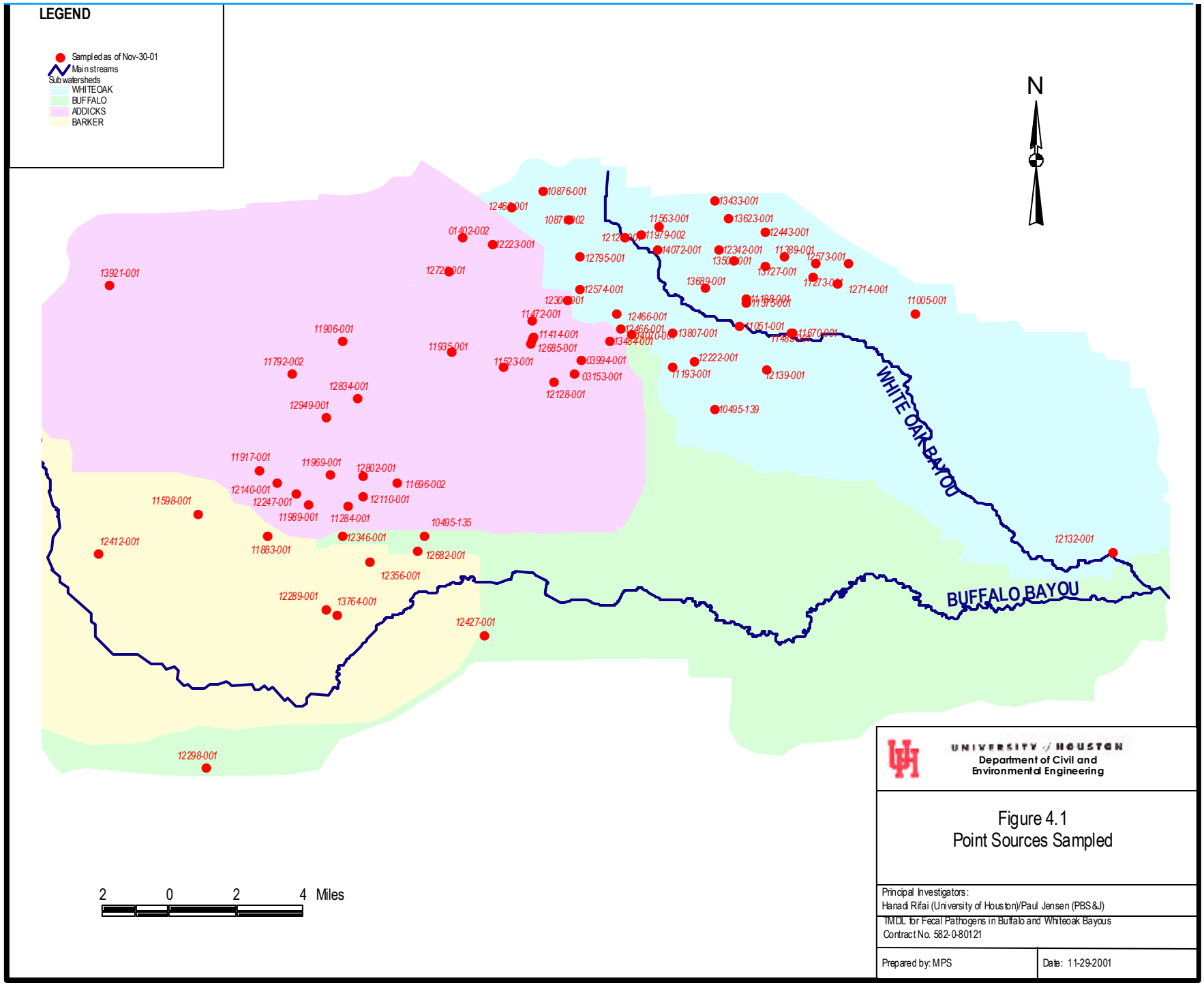

LEGEND
Sampled as of Nov-30-01
Main streams
Subwatersheds
WHITEOAK
BUFFALO
ADDICKS
BARKER
N
WHITE OAK BAYOU
BUFFALO BAYOU
10876-001
13433-001
11563-001
13623-001
12443-001
01402-002
12223-001
11979-002
14072-001
12342-001
11389-001
12573-001
12795-001
13727-001
13921-001
13689-001
12714-001
12574-001
11005-001
11472-001
12466-001
11906-001
11414-001
12685-001
13807-001
11051-001
11935-001
11792-002
11523-001
03994-001
12222-001
03153-001
11193-001
12139-001
12834-001
12128-001
12949-001
10495-139
11917-001
11969-001
12802-001
11696-002
12140-001
12247-001
12110-001
11598-001
11989-001
11284-001
10495-135
12412-001
11883-001
12346-001
12682-001
12132-001
12356-001
12289-001
13764-001
12427-001
12298-001
2 0 2 4 Miles
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 4.1
Point Sources Sampled
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121
Prepared by: MPS
Date: 11-29-2001

Table 4.1 Results from Field Measurements for Point Source Monitoring

Sample ID	Location	Date	DO (mg/L)	pH	Temperature (^oC)	Residual Chlorine (mg/L)	Flow (MGD)	Conductivity (µS/cm)	Turbidity (NTU)	Ammonia (mg/L)	Ortho-phosphorous (mg/L)
10876-001-M	Barwood WWTP	7/24/2001	7.73	7.46	28.46	0	1.3990	694	0.4	0.18	0
10876-002-M	Hastings Green WWTP	7/24/2001	7.13	7.54	29.28	0	1.0760	896	0.4	0	5.5
10876-001-P	Barwood WWTP	7/24/2001	7.47	7.51	29.01	0.03	1.1140	723	0	0	4.96
10876-002-P	Hastings Green WWTP	7/24/2001	6.91	7.65	30.15	0.03	0.7250	906	0.1	0	4.27
12121-M	Harris County MUD 170	7/25/2001		7.41	29.76	0	1.2000	1128	0.9	0.82	3.06
12121-P	Harris County MUD 170	7/25/2001	6.63	7.43	30.14	0.05	1.0000	1075	0.9	0.76	5.33
12795-M	Northwest Harris County MUD 29	7/26/2001	6.92	7.36	30.19	2.85	0.2950	1106	0.7	0	57
11273-M	Harris County MUD 6	7/26/2001	8.62	7.68	29.05	2.32	0.2135	803	0.4	0	12.3
12795-P	Northwest Harris County MUD 29	7/26/2001	4.93	7.3	30.57	0.89	0.0210	1110	0.5	0.02	13.2
11273-P	Harris County MUD 6	7/26/2001	2.29	7.66	29.4	0.31	0.2130	793	0	0	12.5
12443-M	Superior Derrick	7/27/2001	6.62	7.21	27.68	5.07	0.0012	970	2.3	0	14.55
12573-M	William Smith MHP	7/27/2001	6.76	7.41	28.52	5.45	0.0152	707	0.3	0	5.2
12443-P	Superior Derrick	7/27/2001	6.9	7.28	27.99	3.7	0.0013	971	3.4	na	15.4
12573-P	William Smith MHP	7/27/2001	6.89	7.39	28.38	5.74	0.0152	693	0.1	na	5.92
11979-M	White Oak Bend WWTP	7/30/2001	7.72	7.66	29.81	14.2	0.2720	1561	2.1	0.31	10.66
11979-P	White Oak Bend WWTP	7/30/2001	7.86		29.99	7.26	0.2300	1535	2.2	0.16	9.28
13623-M	WHC MUD #21	7/31/2001	8.15	7.76	29.04	11	0.4000	2315	6	0	22.1
11563-M	Reid Road	7/31/2001	7.34	7.56	29.08	na	0.7450	1306	8.2	0.6	5.9
13623-P	WHC MUD #21	7/31/2001	8.66	7.69	29.38	5	0.3300	2348	8.5	na	13.15
11563-P	Reid Road	7/31/2001	7.33	7.7	29.67	na	0.6130	1373	4.1	na	7.18
11375-M	Creekside	8/1/2001	8.47	7.65	27.79	0.89	0.1560	847	3.8	32	2.84
13433-M	Heron Lake	8/1/2001	11.08	7.5	28.79	13.3	0.0024	835	0.8	0	2.39
11375-P	Creekside	8/1/2001	10.81	7.61	28.28	1.27	0.1110	862	3.3	82	2.7
13433-P	Heron Lake	8/1/2001	11.05	7.42	29.28	16.6	0.00002	837	0.6	na	0.79
13912-M	Konecrans Landel	8/2/2001	10.45	6.94	30	0.26	0.0020	692	1.4	0	18.85
11389-M	CB&I	8/2/2001	9.12	7.28	29.4	2.46	0.0091	720	1.2	0.15	12.35
13912-P	Konecrans Landel	8/2/2001	10.18	7.01	30.13	0.58	0.0024	693	0.9	na	17.65
11389-P	CB&I	8/2/2001	9.09	7.26	29.61	1.86	0.0114	715	0.3	0.03	10.75
12466-M	Oceaneering	8/3/2001	10.27	7.37	29.8	0.57	0.0076	1159	1.2	1.04	19.75
14070-M	Weatherford	8/3/2001	10.34	7.15	28.99	3.5	0.0026	311	1.3	0.12	12.95
12466-P	Oceaneering	8/3/2001	13.16	7.35	31.78	0.81	0.0051	1176	1.6	4.15	19.1
14070-P	Weatherford	8/3/2001	10.65	7.06	28.6	4.25	0.0037	614	2.9	0.13	12.5
12223-M	West Harris Couty MUD 15	8/7/2001	11	7.55	28.09	2.83	0.4400	883	5.7	0.09	6.74
01402-M	Wyman-Gordon	8/7/2001	5.94	8.88	29.24	0.21	nm	216	200.4	0.15	1.34
12223-P	West Harris Couty MUD 15	8/7/2001	9.42	7.56	28.88	0.57	0.6500	909	4.8	0.04	5.6
01402-Duplicate	Wyman-Gordon	8/7/2001	na	na	na	0.02	na	na	na	0.09	1.19
12726-M	Harris County MUD 155	8/8/2001	22.4	8.04	28.8	0.08	0.0660	793	1.7	0.09	6.65
12685-M	Harris County MUD 250	8/8/2001	21.22	7.13	28.18	0.34	0.0945	658	1.7	1.65	6.02
12726-P	Harris County MUD 155	8/8/2001	22.19	8.03	29.24	0.09		798	0.9	0.01	7.5
12685-P	Harris County MUD 250	8/8/2001	20.89	7.13	28.85	0.43	0.0831	638	1.7	1.56	5.54
12304-M	Chimney Hill	8/9/2001	21	7.52	30.23	2.2	0.6130	848	1.8	0.11	1.15
12304-P	Chimney Hill	8/9/2001	22.3	7.46	30.86	1.7	0.5980	844	1.3	0.02	1.82

Table 4.1 Results from Field Measurements for Point Source Monitoring

Sample ID	Location	Date	DO (mg/L)	pH	Temperature (°C)	Residual Chlorine (mg/L)	Flow (MGD)	Conductivity (µS/cm)	Turbidity (NTU)	Ammonia (mg/L)	Ortho-phosphorous (mg/L)
12128-M	Horsepen Bayou	8/10/2001	6.21	7.36	29.45	0.19	0.5890	821	1.2	0	7.25
11523-M	Harris County MUD 102	8/10/2001	7.46	8.17	30.05	na	0.5500	955	-0.2	0	8.9
12128-P	Horsepen Bayou	8/10/2001	6.2	7.4	29.9	0.06	0.6360	815	0.7	0	9.24
11523-P	Harris County MUD 102	8/10/2001	7.68	8.01	30.5	na	1.3100	963	0.1	0	10.82
11969-M	Mayde Creek	8/13/2001	7.44	7.76	29.23	0.01	0.0847	814	3.3	54	14.8
12834-M	Harris County MUD167	8/13/2001	7.96	8.18	28.75	2.42	0.0048	826	2.9	0.03	7.42
11969-P	Mayde Creek	8/13/2001	7.45	7.74	29.49	0.01	0.0640	808	2.7	56	11.45
12834-P	Harris County MUD167	8/13/2001	8.26	8.16	29.04	2.32	0.0042	799	3.1		8.86
12834-Duplicate	Harris County MUD167	8/13/2001				2.82				0	7.56
12574-M	Harris County MUD 130	8/14/2001	8.24	7.85	28.09	1.88	0.1640	847	1.2	0.05	10.32
11935-M	NWHC MUD 17	8/14/2001	7.97	7.58	29.67	1.04	0.1450	781	1.6	0.12	9.45
12574-P	Harris County MUD 130	8/14/2001	8.03	7.81	28.03	0.33	0.1430	845	0.3		8.8
11935-P	NWHC MUD 17	8/14/2001	7.9	7.53	30.09	1.22		782	1	0.06	9.45
11989-M	Fry Road MUD	8/15/2001	7.15	7.34	29.93	0.15	0.5250	938	0.7	0.26	12.35
12247-M	WHC MUD 017	8/15/2001	7.53	7.76	30.05	1.47	0.0060	797	1	0	7.95
11989-P	Fry Road MUD	8/15/2001	7.09	7.35	30.21	0.08	0.2302	945	0.6	0.16	13.15
12247-P	WHC MUD 017	8/15/2001	7.5	7.76	30.22	0.57	0.0061	798	0.8	na	8.2
11193-M	Brittmore	8/21/2001	6.35	na	29.63	0	1.45	0.99	3.3	2.8	8.62
12222-M	WXNW	8/21/2001	7.63	na	29.46	0.02	4.5000	0.936	7.9	0.04	13.2
11193-P	Brittmore	8/21/2001	6.52	na	30.19	0.04	0.95	0.982	3.9	1.7	6.2
12222-P	WXNW	8/21/2001	7.56	na	29.59	0.04	1.1800	0.947	8.1	0.03	15.25
12222- Duplicate	WXNW	8/21/2001				0.03				0	14.7
12346-M	West Park MUD	8/22/2001	6.91	na	29.47	1.82	0.1970	0.783	1.1	0.04	6.4
11696-M	Addicks UD	8/22/2001	7.42	na	29.55	0.03	0.1104	0.809	1.3	0	9.9
12346-P	West Park MUD	8/22/2001		na			0.1770				
11696-P	Addicks UD	8/22/2001	7.58	na	29.8	0.11	0.4690	0.836	2		3.3
12110-M	Katy ISD	8/23/2001	7.93	na	27.66	0.49	0.1405	0.696	8.3	0.1	10.4
12110-Duplicate	Katy ISD	8/23/2001				0.1					10.32
12110-P	Katy ISD	8/23/2001	8.04	na	28.34	0.17	0.1825	0.739	6.2		11.6
11414-M	Eli Sasson	8/24/2001	7.34	na	28.27	1.9	0.0115	669	2.6	0.1	12.1
12310-M	Richard Verry	8/24/2001	4.66	na	28.86	0.1	0.0077	750	0.3	28	1.22
11414-P	Eli Sasson	8/24/2001	6.76	na	28.87	0.39	0.0133	672	2.1	10	13.15
12310-P	Richard Verry	8/24/2001	4.99	na	29.61	0.11	0.0063	752	na	24	1.42
14072-M	WHC MUD 10	8/27/2001	6.92	na	28.81	0.03	1.5200	0.934	4.2	>50	10.9
13689-M	WHC MUD 11	8/27/2001	6.88	na	29.09	0	0.1300	1.039	3.1	0	13.9
14072-P	WHC MUD 10	8/27/2001	7.05	na	29.33	0.04	1.3000	0.925	4	>50	12.8
13689-P	WHC MUD 11	8/27/2001	7.19	na	29.48	0	0.2470	1.039	1.2	na	14.65
12479-M	Nottingham	8/28/2001	6.97	6.8	28.46	0.01	0.4430	0.379	0	0.03	12.75
12479-Duplicate	Nottingham	8/28/2001				0.03	0.4080			0.02	13.2
11188-M	Rolling Fork PUD	09/06/01		7.65	28.38	4.25	0.5120	744	1.6	0.01	6.72
11051-M	Vancouver	09/06/01	6.24	7.77	27.99	0.04	0.0266	773	12.3	0.2	11.15
11188-P	Rolling Fork PUD	09/06/01	7.51	7.78	28.72	1.55	0.2510	733	0.6		7.56

Table 4.1 Results from Field Measurements for Point Source Monitoring

Sample ID	Location	Date	DO (mg/L)	pH	Temperature (°C)	Residual Chlorine (mg/L)	Flow (MGD)	Conductivity (µS/cm)	Turbidity (NTU)	Ammonia (mg/L)	Ortho-phosphorous (mg/L)
11051-P	Vancouver	09/06/01	6.51	7.75	28.12	0.04	0.0319	764	0.4	0.34	10.45
11883-M	Castlewood	09/11/01	7.72	7.2	27.72	5.95	0.6100	763	4.9	0.12	10.3
12682-M	MUD #345	09/11/01	7.18	7.23	28.56	0.56	0.1040	904	4	0	13.6
11883-P	Castlewood	09/11/01	6.39	6.94	28.08	0.03	0.4690	760	2.7	0.07	11.35
12682-P	MUD #345	09/11/01	7.28	7.29	28.68	0.14	0.1240	840	3.2	0.12	19.5
13509-M	Bob Smith	09/13/01	6.88	7.55	26.78	0.07	0.0023	745	4	7	13.85
13727-M	Moorpark Village	09/13/01	7.53	7.56	26.81	4.2	0.0192	640	0.6	0	14.35
13509-P	Bob Smith	09/13/01	6.65	7.52	27.04	0.07	0.0035	735	3.6	5.92	13.85
13727-P	Moorpark Village	09/13/01	7.47	7.58	27.24	2.8	0.0055	841	1	na	16.45
13578-M	Cooper Energy Services	09/14/01	2.62	6.33	30.52	0.11	0.0024	720	12.3	2.34	20.15
13807-M	McDonalds Corp	09/14/01	7.72	7.57	27.67	2.16	0.0021	1115	4.7	0	42.4
13578-P	Cooper Energy Services	09/14/01	3.14	6.47	31.14	0.21	0.0047	706	13.7	2.78	21.2
13807-P	McDonalds Corp	09/14/01	7.23	7.48	28.48	1.07	nm	1117	5.4	0	49.9
13921-M	HC Juvenile Boot Camp	09/17/01	7.76	7.06	28.69	11	0.0180	647	91.5	0.83	27.5
13921-M-Duplicate	HC Juvenile Boot Camp	09/17/01	na	na	na	1.6	na	na	na	0.72	27.5
13921-P	HC Juvenile Boot Camp	09/17/01	7.73	6.4	28.77	0.12	0.0030	629	93	0.83	27.5
11284-M	Westlake MUD	09/19/01	6.66	7.37	28.96	0.04	0.7035	856	0	0.27	4.08
12802-M	HC MUD 238	09/19/01	8.29	7.37	29.79	0.9	0.1188	740	5.2	0	12.7
11284-P	Westlake MUD	09/19/01	7.93	7.28	29.41	0.18	0.6248	860	0	0	2.92
12802-P	HC MUD 238	09/19/01	8.19	7.48	29.93	1.73	0.0821	750	1.5	0	11.05
11906-M	HC MUD 157	09/20/01	7.33	7.37	28.94	0.2	0.3200	832	0.7	0	10.7
11792-M	HC MUD 105	09/20/01	7.35	7.47	27.9	0.04	0.3010	709	0.4	0.31	6.74
11906-P	HC MUD 157	09/20/01	7.36	7.36	29.43	>2	0.3100	842	2		9.55
11792-P	HC MUD 105	09/20/01	7.32	7.49	28.26	0.06	0.2410	706	0.1		7.22
12298-M	Ft. Bend Coutny MUD 34	09/25/01	7.91	7.85	24.05	2.68	0.0210	888	3.1	0	6.8
12298-P	Ft. Bend Coutny MUD 34	09/25/01	7.96	7.83	24.1	0.96	0.0513	911	2.3	na	7.04
11485-M	Harris County MUD 023	09/26/01	7.1	7.37	25.81	0.73	0.4520	834	6.2	0	12.05
12139-M	Fairbanks Plaza	09/26/01	7.5	7.8	25.39	0	0.0065	772	0.9	0.16	0.53
11485-P	Harris County MUD 023	09/26/01	8.65	7.39	26.16	0.15	0.2871	817	4.1	0	11.85
12139-P	Fairbanks Plaza	09/26/01	7.64	7.81	25.53	0.06	0.000004	739	1.5	0.07	0.61
11917-M	HCMUD 71	09/27/01	7.87	7.92	26.66	0.59	0.4830	795	0.4	1.99	13.25
11917-dup	HCMUD 71	09/27/01				0.47	0.3900			2.26	9.05
11917-P	HCMUD 71	09/27/01	8.06	7.93	26.94	0.13	0.2500	826	0.9	0.04	9.95
12714-M	Harris County MUD 119	09/28/01	6.56	7.55	27.91	2.6	0.2320	845	5.2	0.05	8.08
12714-outfall	Harris County MUD 119	09/28/01	8.01	7.84	26.32	2.78		842	2.6	0.02	8.38
12714-P	Harris County MUD 119	09/28/01	6.52	7.5	27.92	2.42	0.1220	846	4.5	0.04	8.3
12949-M	HCMUD 284	10/01/01	8.4	7.21	22.47	4.1	0.0055	911	8.2	0	10.75
12140-M	WHC 007	10/01/01	8.6	7.48	25.42	0.12	0.1590	842	3.4	0.04	14.6
12427-M	Aivazian	10/02/01	6.5	7.8	24.47	0.06	nm	587	12.6	0.01	11.75
12427-P	Aivazian	10/02/01	6.73	7.94	25.52	11.2	0.0218	674	12.5	0.01	12
12465-M	TIFCO	10/03/01	9.85	1.65	23.64	0.01	0.0052	6488	2.7	5.4	13.6
12465-P	TIFCO	10/03/01	9.76	1.9	24.17	0.01	0.0021	4137	1.3	3.28	16.55

Table 4.1 Results from Field Measurements for Point Source Monitoring

Sample ID	Location	Date	DO (mg/L)	pH	Temperature (°C)	Residual Chlorine (mg/L)	Flow (MGD)	Conductivity (µS/cm)	Turbidity (NTU)	Ammonia (mg/L)	Ortho-phosphorous (mg/L)
13807-P	McDonalds	10/03/01	7.96	7.32	25.35	2.16	0.0035	7180	9.2	0.04	51.2
13807-P1	McDonalds	10/03/01					0.0058			0.08	98
03153-M	Toshiba Corp.	10/05/01		7	25.5	1.48	0.0287	1133	2.6	0	23.45
03994-M	Varco Shaffer	10/05/01		7.6	24	0.09	0.0022	706	2.4	0	10
03153-P	Toshiba Corp.	10/05/01		6.95	25.3	1	0.0320	1092	4	0	21.05
03994-P	Varco Shaffer	10/05/01		7.57	23.9	0.11	0.0224	736	1.6	0	13.65
03994-P-Duplicate	Varco Shaffer	10/05/01				0.03				0	12.25
11670-M	Sunbelt	10/09/01				0.06	0.4970			0.83	9.44
11670-M-Duplicate	Sunbelt	10/09/01	6.07	6.98	25.33	0.04	0.4970	811	2.4	0.74	9.4
11670-P	Sunbelt	10/09/01	6.54	7.04	26.12	0.07	0.3000		14	0.76	10.08
11598-M	Williamsburg Regional	10/10/01	6.62	7.06	27.36	1.09	0.8120	914	2.3	0	9.9
11598-M-Duplicate	Williamsburg Regional	10/10/01				1.24	0.7950			0	10.6
11598-P	Williamsburg Regional	10/10/01	6.88	7.11	27.8	0.1	0.7090	917	0.9	0	10.5
12682-M	HCMUD 216	10/11/01	8.26	7.92	26.38	0.12	0.0440	654	33.5	0.01	6.88
12289-M	Green Trails	10/11/01				0.03	2.1090			0	10.1
12412-M	Cooper Cameron Corp.	10/15/01	8.12	7.37	21.42	0.08	0.0003	724	8.3	0	9.06
12412-P	Cooper Cameron Corp.	10/15/01	8.28	7.36	21.62	0.03	0.0006	721	8.2	0	6.8
12412-P-Duplicate	Cooper Cameron Corp.	10/15/01				0.06				0	9.3
11472-M	Spencer Road	10/16/01	8.43	7.45	23.59	3.9	0.5500	910	0.5	0	8.74
11472-P	Spencer Road	10/16/01	8.45	7.43	23.22	3.18	0.5100	911	0.8	na	8.42
10495-139-M	Westway WWTP	10/17/01	8.13	7.77	23.56	1.98	1.7900	794	1.6	0	7.9
10495-139-P	Westway WWTP	10/17/01	7.75	7.76	23.32	1.58	0.0900	759	1.6	0	7.3
13484-M	529 #35	10/18/01	8.91	6.91	21.07	0	0.0290	714	5.6	0	12.35
12132-M	White Oak	10/18/01	8.56			1.08	0.0189	512	4.6	0	7.24
13484-P	529 #35	10/18/01	8.97	7.01	21.2	0.89	0.0560	703	4.9	na	12.65
10495-M	P Ten	10/23/01	8.16	7.57	27.67	0.03	1.6000	947	1.6	0.04	7.66
10495-P	P Ten	10/23/01	7.56	7.4	28.12	0.02	0.5760	950	6.4		7.24
10495-Duplicate	P Ten	10/23/01				0.03	0.5760				7.26
11005-M	Champ's Water	10/24/01	7.57	7.74	25.85	0.36	0.0950	682	3.9	0	1.65
12342-M	C&P Utilities	10/24/01	6.29	7.27	25.47	3.3	0.0230	794	0.3	0.06	12.15
11005-P	Champ's Water	10/24/01	6.09	7.54	26.17	0.24	0.2180	680	3.4	0	1.6
12342-P	C&P Utilities	10/24/01	7.2	7.27	25.93	3.32	0.0105	798	0.1	0.02	12.05

Notes/Abbreviations:

M denotes a measurement made early in the morning
P denotes a measurement made at mid-morning
WWTP = waste water treatment plant
na = not available
MUD = municipal utility district
mg = milligram
µS = micro Siemens
WHC = West Harris County
NWHC = North West Harris County
MGD = million gallons per day
nm = not measurable (flow too low to be quantified)
L = liter
cm = centimeter
NTU = Nephelometric Turbidity units

Table 4.2 Methods Used for EC/FC Analysis in Point Source Sampling

Constituent	Method	Description
FC	M9222D	Membrane filtration
EC	IDEXX	IDEXX MPN Quantitray 2000
Total Suspended Solids	E160.2	Filtration, dry weight

Note that the EC analyses are performed using the IDEXX Colilert method that is a separate test from the FC analysis. This difference in methodology may result in EC counts higher than the FC data. Laboratory results from this monitoring component are included in Table 4.3.

Figure 4.2 shows a summary of the EC levels measured at the 76 WWTPs sampled and Table 4.4 includes a summary of the statistical analysis performed with the data. Overall, EC levels ranged from 0 to 22,027 MPN/100 mL with 7.2% of the samples exceeding the water quality criteria (126 MPN/100 mL). FC concentrations, on the other hand, ranged from 0 to 5,000 cfu/100 mL with 2% of the samples exceeding the 200 cfu/100 mL criteria. The exceedances occurred mostly in Whiteoak Bayou with only one observed in Buffalo Bayou.

A correlation analysis was completed to assess the possible relationship between a number of parameters and the EC concentrations. Figures 4.3, 4.4, 4.5, 4.6, and 4.7 show the correlation charts for the following paired data: EC-FC, EC-TSS, EC-Cl^-, EC-NH_3 and EC-PO_4, respectively. However, as can be seen in those figures, no correlations are readily evident.

Table 4.3 Results from Lab Analyses for Point Source Monitoring

Sample ID	Location	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[a]	Fecal Coliforms (cfu/100 mL)[b]	TSS (mg/L)[b]
10876-001-M	Barwood WWTP	07/24/01	1.3990	568.8	2.7	450	4.7
10876-002-M	Hastings Green WWTP	07/24/01	1.0760	78.1	9.5	100	2.7
10876-001-P	Barwood WWTP	07/24/01	1.1140	388.1	6.1	150	<1.0
10876-002-P	Hastings Green WWTP	07/24/01	0.7250	44.2	1.0	11	1.3
12121-001-M	Harris County MUD 170	07/25/01	1.2000	1460.1	21.0	0	2
12121-001-P	Harris County MUD 170	07/25/01	1.0000	1305.5	5.6	0	2.7
12795-M	Northwest Harris County MUD 29	07/26/01	0.2950	1986.3	30.1	7	8.8
11273-M	Harris County MUD 6	07/26/01	0.2135	4.1	1.6	0	<1.0
12795-P	Northwest Harris County MUD 29	07/26/01	0.0210	604.3	322.1	7	7.6
11273-P	Harris County MUD 6	07/26/01	0.2130	12.3	<1	0	1.2
12443-M	Superior Derrick	07/27/01	0.0012	34.0	<1	0	4
12573-M	William Smith MHP	07/27/01	0.0152	2.4	<1	0	3
12443-P	Superior Derrick	07/27/01	0.0013	128.8	14.3	0	4.5
12573-P	William Smith MHP	07/27/01	0.0152	33.0	<1	0	4
11979-M	White Oak Bend WWTP	07/30/01	0.2720	39.3	<1	3	2.5
11979-P	White Oak Bend WWTP	07/30/01	0.2300	<1	<1	0	4.8
11563-M	WHC MUD #21	07/31/01	0.7450	1053.5	15.4	73	13.6
13623-M	Reid Road	07/31/01	0.4000	<1	<1	0	8.4
11563-P	WHC MUD #21	07/31/01	0.6130	918.8	13.3	93	9.5
13623-P	Reid Road	07/31/01	0.3300	<1	<1	0	9.5
11375-M	Creekside	08/01/01	0.1560	2814.3	32.3	2	5.5
13433-M	Heron Lake	08/01/01	0.0024	<1	<1	0	1.5
11375-P	Creekside	08/01/01	0.1110	220.4	3.4	0	4
11375-outfall	Creekside	08/01/01		15530.7	292.7	60	
13433-P	Heron Lake	08/01/01	0.00002	<1	<1	0	1
13912-M	Konecrans Landel	08/02/01	0.0020	<1	<1	0	7.5
11389-M	CB&I	08/02/01	0.0091	573.0	0.0	7	3
13912-P	Konecrans Landel	08/02/01	0.0024	4.9	0.5	2	3.5
11389-P	CB&I	08/02/01	0.0114	28.8	3.1	1	2.5
12466-M	Oceaneering	08/03/01	0.0076	742.7	295.2	4	8.5
14070-M	Weatherford	08/03/01	0.0026	29.1	<1	0	8.5
12466-P	Oceaneering	08/03/01	0.0051	18.3	3.8	0	9

Table 4.3 Results from Lab Analyses for Point Source Monitoring

Sample ID	Location	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[a]	Fecal Coliforms (cfu/100 mL)[b]	TSS (mg/L)[b]
14070-P	Weatherford	08/03/01	0.0037	21.4	<1	0	12
12223-M	West Harris Couty MUD 15	08/07/01	0.4400	16.5	7.4	4	9.5
12223-P	Wyman-Gordon	08/07/01	0.6500	14.0	<1	2	10.5
01402-M	West Harris Couty MUD 15	08/07/01		>24192	1231.2	5000	60
12726-M	Harris County MUD 155	08/08/01	0.0660	665.6	65.8	34	6.5
12685-M	Harris County MUD 250	08/08/01	0.0945	<1	<1	0	8
12726-P	Harris County MUD 155	08/08/01		893.0	96.5	24	8
12685-P	Harris County MUD 250	08/08/01	0.0831	<1	<1	0	7.5
12304-M	Chimney Hill	08/09/01	0.6130	609.6	3.1	2	7
12304-P	Chimney Hill	08/09/01	0.5980	95.3	<1	5	8
11523-M	Harris County MUD 102	08/10/01	0.5500	2202.7	33.3	0	3
12128-M	Horsepen Bayou	08/10/01	0.5890	1081.6	10.5	0	3
11523-P	Harris County MUD 102	08/10/01	1.3100	2130.6	28.6	0	2
12128-P	Horsepen Bayou	08/10/01	0.6360	714.5	26.8	0	1
11969-M	Mayde Creek	08/13/01	0.0847	6131.0	24.7	19	5.5
12834-M	Harris County MUD167	08/13/01	0.0048	6.2	<1	0	5
11969-P	Mayde Creek	08/13/01	0.0640	6998.0	28.1	0	7
12834-P	Harris County MUD167	08/13/01	0.0042	1.0	<1	0	2.5
12574-M	Harris County MUD 130	08/14/01	0.1640	9.2	<1	0	4.7
11935-M	NWHC MUD 17	08/14/01	0.1450	409.8	0.7	4	4.7
12574-P	Harris County MUD 130	08/14/01	0.1430	4.2	2.1	0	7.3
11935-P	NWHC MUD 17	08/14/01		549.0	0.0	3	8
11989-M	Fry Road MUD	08/15/01	0.5250	0.7	0.0	0	<1.0
12247-M	WHC MUD 017	08/15/01	0.0060	397.8	<1	0	2
11989-P	Fry Road MUD	08/15/01	0.2302	2.0	<1	0	2
12247-P	WHC MUD 017	08/15/01	0.0061	305.8	<1	0	2
11193-M	Brittmore	08/21/01	1.4500	8891.0	1295.8	0	7
12222-M	WXNW	08/21/01	4.5000	>24,192	22027.3	0	12
11193-P	Brittmore	08/21/01	0.9500	4531.3	126.9	0	7
12222-P	WXNW	08/21/01	1.1800	20760.2	7597.0	0	12
12346-M	West Park MUD	08/22/01	0.1970	<1	<1	0	1
11696-M	Addicks UD	08/22/01	0.1104	5.2	<1	0	3

Table 4.3 Results from Lab Analyses for Point Source Monitoring

Sample ID	Location	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[a]	Fecal Coliforms (cfu/100 mL)[b]	TSS (mg/L)[b]
11696-P	Addicks UD	08/22/01	0.4690	20.0	2.3	4	8
12110-M	Katy ISD	08/23/01	0.1405	1.6	<1	0	4
12110-P	Katy ISD	08/23/01	0.1825	3.1	<1	0	3.5
11414-M	Eli Sasson	08/24/01	0.0115	<1	<1	0	4
12310-M	Richard Verry	08/24/01	0.0077	6.7	<1	0	<1.0
11414-P	Eli Sasson	08/24/01	0.0133	4.1	<1	0	4
12310-P	Richard Verry	08/24/01	0.0063	2.7	<1	0	1.5
14072-M	WHC MUD 10	08/27/01	1.5200	1506.6	17.3	16	2.5
13689-M	WHC MUD 11	08/27/01	0.1300	2130.6	314.4	58	2
14072-P	WHC MUD 10	08/27/01	1.3000	1018.7	<1	18	2.5
13689-P	WHC MUD 11	08/27/01	0.2470	1299.7	38.5	12	1.5
12479-M	Nottingham	08/28/01	0.4430	2274.9	54.3	30	3
11188-M	Rolling Fork PUD	09/06/01	0.5120	<1	<1	0.0	3.0
11051-M	Vancouver	09/06/01	0.0266	1171.3	49.4	0.0	2.0
11188-P	Rolling Fork PUD	09/06/01	0.2510	<1	<1	0.0	1.0
11051-P	Vancouver	09/06/01	0.0319	1817.2	44.1	0.0	1.0
11883-M	Castlewood	09/11/01	0.6100	<1	<1	0.0	3.0
12682-M	MUD #345	09/11/01	0.1040	22.6	<1	0.0	28.0
11883-P	Castlewood	09/11/01	0.4690	8.9	<1	0.0	2.0
12682-P	MUD #345	09/11/01	0.1240	18.1	<1	2.0	1.0
13509-M	Bob Smith	09/13/01	0.0023	>2419.2	74.1	1.0	6.0
13727-M	Moorpark Village	09/13/01	0.0192	<1	<1	0.0	5.0
13509-P	Bob Smith	09/13/01	0.0035	3480.3	68.3	0.0	10.0
13727-P	Moorpark Village	09/13/01	0.0055	3.2	<1	0.0	5.0
13807-M	McDonalds Corp	09/14/01	0.0021	<1	<1	0.0	8.0
13578-M	Cooper Energy Services	09/14/01	0.0024	<1	<1	0.0	14.0
13807-P	McDonalds Corp	09/14/01		<1	<1	0.0	4.0
13578-P	Cooper Energy Services	09/14/01	0.0047	<1	<1	0.0	20.0
13807-dup		09/14/01		<1	<1	0.0	6.0
13921-M	HC Juvenile Boot Camp	09/17/01	0.0180	84.2	<1	0.0	19.0
13921-M dup	HC Juvenile Boot Camp	09/17/01	na	385.3	<1	18.0	21.0
13921-P	HC Juvenile Boot Camp	09/17/01	0.0030	1528.5	3.0	2.0	21.0

Table 4.3 Results from Lab Analyses for Point Source Monitoring

Sample ID	Location	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[a]	Fecal Coliforms (cfu/100 mL)[b]	TSS (mg/L)[b]
11284-M	Westlake MUD	09/19/01	0.7035	1483.3	8.2	13.0	1.0
12802-M	HC MUD 238	09/19/01	0.1188	7.2	8.6	0.0	4.0
11284-P	Westlake MUD	09/19/01	0.6248	1855.2	7.9	11.0	9.0
12802-P	HC MUD 238	09/19/01	0.0821	6.7	<1	0.0	3.0
11906-M	HC MUD 157	09/20/01	0.3200	3.1	<1	0.0	1.0
11792-M	HC MUD 105	09/20/01	0.3010	1961.6	3.7	36.0	1.0
11906-P	HC MUD 157	09/20/01	0.3100	<1	<1	0.0	1.0
11792-P	HC MUD 105	09/20/01	0.2410	1496.4	6.7	21.0	1.0
11917-M	HCMUD 71	09/24/01	0.4830	190.0	0.7	0.0	1.0
11917-M-dup	HCMUD 71	09/24/01	0.3900	137.9	<1	0.0	1.0
11917-P	HCMUD 71	09/24/01	0.2500	94.6	<1	0.0	1.0
12298-M	Ft. Bend Coutny MUD 34	09/25/01	0.0210	<1	<1	0.0	3.0
12298-P	Ft. Bend Coutny MUD 34	09/25/01	0.0513	2.5	<1	0.0	3.0
11485-M	Harris County MUD 023	09/26/01	0.4520	1.0	<1	0.0	3.5
12139-M	Fairbanks Plaza	09/26/01	0.0065	>24192	2076.0	380.0	3.5
11485-P	Harris County MUD 023	09/26/01	0.2871	3.1	1.0	0.0	2.0
12139-P	Fairbanks Plaza	09/26/01	0.000004	260.6	3.7	0.0	6.0
12714-M	Harris County MUD 119	09/28/01	0.2320	8.4	2.0	0.0	6.5
12714-P	Harris County MUD 119	09/28/01	0.1220	4.5	<1	0.0	4.0
12714-outfall	Harris County MUD 119	09/28/01		2.4	<1	0.0	6.0
12949-M	HCMUD 284	10/01/01	0.0055	<1	<1	0.0	1.0
12140-M	WHC 007	10/01/01	0.1590	4.1	<1	1.0	3.0
12427-M	Aivazian	10/02/01		2419.2	4.5	6.0	<1
12427-P	Aivazian	10/02/01	0.0218	1.5	<1	0.0	1.0
12465-M	TIFCO	10/03/01	0.0052	<1	<1	0.0	13.5
12465-P	TIFCO	10/03/01	0.0021	251.9	193.0	0.0	6.5
13807-P	McDonalds	10/03/01	0.0035	7.2	<1	0.0	10.0
03153-M	Toshiba Corp.	10/05/01	0.0287	<1	<1	0.0	2.5
03994-M	Varco Shaffer	10/05/01	0.0022	<1	<1	0.0	2.0
03153-P	Toshiba Corp.	10/05/01	0.0320	2.7	<1	0.0	1.5
03994-P	Varco Shaffer	10/05/01	0.0224	9.0	<1	0.0	2.0

Table 4.3 Results from Lab Analyses for Point Source Monitoring

Sample ID	Location	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[a]	Fecal Coliforms (cfu/100 mL)[b]	TSS (mg/L)[b]
11670-M	Sunbelt	10/09/01	0.4970	467.3	15.4	1.0	24.5
11670-M-dup	Sunbelt	10/09/01	0.4970	401.3	12.3	1.0	23.0
11670-P	Sunbelt	10/09/01	0.3000	1041.3	24.7	0.0	22.5
11598-M	Williamsburg Regional	10/10/01	0.8120	1245.6	55.1	14.0	4.5
11598-M-dup	Williamsburg Regional	10/10/01	0.7950	964.0	34.0	13.0	4.0
11598-P	Williamsburg Regional	10/10/01	0.7090	1048.8	51.8	10.0	5.5
12682-M	HCMUD 216	10/11/01	0.0440	522.7	<1	0.0	22.5
12289-M	Green Trails	10/11/01	2.1090	169.7	5.8	5.0	3.5
12412-M	Cooper Cameron Corp.	10/15/01	0.0003	52.8	4.8	2.0	20.5
12412-P	Cooper Cameron Corp.	10/15/01	0.0006	46.6	3.8	0.0	23.5
12412-P-Dup	Cooper Cameron Corp.	10/15/01		128.9	15.1	3.0	23.0
11472-M	Spencer Road	10/16/01	0.5500	<1	<1	4.0	2.5
11472-P	Spencer Road	10/16/01	0.5100	<1	<1	0.0	3.0
10495-139-M	Westway WWTP	10/17/01	1.7900	<1	<1	0.0	2.0
10495-139-P	Westway WWTP	10/17/01	0.0900	1.3	<1	0.0	2.0
13484-M	529 #35	10/18/01	0.0290	12.7	<1	0.0	6.0
12132-M	White Oak	10/18/01	0.0189	<1	<1	0.0	4.2
13484-P	529 #35	10/18/01	0.0560	<1	<1	0.0	3.9
10495-M	P Ten	10/23/01	1.6000	2419.2	4.1	3.0	5.6
10495-P	P Ten	10/23/01	0.5760	1672.9	16.6	2.0	7.1
10495-P-Dup	P Ten	10/23/01	0.5760	682.9	0.0	2.0	4.0
11005-M	Champ's Water	10/24/01	0.0950	10.0	2.1	0.0	3.5
12342-M	C&P Utilities	10/24/01	0.0230	48.4	2.0	0.0	4.5
11005-P	Champ's Water	10/24/01	0.2180	3.8	<1	0.0	2.0
12342-P	C&P Utilities	10/24/01	0.0105	9.9	0.0	0.0	6.0

Notes/Abbreviations:

[a] Parameter analyzed at UH lab. The results are the average of triplicates for a given dilution. At least two different dilutions were prepared for each sample (1:1 and 1:10). If historical data showed high levels a third dilution (1:100) was prepared

[b] Parameter analyzed at NWDLS lab

M denotes a measurement made early in the morning

P denotes a measurement made at mid-morning

E. coli = Escherichia coli

cfu = colony forming units

MGD = million gallons per day

MPN = most probable number

TSS = total suspended solids

mg = milligram

L = liter

Samples exceeding the EC criterion of 126 MPN/100 mL are highlighted in green

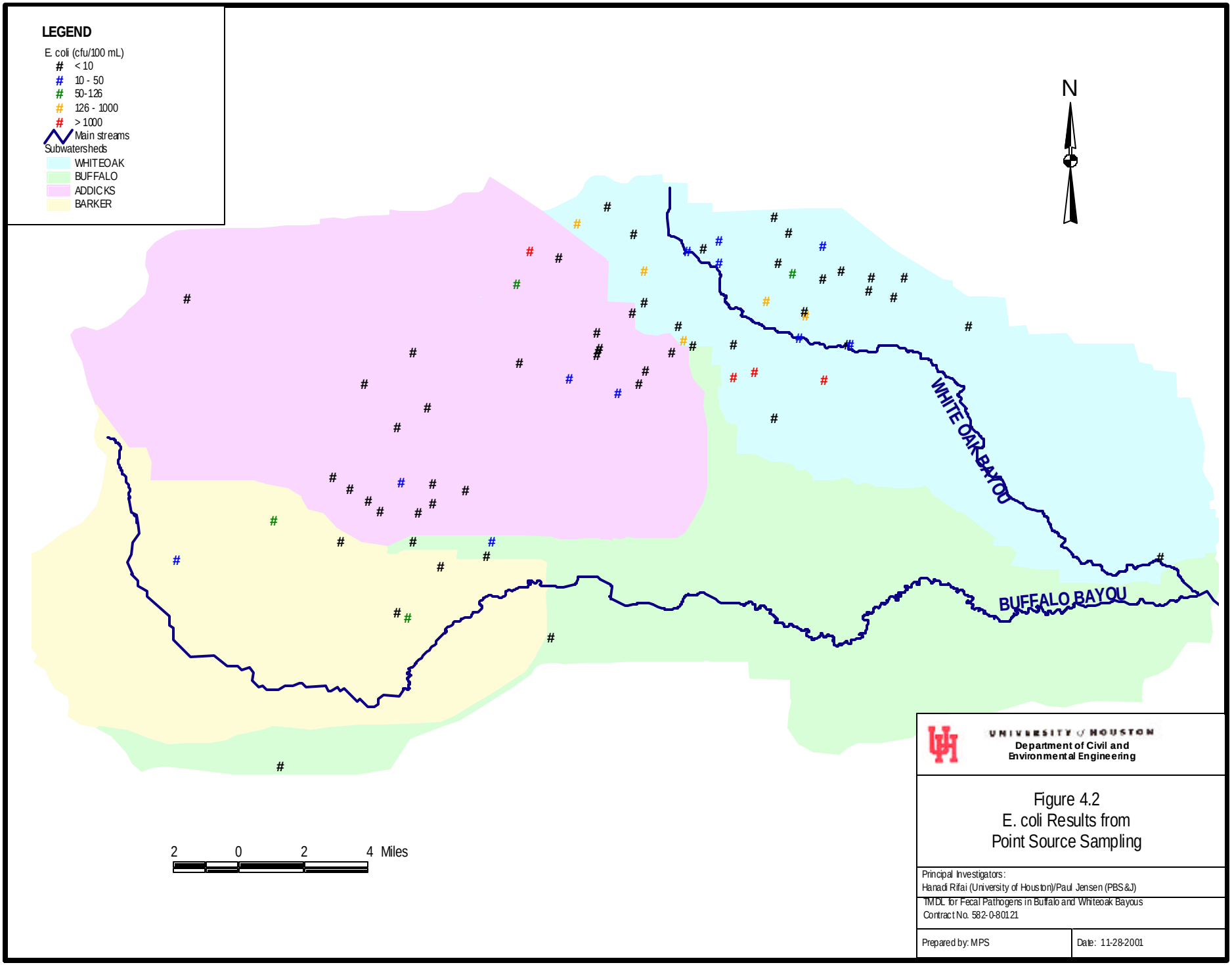


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Figure 4.2
E. coli Results from
Point Source Sampling

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: MPS

Date: 11-28-2001

Table 4.4 Statistical Summary of Data from Point Source Sampling

	Total Coliforms (MPN/100 mL)	*E coli* (MPN/100 mL)	Fecal Coliforms (cfu/100 mL)	TSS (mg/L)	Turbidity (NTU)	Ammonia (mg/L)	Ortho-phosphorous (mg/L)
ALL SAMPLES							
number of measurements	152	152	152	151	142	127	150
minimum	<1	0.0	0.0	1.0	0.0	0.00	0.0
25th percentile	2.4	0.5	0.0	2.0	0.9	0.00	7.1
median	31.1	0.5	0.0	4.0	2.1	0.04	10.0
75th percentile	930.1	12.6	3.0	7.6	4.1	0.31	13.1
maximum	> 24,192	22,027	5,000	60.0	200.4	51	57
geometric mean	36.0	2.7	0.5				
% exceeding regulatory level		7.2%	2.0%				
PEAK FLOW SAMPLES							
number of measurements	80	80	80	79	74	78	79
minimum	0.5	0.5	0.1	1	0	0	0
25th percentile	0.9	0.5	0.1	2.5	0.925	0	6.8
median	43.8	0.5	0.1	4	2.3	0.04	10.1
75th percentile	1104.0	15.4	4.3	7	4.675	0.25	12.9
maximum	> 24,192	22027	5000	60	200.4	51	57
geometric mean	39.0	3.2	0.7				
% exceeding regulatory level		8.8%	3.8%				
OFF-PEAK FLOW SAMPLES							
number of measurements	69	72	72	72	68	49	71
minimum	0.5	0.5	0.1	1	0	0	0.61
25th percentile	2.7	0.5	0.1	2	0.8	0	7.2
median	18.3	0.5	0.1	4	1.85	0.04	10.0
75th percentile	549.0	9.0	2.0	8	4	0.76	13.2
maximum	3480	7597	150	23.5	93	5.92	51.2
geometric mean	28.0	2.3	0.3				
% exceeding regulatory level		5.6%	0.0%				

Notes:

Values below the detection limit (i.e. <1 MPN/100 mL) were assumed to be equal to half of the detection limit (0.5 MPN/100 mL) for statistical analysis purposes

Values above the detection limit (i.e. > 24,192 MPN/100 mL) were assumed to be equal to 24,200 MPN/100 mL

MPN = most probable number

cfu = colony forming unit

mg = milligram

mL = milliliter

NTU = Nephelometric turbidity units

L = liter

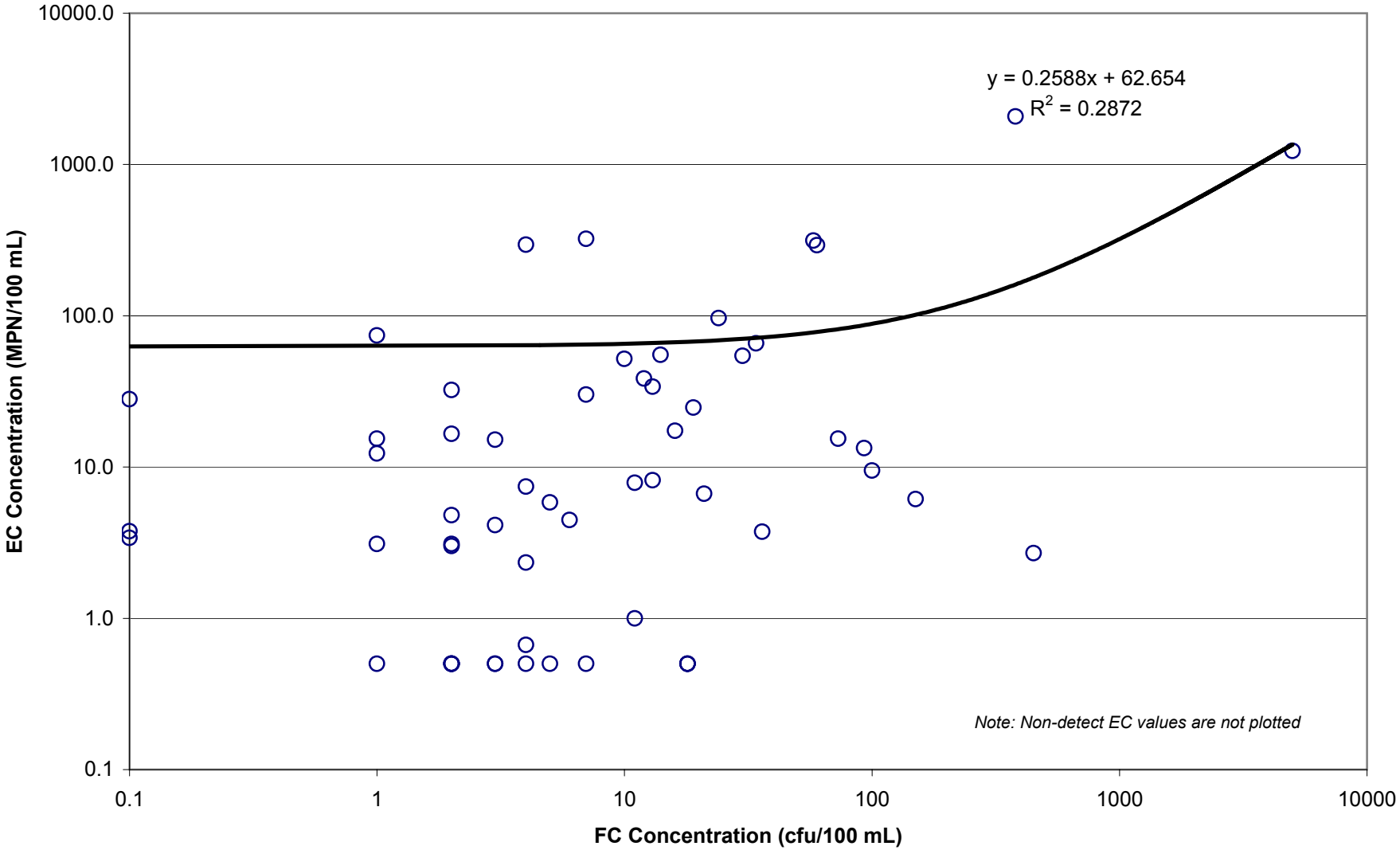

Figure 4.3 EC versus FC Concentrations

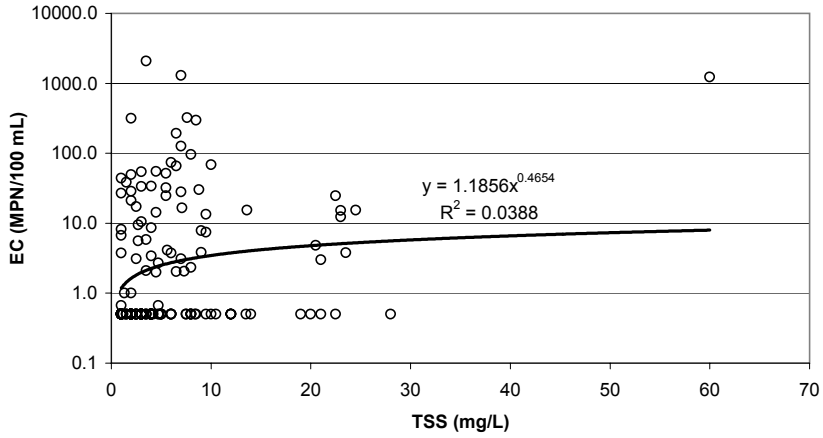

Figure 4.4 EC versus TSS Concentrations

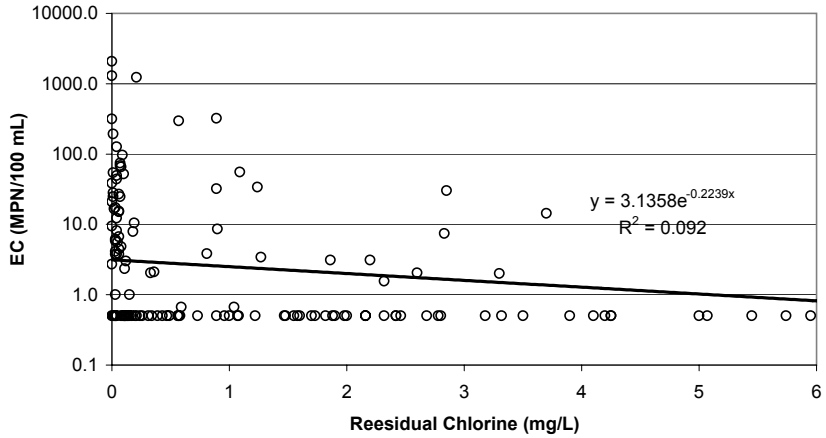

Figure 4.5 EC versus Residual Chlorine Concentrations

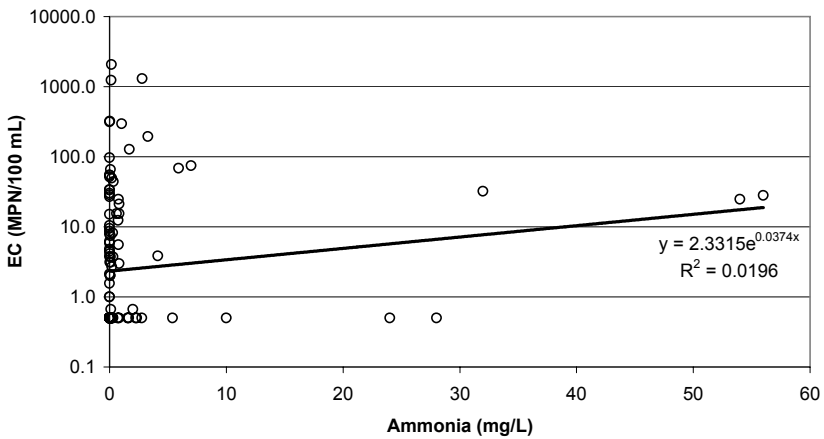

Figure 4.6 EC versus Ammonia Concentrations

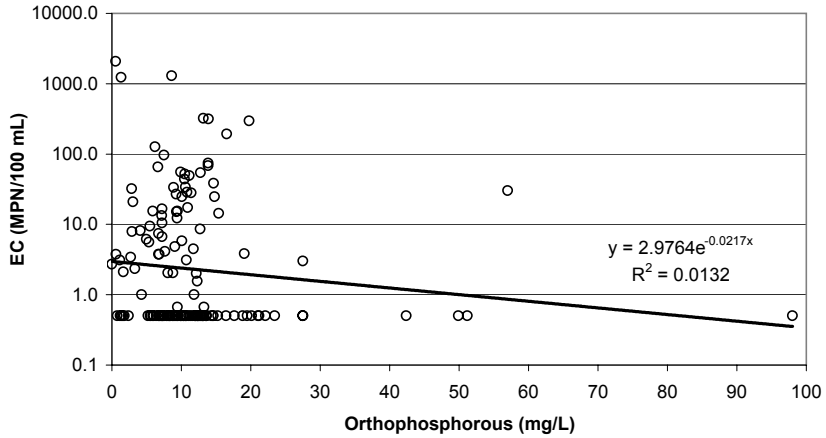

Figure 4.7 EC versus Ortho-phosphorous Concentrations

Note: Non-detect EC values were plotted as half of the detection limit (i.e. 0.5 MPN/100 mL)

To calculate the EC and FC loads from the WWTPs to the bayous, the measured concentration for a given sample was multiplied by the instantaneous flow observed at the time the sample was taken and an average load was calculated for each plant (Table 4.5). The calculated loads from the 41 WWTPs discharging to Buffalo Bayou sampled are $1.9x10^{12}$ MPN/yr and $8.5x10^{11}$ cfu/yr for EC and FC, respectively. The estimated loads to Whiteoak Bayou from the 35 WWTPs sampled are $7.6x10^{14}$ MPN/yr and $7.5x10^{12}$ cfu/yr for EC and FC, respectively. The total flow from sampled point sources was 18.24 cfs for Buffalo Bayou and 20.77 cfs for Whiteoak Bayou. When including the both the sampled and not sampled WWTP, the total inflows to the bayous from point sources are 41.45 cfs for Buffalo Bayou and 40.33 cfs for Whiteoak Bayou, which correspond to 41% and 84% of the median flows (Typical dry weather flow) in these bayous, respectively.

Table 4.5 Loads from Point Sources

	Watershed	Flow		Loads	
		MGD	cfs	EC (MPN/yr)	FC (cfu/yr)
SAMPLED	Buffalo Bayou				
	Addicks reservoir	6.43	9.94	7.65E+11	3.42E+11
	Barker reservoir	3.98	6.15	1.01E+12	4.64E+11
	Below dam	1.39	2.14	1.29E+11	4.16E+10
	Total Buffalo Bayou	11.79	18.24	1.90E+12	8.48E+11
	Whiteoak Bayou	13.43	20.77	7.62E+14	7.53E+12
NOT SAMPLED[a]	Buffalo Bayou[b]	15.00	23.21	1.13E+12	1.04E+11
	Whiteoak Bayou[c]	12.64	19.55	1.07E+12	8.73E+10
BOTH	Buffalo Bayou				
	Reservois + below dam	26.79	41.45	3.03E+12	9.52E+11
	Below dam only	16.39	25.35	1.26E+12	1.45E+11
	Whiteoak Bayou	26.07	40.33	7.63E+14	7.62E+12

Notes:

[a] WWTPs that were not sampled as part of this sampling effort (either flow > 1 MGD or access denied)

[b] Loads were calculated using the flow-weighted geometric mean for EC and the geometric mean for FC from the sampled plants in the watershed (5.4 MPN/100 mL and 0.5 cfu/100 mL, respectively). Flows are 5-yr averages from self-reporting data

[c] Loads were calculated using the flow-weighted geometric mean for EC and the geometric mean for FC from the sampled plants in the watershed (6.1 MPN/100 mL and 0.5 cfu/100 mL, respectively). Flows are 5-yr averages from self-reporting data.

Values below the detection limit (i.e. <1 MPN/100 mL) were assumed to be equal to half of the detection limit (0.5 MPN/100 mL for EC and 0.1 cfu/100 mL for FC) for load calculations

Values above the detection limit (i.e. > 24,192 MPN/100 mL) were assumed to be equal to 24,200 MPN/100 mL

EC= *E. coli* FC = fecal coliform

MGD = million gallons per day cfs = cubic feet per second

MPN = most probable number cfu = colony forming unit

4.2 SAMPLING PIPE DISCHARGES TO THE BAYOUS UNDER DRY-WEATHER CONDITIONS

This component included sampling of active piped outfalls into the bayous (only main stems) under dry-weather[1] conditions to identify discharges via storm sewers or other unidentified outfalls. The observed leaks may come from a sanitary sewer problem of some type or unpermitted discharges. The sampling work included a review of routine monitoring data in the bayous to identify locations where a sudden increase in indicator bacteria occurred, and a survey of pipes discharging under dry-weather conditions. In dry weather all storm sewer outfalls should be dry so any observed flow of unknown origin could be an unpermitted discharge or a water or sanitary leak. The first activity completed for this component was to obtain the maps of sanitary and storm sewer lines from the City of Houston (GIMS database) and to locate the pipe outfalls to the two bayous. The unpermitted discharge sampling included two components: (i) on-foot reconnaissance and (ii) in-bayou reconnaissance and sampling.

In general, this effort has been undertaken by two-person teams that worked in dry weather only. The sampling teams were equipped with maps of the storm sewer system and the locations of the outfalls. Prior to sampling, the teams walked along the bayous and main tributaries to perform reconnaissance of the stormsewer infrastructure. During this reconnaissance effort, the teams identified the number of outfalls that were discharging into the bayous and confirmed their presence in the GIMS database so that their properties could be

[1] Dry-weather was defined for this project as three consecutive days with no rainfall

determined (diameter, length, material, and age). If an outfall was not found in the GIMS maps, it was noted with its diameter, location and material. Reconnaissance activities for Whiteoak Bayou were completed by November 28, 2001. For Buffalo Bayou, on-foot inspections were initiated but, due to the lack of maintenance trails along the bayou, reconnaissance activities were completed using a canoe. Figures 4.8 and 4.9 include selected photographs taken during this activity.

Once all the outfalls were located and identified, sampling activities were initiated. The sampling points were based on locatable outfalls discharging under dry-weather conditions. Sampling of discharges into Whiteoak Bayou was initiated on November 20, 2001. The geographic locations were verified with a Global Positioning System (GPS) (Magellan GPS 315 receiver with 25 meters or better RMS accuracy). The sampling crew first determined if there was flow, and then determined if there was a residual chlorine level indicating a drinking water leak of some type. If the residual chlorine value was greater than 0.5 mg/L, no sampling was done other than estimating the flow. If the flow was significant, it was reported as a water leak. If the water was not chlorinated, samples were collected for bacterial and TSS analyses. In addition to these analyses, probe parameters (DO, temperature, pH, turbidity, and conductivity) as well as ammonia and ortho-phosphorous concentrations were measured. Each of the samples was analyzed for EC at the University of Houston laboratory and for FC and TSS at North Water District Laboratory Services (NWDLS). The methods employed for these analyses are those discussed in section 4.1.

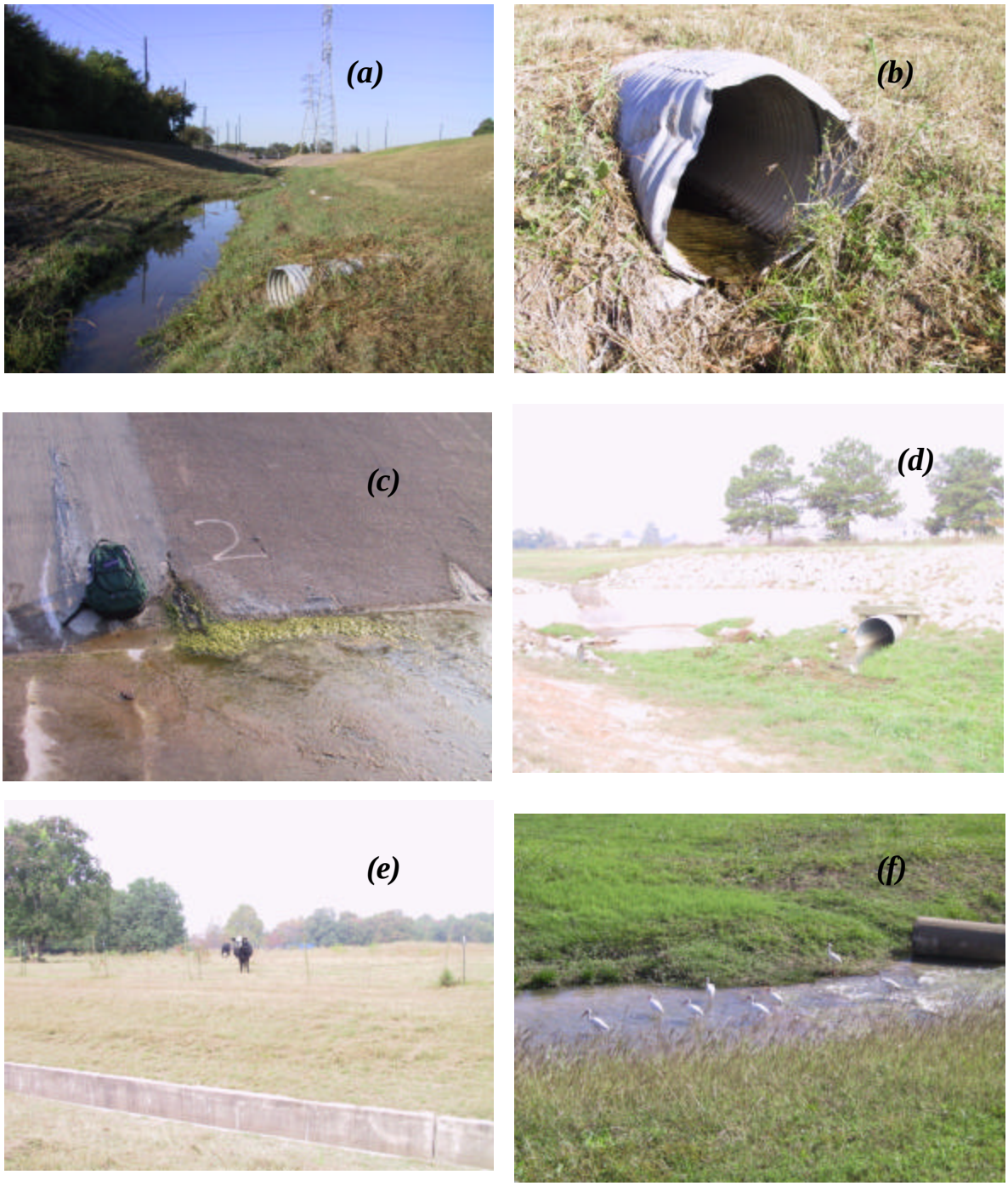

Figure 4.8 Whiteoak Bayou

(a) View of WO branch at Jones Rd. (b) Discharging pipe (c) Concrete cracks discharging water with high organic content as indicated by algae formation (d) Leaking pipe (e) Pasture upstream of the intersection with Jones Rd. (f) Birds in WO bayou

Figure 4.9 Buffalo Bayou
(a) View of the banks along the bayou (b) Canoeing along the bayou

4.2.1 Summary of Results from Sampling of Pipe Discharges under Dry-Weather

Figure 4.10 shows the locations of the storm sewer sampling. Tables 4.6 and 4.7 include the results from this component. Table 4.7 shows that, in general, EC levels were high with concentrations varying between 12 and 241,920 MPN/100 mL. Forty seven out of the 92 samples (51.1%) exceeded 126 MPN/100 mL, and 16 samples exhibited EC counts in excess of 5,000 MPN/100 mL. FC concentrations varied between 1 and 26,000 cfu/100 mL with 41.4% of the samples exceeding the water quality criterion (200 cfu/100 mL).

4.2.2 Analysis of Data from Sampling of Dry-Weather Inflows

Table 4.8 includes a statistical summary of *E. coli* concentrations obtained from the pipe discharge data. To further analyze the collected data, outfalls were divided into two types: stormsewer and wastewater pipes. The dry-weather pipe discharge sampling sites were first input into ArcView GIS. To do this, the latitude and longitude obtained from the Magellan GPS unit were converted into decimal degrees. Then, the points were projected from NAD83 (decimal degree) into NAD27 (feet) to match the City of Houston GIMS maps. To determine whether the sampled pipes were wastewater or stormsewer lines, both City of Houston GIMS data files and field knowledge were used. Any sampling points that were directly over or within a short distance of a pipe on the GIMS maps were considered to be from that pipe. Field knowledge was also used to determine what type of pipe was sampled. Because the Magellan GPS has an accuracy of 25 m, it is possible that the unit did not always provide a point that would

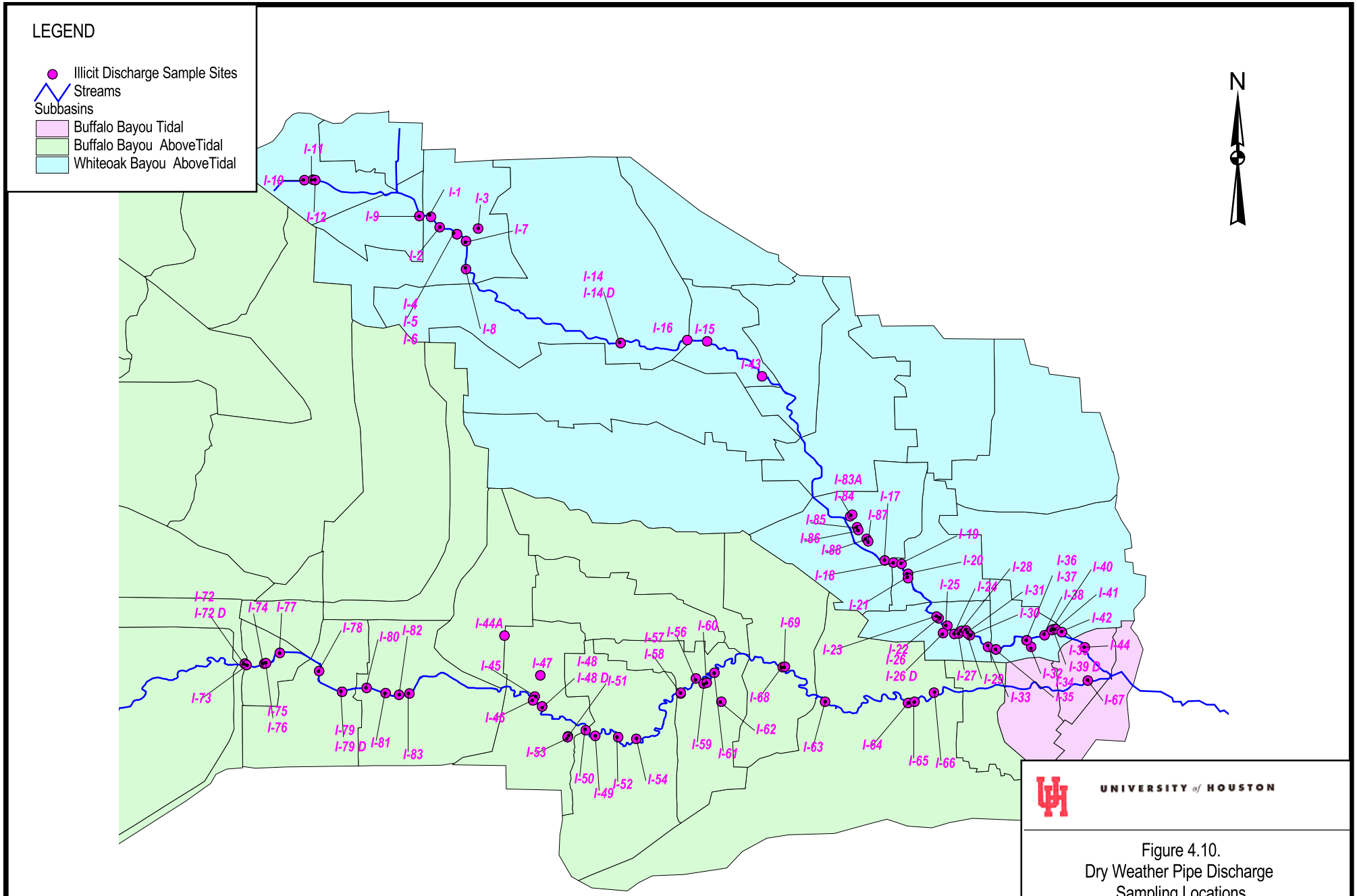

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Figure 4.10.
Dry Weather Pipe Discharge
Sampling Locations

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: JED Date: 06-05-02

Table 4.6 Results from Field Measurements for Dry-weather Discharges Monitoring

Sample ID	Location		Date	Pipe Size	DO (mg/L)	pH	Temp (°C)	Flow (MGD)	Conductivity (µS)	Turbidity (NTU)	Residual Chlorine (mg/L)	Total Chlorine (mg/L)	Ammonia (mg/L)	Ortho-phosphorous (mg/L)	Type of Pipe
	Latitude	Longitude													
I-1	29 55 037	95 34 934	11/20/2001	1 m				0.0001522			0.04	0.04	0.06	7.6	*
I-2	29 54 826	95 34 761	11/20/2001	3/4 m	6.38	7.8	17.89	0.0008780	1244	9.7	0.26	0.24	1.36	2.49	*
I-3	29 54 804	95 34	11/20/2001	4 ft	7.2	8.44	12.87	0.0006468	1000	2.2	0	0	0	1.69	*
I-4	29 54 698	95 34 417	11/20/2001	3.5 ft	7.4	8.5	20.16	0.0114135	1209	7.7	0.55	0.55	0.02	0	*
I-5	29 54 687	95 34 413	11/20/2001	3.5 ft	6.24	8.4	13.86	0.0008152	1036	5.1	0.12	0	0	0.74	*
I-7	29 54 556	95 34 243	11/20/2001	4.5 ft	10.38	7.97	18.61	0.0045654	1389	7	0.02	0.04	0.03	0.71	*
I-8	29 54 556	95 34 243	11/20/2001	3 ft	12.65	8.28	17.11	0.0011160	2607	5.9	0	0	0.03	1.03	*
I-9	29 55 054	95 35 161	1/17/2002	2 ft	9.22	7.49	22.11	0.0101453	957	1	0.04	na			WW
I-10	29 55 765	95 37 439	1/17/2002	3 ft	11.09	8.47	18.1	0.0018857	693	2.6	0.05	na			*
I-11	29 55 772	95 97 274	1/17/2002	3.5 ft	11.4	8.58	18.51	0.0047556	687	6.3	0.044	na			*
I-12	29 55 763	95 37 223	1/17/2002	2.5 ft	12.14	8.54	17.75	0.0018479	671	0.9	0	na			*
I-14	29 52 538	95 31 177	1/22/2002	3.5 ft	8.16	7.81	15.86	0.0009912	360	27.5	0	0.01	0.01	0.29	*
I-15	29 52 574	95 29 460	1/22/2002	na	7.47	7.62	18.74		227	3.2	0	0.08	0.04	0.35	SW
I-16	29 52 596	95 29 854	1/22/2002	4 ft	9.5	7.83	17.12	0.0019657	1019	2.3	0	0.7			WW
I-17	29 48 233	95 25 951	2/12/2002	box culvert	9.87	7.93	11.93	0.2130515	996	4.9	0.11	0	0	0.62	SW
I-18	29 48 187	95 25 775	2/12/2002	box culvert	10.1	8.21	14.84	0.05935007	318	3.6	1.55	2.3	0.3	0.27	SW
I-19	29 48 166	95 25 616	2/12/2002	4 ft	5.6	7.43	16.39	0.0456539	685	68.9	0.11	0	1.2	1.22	SW
I-20	29 47 963	95 25 488	2/12/2002	3.5 ft.	9.37	8.15	18.96	0.0319577	551	5.3	0.11	0.39	0.2	10.95	SW
I-21	29 47 884	95 25 483	2/12/2002	6 ft.	10.82	8.54	14.55	0.00228269	441	5.4	1.29	1.6	0.79	0.39	SW
I-22	29 47 088	95 24 876	2/12/2002	1 m.	10.1	7.94	15.15	0.0114135	na	29.7	0.02	0.02	0.56	0.46	WW
I-23	29 47 116	95 24 917	2/12/2002	3 ft.	9.92	7.9	16.29	0.0067635	421	47.1	0	0	0	0	WW
I-24	29 46 779	95 24 570	2/12/2002	3 ft.	10.1	8.03	15.65	0.0001171	na	26.8	0.13	0	0.69	3.37	WW
I-25	29 46 946	95 24 709	2/12/2002	1 m	9.15	7.85	13.17	0.0001505	1135	15.6	0.05	0	0.17	0.99	SW
I-26	29 46 794	29 46 794	2/12/2002	1m	8.37	6.9	15.93	0.0015218	837	268.6	0.05	>2.2			SW
I-27	29 46 787	95 24 482	2/12/2002	3.5 m	7.11	8.55	17.43	0.0001141	1467	7.5	0	0	2.82	4.22	SW
I-28	29 46 841	95 24 425	2/12/2002	2 ft.	7.28	7.1	19.24	0.0006617	1286	5	0	0	0.33	1.39	SW
I-29	29 46 845	95 24 333	2/12/2002	2 ft.	8.84	7.77	16.97	0.0045654	1840	14.1	0.05	0	0	2.28	WW
I-30	29 46 752	95 24 262	2/12/2002	4 ft.	11.07	8.47	18.16	0.0202906	542	1.1	0.03	0	0	0.18	WW
I-31	29 46 787	95 24 301	2/12/2002	4 ft.	11.23	8.2	17.61	0.0001556	1534	11.2	0.07	0.05		1.11	SW
I-32	29 46.519	95 23.048	2/25/2002	2 ft	N/A	8.37	19.27	0.0004891	441	28	0.05	0	0	0.06	SW
I-33	29 46.523	95 23.905	2/25/2002	3.5 ft	N/A	8.42	18.08	0.0013044	415	1.4	0.04	0.01	0	0.09	SW
I-34	29 46.472	95 23.746	2/25/2002	no pipe	N/A	9.33	19.68	0.0003845	329	4.3	0.05	0	0	0.32	SW
I-35	29 46.468	95 23.739	2/25/2002	1.5m	N/A	8.05	20.34	0.0913078	438	2.7	0.09	0.35	0.25	0.22	SW
I-36	29 46.651	95 23.140	2/26/2002	2.5 ft	11.28	7.96	8.88	0.0006297	500	1.9	0.04	0	0	1.05	SW
I-37	29 46.649	95 23.127	2/26/2002		10.42	7.82	9.3	0.0004150	1393	1.3	0	0	0.01	0.34	SW
I-38	29 46.753	95 22.784	2/26/2002		10.46	8.39	6.84	0.0000692	2801	23	0.05	0.03	0.09	0.94	SW
I-39	29 46.866	95 22.618	2/28/2002	0.5 ft	7.57	7.33	17.09	0.01141347	771	5.7	1.4	1.92	0.47	7.38	SW
I-40	29 46.856	95 22.638	2/28/2002	1 m	8.08	8.18	15.47	0.0050727	2000	1.1	0.02	0	0	0.73	SW
I-41	29 46.873	95 22.568	2/28/2002	2 ft	7.63	7.72	10.71	0.0001863	1937	4.1	0.04	0.19	0.36	0.46	SW
I-42	29 46.810	95 22.438	2/28/2002	2 ft	5.8	7.6	10.39	0.0027718	808	4.5	0.07	0.04	0.25	1.32	SW
I-43	29 51.875	95 28.376	3/12/2002	3.5ft	8.84	7.53	19.91	0.0106526	496	2.4	0	0.12	1.28	0	WW
I-44	29 46.512	95 21.982	3/12/2002	1.5 m	6.68	7.87	20.61	0.0136962	779	67.3	0.12	0	4.3	na	SW
I-44A	29 46.748	95 33.473	4/24/2002	1.5 m	8.63	7.17	25.8	0.0821770	1169	N/A	0	N/A	0.52	0.06	SW
I-45	29 45.539	95 32.872	4/24/2002	2.5 ft	9.23	7.24	25.9	0.0009131	433	N/A	0.04	0	0.29	0.07	SW
I-46	29 45.464	95 32.917	4/24/2002	2.5 ft	6.97	7.11	24.4	0.0015979	818	N/A	0.03	0	1.46	0.33	SW
I-47	29 45.955	95 32.767	4/24/2002	2.5 ft	7.07	7.04	26.4	0.0000543	647	N/A	0	0	0.43	0	SW
I-48	29 45.339	95 32.735	4/24/2002		8.08	7.24	23.7	0.0042393	435	N/A	0	0	0	0.09	WW
I-49	29 44.762	95 31.679	4/24/2002		10.2	7.04	24.4	0.0045654	200	N/A	0	0	0.91	0	SW
I-50	29 44.876	95 31.868	4/25/2002		6.09	7.19	23.4	0.0031607	430	N/A	0.01	0	0.47	0.4	SW
I-51	29 44.745	95 31.220	4/25/2002		9.02	7.09	25	0.0011045	600	N/A	0	0	0.38	0.34	SW
I-52	29 44.727	95 31.225	4/25/2002		8.61	7.21	22.6	0.0015522	689	N/A	0	0	0.33	0	SW
I-53	29 44.727	95 31.226	4/25/2002		6.1	6.77	26.9	0.0035118	436	N/A	0.01	0	1.17	0.38	SW
I-54	29 44.701	95 30.865	4/25/2002		8.57	6.71	25.3		640	N/A	0.03	0	1.15	0	SW
I-56	29 45.896	95 29.686	5/2/2002		7.52	7.52	28.5	0.0004429	549	N/A	0.06	0.05	0.64	0.41	SW
I-57	29 45.602	95 29.982	5/2/2002	3 ft	9.01	6.87	28.1	0.0167398	445	N/A	0.01	0.02	0.77	0.43	SW
I-58	29 45.616	95 29.987	5/2/2002	0.5 ft	8.51	7.68	29.8	0.0219139	559	N/A	0.08	0	0.22	0.01	SW
I-59	29 45.794	95 29.534	5/2/2002	3 ft	4.28	7.4	26.5	0.0002663	1315	N/A	0.01	0.01	2.13	1	SW
I-60	29 45.811	95 29.473	5/2/2002	4.5 ft	5.75	7.67	29.8	0.0060872	437	N/A	0.01	0.02	1.63	1.48	SW
I-61	29 46.006	95 29.319	5/2/2002	0.5 ft	8.93	8.93	28.5	0.0009925	695	N/A	0.05	0.08	2.72	0.01	SW
I-62	29 45.438	95 27.181	5/4/2002	2.5 ft	1.005	5.17	25.7	0.0179657	N/A	N/A	0	0.04	0.26	0.12	SW
I-63	29 45.430	95 27.132	5/4/2002		0.901	5.09	25.6	0.0002410	N/A	N/A	0.1	0.16	1.26	0.43	SW
I-64	29 45.405	95 25.484	5/4/2002	trib	0.741	5.16	27	0.0055799	N/A	N/A	0.02	0.04	6.22	0.8	SW
I-65	29 45.431	95 25.355	5/4/2002	1.8 m	0.98	5.15	24.6	0.0228269	N/A	N/A	0.03	0	2.14	0.64	WW
I-66	29 45.620	95 24.971	5/4/2002	1.5 m	0.982	5.26	26.7	0.0041089	N/A	N/A	0.04	0.07	0.88	0.26	WW
I-67	29 45.849	95 21.926	5/8/2002	1 foot	0.967	4.56	26.4	0.0004264	464	N/A	0	0.05	5.48	0.13	SW
I-68	29 46.118	95 27.967	5/8/2002	18 inch	0.952	7.11	25.6	0.0004723	N/A	N/A	0.03	0	0.28	0	SW
I-69	29 46.128	95 27.926	5/8/2002	trib	0.959	8.08	24.5	0.0033083	N/A	N/A	0.04	0.04	0.46	0.04	SW
I-72	29 46.187	95 38.622	5/9/2002	2.5 ft	1.012	7.64	29.4	0.0296750	820	N/A	0.04	0.03	0.32	0	WW
I-73	29 46.158	95 38.583	5/9/2002		1.03	8.19	28	0.0004565	447	N/A	0	0.01	0.85	0.1	WW
I-74	29 46.187	95 38.230	5/9/2002		10.23	8.98	24.7	0.0049166	878	N/A	0.01	0	0.77	0.05	WW
I-75	29 46.202	95 38.205	5/9/2002		9.6	7.88	25.8	0.0062255	440	N/A	0.1	0.08	0	0.07	SW
I-76	29 48.201	95 38.204	5/9/2002		13.51	4.37	24.3	0.0001902	3	N/A	0.01	0.02	1.76	0.01	SW
I-77	29 46.400	95 37.928	5/9/2002	4.5 ft	16.4	6.48	25.4	0.0209247	1052	N/A	0.1	0.1	0.13	0.04	SW
I-78	29 45.630	95 36.846	5/9/2002			9.2			472	N/A	0.37	0.49	1	0	WW
I-79	29 45.628	95 36.697	5/10/2002	8 ft		5.44	24.4	0.0410885	687	N/A	0.05		1	0.06	SW
I-79dup			5/10/2002							N/A			1.02	0.05	SW
I-80	29 45.708	95 36.209	5/10/2002		12.28	6.74	24.4	0.0004923	1251	N/A	0.03	0	0.58	0	SW
I-81	29 45.607	95 35.832	5/10/2002	8 ft	7.83	5.2		0.0010145	831	N/A	0.03	0.04	0.16	0	SW
I-82	29 45.569	95 35.564	5/10/2002	8 ft	7.16	3.36	26.3	0.0002156	381	N/A	0.13	0.09	0.7	1.44	SW
I-83	29 45.592	95 35.356	5/10/2002	8 ft	7.6	4.82	26.9	0.1677781	483	N/A	0.19	0.26	0.29	0	WW
I-83A			5/16/2002	3 ft	2.03	7.77	28.91	0.0000342	1751	74	0.18	0.07	0.3	0.2	WW
I-84			5/16/2002	3 ft	6.00	7.77	27.17	0.0188307	829	36.5	0.06	0	5.5	>13.75	WW
I-85			5/16/2002	3 ft	10.42	8.58	27.73	0.0002417	3090	1.7	0.11	0.01	0	0	SW
I-86			5/16/2002	6 ft.	12.57	8.6	24.38	0.0185963	804	0	0.06	0.25	0.87	0.06	SW
I-87			5/16/2002	box culvert	13.53	9.75	31.47	0.0011105	299	0.4	0.05	0	0.24	0.01	
I-88			5/16/2002	3 ft	12.07	8.2	27.42	0.0001756	1274	0	0.12	0	0.5	0.1	SW

Notes/Abbreviations:

MGD - million gallons per day
N/A - parameter not available
Samples highlighted in blue are likely drinking water leaks (high residual chlorine values)
Occassionally, sample IDs were duplicated. To distinguish between samples with same ID, the second sample was assigned an "A" at the end of its ID
MGD = million gallons per day
NTU = Nephelometric turbidity units
L = liter

WW - wastewater line
SW - stormwater line
* - no data to determine type of pipe available
The suffix "dup" stands for field duplicate
µS = micro-Siemens
mg = milligram
ft = foot

Table 4.7 Results from Lab Analyses for Dry-weather Discharges Monitoring

Sample ID	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[b]	Fecal Coliforms (cfu/100 mL)[c]	TSS (mg/L)[c]
I-1	11/20/2001	0.0002	> 241,920	6,389	4,300	8
I-2	11/20/2001	0.0009	141,360	9,087	5,000	10
I-3	11/20/2001	0.0006	15,531	274	40	2
I-4	11/20/2001	0.0114	<1	19	0	3
I-5	11/20/2001	0.0008	17,329	143	470	2
I-6	11/20/2001		98,040	416		
I-7	11/20/2001	0.0046	> 241,920	1,212	1,400	<1.0
I-8	11/20/2001	0.0011	105,013	10,608	5,600	3
I-9	1/17/2002	0.0101	10,462	37	1	5
I-10	1/17/2002	0.0019	2,419	28	0	1
I-11	1/17/2002	0.0048	236	19	2	5
I-12	1/17/2002	0.0018	3,871	22	0	1
I-14	1/22/2002	0.0010	28,345	27	25	16
I-14dup	1/22/2002		19,863	23	20	16
I-15	1/22/2002		24,192	20	200	7
I-16	1/22/2002	0.0020	173,287	106	140	7
I-17	2/12/2002	0.2131	4,525	108	52	4
I-18	2/12/2002	0.0594	30	19	0	2
I-19	2/12/2002	0.0457	> 241,920	10,295	3,800	48
I-20	2/12/2002	0.0320	156	20	0	9
I-21	2/12/2002	0.0023	368	19		
I-22	2/13/2002	0.0114	241,917	3,429	2,400	21
I-23	2/13/2002	0.0068	19,164	19	10	31
I-24	2/13/2002	0.0001	> 241,920	477	350	21
I-25	2/14/2002	0.0002	135,663	19	25	20
I-26	2/14/2002	0.0015	> 241,920	17,384	1	125
I-26dup	2/14/2002		> 241,920	12,673	3	146
I-27	2/14/2002	0.0001	72,290	19	15	12
I-28	2/14/2002	0.0007	17,370	23	11	7
I-29	2/15/2002	0.0046	22,300	5,774	8	11
I-30	2/15/2002	0.0203	2,419	30	0	2
I-31	2/15/2002	0.0002	3,708	12	0	6
I-32	2/25/2002	0.0005	24,192	646	460	13
I-33	2/25/2002	0.0013	20,760	42	6	2
I-34	2/25/2002	0.0004	16,430	20	9	24
I-35	2/25/2002	0.0913	9,506	29	0	3
I-36	2/26/2002	0.0006	11,400	542	330	3
I-37	2/26/2002	0.0004	5,242	1,157	520	3
I-38	2/26/2002	0.0001	12,033	205	170	42
I-39	2/28/2002	0.0114	1,300	18	0	12
I-39dup	2/28/2002		2,203	19	0	10
I-40	2/28/2002	0.0051	60,195	1,205	420	<1.0
I-41	2/28/2002	0.0002	42,290	54	32	23
I-42	2/28/2002	0.0028	1,553	24	25	4
I-43	3/12/2002	0.0107	>241920	75	32	4
I-44	3/12/2002	0.0137	>241920	>241920	6,200	58
I-44A	4/24/2002	0.0822	141,360	4,062	3,800	2
I-45	4/24/2002	0.0009	4,166	31	20	16
I-46	4/24/2002	0.0016	>241920	53,390	11,000	9
I-47	4/24/2002	0.0001	8,070	33	31	6
I-48	4/24/2002	0.0042	155,307	895	360	703
I-48dup	4/24/2002		148,334	1,073		
I-49	4/24/2002	0.0046	185,958	2,123	1,200	23
I-50	4/25/2002	0.0032	1,011	215	40	3

Table 4.7 Results from Lab Analyses for Dry-weather Discharges Monitoring

Sample ID	Date	Flow (MGD)	Total Coliforms (MPN/100 mL)[a]	*E coli* (MPN/100 mL)[b]	Fecal Coliforms (cfu/100 mL)[c]	TSS (mg/L)[c]
I-51	4/25/2002	0.0011	66,680	99	50	15
I-52	4/25/2002	0.0016	6,135	73	60	5
I-53	4/25/2002	0.0035	>241920	757	800	16
I-54	4/25/2002		15,732	678	130	22
I-56	5/2/2002	0.0004	17,697	125	38	3
I-57	5/2/2002	0.0167	>241920	3,674	2	7
I-58	5/2/2002	0.0219	337	79	3	3
I-59	5/2/2002	0.0003	122	18	1	23
I-60	5/2/2002	0.0061	>241920	173,287	26,000	8
I-61	5/2/2002	0.0010	2,419	30	9	5
I-62	5/4/2002	0.0180	73,440	1,765	4,000	<1.0
I-63	5/4/2002	0.0002	135,663	65	5,200	<1.0
I-64	5/4/2002	0.0056	74,805	904	2,600	22
I-65	5/4/2002	0.0228	133,646	12,392	880	3
I-66	5/4/2002	0.0041	241,917	8,931	20,000	8
I-67	5/8/2002	0.0004	>241920	724	3,200	14
I-68	5/8/2002	0.0005	1,327	26	22	2
I-69	5/8/2002	0.0033	92,340	940	17,500	13
I-72	5/9/2002	0.0297	15,163	22	7	<1.0
I-72dup	5/9/2002		17,151	22		
I-73	5/9/2002	0.0005	19,863	23	0	13
I-74	5/9/2002	0.0049	19,861	99	38	2
I-75	5/9/2002	0.0062	220,273	4,467	2,000	6
I-76	5/9/2002	0.0002	>241920	1,164	2,900	14
I-77	5/9/2002	0.0209	198,628	1,211	1,800	6
I-78	5/9/2002		<1	19	0	1
I-79	5/10/2002	0.0411	49,135	11,023	1,500	14
I-79dup	5/10/2002		50,710	9,969		
I-80	5/10/2002	0.0005	24,192	4,372	2,300	5
I-81	5/10/2002	0.0010	19,863	53	47	9
I-82	5/10/2002	0.0002	20,760	63	31	8
I-83	5/10/2002	0.1678	28	18	1	2
I-83A	5/16/2002	0.0000		455	60	46
I-84	5/16/2002	0.0188		241,920	20,000	46
I-85	5/16/2002	0.0002		2,149	210	6
I-86	5/16/2002	0.0186		2,391	300	4
I-87	5/16/2002	0.0011		16,712	2,800	9
I-88	5/16/2002	0.0002		209	240	11

Notes/Abbreviations:

[a] Parameter analyzed at UH lab. The results are the average of duplicates for a given dilution. Three different dilutions were prepared for each sample (1:1, 1:10 and 1:100).

[b] Parameter analyzed at UH lab. The results are the average of duplicates of all the dilutions that could be read. Three different dilutions were prepared for each sample (1:1, 1:10 and 1:100).

[c] Parameter analyzed at NWDLS lab.

E. coli = Escherichia coli

MPN = most probable number

cfu = colony forming units

TSS = total suspended solids

WW - wastewater line

SW - stormwater line

* - no data to determine type of pipe available

Samples exceeding the EC criterion of 126 MPN/100 mL are highlighted in green

Occassionally, sample IDs were duplicated. To distinguish between samples with same ID, the second sample was assigned an "A" at the er

The suffix "dup" stands for field duplicate

Table 4.8 Summary of Statistics on *E. coli* Data (MPN/100 mL)

Sample ID	Mean	Standard Deviation	n	Confidence Interval (α=0.05)
I-1	6389.0	255.6	4	6389 ± 250
I-2	9086.6	2163.1	4	9087 ± 2120
I-3	273.9	139.7	6	274 ± 112
I-4	18.5	24.5	6	19 ± 20
I-5	142.8	24.5	6	143 ± 20
I-6	416.0	239.4	6	416 ± 192
I-7	1212.0	197.1	6	1212 ± 158
I-8	10608.1	627.3	4	10608 ± 615
I-9	37.1	16.6	6	37 ± 13
I-10	27.6	18.4	6	28 ± 15
I-11	18.5	24.5	6	19 ± 20
I-12	22.2	22.4	6	22 ± 18
I-14	27.3	18.5	6	27 ± 15
I-14dup	23.3	22.6	6	23 ± 18
I-15	20.1	23.3	6	20 ± 19
I-16	105.8	46.3	6	106 ± 37
I-17	108.4	71.3	6	108 ± 57
I-18	18.5	24.5	6	19 ± 20
I-19	10295.4	1564.2	4	10295 ± 1533
I-20	20.4	23.0	6	20 ± 18
I-21	18.9	24.1	6	19 ± 19
I-22	3429.2	1070.2	5	3429 ± 938
I-23	18.7	24.3	6	19 ± 19
I-24	477.1	240.2	6	477 ± 192
I-25	18.8	24.3	6	19 ± 19
I-26	17383.6	5646.0	4	17384 ± 5533
I-26dup	12673.0	11788.3	4	12673 ± 11552
I-27	18.8	24.3	6	19 ± 19
I-28	22.6	22.0	6	23 ± 18
I-29	5773.5	1263.1	4	5774 ± 1238
I-30	29.9	19.2	6	30 ± 15
I-31	11.8	19.1	6	12 ± 15
I-32	645.8	210.7	6	646 ± 169
I-33	41.6	21.9	6	42 ± 18
I-34	19.5	23.6	6	20 ± 19
I-35	29.3	19.0	6	29 ± 15
I-36	542.1	160.9	6	542 ± 129
I-37	1157.2	357.8	6	1157 ± 286
I-38	204.8	156.7	6	205 ± 125
I-39	18.4	24.6	6	18 ± 20
I-39dup	18.5	24.5	6	19 ± 20
I-40	1205.2	158.4	6	1205 ± 127
I-41	53.7	10.5	6	54 ± 8
I-42	24.1	22.1	6	24 ± 18
I-43	74.7	111.7	6	75 ± 89
I-44	>241,920		6	
I-44(B)	4061.8	1190.5	4	4062 ± 1167
I-45	30.9	18.5	6	31 ± 15
I-46	53390.0	nc	2	53390 ± 8918
I-47	32.9	13.7	6	33 ± 11
I-48	894.9	154.0	6	895 ± 123

Table 4.8 Summary of Statistics on *E. coli* Data (MPN/100 mL)

Sample ID	Mean	Standard Deviation	n	Confidence Interval (α=0.05)
I-48dup	1073.4	365.1	6	1073 ± 292
I-49	2123.4	499.7	5	2123 ± 438
I-50	215.3	130.3	6	215 ± 104
I-51	98.8	79.6	6	99 ± 64
I-52	73.1	48.0	6	73 ± 38
I-53	756.7	373.4	6	757 ± 299
I-54	678.3	249.0	6	678 ± 199
I-56	125.0	140.6	6	125 ± 113
I-57	3674.0	1160.0	4	3674 ± 1137
I-58	79.0	163.2	6	79 ± 131
I-59	17.6	25.2	6	18 ± 20
I-60	173287*		1	
I-61	29.9	19.5	6	30 ± 16
I-62	1764.7	160.8	6	1765 ± 129
I-63	64.8	23.0	6	65 ± 18
I-64	904.0	117.4	6	904 ± 94
I-65	12392.3	2115.4	4	12392 ± 2073
I-66	8931.4	1854.7	4	8931 ± 1818
I-67	724.3	266.2	6	724 ± 213
I-68	26.4	20.5	6	26 ± 16
I-69	940.5	307.8	6	940 ± 246
I-72	22.4	21.7	6	22 ± 17
I-72dup	22.1	22.3	6	22 ± 18
I-73	22.9	22.0	6	23 ± 18
I-74	98.6	79.4	6	99 ± 64
I-75	4466.8	761.8	4	4467 ± 747
I-76	1164.4	368.8	6	1164 ± 295
I-77	1211.2	340.3	6	1211 ± 272
I-78	18.5	24.5	6	19 ± 20
I-79	11023.1	1989.5	4	11023 ± 1950
I-79dup	9969.4	2403.8	4	9969 ± 2356
I-80	4372.3	1082.4	4	4372 ± 1061
I-81	53.2	9.5	6	53 ± 8
I-82	63.4	18.8	6	63 ± 15
I-83	18.4	24.6	6	18 ± 20
I-83A	454.8	150.3	6	455 ± 120
I-84	>241,920		6	
I-85	2149.4	4744.9	6	2149 ± 3797
I-86	2390.7	5468.0	6	2391 ± 4375
I-87	16711.7	8027.4	4	16712 ± 7867
I-88	209.2	151.1	6	209 ± 121

Samples exceeding the EC criterion of 126 MPN/100 mL are highlighted in green

MPN = most probable number, mL = milliliter

n = number of replicates

α = confidence level (a value of 0.05 means that 5% of the time the mean woul be outside the confidence interval)

* Value correspond to the result of a single sample

nc = standard deviation not calculated because n < 3

directly overlap a pipe on the GIMS maps. The field sampling crews noted on the field sheets whether they suspected a particular pipe was wastewater as determined from odor, size, flow, pipe upkeep and overall appearance of the water. Figure 4.11 shows the locations of the storm water and wastewater sample sites. It is noted that the most upstream points in Whiteoak Bayou were outside the area covered by the GIMS maps, therefore, field knowledge was used to determine if a pipe corresponded to a storm water or a wastewater line (see "No Data" points on Figure 4.11).

Figure 4.12 presents the pipe locations identifies as wastewater outfalls along with the locations of the sampled WWTPs for the point source component. It is noted that only three of the outfall locations could be linked to a sampled WWTP. In two of the three cases, the EC concentrations measured at the plants were of the same order of magnitude as the observed concentrations in the outfalls as can be seen in Table 4.9. In the case of the third plant, the concentration in the outfall was one order of magnitude higher than that measured in the plant but both measurements met the water quality standard. Figure 4.12 shows that the wastewater outfalls with concentrations higher than the water quality standard (yellow dots in the figure) could not be linked to a sampled WWTP.

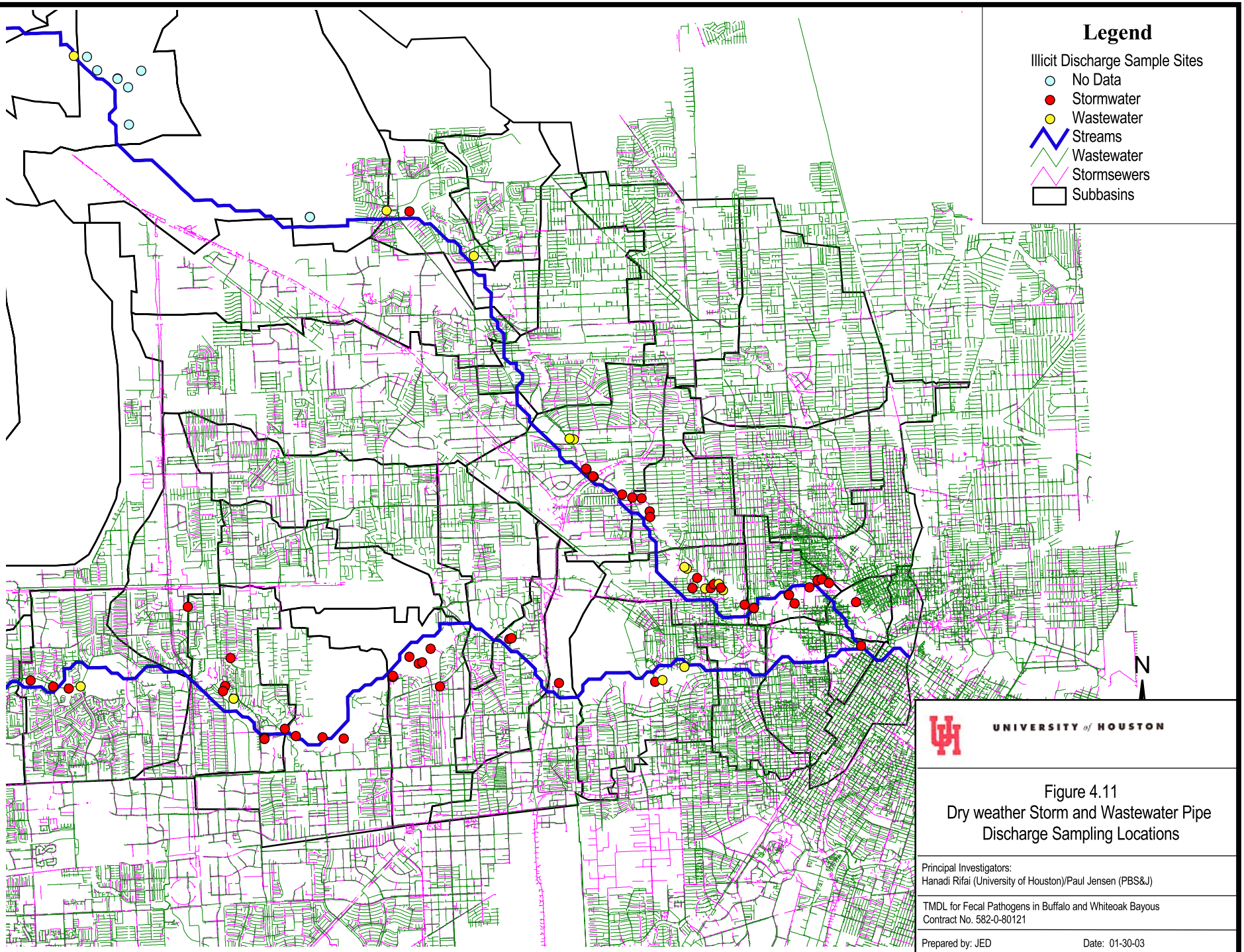

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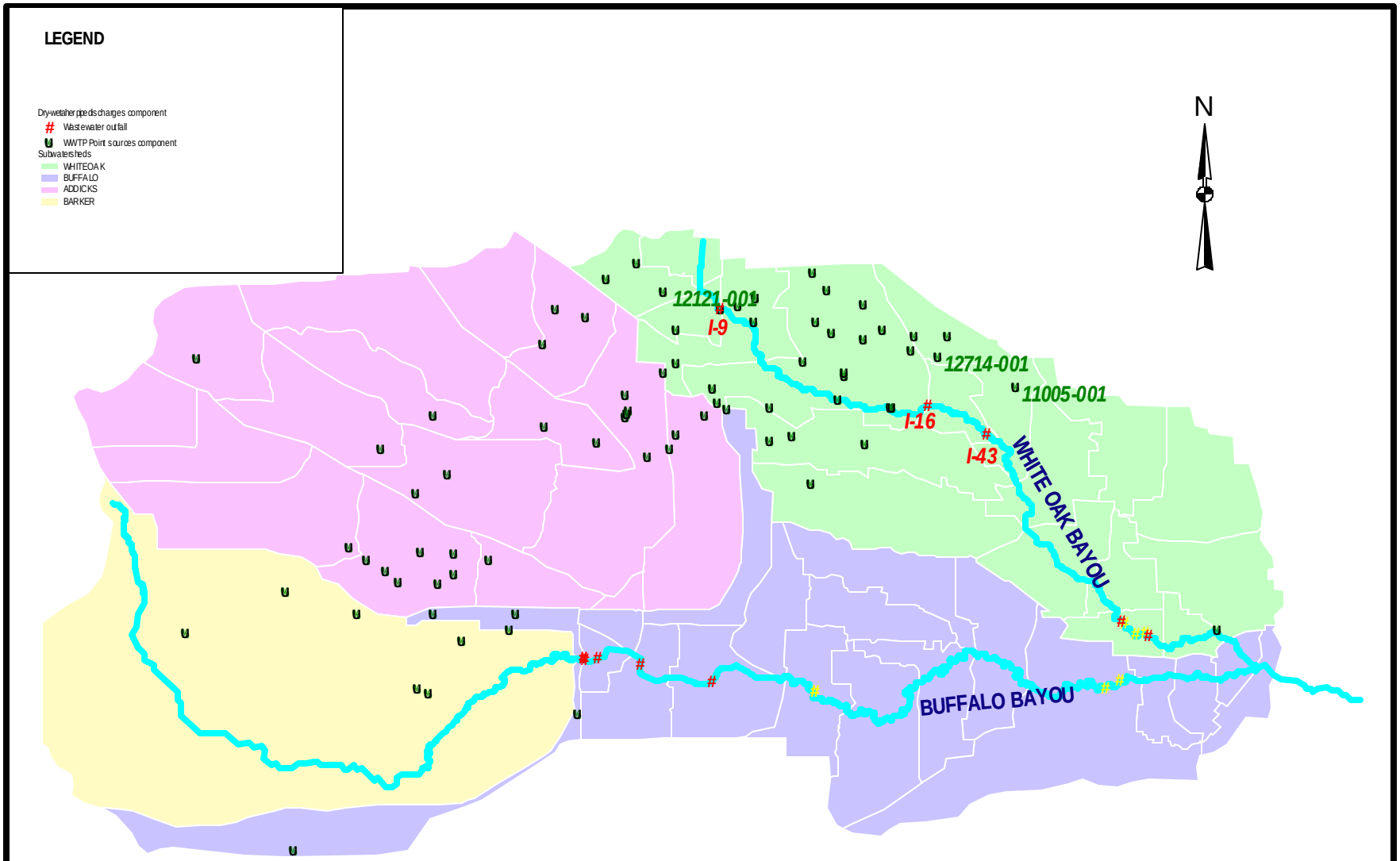
Figure 4.11
Dry weather Storm and Wastewater Pipe Discharge Sampling Locations

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: JED Date: 01-30-03



NOTE: The wastewater outfalls highlighted in yellow correspond to the ones that exceeded the water quality criteria.

2 0 2 4 Miles

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Figure 4.12
Sampled WWTPs vs Piped Outfalls determined to be Wastewater

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: MPS

Date: 09-13-2002

Table 4.9 Comparison of EC concentrations measured after the chlorine contact chamber and at the point of release to the bayou

Sample at point of release to the bayou		Sample after the contact chamber	
Sample ID	**EC Concentration (MPN/100 mL)**	**Sample ID**	**EC Concentration (MPN/100 mL)**
I-9	37	12121-001	21
I-16	106	12714-001	8.1
I-43	75	11005-001	70

Table 4.10 presents the statistical analysis for both storm water and wastewater outfalls. It can be seen that concentrations from storm water discharges are very similar to the ones from wastewater discharges (i.e. both geometric means and averages are within the same order of magnitude). A *t*-test was used to compare the wastewater and storm water samples and there was no significant difference found ($p = 0.203$[2], $\alpha = 0.05$ [3]) between the 2 datasets.

Geometric means of EC and FC concentrations from storm water were higher in Buffalo Bayou than in Whiteoak Bayou, whereas wastewater discharges exhibited higher EC and FC geometric means in Whiteoak than they did in Buffalo Bayou. Figures 4.13 and 4.14 show the distribution of EC data for storm water and wastewater discharges, respectively.

---

[2] The p-value is the observed significance level and it is the basis for deciding whether or not to reject the null hypothesis

[3] α is the significance level used to reject the null hypothesis

Table 4.10 Dry-weather Discharge Sampling Results

		***E. coli* (MPN/100 mL)**						**Fecal Coliform (cfu/100 mL)**					
	Bayou	**n**	**Mean**	**Median**	**Geometric Mean**	**Standard Deviation**	**Variance**	**n**	**Mean**	**Median**	**Geometric Mean**	**Standard Deviation**	**Variance**
Storm water points	Buffalo	29	9135.4	724.3	503.2	33086.32	1094704362	30	3082.8	1000.0	307.9	5742.65	32977982
	Whiteoak	38	2084.9	81.0	174.3	4341.99	18852845	36	735.1	36.0	24.0	1520.29	2311289.7
	Total	*67*	*5136.6*	*204.8*	*275.8*	*22076.62*	*487377092*	*66*	*1802.2*	*95.0*	*76.5*	*4164.78*	*17345402*
Waste water points	Buffalo	8	2811.1	60.7	192.2	4944.01	24443186	8	2660.8	22.5	19.0	7012.92	49181101
	Whiteoak	9	1155.6	105.8	207.2	2047.17	4190906	10	2300.1	46.0	45.3	6262.78	39222425
	Total	*17*	*1934.7*	*98.6*	*200.0*	*3676.24*	*13514744*	*18*	*2460.4*	*35.0*	*30.8*	*6407.02*	*41049863*
All sampled points		84	4488.6	133.9	258.4	19794.77	391833011	84	1943.3	56.0	63.0	4697.38	22065370

n = number of samples
MPN = most probable number
mL = milliliter
cfu = colony forming unit

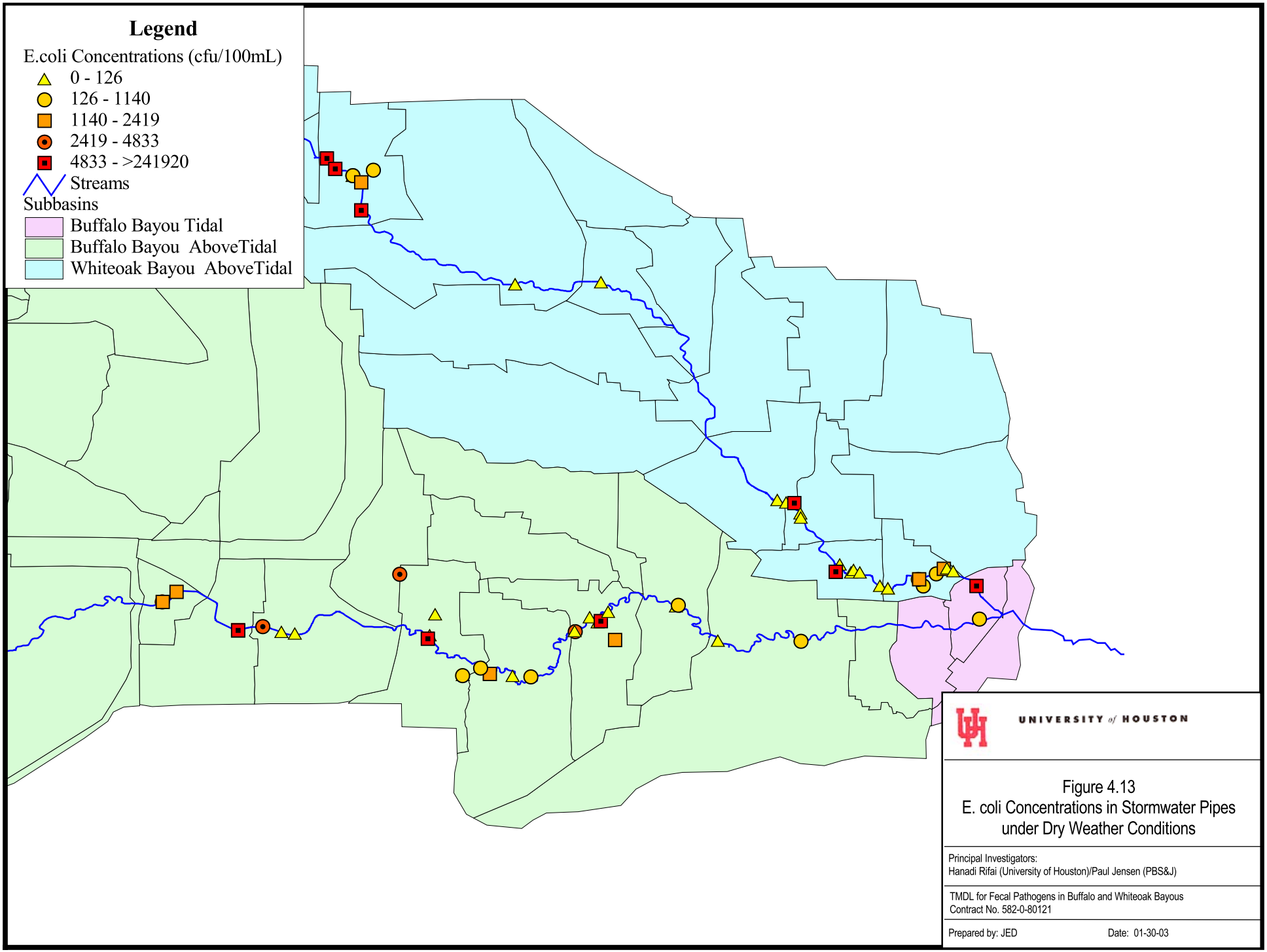


Figure 4.13
E. coli Concentrations in Stormwater Pipes under Dry Weather Conditions

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: JED Date: 01-30-03

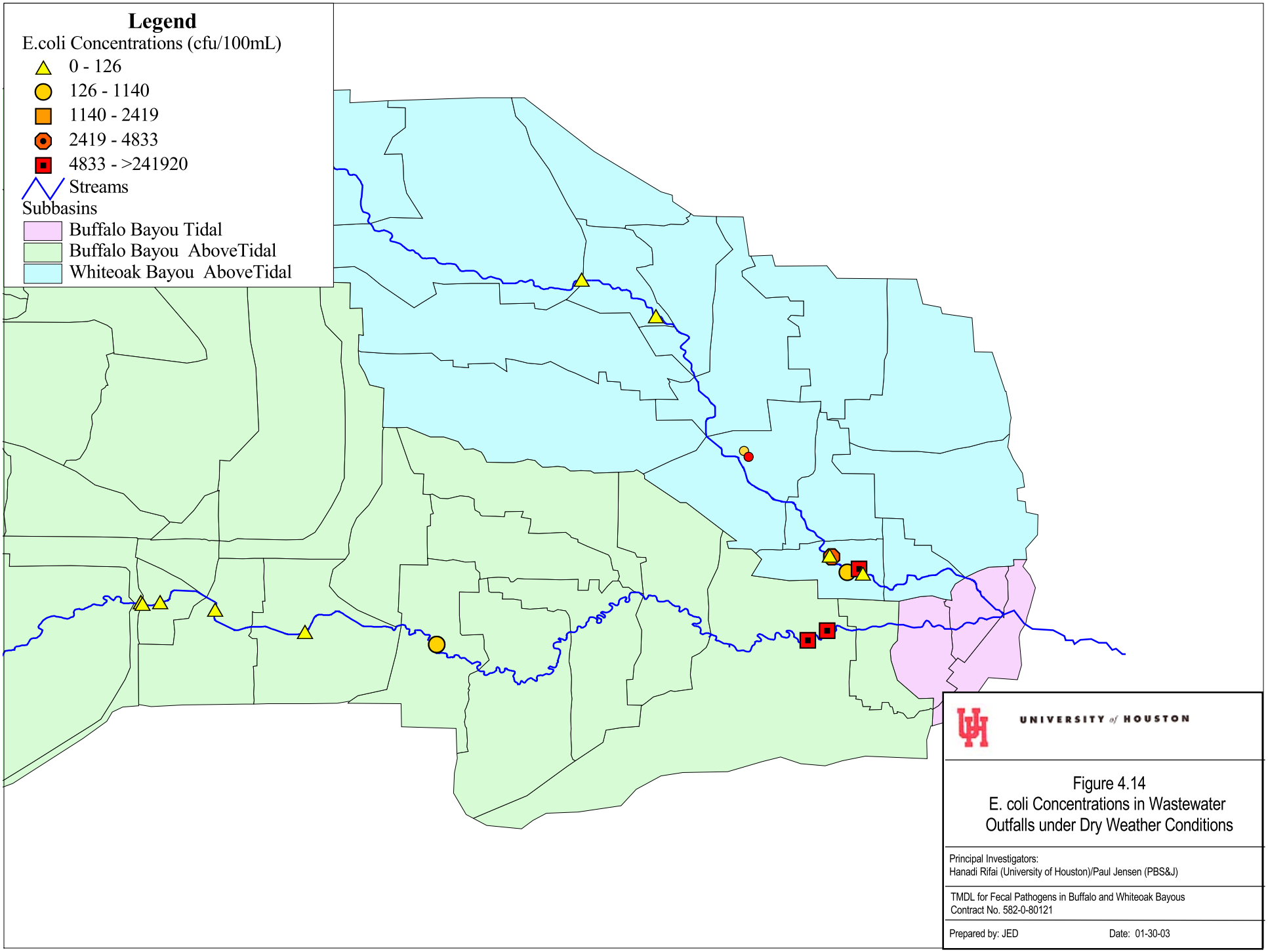


Figure 4.14
E. coli Concentrations in Wastewater Outfalls under Dry Weather Conditions

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: JED Date: 01-30-03

Estimated loads of EC and FC to both bayous from leaky pipes were calculated by multiplying the concentrations of the 84 sampling points and the measured flow. The calculated loads are included in Table 4.11. Overall, the loads from all sampling points were one order of magnitude higher for EC than for FC (i.e. $1.5x10^{14}$ MPN/yr for EC compared to $2.2x10^{13}$ cfu/yr for FC). Bacterial loads followed the same trend observed for the geometric means: loads from flows coming out of storm sewer pipes were higher for Buffalo Bayou than for Whiteoak Bayous, while loads from wastewater pipes were greater for Whiteoak Bayou than for Buffalo Bayou.

The total measured flow from dry-weather pipe discharges was 0.76 cfs for Buffalo Bayou and 0.93 cfs for Whiteoak Bayou. These values correspond to 1% and 2% of the median flows in these bayous, respectively.

Overall, EC and FC loads from pipe discharges into Buffalo Bayou under dry weather conditions were higher than those from point sources (Tables 4.5 and 4.11); while for Whiteoak Bayou, the EC load from point sources was higher than that from dry weather pipe discharges ($7.62x10^{14}$ vs. $7.24x10^{13}$ MPN/100 mL) and the FC loads from both sources were of the same order of magnitude.

Table 4.11 Loads from Pipes Discharging under Dry-weather Conditions

		Flow (MGD)	Flow (cfs)	EC (MPN/yr)	FC (cfu/yr)
Storm sewers	Whiteoak	0.52	0.80	8.55E+12	2.96E+12
	Buffalo	0.26	0.40	7.45E+13	1.16E+13
	Both bayous	0.78	1.20	8.30E+13	1.46E+13
Wastewater sewers	Whiteoak	0.08	0.13	6.39E+13	5.59E+12
	Buffalo	0.23	0.36	4.53E+12	1.44E+12
	Both bayous	0.32	0.49	6.84E+13	7.03E+12
All sampling points	Whiteoak	0.60	0.93	7.24E+13	8.55E+12
All sampling points	Buffalo	0.49	0.76	7.90E+13	1.31E+13

MGD = million gallons per day
cfs = cubic feet per second
MPN = most probable number
cfu = colony forming unit
yr = year
EC = *E. coli*
FC = fecal coliform

CHAPTER 5

HSPF MODELING

The objective of the modeling effort is to develop, calibrate and apply a model to simulate the fate and transport of indicator bacteria in Buffalo and Whiteoak Bayous. The developed model will be used to elucidate the effects of various sources and examine the effects of specific control measures.

5.1 DEVELOPMENT OF HSPF MODELS

This section summarizes the development of two HSPF models for the simulation of *E. coli* (EC) in Buffalo (BB) and Whiteoak (WOB) Bayous. The models include bacteria associated with the water column, suspended sediments and sediments on the streambed. Sediment transport as well as scour and deposition were simulated. Bacteria build-up and wash-off were also included in the simulations. The field studies conducted in the summer of 2001 provided a substantial amount of the data which were used in the modeling effort.

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

- **Physical Input**
  - Delineation of Subwatersheds
  - Meteorological Data
  - Land Use Discretization
  - Soil Characteristics
  - Reach Characteristics

- **Bayou Flow**
  - Point Sources
  - Dry Weather Discharges
  - Upstream Inflow (Buffalo Bayou only)
- **Sources and sinks of bacteria**
  - Point sources
  - Dry Weather Discharges
  - Stormwater Runoff (Buildup and Wash-off)
  - Sediment Scour and deposition
  - Upstream inflows (BB only)
- **Fate and transport**
  - Net decay (die-off minus regrowth)
  - Adsorption and Transfer Rates

Figure 5.1 shown below illustrates the conceptual model and the processes included in the HSPF models. The detailed conceptual model on a subwatershed specific basis is presented in Figure 5.2. As can be seen from Figures 5.1 and 5.2, the main sources of bacteria include point sources (WWTPs), upstream sources, stormwater runoff, sediment resupply, non-point sources and unidentified discharges under dry-weather. The main sinks are die-off and settling.

The following subsections provide a detailed discussion of each of these processes and the approach taken to incorporate these processes into the HSPF models. This chapter also

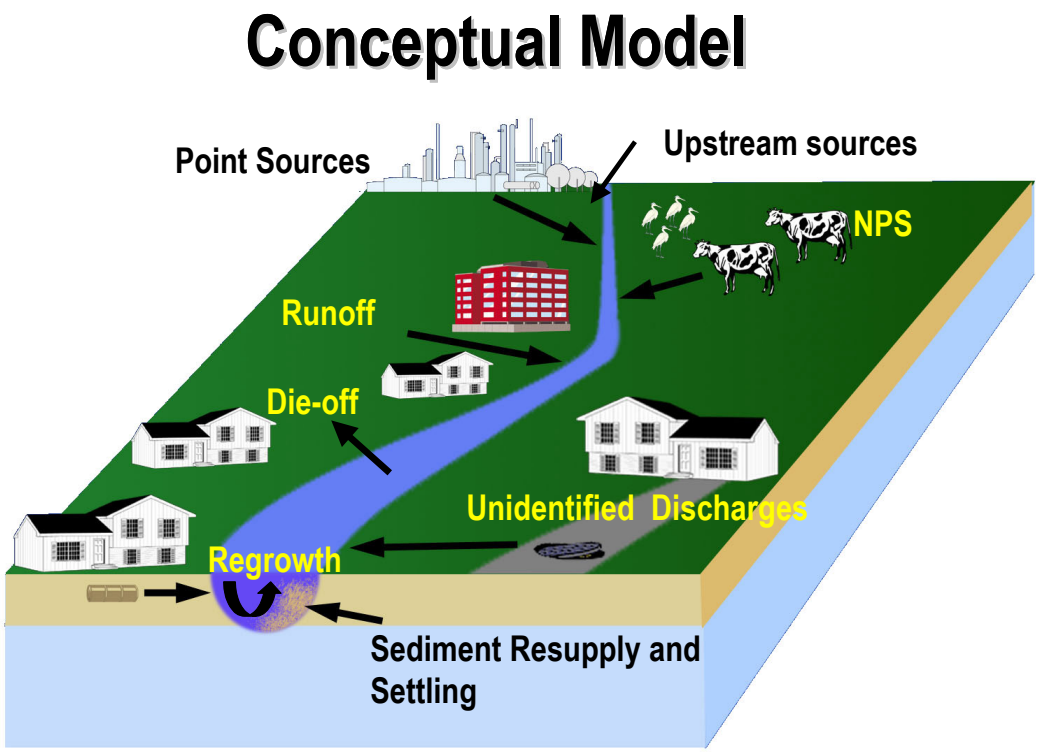


Figure 5.1

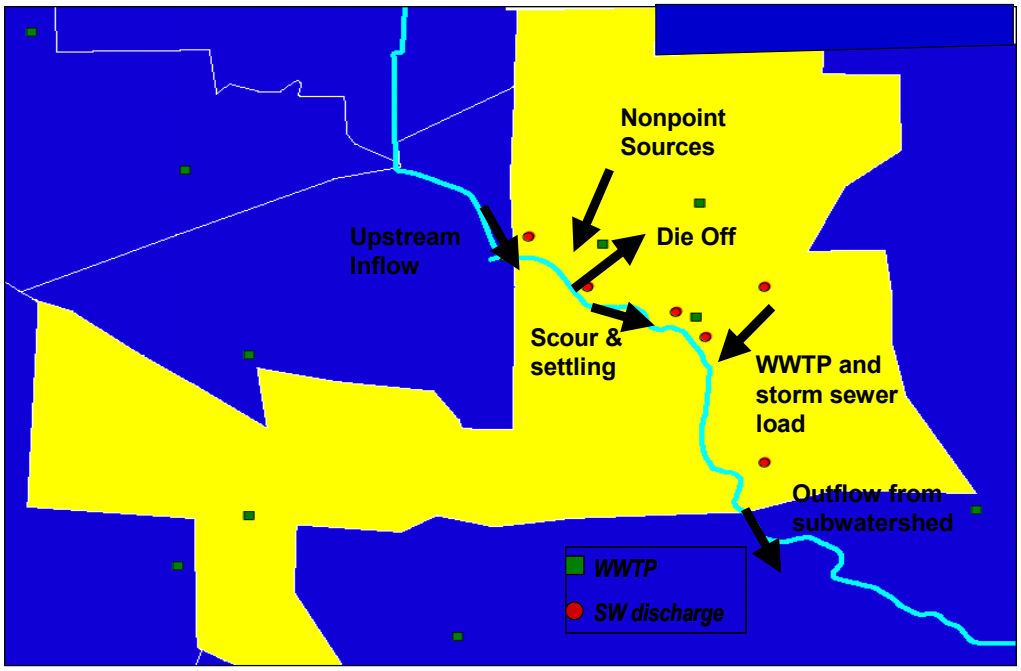


Figure 5.2

details the calibration and sensitivity analyses undertaken for the Buffalo and Whiteoak Bayou models. Finally, several loading scenarios are presented to assist in TMDL development.

5.1.2 Physical Input Data

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

(1) the selection of subwatersheds,

(2) meteorologic data,

(3) land use data and

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

5.1.2.1 Delineation of Subwatersheds

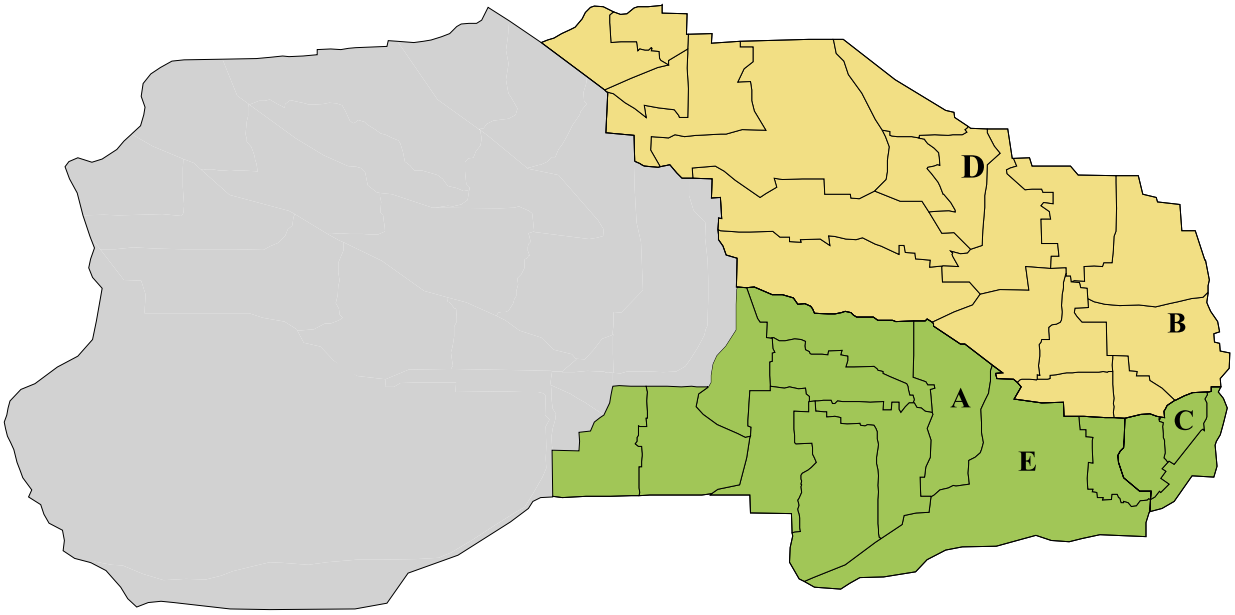
The Buffalo and Whiteoak Bayou watersheds cover a total of 465 square miles within the San Jacinto River basin in Texas. In order to better simulate the fate and transport of *E. coli*, these watersheds were divided into a total of 15 subwatersheds for Buffalo Bayou and 21 subwatersheds for Whiteoak Bayou.

Initial subwatershed delineation was based upon flood hazard models provided by the Harris County Flood Control District (HCFCD). Several modifications to the HCFCD subwatersheds delineation were made based upon locations of stream gages, locations of bacteria monitoring stations, locations of confluences with major tributaries, variation of channel characteristics, drainage patterns and desired spatial resolution for scenario simulations.

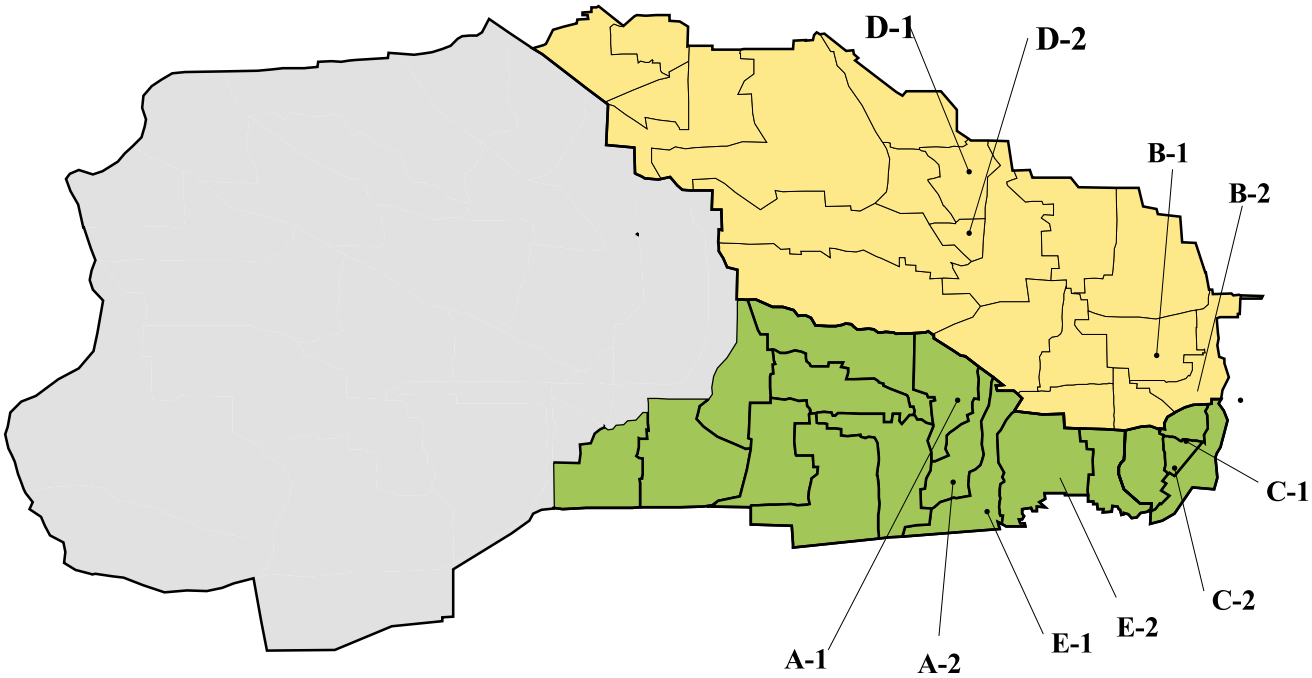
Figure 5.3 illustrates the differences between the initial watershed delineation obtained from HCFCD and the final delineation used in the HSPF model. Note that the subwatersheds

above Barker and Addicks Reservoirs (noted as Reservoirs in Figure 5.3) are not included in the model. The subwatershed labeled A in the original HCFCD delineation was split into two separate subwatersheds, A-1 and A-2 to co-locate the downstream end of the subwatershed with an existing sampling station. This is also true for the subwatershed E, which was split into two separate subwaterseheds. Another subwatershed, B, was split and slightly extended to accommodate the stream station for Little Whiteoak Bayou and better delineate the tributary's watershed. Subwatershed C in the original HCFCD delineation was divided so one portion of the watershed drains to Buffalo Bayou and the other drains to Whiteoak Bayou. Finally, the boundaries of subwatershed D were adjusted to better delineate the watershed for Vogel Creek, and thus D was split into D-1 and D-2. Finally, the lower portion of the subwatershed (as shown in the original HCFCD delineation) was not included in the final delineation because these areas were not considered to contribute significant amounts of bacterial runoff. The modified delineation was used to define bayou reaches and setup the HSPF data file.

Subwatershed identification numbers, which correspond to the pervious and impervious land segment IDs as well as the stream reaches, are shown in Figure 5.4.



Original Harris County Flood Control District (HCFCD) Subwatershed Delineation



Modified HCFCD Subwatershed Delineation for HSPF

Legend

Watersheds
- Buffalo Bayou
- Whiteoak Bayou
- Reservoirs

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Figure 5.3. Changes in the HCFCD Subwatershed Delineation.

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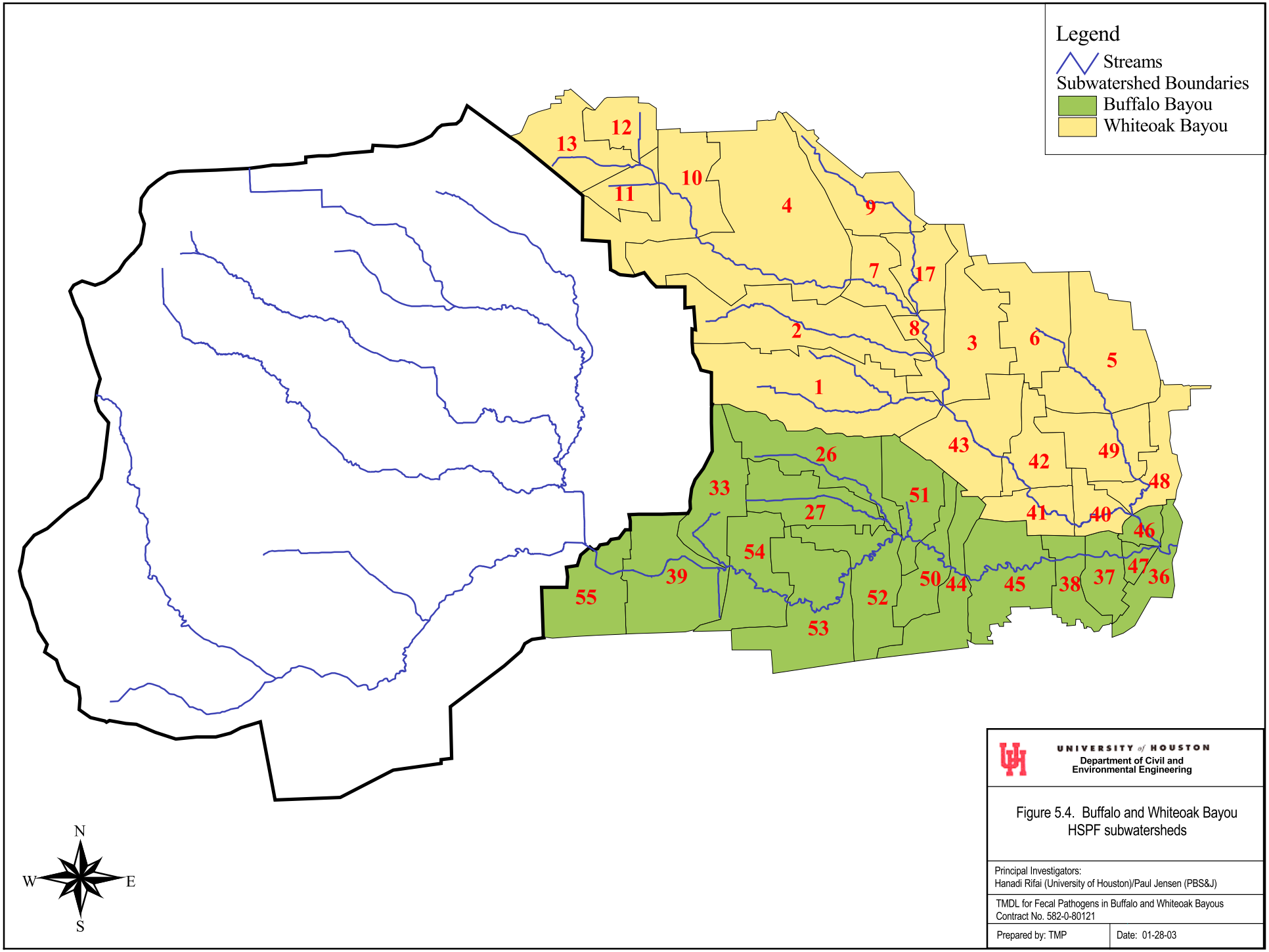

Figure 5.4. Buffalo and Whiteoak Bayou HSPF subwatersheds

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

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5.1.2.2 Meteorologic Data

Rainfall data from April 1, 1999 to December 31, 2001 were provided by the City of Houston for the selected rain gages shown in Figure 5.5. These gages were selected based on the completeness of the rain data and the relative locations of the rain gages to subwatersheds; rain data were assigned to subwatersheds as shown in Table 5.1 below.

Table 5.1. Assignment of Rain Gages to Subwatershed.

Rain Gage	Subwatersheds	Watershed
14	1-4, 6-13,17	Whiteoak Bayou
21	26, 27, 33, 56	Buffalo Bayou
30	28, 34, 35, 39, 53-55	Buffalo Bayou
32	43-45, 50-52	Buffalo and Whiteoak Bayou
34	5, 37-38, 40-42, 46-49	Buffalo and Whiteoak Bayou
35	36	Buffalo Bayou

The hourly rainfall data were processed using the Input / Output for Watershed Data Management files program (IOWDM, Version 2.0, 1993) into the binary WDM files HSPF uses to input and output time series.

Both potential evaporation and potential evapotranspiration data are also required by HSPF. Evaporation is the process by which water is transformed into water vapor and evapotranspiration is plant transpiration combined with evaporation from the soil. The BASINS modencludes hourly time series from 1970 to 1995 for both of these data types. As an initial approach, the 1993 to 1995 data were adopted to represent the 1999 to 2001 period. These data were later updated using the evaporation data obtained from the Texas Water Development Board

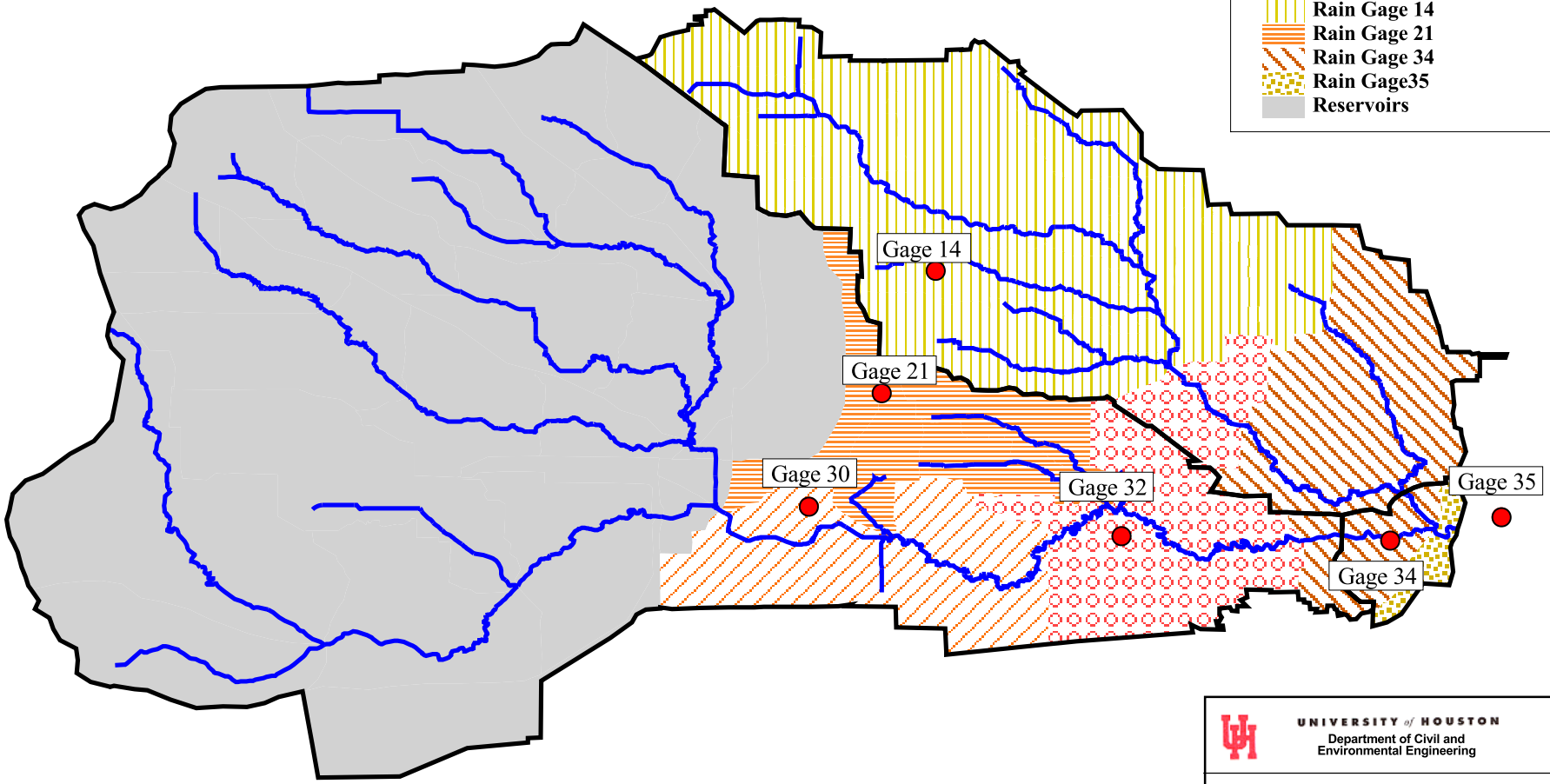

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Figure 5.5. HSPF rain gages and their associated subbasins.

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Contract No. 582-0-80121

Prepared by: TMP | Date: 08-05-02

(TWDB) (Texas Water Development Board 2000).

To update the data obtained from BASINS, monthly evaporation data were obtained from the Texas Water Development Board website. Evaporation data are available from the TWDB website for various regions of the state, as divided into quadrangles. Data from quadrangles 812 and 813 were downloaded for the years 1999 to 2000. The data were first averaged over the two quadrangles. The 2001 monthly data were then derived by averaging the 1999 and 2000 data for the same month. These derived monthly data were then converted to hourly data following the same distribution as the 1993 to 1995 hourly series from BASINS. The same ratio between the BASINS' evaporation and evapotranspiration was maintained to develop the evapotranspiration time series. The resulting hourly time series were processed to a WDM file as input to the HSPF model.

Figure 5.6 shows the derived evaporation (EVAP) and evapotranspiration (ET) data used in the HSPF model for both Buffalo and Whiteoak Bayous. The fluctuations in the data are seasonal, with the lowest rates occurring in January and the highest rates in July for both EVAP and ET.

5.1.2.3 Land Use Discretization

Land use data were first retrieved from BASINS 3.0, as shown in Figure 5.7. These land use/land cover data are part of the US EPA's Spatial Data Library and were collected in the early 1980's. After examining this land use information, the project team found that the data were grossly inaccurate. For example, much of the upper Buffalo Bayou Watershed was classified as barren land, a classification that is not consistent with the urban nature of the watershed.

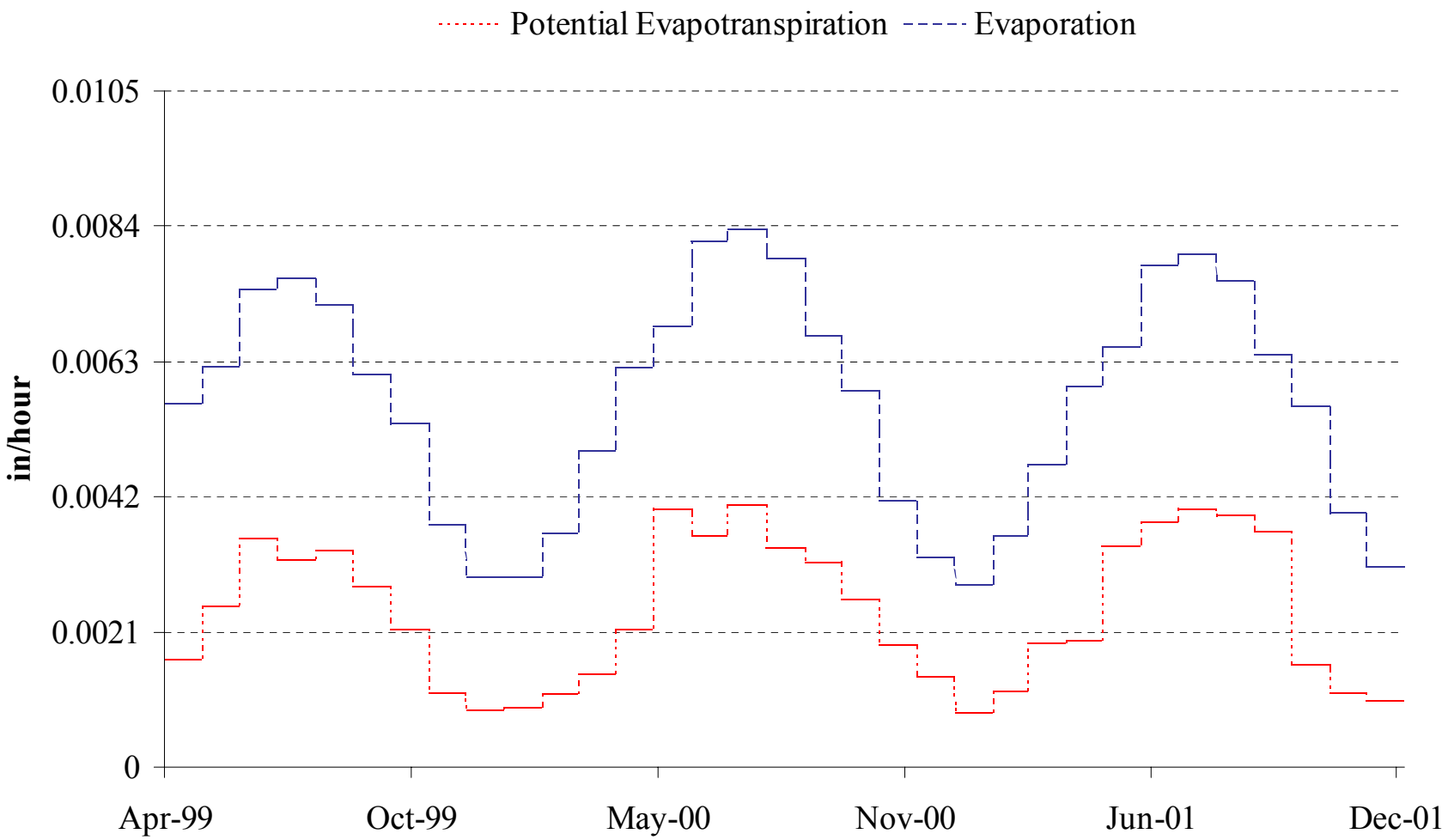
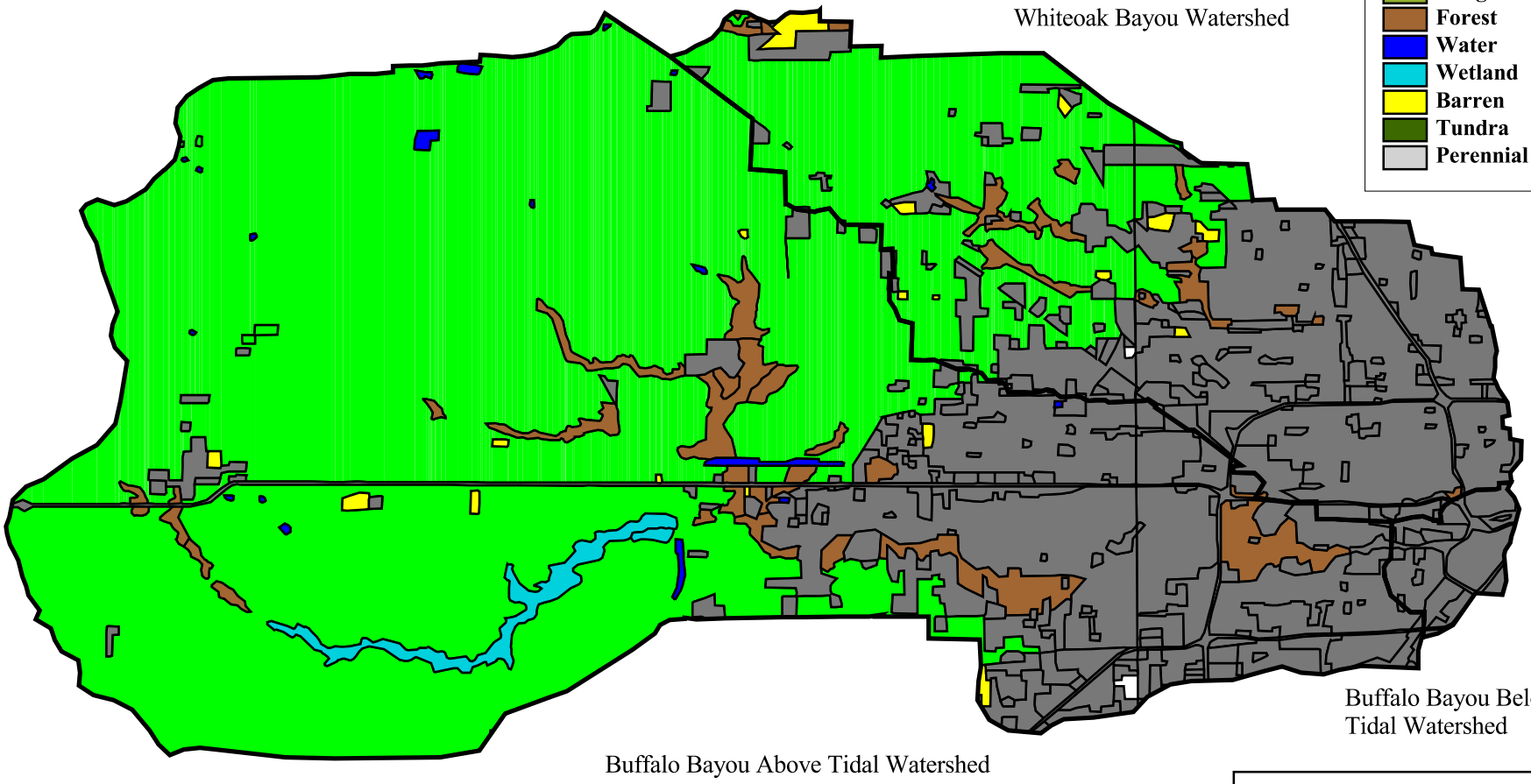
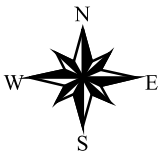


Figure 5.6 Evaporation and Evapotranspiration Data used in HSPF





Data Source: US EPA BASINS 3.0. Data colected early 1980's.

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Figure 5.7. BASINS Landuse for Buffalo and Whiteoak Bayou Watersheds

Principal Investigators:
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Contract No. 582-0-80121

Prepared by: TMP | Date: 08-05-02

Consequently, a more current land use data set (2001) was obtained from the Houston-Galveston Area Council (H-GAC) and used for model development.

The H-GAC land use data are based primarily on classifications of land cover derived from year 2000 satellite image data and aerial photography as well as other sources of information including:

1. Landsat 7 ETM multi-spectral satellite images from November 1999 and February 2000 with 30-meter resolution;
2. Appraisal data of third quarter of 1999 from County Appraisal Districts;
3. Year 2000 public utility connections data; and
4. Census 2000 blocks and Census 2000 population.

As shown in Figure 5.8, the H-GAC land use data include estimates for the following categories of land use/land cover: residential (predominantly single family subdivisions, single family residence, and mobile homes), commercial (all developed non-residential uses, some apartment complexes), open land (undeveloped land, including parks and rights of way), water and other (indeterminate land classifications that are primarily open land and/or water).

In HSPF, the modeled area is divided into pervious and impervious subwatersheds. The pervious subwatersheds are considered to be land segments that have adequate infiltration to affect the water budget. The model does not calculate infiltration in impervious subwatersheds (Bicknell et al. 1996).

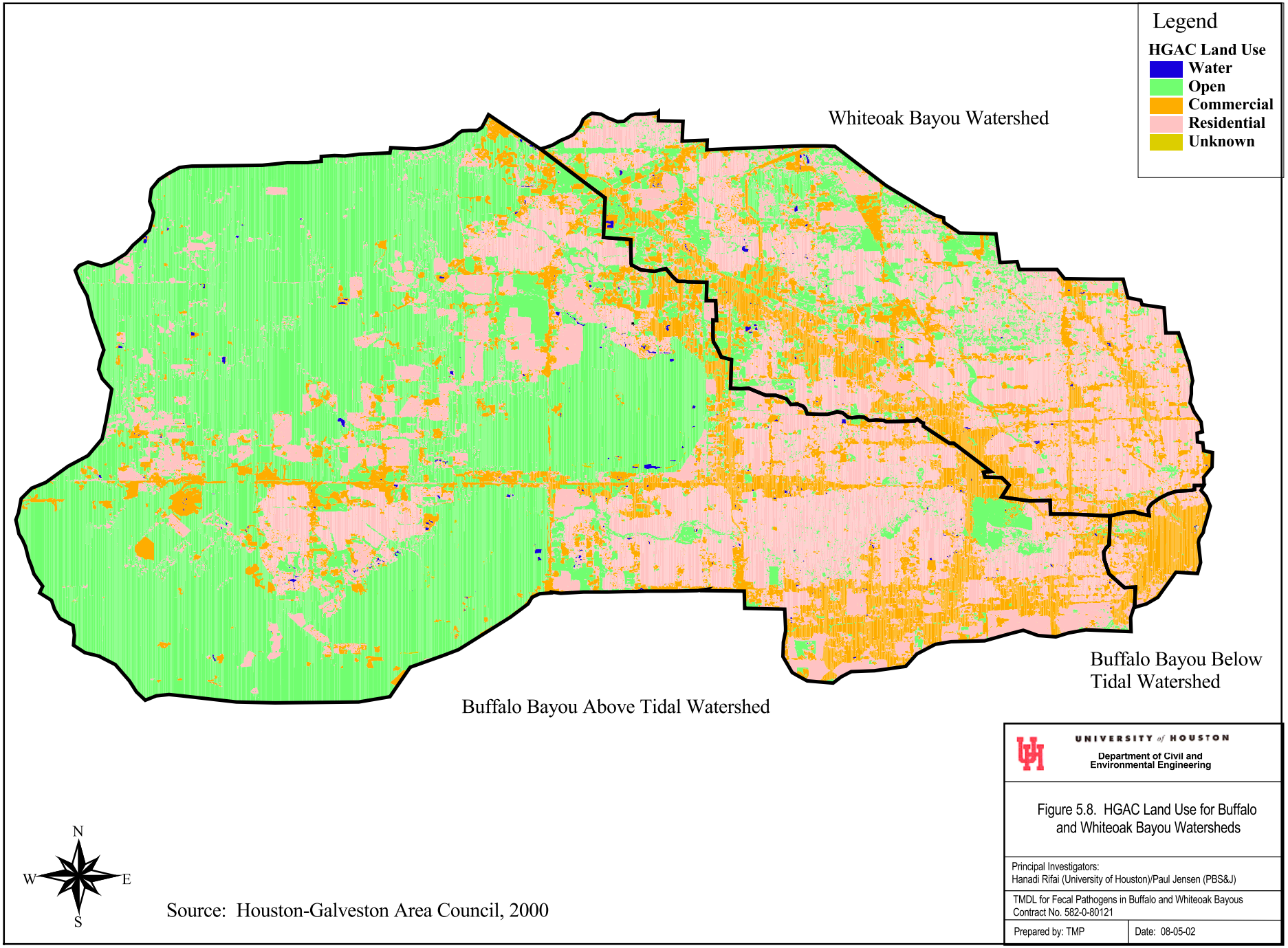
Legend
HGAC Land Use
Water
Open
Commercial
Residential
Unknown
Whiteoak Bayou Watershed
Buffalo Bayou Below Tidal Watershed
Buffalo Bayou Above Tidal Watershed
N
W
E
S
Source: Houston-Galveston Area Council, 2000
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Figure 5.8. HGAC Land Use for Buffalo and Whiteoak Bayou Watersheds
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
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Prepared by: TMP
Date: 08-05-02

To convert the land use areas provided by H-GAC to pervious and impervious areas, the following assumptions were made:

a) Residential – 50% impervious (see Table 5.2.);

b) Commercial – 100% impervious;

c) Open land – 100% pervious;

d) Water – 100% impervious; and

e) Other - 50% impervious.

The total pervious and impervious areas for each subwatershed were calculated using:

*Impervious area = commercial + 50%*residential + water + 50%*other* (5-1)

*Pervious area = 50%*residential + open + 50%*other* (5-2)

Table 5.3 shows the total pervious and impervious areas for the subwatersheds calculated using the above formulas.

5.1.2.4 Soil Characteristics

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

Table 5.2
Residential area impervious cover calculations:

Unit Area of Lot plus Right of Way (ROW):						
A typical house lot =	70	x	110	=	7700	ft^2
A typical street Right of Way =	60	ft				
Total lot area = Lot + 1/2 ROW =	140					
Total Residental Pervious Cover (ft^2) =						
(Lot plus 1/2 of Right of Way)	70	x	(110+30)	=	9800	ft^2
Impervious Area:						
A typical house (ft^2) =		+	2000	ft^2		
Garage =		+	659	ft^2		
Driveway (10 feet wide) =		+	700	ft^2		
Street (half of a 28-ft street) =		+	980	ft^2		
Sidewalk (4 ft) =		+	280	ft^2		
Walkway (3ft) =		+	150	ft^2		
Total =			4769			
Note: Patios and other impervious areas are about the same size as the green or pervious areas, such as those in a neighborhood park or in a residential development.						
Impervious Cover Percentage =	4769/9800	=			49%	

Confirmatory Calculations

City of Houston Runoff Coefficients (C) for Land Use[1]	
Residential lots > 1/2 acre	0.35
Residential lots 1/4 - 1/2 acre	0.45
Residential lots < 1/4 acre	0.55
These runoff coefficients are defined by:	$C = 0.6 * I_A + 0.2$
Calculating Impervious Cover from the Runoff Coefficients:	
Residential lots > 1/2 acre	25.00%
Residential lots 1/4 - 1/2 acre	41.67%
Residential lots < 1/4 acre	58.33%
These values indicate that the assumption of 50% impervious cover is a reasonable one.	

[1] The City of Houston design criteria call for specific runoff coefficient (C) values to be used for specific land uses when doing drainage calculations.

TABLE 5.3
LAND USE AREAS (in acres) FROM H-GAC

Subbasin	1	2	3	4	5	6	7	8
Pervious	3,196.83	2,493.41	2,567.58	6,299.35	2,211.70	1,826.95	975.26	416.62
Impervious	4,489.15	3,741.58	1,844.39	4,836.16	3,056.83	2,018.67	838.03	345.46
% Impervious	58.41%	60.01%	41.80%	43.43%	58.02%	52.49%	46.22%	45.33%
Total	7,685.98	6,234.98	4,411.97	11,135.51	5,268.52	3,845.62	1,813.29	762.08
Subbasin	9	10	11	12	13	17	26	27
Pervious	1,645.73	2,366.44	662.52	970.47	1,695.05	1,151.85	1,787.36	1,128.62
Impervious	1,532.43	2,258.85	835.87	722.26	1,219.30	846.21	2,301.38	1,735.57
% Impervious	48.22%	48.84%	55.78%	42.67%	41.84%	42.35%	56.29%	60.60%
Total	3,178.16	4,625.30	1,498.39	1,692.73	2,914.35	1,998.06	4,088.74	2,864.19
Subbasin	33	36	37	38	39	40	41	42
Pervious	1,148.68	175.74	397.25	497.35	2,183.76	436.69	480.22	853.23
Impervious	1,851.03	1,410.94	1,170.60	1,132.86	2,494.64	779.06	1,215.44	1,317.56
% Impervious	61.71%	88.92%	74.66%	69.49%	53.32%	64.08%	71.68%	60.69%
Total	2,999.71	1,586.68	1,567.85	1,630.21	4,678.40	1,215.75	1,695.66	2,170.79
Subbasin	43	44	45	46	47	48	49	50
Pervious	1,321.49	866.74	2,081.80	141.78	8.49	905.95	1,157.17	638.05
Impervious	2,830.07	1,808.04	1,856.59	527.69	449.35	1,367.03	1,858.44	1,365.25
% Impervious	68.17%	67.60%	47.14%	78.82%	98.15%	60.14%	61.63%	68.15%
Total	4,151.56	2,674.78	3,938.39	669.47	457.84	2,272.98	3,015.61	2,003.31
Subbasin	51	52	53	54	55			
Pervious	1,014.31	1,372.89	1,964.02	1,441.28	1,684.09			
Impervious	1,505.18	2,139.61	2,970.15	1,818.69	1,490.67			
% Impervious	59.74%	60.91%	60.20%	55.79%	46.95%			
Total	2,519.49	3,512.50	4,934.17	3,259.97	3,174.76			

Landuse	Buffalo Bayou		Whiteoak Bayou		TOTAL	
	Acreage	%	Acreage	%	Acreage	%
Pervious	18,532	39.80%	33,635	46.98%	46,443	45.40%
Impervious	28,028	60.20%	37,953	53.02%	55,847	54.60%
Total	46,560	100.00%	71,587	100.00%	102,290	100.00%

The distribution of the soil series types is described in Table 5.4 and is shown in Figure 5.9. The soils in the upper watershed of Whiteoak Bayou are primarily in the Clodine soil series, as shown in the figure and table. The lower portions of the watershed are primarily from the Bernard and Katy soil series. In Buffalo Bayou, the majority of the soils are made up of the Aldine, Clodine and Edna soil series. A small portion of the lower watershed in Buffalo Bayou is comprised of the Bernard series.

Table 5.5 presents the seven types of surficial soils that are found in the Buffalo and Whiteoak Bayou watersheds. The permeability of all soils in these watersheds is considered to be very slowly to moderately permeable. The agronomic drainage class of the watershed soils range from somewhat poorly to moderately well drained. The slopes of these series are nearly level, ranging from 0 to 3 percent. The minimum available water holding capacity is very similar for all of the soil series, ranging form 0.10 to 0.15 in/in and the maximum is generally 0.5 in/in higher than the minimum.

The NRCS groups the runoff potential into four hydrologic soil groups, with group A being the highest infiltration rate and group D being the slowest. The hydric group of the soils in Buffalo and Whiteoak Bayou watersheds is mostly group D, which indicates that these soils have a very low infiltration rate, and thus a high-runoff potential when thoroughly wet. The infiltration rate of the Wockley soil series is considered low, as it is in hydric group C (Soil Survey Division Natural Resources Conservation Service United States Department of Agriculture). It is noted that while the soil series in the study area suggest relatively low

Table 5.4. STATSGO Soil Composition by Subwatershec

Whiteoak Bayou

Subwatershed ID	Area (Acres)							Total Acres in Subwatershed
	ALDINE TX007	BERNARD TX048	CLODINE TX100	EDNA TX163	KATY TX248	LAKE CHARLES TX276	WOCKLEY TX618	
1		1836.0	4977.5		866.8			7680.3
2			4935.5		1305.8			6241.3
3			2694.7		1716.8			4411.4
4			11129.2		5.9			11135.0
5			5263.8					5263.8
6			3848.1					3848.1
7			692.1		1122.7			1814.8
8					760.3			760.3
9			3175.5					3175.5
10			4362.6				262.0	4624.5
11			1430.7				68.5	1499.2
12			0.0				1690.5	1690.5
13			1206.5		310.2		1400.3	2916.9
17			1521.1		478.4			1999.6
40	0.5	898.9	305.4		9.1			1213.9
41	44.2	663.4	43.9		941.9			1693.4
42			1104.0		1071.7			2175.6
43		55.5	1072.5		3022.1			4150.2
48		1137.1	1134.8					2271.9
49		48.2	2969.8					3018.0
Total	**44.7**	**4639.2**	**51867.6**	**0.0**	**11611.6**	**0.0**	**3421.3**	**71584.3**
%	**0.1%**	**6.5%**	**72.5%**	**0.0%**	**16.2%**	**0.0%**	**4.8%**	

Buffalo Bayou

Subwatershed ID	Area (Acres)							Total Acres in Subwatershed
	ALDINE TX007	BERNARD TX048	CLODINE TX100	EDNA TX163	KATY TX248	LAKE CHARLES TX276	WOCKLEY TX618	
26	135.2	1109.4	2300.1		543.4			4088.1
27	187.5		2638.7		44.5			2870.7
33	90.3		2911.1					3001.4
36	323.1	168.9		56.7	202.4	835.5		1586.6
37	312.8	74.4		817.8	179.1	186.1		1570.3
38	289.7	149.0		697.8	490.9			1627.4
39	1216.0		142.4	712.3	2451.4	159.9		4682.0
44	478.8			685.0	417.9	1093.1		2674.7
45	1567.2	264.0		2111.0				3942.2
46	298.2	371.9						670.0
47	183.5			11.5		262.5		457.5
50	645.7			67.5	372.8	915.5		2001.6
51	452.3	194.3			1807.8	63.2		2517.6
52	905.3		678.0	560.7		1362.5		3506.4
53	1424.6		1002.6	2117.0	170.6	213.6		4928.4
54	809.9		1383.1	771.4	298.0			3262.4
55	893.3			1561.2	302.6	417.2		3174.3
Total	**10213.3**	**2331.9**	**11056.1**	**10169.9**	**7281.5**	**5509.1**	**0.0**	**46561.8**
%	**21.9%**	**5.0%**	**23.7%**	**21.8%**	**15.6%**	**11.8%**	**0.0%**	

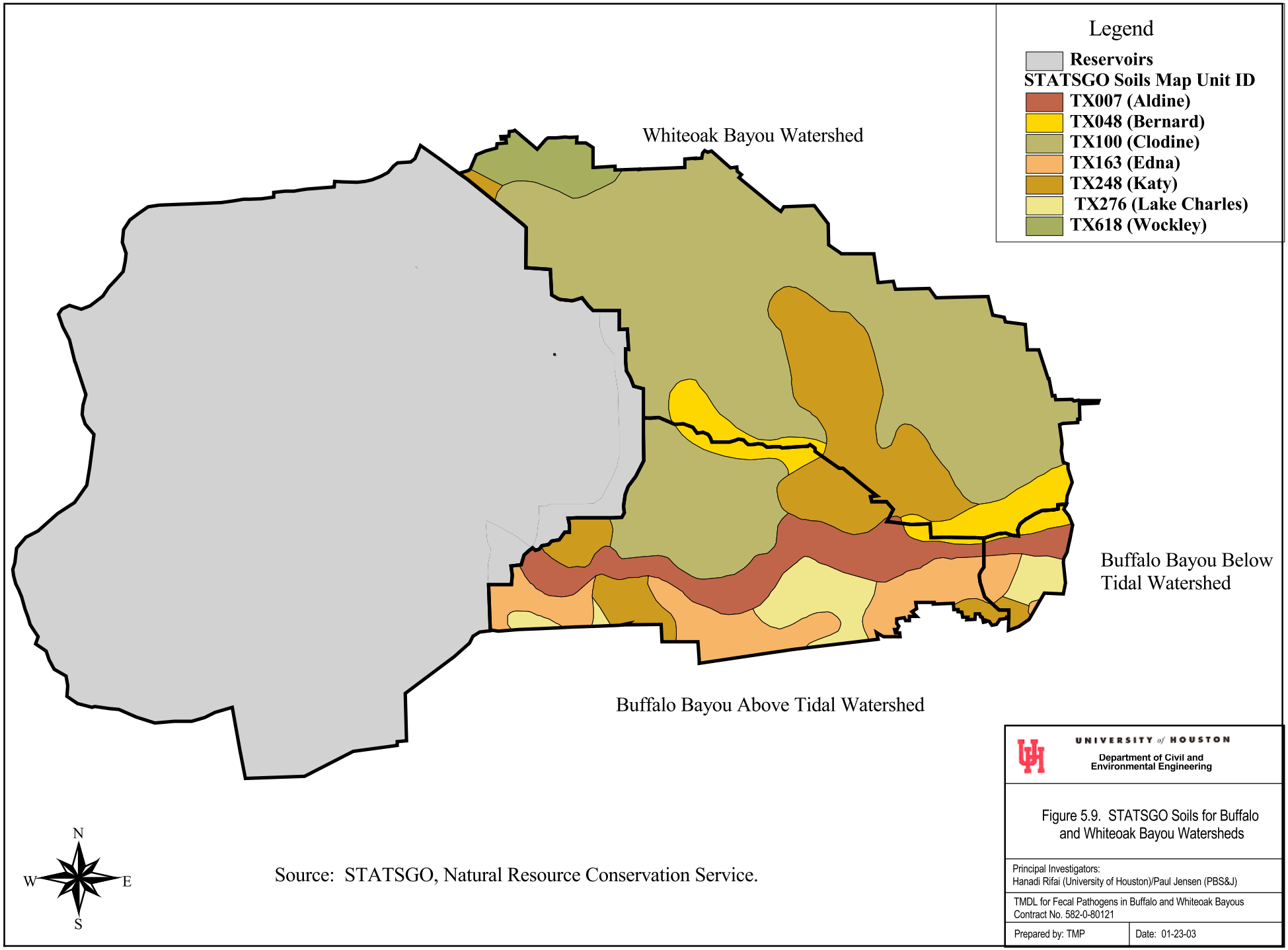

Legend
Reservoirs
STATSGO Soils Map Unit ID
TX007 (Aldine)
TX048 (Bernard)
TX100 (Clodine)
TX163 (Edna)
TX248 (Katy)
TX276 (Lake Charles)
TX618 (Wockley)
Whiteoak Bayou Watershed
Buffalo Bayou Below Tidal Watershed
Buffalo Bayou Above Tidal Watershed
N
W
E
S
Source: STATSGO, Natural Resource Conservation Service.
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 5.9. STATSGO Soils for Buffalo and Whiteoak Bayou Watersheds
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121
Prepared by: TMP
Date: 01-23-03

Table 5.5. Soil Characteristics of STATSGO Soils.

Map Unit ID	Soil Series Name	Min Available Water Capacity (in/in)	Max Available Water Capacity (in/in)	Min Bulk Density (g/cm^3)	Hydric Group
TX007	ALDINE	0.11	0.15	1.3	D
TX048	BERNARD	0.15	0.2	1.2	D
TX100	CLODINE	0.15	0.2	1.35	D
TX163	EDNA	0.10	0.15	1.4	D
TX248	KATY	0.15	0.2	1.3	D
TX276	LAKE CHARLES	0.15	0.2	1.2	D
TX618	WOCKLEY	0.15	0.2	1.4	C

infiltration rates, the modeled infiltration rate was higher than the typical type D rate. According to the US EPA (2001), soils in hydric group C correspond to HSPF infiltration parameter values between 0.05 and 0.1 in/hr. Hydric group D is estimated to have infiltration parameters around 0.01 to 0.05 in/hr.

5.1.2.5 Reach Characteristics

A set of HEC-1 and HEC-2 Federal Emergency Management Agency flood hazard models (1996 version) were obtained from the Harris County Flood Control District (HCFCD) for Buffalo Bayou, Whiteoak Bayou and their tributaries. Information regarding the reaches was extracted from the HEC-1 and HEC-2 model input files. A summary of the stream reach characteristics is presented in Table 5.6. The reaches used in the model vary from 0.62 miles to 6.7 miles long. The watersheds have a flat topography, with slopes in the Buffalo and Whiteoak Bayou watersheds ranging from 0.0003 ft/ft to 0.0027 ft/ft.

5.1.3 Hydrologic and Hydraulic Model Input

In order for HSPF to route water flow downstream, it must be supplied with rating curves that describe the reach response to a volume of water. Additionally, other flow inputs such as those from point sources and dry weather storm sewer discharges, as well as the upstream input from the reservoirs on Buffalo Bayou require routing factors as well. The following data provide the basis for the hydrologic modeling performed with HSPF.

Table 5.6. Reach Characteristics

Subwatershed	Reach Length (Miles)	Slope (ft/ft)	Bayou
26	4.11	0.0024	Buffalo Bayou
27	3.38	0.0027	Buffalo Bayou
33	3.39	0.0008	Buffalo Bayou
37	1.04	0.0006	Buffalo Bayou
38	0.9	0.0003	Buffalo Bayou
39	3.4	0.0005	Buffalo Bayou
44	0.62	0.0008	Buffalo Bayou
45	4.3	0.0003	Buffalo Bayou
47	0.99	0.0012	Buffalo Bayou
50	1.74	0.0003	Buffalo Bayou
51	0.78	0.0005	Buffalo Bayou
52	3.1	0.0004	Buffalo Bayou
53	4.08	0.0005	Buffalo Bayou
54	2.78	0.0005	Buffalo Bayou
55	1.54	0.0006	Buffalo Bayou
1	5.782	0.0013	Whiteoak Bayou
2	6.703	0.0010	Whiteoak Bayou
3	1.459	0.0009	Whiteoak Bayou
4	5.135	0.0010	Whiteoak Bayou
5	2.042	0.0017	Whiteoak Bayou
6	2.296	0.0019	Whiteoak Bayou
7	2.488	0.0006	Whiteoak Bayou
8	1.621	0.0019	Whiteoak Bayou
9	4.046	0.0012	Whiteoak Bayou
10	2.21	0.0009	Whiteoak Bayou
11	1.133	0.0010	Whiteoak Bayou
12	1.558	0.0007	Whiteoak Bayou
13	1.986	0.0006	Whiteoak Bayou
17	2.405	0.0012	Whiteoak Bayou
40	2.023	0.0009	Whiteoak Bayou
41	1.955	0.0009	Whiteoak Bayou
42	1.3	0.0012	Whiteoak Bayou
43	2.349	0.0009	Whiteoak Bayou
46	1.396	0.0007	Whiteoak Bayou
48	1.813	0.0018	Whiteoak Bayou
49	2.088	0.0014	Whiteoak Bayou

5.1.3.1 Hydraulic Rating Curves

Hydraulic data needed for HSPF include routing factors and rating curves that relate water depth, water surface area, and water volume with outflow discharge. With this information, FTABLEs, which summarize the geometric and hydraulic properties, can then be developed for each stream being modeled.

The HEC-1 models were first used to simulate the watersheds' responses to rainfall for a set of flow conditions, which included the 10-, 50-, 100- and 500-year flows. To develop the rating curves for low flow periods, the 10- and 50-year flows were divided by 10, 100 and 1000. These rating curves were then used to execute HEC-2, which calculates the water surface profiles based upon the HEC-1 model runs. Tables 5.7, 5.8, 5.9 and 5.10 list the developed hydraulic data for Buffalo Bayou main stem, Buffalo Bayou tributary, Whiteoak Bayou main stem and Whiteoak Bayou tributary reaches, respectively. These data were used to develop reach FTABLES to describe the relationship between depth, surface area, volume and volume dependant storage.

5.1.3.2 Wastewater Treatment Plant Flows

The average flows from the wastewater dischargers in the two watersheds was obtained from an existing study (PBS&J, 2001). The 2001 study made use of self-monitoring report records of wastewater dischargers obtained from Texas Commission on Environmental Quality (TCEQ) for the period from September 1995 to February 2000. Figure 5.10 shows the location of these dischargers. The mean flows from each wastewater discharger within a subwatershed were added

TABLE 5.7
HYDRAULIC DATA FOR BUFFALO BAYOU MAIN STEM REACHES

						10-Year/1000				10-Year/100				10-Year/10				10-Year				50-Year/1000			
		Data related to "To Station"																							
Reach ID	From Station No.	To Station No.	Bottom Elev. (ft)	Cumul Reach Length (ft)	Cumul Reach Length (mi)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
34	2508+89	2433+08	51.10	7,581.00	1.4358	1.03	2.61	4.22	2.86	2.69	3.96	10.55	28.60	8.31	8.57	44.17	286.00	25.31	32.52	355.56	2,860.00	1.16	2.72	4.67	3.90
35	2509+20	2508+89	57.60	808.95	0.1532	0.27	0.32	0.08	1.45	0.76	0.39	0.25	14.50	3.08	0.70	1.53	145.00	19.41	2.66	29.14	1,450.00	0.30	0.32	0.09	2.00
36	1099+04	1060+65	-13.00	3,839.00	0.7271	22.25	14.67	207.72	46.60	22.26	14.67	207.83	466.00	22.83	14.96	218.10	4,660.00	39.37	34.17	622.48	46,600.00	22.25	14.67	207.72	61.30
37	1206+38	1151+37	-6.50	5,501.00	1.0419	15.75	18.69	138.22	16.30	15.76	18.71	138.49	163.00	16.87	22.09	164.19	1,630.00	38.24	101.10	1,491.71	16,300.00	15.75	18.69	138.22	21.80
38	1253+69	1206+38	-3.00	4,731.00	0.8960	12.25	15.85	87.56	16.30	12.27	16.00	87.96	163.00	13.75	18.77	120.94	1,630.00	35.10	77.75	967.38	16,300.00	12.25	15.85	87.56	21.80
39	2351+53	2171+92	37.00	17,961.00	3.4017	1.87	9.27	8.74	11.10	5.14	14.08	36.50	111.00	13.36	36.26	201.65	1,110.00	30.30	208.52	1,676.31	11,100.00	2.07	9.74	10.07	13.90
44	1513+43	1480+93	5.60	3,250.00	0.6155	3.66	3.10	6.44	15.10	4.56	3.76	11.70	151.00	11.79	7.30	52.91	1,510.00	32.31	36.51	415.71	15,100.00	3.68	3.11	6.55	20.50
45	1480+93	1253+69	-1.80	22,724.00	4.3038	11.05	45.66	264.46	16.30	11.08	46.52	274.05	163.00	13.18	69.22	540.28	1,630.00	34.67	319.60	4,357.95	16,300.00	11.05	45.67	264.55	21.80
47	1151+37	1099+04	-13.00	5,233.00	0.9911	22.25	21.11	246.57	46.60	22.26	21.12	246.81	466.00	23.19	22.62	269.48	4,660.00	42.91	76.29	1,108.03	46,600.00	22.25	21.11	246.57	61.30
50	1605+13	1513+43	8.20	9,170.00	1.7367	1.13	7.63	13.50	14.80	3.14	10.57	35.33	148.00	11.16	20.17	158.49	1,480.00	31.25	94.90	1,289.77	14,800.00	1.19	7.86	14.35	19.70
51	1646+28	1605+13	11.20	4,115.00	0.7794	1.52	2.97	2.69	14.80	4.40	5.46	13.11	148.00	12.97	10.79	77.88	1,480.00	32.28	26.98	475.65	14,800.00	1.74	3.16	3.16	19.70
52	1809+98	1646+28	13.40	16,370.00	3.1004	2.53	9.16	15.90	14.30	5.24	14.46	52.63	143.00	12.75	36.78	243.97	1,430.00	31.54	156.07	2,100.41	14,300.00	2.77	9.67	18.20	18.90
53	2025+38	1809+98	19.40	21,540.00	4.0795	5.01	12.06	18.55	12.20	7.96	21.08	68.12	122.00	15.64	45.86	331.39	1,220.00	33.14	251.99	2,834.47	12,200.00	5.29	13.05	21.88	17.00
54	2171+92	2025+38	29.30	14,654.00	2.7754	2.44	7.48	11.29	12.20	5.99	14.48	48.03	122.00	14.64	38.75	239.27	1,220.00	32.41	147.41	1,680.86	12,200.00	2.79	8.19	13.55	17.00
55	2433+08	2351+53	46.00	8,155.00	1.5445	1.60	2.73	2.45	6.80	4.07	6.08	12.36	68.00	11.65	16.00	82.33	680.00	28.85	91.46	641.08	6,800.00	1.75	2.95	2.85	8.40
56																									

		50-Year/100				50-Year/10				50-Year				100-Year				500-Year				500-Year * 10			
Reach ID	To Station No.	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
34	2433+08	2.95	4.28	12.20	39.00	9.34	9.93	53.77	390.00	27.60	139.45	505.50	3,900.00	28.44	248.72	675.15	4,440.00	29.90	393.56	1,147.12	5,330.00	94.53	682.05	43,939.82	53,300.00
35	2508+89	0.88	0.41	0.31	20.00	4.14	0.83	2.34	200.00	21.83	2.82	35.86	2,000.00	22.70	2.82	38.35	2,200.00	24.16	2.82	42.46	2,800.00	88.05	74.28	4,432.64	28,000.00
36	1060+65	22.26	14.67	207.91	613.00	23.23	15.18	225.18	6,130.00	44.14	44.03	819.22	61,300.00	45.76	45.71	901.59	66,500.00	48.25	69.36	1,044.71	75,000.00	114.30	289.84	19,755.46	750,000.00
37	1151+37	15.77	18.73	138.69	218.00	17.58	24.92	182.31	2,180.00	43.47	145.91	2,132.29	21,800.00	45.93	172.71	2,517.88	24,500.00	48.69	217.56	3,069.41	29,500.00	137.13	312.15	30,208.78	295,000.00
38	1206+38	12.28	16.11	88.28	218.00	14.59	19.74	139.25	2,180.00	40.30	108.45	1,447.45	21,800.00	42.74	125.27	1,725.80	24,500.00	45.53	156.08	2,109.39	29,500.00	133.77	222.53	21,410.53	295,000.00
39	2171+92	5.72	14.68	43.07	139.00	14.67	43.45	253.09	1,390.00	33.81	784.06	2,928.63	13,900.00	35.29	964.07	3,899.45	16,500.00	37.14	1,197.21	5,664.68	19,800.00	106.87	1,439.24	102,495.16	198,000.00
44	1480+93	4.97	4.00	13.75	205.00	13.53	8.22	66.46	2,050.00	36.83	45.23	598.30	20,500.00	38.96	48.50	696.50	23,200.00	41.77	57.39	840.65	27,800.00	127.21	107.51	9,742.49	278,000.00
45	1253+69	11.11	47.02	280.49	218.00	14.21	76.09	646.85	2,180.00	39.76	379.10	6,032.94	21,800.00	42.13	425.71	6,940.30	24,500.00	44.90	499.68	8,240.17	29,500.00	132.79	981.61	90,665.75	295,000.00
47	1099+04	22.27	21.13	246.99	613.00	23.80	23.02	284.80	6,130.00	48.00	115.88	1,610.44	61,300.00	50.55	141.79	1,931.62	66,500.00	53.70	176.65	2,407.59	75,000.00	141.70	268.57	25,792.91	750,000.00
50	1513+43	3.75	11.34	42.26	197.00	12.90	22.90	195.42	1,970.00	35.59	109.12	1,729.57	19,700.00	37.64	118.68	1,964.53	22,300.00	40.60	168.84	2,405.86	26,800.00	125.06	238.85	22,454.21	268,000.00
51	1605+13	5.06	5.74	16.23	197.00	14.70	12.29	97.67	1,970.00	36.48	29.81	595.38	19,700.00	38.52	33.10	659.62	22,300.00	41.56	38.11	767.62	26,800.00	125.85	126.15	10,921.16	268,000.00
52	1646+28	5.74	15.43	62.02	189.00	14.44	49.19	311.85	1,890.00	35.75	193.37	2,790.79	18,900.00	37.76	214.55	3,175.64	21,300.00	40.77	281.13	3,900.07	25,600.00	124.59	557.82	48,303.98	256,000.00
53	1809+98	8.66	22.95	84.64	170.00	17.32	61.20	428.51	1,700.00	37.08	349.85	4,049.70	17,000.00	38.68	417.13	4,592.87	19,000.00	41.36	641.28	5,822.46	22,800.00	120.67	933.68	76,295.73	228,000.00
54	2025+38	6.80	15.89	58.10	170.00	16.51	45.42	306.21	1,700.00	36.51	293.67	2,496.10	17,000.00	37.82	422.66	2,970.03	19,000.00	39.94	632.62	4,014.69	22,800.00	113.36	1,225.39	89,534.32	228,000.00
55	2351+53	4.52	6.47	14.74	84.00	12.78	18.09	100.47	840.00	31.10	289.48	1,080.61	8,400.00	31.87	351.09	1,354.59	9,400.00	33.21	429.40	1,961.75	11,500.00	98.56	714.63	47,199.82	115,000.00
56																									

TABLE 5.8
HYDRAULIC DATA FOR BUFFALO BAYOU TRIBUTARY REACHES

						10-Year/1000				10-Year/100				10-Year/10				10-Year				50-Year/1000			
	Data related to "To Station"																								
Reach ID	From Station No.	To Station No.	U/S Bottom Elev. (ft)	D/S Bottom Elev. (ft)	Cumul Reach Length (mi)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
56	453+90	4+75	103.80	55.80	8.5066	0.80	11.02	3.06	2.61	1.90	14.75	10.93	26.10	4.48	25.02	53.96	261.00	11.11	279.66	429.58	2,610.00	0.90	11.22	3.48	3.54
27	0+03	0+00	76.80	28.50	3.3826	0.40	14.52	156.11	2.43	1.14	15.33	166.62	24.25	4.01	18.49	213.21	242.50	14.07	39.31	454.64	2,425.00	0.45	14.58	156.79	3.32
26	218+97	2+11	73.80	20.70	4.1073	1.36	9.13	3.97	7.35	3.23	11.92	14.44	73.50	8.02	17.67	65.28	735.00	18.60	83.64	414.22	7,350.00	1.53	9.43	4.58	9.92
28	903+05	-201+69	71.20	51.10	1.2494	1.10	4.28	3.69	7.03	3.12	6.79	7.19	70.25	9.60	14.38	40.34	702.50	12.71	115.15	202.12	7,025.00	1.31	4.47	3.94	10.86
33	(No HEC model available - assume the same as subwatershed 27).																								

		50-Year/100				50-Year/10				50-Year				100-Year				500-Year				500-Year * 10			
Reach ID	To Station No.	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
56	4+75	2.13	15.55	13.30	35.40	5.02	27.38	67.93	354.00	12.54	449.67	703.93	3,540.00	13.15	605.94	954.51	3,950.00	14.10	987.04	1,484.78	4,680.00	28.34	2,910.31	34,448.79	46,800.00
27	0+00	1.34	15.50	169.62	33.17	4.76	19.37	226.08	331.70	15.93	73.13	525.94	3,317.00	16.60	82.05	556.17	3,700.00	18.08	261.98	682.48	4,712.00	37.74	1,232.25	6,691.56	47,120.00
26	2+11	3.63	12.36	17.35	99.20	9.00	19.16	81.85	992.00	20.75	138.60	545.70	9,920.00	21.61	176.25	620.05	11,210.00	23.59	294.87	846.60	14,000.00	47.69	1,718.49	18,026.94	140,000.00
28	-201+69	3.88	7.20	8.78	108.55	10.52	26.16	55.69	1,085.50	13.35	169.32	293.75	10,855.00	13.62	197.40	351.94	12,785.00	14.09	269.00	478.39	17,500.00	20.79	839.36	4,149.69	175,000.00
33	(No HEC model available - assume the same as subwatershed 27).																								

TABLE 5.9
HYDRAULIC DATA FOR WHITE OAK BAYOU MAIN STEM REACHES

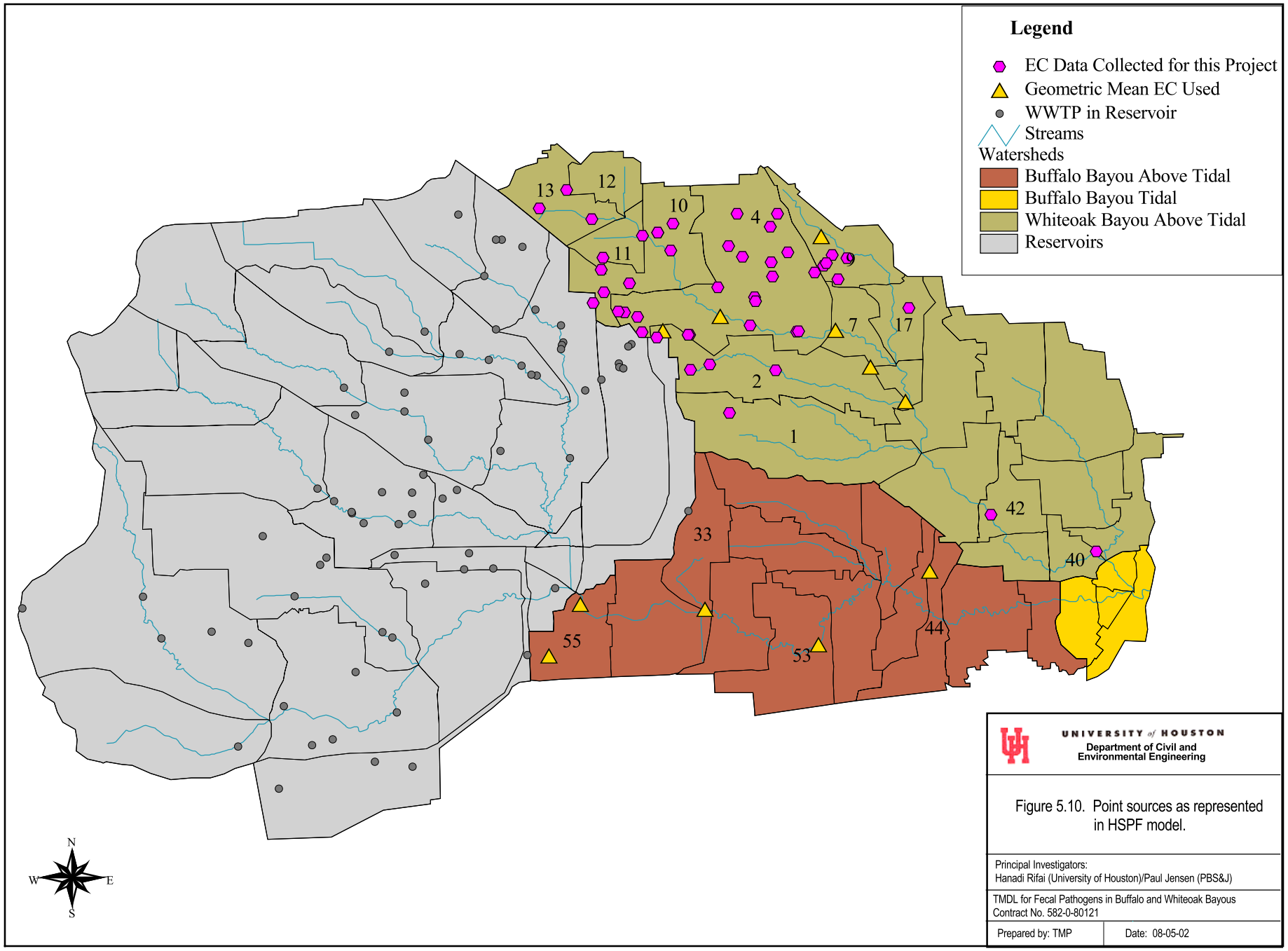
					Data related to "To Station"	10-Year/1000				10-Year/100				10-Year/10				10-Year				50-Year/1000			
Reach ID	From Station No.	To Station No.	Bottom Elev. (ft)	Cumul Reach Length (ft)	Cumul Reach Length (mi)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
3	555+90	478+85	36.50	7,705.00	1.4593	1.21	1.64	1.39	15.78	3.69	8.91	10.76	157.81	8.01	11.72	49.25	1,578.10	26.27	34.82	452.16	15,781.00	1.41	1.73	1.65	20.56
4	1043+96	772+85	68.20	27,111.00	5.1347	1.11	12.94	13.06	9.46	2.04	17.74	38.67	94.58	5.83	89.21	331.45	945.80	18.37	1,164.87	2,824.98	9,458.00	1.15	13.32	14.16	11.65
7	772+85	641+50	60.10	13,135.00	2.4877	0.32	17.03	15.68	11.63	1.01	18.85	33.59	116.31	3.36	33.61	120.03	1,163.10	14.65	393.67	1,431.26	11,631.00	0.34	17.10	16.35	13.72
8	641+50	555+90	43.70	8,560.00	1.6212	0.93	10.97	6.53	14.84	3.20	20.07	23.61	148.41	6.83	26.30	110.97	1,484.10	23.35	45.47	587.77	14,841.00	1.06	11.02	6.97	18.85
10	1160+15	1043+96	94.60	11,669.00	2.2100	1.07	12.02	3.37	6.48	2.86	14.60	13.75	64.75	6.67	24.52	70.75	647.50	15.13	104.37	389.78	6,475.00	1.20	12.17	4.09	8.77
11	1219+95	1160+15	105.60	5,980.00	1.1326	0.28	5.10	0.85	4.05	0.92	5.82	3.41	40.53	3.44	7.44	15.57	405.30	11.78	15.01	100.19	4,053.00	0.33	5.14	1.00	5.49
13	1324+79	1219+95	111.70	10,484.00	1.9856	0.25	9.43	1.56	1.67	0.61	9.92	4.74	16.71	2.18	11.83	19.13	167.10	8.71	32.95	107.12	1,671.00	0.29	9.47	1.77	2.26
40	182+50	75+40	-0.90	10,682.00	2.0231	15.21	16.83	111.18	22.84	15.22	16.87	111.67	228.36	16.55	22.56	150.03	2,283.60	33.35	110.02	1,414.40	22,836.00	15.21	16.83	111.18	27.44
41	285+71	182+50	8.66	10,321.00	1.9547	6.32	8.45	16.28	23.09	6.40	11.42	27.23	230.92	10.24	16.69	101.84	2,309.20	31.44	56.56	864.15	23,092.00	6.32	8.65	16.62	27.42
42	354+85	285+71	17.50	6,864.00	1.3000	2.24	2.01	1.78	22.60	4.20	8.31	12.07	225.96	10.13	11.53	58.53	2,259.60	33.27	34.13	577.12	22,596.00	2.36	2.74	2.22	27.32
43	478+85	354+85	25.70	12,400.00	2.3485	1.33	3.64	3.06	22.09	2.88	15.38	21.17	220.92	6.96	20.58	96.01	2,209.20	28.66	58.63	846.17	22,092.00	1.36	5.15	4.03	28.60
46	75+40	1+60	-6.34	7,370.00	1.3958	20.34	38.62	271.76	29.06	20.34	38.67	272.04	290.63	20.51	41.84	299.26	2,906.30	30.58	88.16	1,286.17	29,063.00	20.34	38.62	271.76	35.96

		50-Year/100				50-Year/10				50-Year				100-Year				500-Year				500-Year * 8.0			
Reach ID	To Station No.	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
3	478+85	3.95	9.07	12.66	205.62	9.08	12.38	59.93	2,056.20	31.27	202.72	955.30	20,562.00	32.29	259.65	1,140.03	21,923.00	34.51	396.49	1,762.69	25,507.00	105.03	619.46	44,364.18	204,056.00
4	772+85	2.22	18.78	44.41	116.50	6.47	93.53	407.44	1,165.00	19.43	2,011.74	4,270.14	11,650.00	19.90	2,275.96	5,081.09	12,591.00	20.98	2,692.44	6,634.07	14,883.00	76.92	4,016.11	187,162.66	119,064.00
7	641+50	1.10	19.12	36.42	137.23	3.69	52.93	142.30	1,372.30	17.07	848.11	2,427.01	13,723.00	17.56	994.93	2,891.82	14,902.00	18.86	1,237.07	4,101.19	17,399.00	83.48	1,706.36	104,981.83	139,192.00
8	555+90	3.40	20.33	26.73	188.45	7.60	27.16	124.73	1,884.50	28.49	263.40	1,078.84	18,845.00	28.89	303.50	1,229.69	19,991.00	30.81	442.46	1,911.24	23,735.00	98.34	920.22	61,100.36	189,880.00
10	1043+96	3.33	15.27	17.24	87.74	7.34	25.56	86.01	877.40	16.00	328.99	646.09	8,774.00	16.31	472.46	810.10	9,697.00	17.00	873.23	1,320.89	12,302.00	55.40	3,069.99	101,087.64	98,416.00
11	1160+15	1.10	5.93	4.11	54.92	4.07	7.86	19.35	549.20	13.23	74.90	149.92	5,492.00	13.71	164.10	191.61	6,198.00	14.71	424.17	425.37	7,915.00	44.67	1,893.60	48,571.70	63,320.00
13	1219+95	0.72	10.05	5.62	22.59	2.58	12.33	23.33	225.90	10.16	50.03	150.05	2,259.00	10.69	57.13	169.81	2,598.00	11.53	71.68	192.95	3,339.00	38.69	2,720.73	55,727.55	26,712.00
40	75+40	15.23	16.89	111.92	274.42	17.14	25.62	167.00	2,744.20	38.23	135.68	1,968.19	27,442.00	38.64	139.61	2,038.01	29,680.00	43.64	264.45	3,037.11	35,837.00	132.40	473.05	43,849.74	286,696.00
41	182+50	6.44	11.58	29.14	274.23	11.11	17.51	116.31	2,742.30	36.63	174.24	1,329.01	27,423.00	38.17	294.35	1,723.31	29,800.00	42.21	646.84	3,729.96	35,823.00	126.48	871.86	73,104.39	286,584.00
42	285+71	4.45	8.46	13.79	273.22	10.95	12.06	68.10	2,732.20	37.71	371.05	1,213.71	27,322.00	39.33	519.56	1,920.03	30,203.00	43.19	658.00	3,944.83	35,780.00	121.21	674.75	56,382.73	286,240.00
43	354+85	3.07	15.76	25.06	286.03	7.77	21.76	116.25	2,860.30	33.24	252.21	1,471.70	28,603.00	34.28	360.88	1,800.46	31,709.00	36.65	587.47	2,739.26	37,858.00	113.77	906.81	68,806.70	302,864.00
46	1+60	20.34	38.70	272.22	359.57	20.66	43.05	314.93	3,595.70	35.34	131.13	1,877.71	35,957.00	36.12	133.26	1,929.66	38,056.00	39.79	185.52	2,744.89	46,041.00	133.67	328.36	30,964.37	368,328.00

TABLE 5.10
HYDRAULIC DATA FOR WHITE OAK BAYOU TRIBUTARY REACHES

		Data related to "To Station"				10-Year/1000				10-Year/100				10-Year/10				10-Year				50-Year/1000			
Reach ID	From Station No.	To Station No.	U/S Bottom Elev. (ft)	D/S Bottom Elev. (ft)	Cumul Reach Length (mi)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
9	340+60	127+00	99.50	74.40	4.0455	0.40	3.89	1.57	1.50	1.32	6.71	5.88	15.00	4.06	13.59	30.32	150.00	10.57	203.95	276.29	1,500.00	0.47	4.21	1.84	2.09
17	127+00	0+00	73.40	57.60	2.4053	0.39	4.43	1.98	3.14	1.62	5.87	6.54	31.42	6.36	11.24	32.85	314.20	16.15	241.16	412.06	3,142.00	0.46	4.61	2.26	4.12
2	354+00	0+00	91.50	54.60	6.7032	0.80	13.92	13.76	3.27	1.96	17.88	27.36	32.68	5.45	32.66	97.35	326.80	10.83	64.73	422.48	3,268.00	0.90	14.38	14.86	4.54
1	320+29	15+01	87.10	47.10	5.7822	0.22	9.27	2.48	5.95	0.92	10.54	10.76	59.50	4.02	12.92	45.15	595.00	13.68	80.37	278.23	5,950.00	0.27	9.65	3.00	8.00
6	439+78	318+63	74.60	52.07	2.2964	0.36	105.04	132.60	1.85	0.86	88.62	122.72	18.50	3.14	101.80	136.08	185.00	13.23	411.05	472.07	1,850.00	0.41	93.75	123.19	2.50
5	318+63	210+79	51.70	33.13	2.0424	0.68	4.44	1.79	6.33	1.93	5.42	5.35	63.26	5.19	6.06	23.17	632.60	23.86	192.24	370.13	6,326.00	0.74	4.62	1.97	7.59
49	210+79	100+29	32.80	17.20	2.0879	2.00	6.74	4.24	7.93	3.71	10.65	15.47	79.34	8.30	13.52	64.16	793.40	23.23	46.02	492.27	7,934.00	2.07	7.09	4.65	9.30
48	100+29	5+80	17.00	-0.50	1.8125	0.97	5.03	3.63	8.68	2.29	7.94	13.23	86.84	6.26	11.44	54.06	868.40	27.78	77.60	688.25	8,684.00	1.03	5.23	3.95	10.31

		50-Year/100				50-Year/10				50-Year				100-Year				500-Year				500-Year * 10			
Reach ID	To Station No.	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)	Depth (ft)	Cumul Surface Area (acres)	Cumul Volume (ac-ft)	Flow (cfs)
9	127+00	1.55	7.22	7.30	20.90	4.55	15.15	38.35	209.00	11.82	334.50	452.45	2,090.00	12.40	386.21	523.69	2,380.00	13.37	552.71	783.04	3,000.00	30.64	1,126.23	10,732.27	30,000.00
17	0+00	1.92	6.14	7.77	41.18	7.17	12.42	40.58	411.80	17.92	421.33	839.52	4,118.00	18.61	493.96	1,136.52	4,573.00	19.71	617.06	1,619.49	5,500.00	31.18	914.10	17,558.52	55,000.00
2	0+00	2.28	18.92	31.93	45.43	5.91	35.41	119.64	454.30	12.15	199.46	613.12	4,543.00	12.67	603.06	973.83	5,107.00	13.77	1,409.86	1,840.73	6,500.00	25.63	3,898.00	70,242.54	65,000.00
1	15+01	1.10	10.59	12.93	80.00	5.01	15.75	56.81	800.00	15.55	580.46	1,059.49	8,000.00	16.16	898.26	1,584.77	8,800.00	17.64	1,315.46	2,426.86	10,900.00	31.68	4,708.94	113,972.54	109,000.00
6	318+63	0.98	88.75	122.95	25.00	4.07	104.80	140.43	275.00	14.19	562.88	744.40	2,500.00	14.66	604.62	831.15	2,700.00	15.25	761.94	1,379.77	3,300.00	50.92	1,737.94	125,105.94	26,400.00
5	210+79	2.08	5.44	6.20	75.91	5.85	6.53	29.14	835.01	27.36	420.03	996.72	7,591.00	28.70	574.68	1,459.51	8,130.00	29.89	776.35	2,197.11	9,800.00	64.22	2,232.01	75,514.91	78,400.00
49	100+29	3.91	10.86	17.06	93.00	10.03	16.26	82.92	1,023.00	24.57	99.92	745.80	9,300.00	25.10	143.54	872.84	10,030.00	26.02	227.36	1,102.38	11,300.00	52.02	1,962.01	37,762.74	90,400.00
48	5+80	2.42	8.11	14.59	103.05	7.28	13.91	89.06	1,133.55	29.35	89.24	831.72	10,305.00	29.84	92.68	875.19	11,129.00	30.80	99.24	948.33	12,800.00	43.40	506.03	10,828.87	102,400.00



UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering

Figure 5.10. Point sources as represented in HSPF model.

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: TMP | Date: 08-05-02

together and the resulting flow used as the total point source flow into the subwatershed. Table 5.11 lists each plant within the two watersheds with the Summer 2001 single grab-sample flow as well as the 5-year mean flows from self-reporting data. The majority of the flows sampled in the Summer of 2001 were greater than 5-year mean model flows. The model flows were processed into a WDM file for HSPF modeling and are assumed constant over time.

5.1.3.3 Dry Weather Storm Sewer Flow

Storm sewer discharges into the bayous under dry-weather conditions collected in Summer 2001 as part of this project were input into the model. The sampling locations are shown in Figure 4.10. As a part of the sampling, the flow was estimated for each dry weather storm sewer sample that was collected. These flows were assigned to the subwatershed where the dry weather storm sewer discharge occurred and then compiled into a WDM file. If a dry weather storm sewer discharge was not observed in a particular subwatershed, then no dry weather storm sewer discharges were included in that subwatershed. The dry weather storm sewer discharge flows were considered constant over time (Table 5.12).

Due to limitations on the number of WDM files that HSPF allows, the dry weather storm sewer discharge and point source data were combined into one data-set for model input.

TABLE 5.11
WWTP FLOW

TNRCC ID[1]	Sampled in Summer 2001[2] Flow (MGD)	Model[3] Flow (MGD)	Subwatershed	Bayou
10495-030		9.226	33	BB
12233		0.001	44	BB
10584		2.248	53	BB
10495-109		4	55	BB
10495-139	0.940	0.393	1	WOB
10495-076		8.757	2	WOB
11193	0.032	0.304	2	WOB
12139	0.003	0.019	2	WOB
12222	2.840	0.023	2	WOB
11538		1.014	4	WOB
12552		0.005	4	WOB
13939		0.0010	4	WOB
13983		0.0009	4	WOB
03014-000		0.008	4	WOB
11051	0.029	0.016	4	WOB
11188	0.382	0.264	4	WOB
11273	0.213	0.411	4	WOB
11375	0.134	0.099	4	WOB
11389	0.010	0.018	4	WOB
11485	0.370	0.450	4	WOB
11670	0.399	0.342	4	WOB
12342	0.017	0.014	4	WOB
12443	0.001	0.001	4	WOB
12466	0.006	0.001	4	WOB
12552-002		0.003	4	WOB
13433	0.001	0.001	4	WOB
13509	0.003	0.005	4	WOB
13578	0.004	0.004	4	WOB
13623	0.365	0.059	4	WOB
13689	0.189	0.217	4	WOB
13727	0.012	0.007	4	WOB
13807	0.003	0.001	4	WOB
10495-099		1.401	7	WOB
11153		1.331	9	WOB
11651		0.015	9	WOB
11797		0.009	9	WOB
01899-000		0.011	9	WOB
12573	0.015	0.006	9	WOB
12714	0.177	0.127	9	WOB
13912	0.002	0.002	9	WOB
12397		0.004	10	WOB
12681		0.076	10	WOB
11563	0.679	0.627	10	WOB
11979	0.251	0.184	10	WOB
12574	0.154	0.046	10	WOB
14072	1.410	1.410	10	WOB
12121	1.100	0.904	11	WOB
12795	0.158	0.087	11	WOB
10876	1.257	0.983	13	WOB
10876-002	0.901	0.714	13	WOB
12465	0.004	0.005	13	WOB
11005	0.157	0.123	17	WOB
12132	0.019	0.038	40	WOB
13764	0.443	0.028	42	WOB

[1] Outfall ID is included only if different from 001

[2] Sampled during Summer 2001

[3] Flow used to calculate load for model input, 5-yr average from self-reporting data

Notes and abbreviations:

BB - Buffalo Bayou
dL - deciliter
EC - *E. coli*
MGD - million galllons per day
MPN - most probable number
WOB - Whiteoak Bayou

Yellow shading with dark outline indicates WWTPs that did not have flows in the compiled T
Instantaneous flow taken during Summer 2001 sampling used for load calculation.

TABLE 5.12
DRY WEATHER STORM SEWER FLOW

Sample ID	E coli (MPN/ dL)	Sub watershed	Flow (MGD)	Bayou
I-73	23	34	4.57E-04	BB
I-74	99	34	4.92E-03	BB
I-75	4,467	34	6.23E-03	BB
I-76	1,164	34	1.90E-04	BB
I-77	1,211	34	2.09E-02	BB
I-72	22	35	2.97E-02	BB
I-80	4,372	39	4.92E-04	BB
I-81	53	39	1.01E-03	BB
I-82	63	39	2.16E-04	BB
I-83	18	39	1.68E-01	BB
I-63	65	44	2.41E-04	BB
I-64	904	45	5.58E-03	BB
I-65	12,392	45	2.28E-02	BB
I-66	8,931	45	4.11E-03	BB
I-67	724	47	4.26E-04	BB
I-68	26	50	4.72E-04	BB
I-69	940	50	3.31E-03	BB
I-56	125	52	4.43E-04	BB
I-57	3,674	52	1.67E-02	BB
I-58	79	52	2.19E-02	BB
I-59	18	52	2.66E-04	BB
I-60	173,287	52	6.09E-03	BB
I-61	30	52	9.92E-04	BB
I-62	1,765	52	1.80E-02	BB
I-49	2,123	53	4.57E-03	BB
I-52	73	53	1.55E-03	BB
I-44	>241920	54	1.37E-02	BB
I-44A	4,062	54	8.22E-02	BB
I-45	31	54	9.13E-04	BB
I-46	53,390	54	1.60E-03	BB
I-47	33	54	5.43E-05	BB
I-48	984	54	4.24E-03	BB
I-50	215	54	3.16E-03	BB
I-51	99	54	1.10E-03	BB
I-53	757	54	3.51E-03	BB
I-79	10,496	55	4.11E-02	BB

Sample ID	E coli (MPN/ dL)	Sub watershed	Flow (MGD)	Bayou
I-14	25	4	9.91E-04	WOB
I-16	106	4	1.97E-03	WOB
I-43	75	7	1.07E-02	WOB
I-1	6,389	10	1.52E-04	WOB
I-2	9,087	10	8.78E-04	WOB
I-3	274	10	6.47E-04	WOB
I-4	19	10	1.14E-02	WOB
I-5	143	10	8.15E-04	WOB
I-7	1,212	10	4.57E-03	WOB
I-8	10,608	10	1.12E-03	WOB
I-9	37	11	1.01E-02	WOB
I-10	28	13	1.89E-03	WOB
I-11	19	13	4.76E-03	WOB
I-12	22	13	1.85E-03	WOB
I-32	646	40	4.89E-04	WOB
I-34	20	40	3.84E-04	WOB
I-35	29	40	9.13E-02	WOB
I-36	542	40	6.30E-04	WOB
I-37	1,157	40	4.15E-04	WOB
I-38	205	40	6.92E-05	WOB
I-39	18	40	1.14E-02	WOB
I-40	1,205	40	5.07E-03	WOB
I-41	54	40	1.86E-04	WOB
I-42	24	40	2.77E-03	WOB
I-22	3,429	41	1.14E-02	WOB
I-23	19	41	6.76E-03	WOB
I-24	477	41	1.17E-04	WOB
I-25	19	41	1.51E-04	WOB
I-26	15,028	41	1.52E-03	WOB
I-27	19	41	1.14E-04	WOB
I-28	23	41	6.62E-04	WOB
I-29	5,774	41	4.57E-03	WOB
I-30	30	41	2.03E-02	WOB
I-31	12	41	1.56E-04	WOB
I-33	42	41	1.30E-03	WOB
I-18	19	42	5.94E-02	WOB
I-19	10,295	42	4.57E-02	WOB
I-20	20	42	3.20E-02	WOB
I-21	19	42	2.28E-03	WOB
I-17	108	43	2.13E-01	WOB
I-83A	455	43	3.42E-05	WOB
I-84	>241920	43	1.88E-02	WOB
I-85	2,149	43	2.42E-04	WOB
I-86	2,391	43	1.86E-02	WOB
I-87	16,712	43	1.11E-03	WOB
I-88	209	43	1.76E-04	WOB

Notes and abbreviations:
BB - Buffalo Bayou
MPN - Most probable number
WOB - Whiteoak Bayou

5.1.4 Upstream Flow Input to Buffalo Bayou

The HSPF model simulates the runoff process and requires hourly inputs of rain and upstream boundary conditions. Whiteoak Bayou begins just north of Jones Road, and therefore there is not an upstream input to the bayou. Modeling for Buffalo Bayou, on the other hand, begins at State Highway 6, the location where Segment 1014 begins (30 TAC 307 Appendix C). This results in an upstream input being received from Barker and Addicks Reservoirs to Buffalo Bayou.

Flow from the USGS gage at Dairy Ashford was used to establish the upstream flow input. The main reason that this gage was chosen over the Barker/Addicks Reservoir discharge was that the USGS gage can supply hourly data, whereas the reservoir data are only available in 6-hour increments.

The flow data at Dairy Ashford are considered to be reliable, but some gaps in the flow data were present over the simulation period of 4/1/99-9/30/01. These gaps were filled using one of two methodologies: the first approach was to fill in data gaps with a constant value using the closest antecedent flow, if the downstream gage (West Belt) showed a steady flow and no rain fell at gages 21 and 30 (See Figure 5.5). Otherwise, a second approach using the ratio of the average flows at Dairy Ashford and West Belt to scale back the West Belt flow data appropriately and estimate the Dairy Ashford flow was employed. Figure 5.11 presents the resulting flow time series input into the model. An artifact of this modeling approach (to use the Dairy Ashford flow as model input at highway 6) was that the runoff from the drainage area above Dairy Ashford

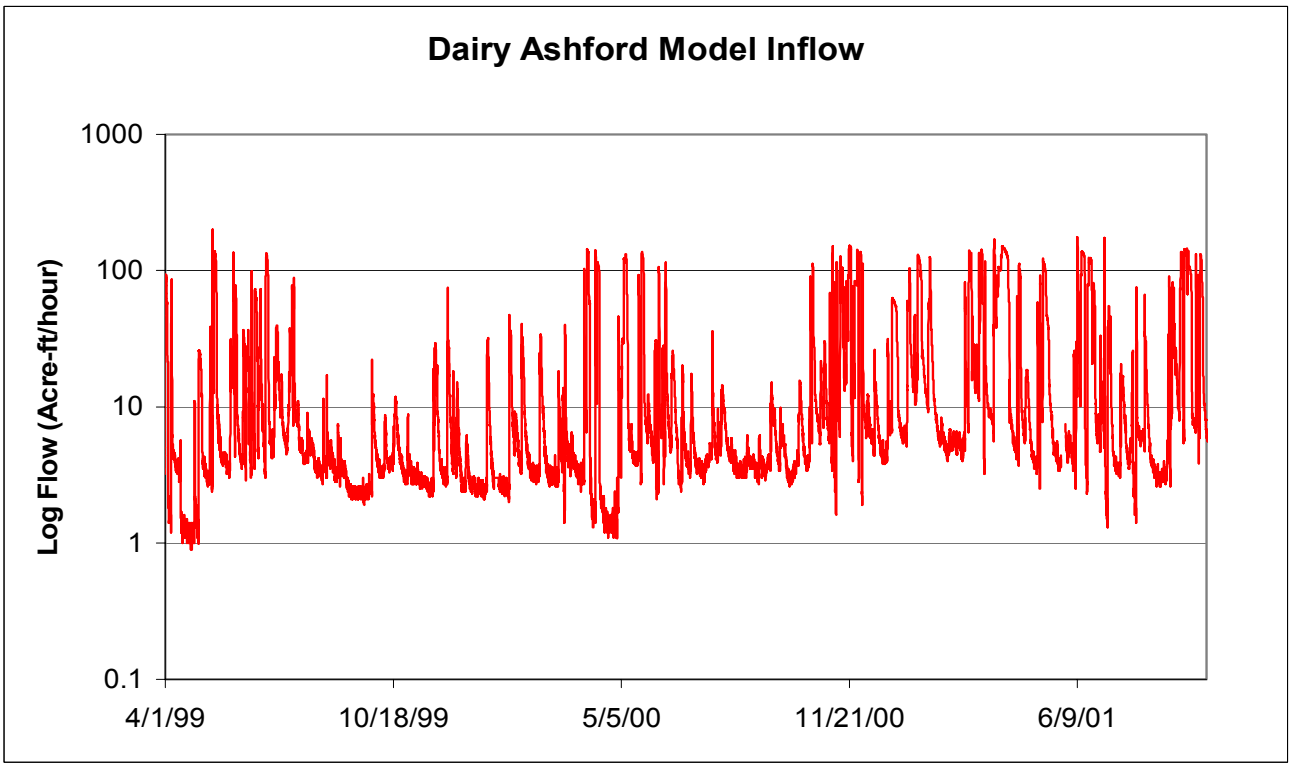


Figure 5.11

Note: Dairy Ashford model inflows were modified from the USGS measured flow as described in Section 5.1.4.

(subwatershed 55) had to be suppressed to avoid duplication of flows in the model.

5.1.5 *E. coli* Source Representation

In the final report for Work Order #1 (University of Houston 2001), several potential sources of indicator bacteria levels were identified. These sources are as follows (in no particular order):

1. Point Sources

    a. Treated effluent from point sources not disinfected completely,

    b. Bacteria from the 2 reservoirs (Buffalo Bayou only),

2. Non-point Sources

    a. Dry weather storm sewer discharges due to sewer leaks, blockage, or other unknow sources

    b. Bacteria in runoff from sediments, urban sources, birds and other wildlife

5.1.5.1 Point Sources

<u>5.1.5.1.1. Wastewater Treatment Plants</u>

EC data from point sources gathered in this project during Summer 2001 were used as model input (See Section 4.1 and Figure 5.10 for locations). The wastewater treatment plant sampling included sampling at two distinct flow periods: peak flow and off-peak flow. The peak and off-peak flow concentrations at each plant were averaged together and used to develop subwatershed specific flow-weighted geometric mean EC concentrations. The flow-weighted geometric mean for all the sampled plants within the watershed was applied to plants that were not sampled in this project (6 MPN/dL was calculated for WOB and 5 MPN/dL was used for BB).

Table 5.13 presents the point source EC data used for model development. This table presents the data that were collected during the Summer 2001 sampling as well as the final EC concentration used in the model for each plant.

5.1.5.1.2. Upstream EC Input from Addicks and Barker Reservoirs

The HSPF model for Buffalo Bayou requires hourly inputs of EC at the upstream boundry of the model. In the case of Buffalo Bayou, the situation is complicated by the fact that bacteria concentrations have only been measured every few months during the calibration period, April 1, 1999 through September 30, 2001 at two of the stations (Highway 6 and Dairy Ashford). Another difficulty is that flow is only available for the Dairy Ashford location.

A summary of historical data collected by the USGS between 1978 and 1980 for a study on the Barker and Addicks reservoirs is presented in Table 5.14. These data show that, in general, there are historically high concentrations of EC coming from the tributaries and being discharged from the reservoirs. Additionally, the reservoirs appear to be attenuating the bacterial concentrations. The total outflow from the reservoirs and the Dairy Ashford USGS gage flow are shown in Figure 5.12. The flow from the reservoirs often makes up a good portion of the flows at Dairy Ashford, as seen in the correlation plot in Figure 5.12. It is clear that the high

TABLE 5.13
WWTP EC CONCENTRATION

TNRCC ID[1]	Sampled in Summer 2001[2] EC (MPN/dL)	Model[3] EC (MPN/dL)	Subwatershed	Bayou
10495-030		5	33	BB
12233		5	44	BB
10584		5	53	BB
10495-109		5	55	BB
10495-139	1	1	1	WOB
10495-076		6	2	WOB
11193	711	711	2	WOB
12139	1211	1211	2	WOB
12222	2419	2419	2	WOB
11538		6	4	WOB
12552		6	4	WOB
13939		6	4	WOB
13983		6	4	WOB
03014-000		6	4	WOB
11051	47	47	4	WOB
11188	1	1	4	WOB
11273	1	1	4	WOB
11375	18	18	4	WOB
11389	2	2	4	WOB
11485	1	1	4	WOB
11670	17	17	4	WOB
12342	1	1	4	WOB
12443	7	7	4	WOB
12466	150	150	4	WOB
12552-002		6	4	WOB
13433	1	1	4	WOB
13509	71	71	4	WOB
13578	1	1	4	WOB
13623	1	1	4	WOB
13689	176	176	4	WOB
13727	1	1	4	WOB
13807	1	1	4	WOB
10495-099		6	7	WOB
11153		6	9	WOB
11651		6	9	WOB
11797		6	9	WOB
01899-000		6	9	WOB
12573	1	1	9	WOB
12714	1	1	9	WOB
13912	1	1	9	WOB
12397		6	10	WOB
12681		6	10	WOB
11563	14	14	10	WOB
11979	1	1	10	WOB
12574	1	1	10	WOB
14072	9	9	10	WOB
12121	13	13	11	WOB
12795	176	176	11	WOB
10876	4	4	13	WOB
10876-002	5	5	13	WOB
12465	97	97	13	WOB
11005	1	1	17	WOB
12132	1	1	40	WOB
13764	54	54	42	WOB

[1] Outfall ID is included only if different from 001
[2] Sampled during Summer 2001
[3] Concentration used to calculate load for model input

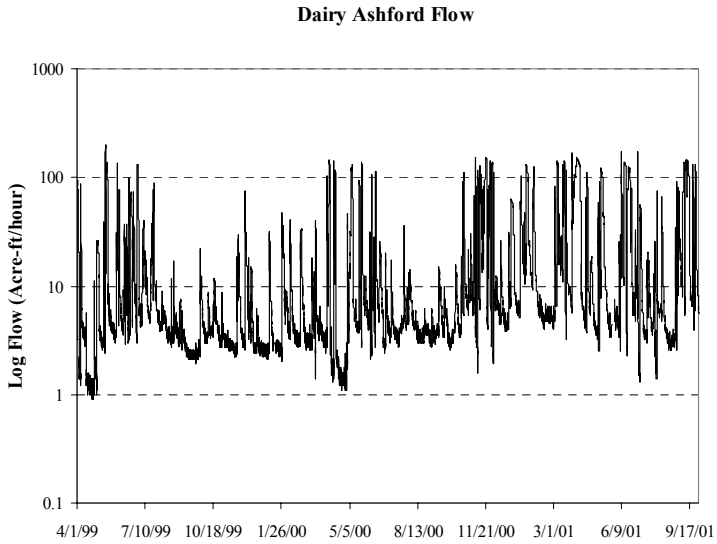
Notes and abbreviations:
BB - Buffalo Bayou
dL - deciliter
EC - *E. coli*
MGD - million galllons per day
MPN - most probable number
WOB - Whiteoak Bayou

Flow-weighted geometric mean concentrations (FWGMC) calculated on watershed basis for WWTPs not sampled during Summer 2001. For Buffalo Bayou, FWGMC calculated using plants sampled in reservoir subwatersheds.

Table 5.14. USGS Historical Indicator Bacteria Concentrations

	Mean FC Concentration (cfu/dL)	Converted Mean EC Concentration (cfu/dL)*
Addicks	6307	3973.41
	1090	686.7
	737	464.31
Barker	3220	2028.6
	763	480.69
	663	417.69

Source: USGS WRI 86-4356, 1987. Samples collected from 1978-1981.
* EC = FC/126



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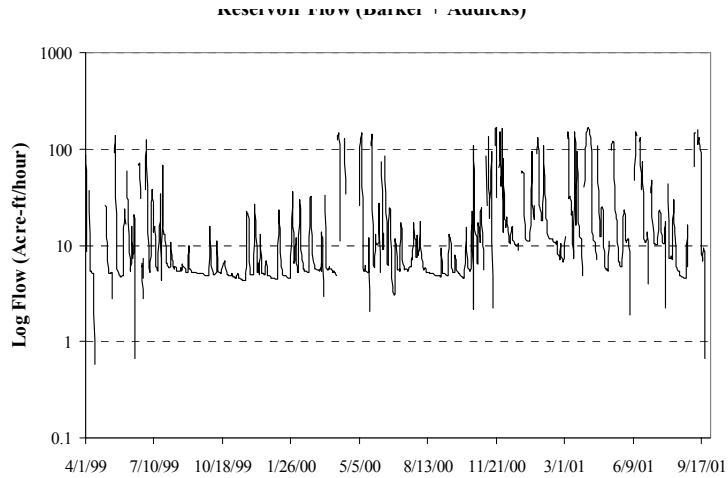
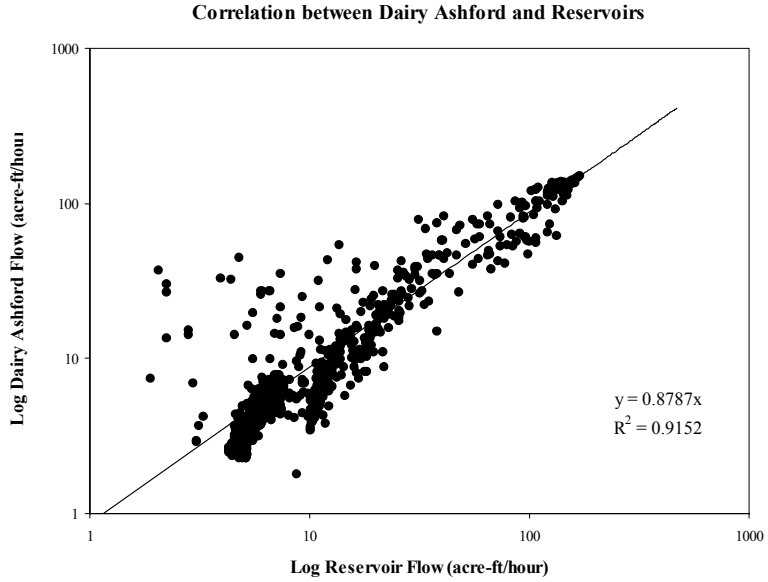




C

Figure 5.12.

flows at Dairy Ashford usually correlate with high flows from the reservoirs.

The relationship between EC concentrations at Barker Reservoir and Dairy Ashford is presented in Figure 5.13. The correlation between the EC concentrations at the two sites is not strong, with an R^2 of 0.2397. This correlation is relatively high for bacteria data. Therefore, for modeling purposes, the data from Dairy Ashford were used to develop the EC input for upstream sources as discussed below.

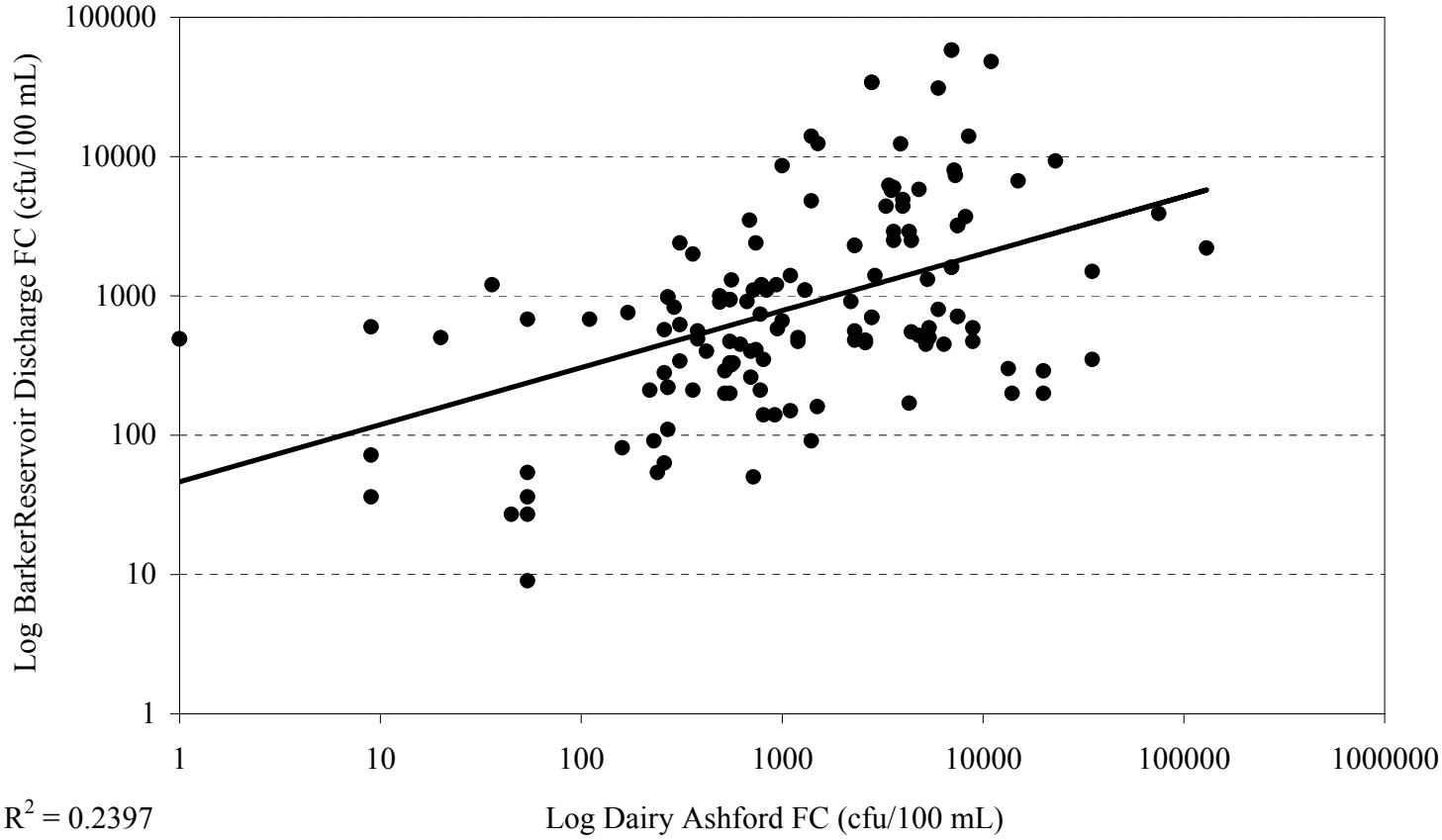
Developing a time-series input for EC at Dairy Ashford first involved performing a linear regression of historical bacteria concentration data versus flow measured at Dairy Ashford. This linear regression was preceded by a conversion of fecal coliform concentrations to *E. coli* concentrations using the ratio of their water quality standards so that EC = (200/126) x FC. The linear regression relationship was computed using any observed EC/FC data available (both from the TCEQ and the runoff sampling conducted for Summer 2001) at Dairy Ashford. The following model resulted from this regression (Figure 5.14):

$$EC = 250.83 \times Flow^{0.7449} \qquad (5\text{-}3)$$

While most streams exhibit a positive correlation between bacteria concentrations and flow, the correlation is very weak in Buffalo Bayou at Dairy Ashford as evidenced by the low R^2 value of 0.131. This finding was noted in general for Buffalo and Whiteoak Bayous in the Final Report for Work Order 1 (University of Houston and PBS&J, 2001). Despite the poor correlation, the approach was considered appropriate for the purposes of model development.

Figure 5.13

Correlation between Dairy Ashford and Barker Reservoir Discharge EC Concentrations



Note: Data from stations 11362 (Dairy Ashford) and 11364 (Barker Reservoir Discharge) were used for the development of this plot.

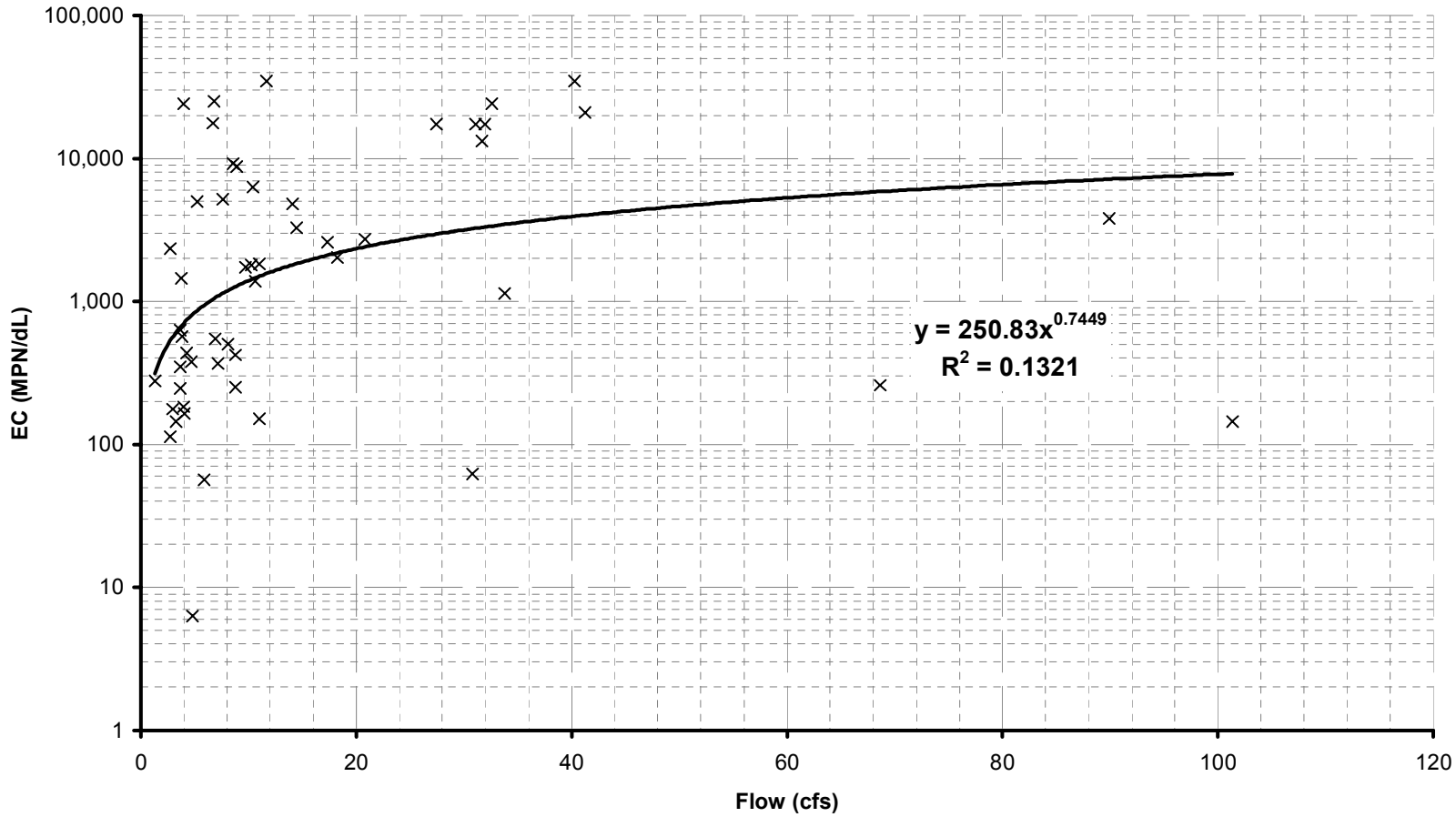


FIGURE 5.14
REGRESSION OF HISTORICAL DATA FROM BB AT DAIRY ASHFORD

Minor adjustments to this relationship, however, were necessitated to improve the model calibration.

First, gaps in the Dairy Ashford flow data record were identified. EC concentrations were then estimated using the detailed runoff observations gathered for this project from the summer of 2001 and similar flow values were assigned similar EC concentrations to those observed in summer 2001. Finally, concentrations predicted by the regression model were reduced when the flows were high as a result of the Addicks and Barker Reservoirs releasing impounded water. A fixed value of 2000 MPN/dL was employed. The improvements made to the upstream EC input were examined to ensure that consistent judgments were applied and that the estimates were consistent with the observed data. The final modeled upstream EC input times series with observed data is shown in Figure 5.15.

5.1.5.2 Nonpoint Sources

Non-point sources that are considered in the model include dry weather storm sewer discharges, sediment scour and deposition, and non-point source build up. The dry weather storm sewer discharges were combined with the point sources as will be seen in the following section.

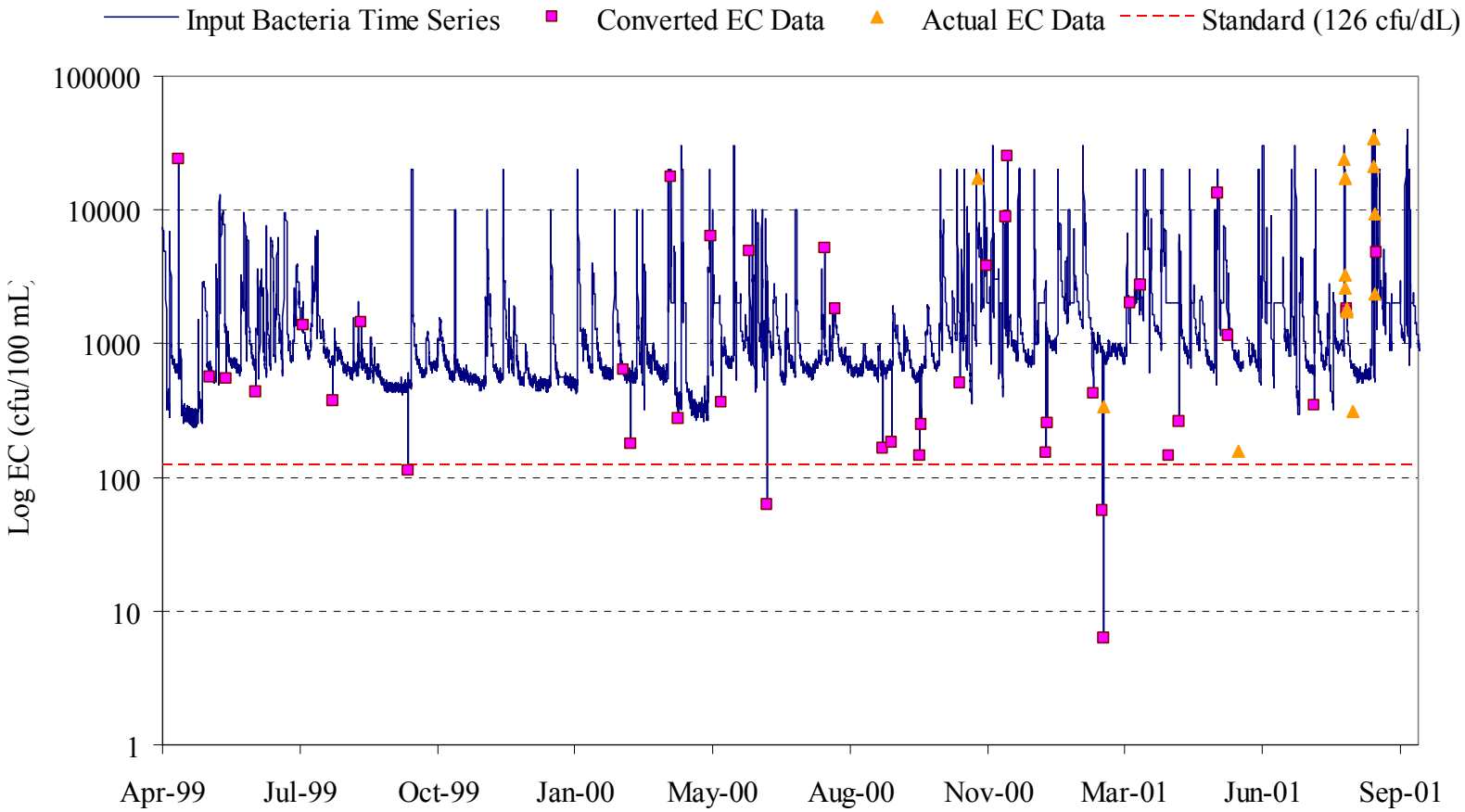


Figure 5.15. Upstream Input Bacteria Concentration to Buffalo Bayou.

5.1.5.2.1 Dry Weather Storm Sewer Discharges

EC concentrations from dry weather storm sewer discharges from the Summer 2001 sampling effort were used as input (See Section 4.2 and Figure 4.10 for locations). These dry weather storm sewer discharges may include discharge of untreated sewage due to sewer leaks or blockage or bacteria inputs from illegal wastewater connection discharges. The dry weather storm sewer discharges were assigned to the subwatershed where the sample was collected and geometric mean concentrations were calculated per subwatershed. The resulting EC inputs were assumed to be constant over time. Table 5.15 presents the resulting dry weather storm sewer EC loads for each of the subwatersheds in BB and WO Bayous.

As stated previously, point sources and dry weather storm sewer discharge EC contributions are combined into one WDM file. They are considered as separate sources and only lumped due to model restrictions. The total flows and loads entered into the model are presented in Table 5.16.

Yearly loads were calculated from the field data collected for both point sources and dry-weather inflows that were presented in Sections 4.1 and 4.2. These loads calculated from field data were compared to the loads that were input to the model. Table 5.17 presents the results of these comparisons. It is clear that in WOB, the modeled loads are two orders of magnitude smaller than those estimated from the field data and flow-weighted geometric mean (where observed data not collected). This difference stems from differences in flows. Field-gathered flows are much higher than the 5-year average flow used in the model (cumulative mean flows totaled 9,500 MG/year

TABLE 5.15
DRY WEATHER STORM SEWER EC CONCENTRATIONS

Sample ID	Sub watershed	Load (cfu/hr)	Cumulative Load (cfu/hr)	Subwatershed Load (cfu/hr)	Bayou
I-14	4	3.91E+04	3.91E+04		WOB
I-16	4	3.28E+05	3.67E+05	3.67E+05	WOB
I-43	7	1.25E+06	1.25E+06	1.25E+06	WOB
I-1	10	1.53E+06	1.53E+06		WOB
I-2	10	1.26E+07	1.41E+07		WOB
I-3	10	2.79E+05	1.44E+07		WOB
I-4	10	3.33E+05	1.47E+07		WOB
I-5	10	1.84E+05	1.49E+07		WOB
I-7	10	8.73E+06	2.36E+07		WOB
I-8	10	1.87E+07	4.23E+07	4.23E+07	WOB
I-9	11	5.93E+05	5.93E+05	5.93E+05	WOB
I-10	13	8.20E+04	8.20E+04		WOB
I-11	13	1.39E+05	2.21E+05		WOB
I-12	13	6.47E+04	2.85E+05	2.85E+05	WOB
I-32	40	4.98E+05	4.98E+05		WOB
I-34	40	1.18E+04	5.10E+05		WOB
I-35	40	4.22E+06	4.73E+06		WOB
I-36	40	5.38E+05	5.27E+06		WOB
I-37	40	7.58E+05	6.03E+06		WOB
I-38	40	2.23E+04	6.05E+06		WOB
I-39	40	3.32E+05	6.38E+06		WOB
I-40	40	9.64E+06	1.60E+07		WOB
I-41	40	1.58E+04	1.60E+07		WOB
I-42	40	1.05E+05	1.61E+07	1.61E+07	WOB
I-22	41	6.17E+07	6.17E+07		WOB
I-23	41	1.99E+05	6.19E+07		WOB
I-24	41	8.81E+04	6.20E+07		WOB
I-25	41	4.45E+03	6.20E+07		WOB
I-26	41	3.61E+07	9.81E+07		WOB
I-27	41	3.38E+03	9.81E+07		WOB
I-28	41	2.36E+04	9.81E+07		WOB
I-29	41	4.16E+07	1.40E+08		WOB
I-30	41	9.56E+05	1.41E+08		WOB
I-31	41	2.90E+03	1.41E+08		WOB
I-33	41	8.57E+04	1.41E+08	1.41E+08	WOB
I-18	42	1.73E+06	1.73E+06		WOB
I-19	42	7.41E+08	7.43E+08		WOB
I-20	42	1.03E+06	7.44E+08		WOB
I-21	42	6.82E+04	7.44E+08	7.44E+08	WOB
I-17	43	3.64E+07	3.64E+07		WOB
I-83A	43	2.46E+04	3.65E+07		WOB
I-84	43	#VALUE!	#VALUE!		WOB
I-85	43	8.19E+05	#VALUE!		WOB
I-86	43	7.01E+07	#VALUE!		WOB
I-87	43	2.93E+07	#VALUE!		WOB
I-88	43	5.79E+04	#VALUE!	#VALUE!	WOB

Sample ID	Sub watershed	Load (cfu/hr)	Cumulative Load (cfu/hr)	Subwatershed Load (cfu/hr)	Bayou
I-73	34	1.65E+04	1.65E+04		BB
I-74	34	7.65E+05	7.81E+05		BB
I-75	34	4.39E+07	4.46E+07		BB
I-76	34	3.49E+05	4.50E+07		BB
I-77	34	4.00E+07	8.50E+07	8.50E+07	BB
I-72	35	1.05E+06	1.05E+06	1.05E+06	BB
I-80	39	3.40E+06	3.40E+06		BB
I-81	39	8.51E+04	3.48E+06		BB
I-82	39	2.16E+04	3.50E+06		BB
I-83	39	4.87E+06	8.38E+06	8.38E+06	BB
I-63	44	2.46E+04	2.46E+04	2.46E+04	BB
I-64	45	7.96E+06	7.96E+06		BB
I-65	45	4.46E+08	4.54E+08		BB
I-66	45	5.79E+07	5.12E+08	5.12E+08	BB
I-67	47	4.87E+05	4.87E+05	4.87E+05	BB
I-68	50	1.97E+04	1.97E+04		BB
I-69	50	4.91E+06	4.93E+06	4.93E+06	BB
I-56	52	8.73E+04	8.73E+04		BB
I-57	52	9.70E+07	9.71E+07		BB
I-58	52	2.73E+06	9.98E+07		BB
I-59	52	7.39E+03	9.98E+07		BB
I-60	52	1.66E+09	1.76E+09		BB
I-61	52	4.67E+04	1.76E+09		BB
I-62	52	5.00E+07	1.81E+09	1.81E+09	BB
I-49	53	1.53E+07	1.53E+07		BB
I-52	53	1.79E+05	1.55E+07	1.55E+07	BB
I-44	54	5.23E+09	5.23E+09		BB
I-44A	54	5.26E+08	5.75E+09		BB
I-45	54	4.45E+04	5.75E+09		BB
I-46	54	1.35E+08	5.89E+09		BB
I-47	54	2.82E+03	5.89E+09		BB
I-48	54	6.58E+06	5.89E+09		BB
I-50	54	1.07E+06	5.89E+09		BB
I-51	54	1.72E+05	5.89E+09		BB
I-53	54	4.19E+06	5.90E+09	5.90E+09	BB
I-79	55	6.80E+08	6.80E+08	6.80E+08	BB

TABLE 5.16
POINT SOURCE AND DRY WEATHER STORM SEWER MODEL INPUT

Subwatersheds	WWTP		Dry Weather Storm Sewer		Total		Watershed
	Load (cfu/hr)	Flow (MGD)	Load (cfu/hr)	Flow (MGD)	Load (cfu/hr)	Flow (MGD)	
28							BB
33	7.96E+07	9.23			7.96E+07	9.23	BB
34			8.50E+07	3.27E-02	8.50E+07	0.03	BB
35			1.05E+06	2.97E-02	1.05E+06	0.03	BB
39			8.38E+06	1.70E-01	8.38E+06	0.17	BB
44	6.47E+03	7.50E-04	2.46E+04	2.41E-04	3.11E+04	0.00	BB
45			5.12E+08	3.25E-02	5.12E+08	0.03	BB
47			4.87E+05	4.26E-04	4.87E+05	0.00	BB
50			4.93E+06	3.78E-03	4.93E+06	0.00	BB
52			1.81E+09	6.44E-02	1.81E+09	0.06	BB
53	1.94E+07	2.25	1.55E+07	6.12E-03	3.49E+07	2.25	BB
54			5.90E+09	1.10E-01	5.90E+09	0.11	BB
55	3.05E+07	3.53	6.80E+08	4.11E-02	7.11E+08	3.57	BB
56							BB
1	3.10E+05	0.39			3.10E+05	0.39	WOB
2	5.51E+08	9.10			5.51E+08	9.10	WOB
4	8.59E+07	2.94	3.67E+05	2.96E-03	8.63E+07	2.94	WOB
7	1.36E+07	1.40	1.25E+06	1.07E-02	1.48E+07	1.41	WOB
9	1.35E+07	1.50		0.00E+00	1.35E+07	1.50	WOB
10	3.50E+07	2.35	4.23E+07	1.96E-02	7.73E+07	2.37	WOB
11	4.31E+07	0.99	5.93E+05	1.01E-02	4.37E+07	1.00	WOB
13	1.35E+07	1.70	2.85E+05	8.49E-03	1.38E+07	1.71	WOB
17	2.52E+05	0.12			2.52E+05	0.12	WOB
40	2.97E+04	0.04	1.61E+07	1.13E-01	1.62E+07	0.15	WOB
41			1.41E+08	4.71E-02	1.41E+08	0.05	WOB
42	2.36E+06	0.03	7.44E+08	1.39E-01	7.47E+08	0.17	WOB
43			7.32E+09	2.52E-01	7.32E+09	0.25	WOB

Table 5.17. Comparison of Point Source and Dry-weather Inflow EC Loadings from Measured and Modeled Data

	Whiteoak		Buffalo Bayou	
	Point Source	**Dry-weather Inflows**	**Point Source**	**Dry-weather inflows**
Field Data Flow (MG/year) *	9.51E+03	2.19E+02	5.98E+03	1.79E+02
Field Data Concentration (MPN/100 mL)	0.5-22,027	1-240,920	0.5-295	1-173,287
Modeled Flow (MG/year)	7.51E+03	2.20E+08	6.49E+03	1.79E+08
Modeled Concentration (MPN/100 mL)	0.5-22,027	1.7-4764	5	6.5-11,287
Model PS + Dry-weather Inflows (MG/year	1.73E+04		6.88E+03	
Model Flow-weighted Geomean (MPN/100 mL	1.57E+04		5.26E+03	
Field Load	7.63E+14	7.24E+13	1.26E+12	7.89E+13
Model Load	6.64E+12	7.24E+13	2.17E+12	7.23E+13

[*] does not include plants above the reservoirs

[1] All loadings given in MPN/year

[2] See Tables 4.5 and 4.11 for actual data

MPN = most probable number

whereas cumulative 5-yr average was 7,508 MG/year). Since the flows were only sampled on one day for the field data, this discrepancy is understandable. For BB, no point source samples were collected in the modeled subwatersheds. A calculation of the total load for the entire Buffalo Bayou watershed was made using field data and a 5-year average flow for each plant to compare to the field data calculated in Section 4.2. Looking at comparisons for the entire Buffalo Bayou watershed (including the reservoir watersheds) shows that loads are quite comparable. The dry-weather pipe flows, on the other hand, are very similar to those collected from the field. Table 5.17a presents a summary of the point source and dry-weather inflow input to the model by subwatershed.

5.1.5.2.2 Sediment Scour and Deposition

The monitoring activities conducted in the summer of 2001 under this TMDL project provided strong evidence that unconsolidated bottom sediment in the bayous is a bacterial reservoir (See section 3.1.4). In order to simulate bacteria sources and sinks associated with the sediment, the HSPF models were constructed to include sediment simulations.

Sediment simulations in HSPF include the production and removal of sediment from pervious and impervious land segments, as well as transport in reach segments. The processes simulated in the model include sediment detachment and wash-off from the watershed surface,

Table 5.17A
Buffalo Bayou Dry Weather Pipe Discharge and Point Source Flow Summary

Sample ID	Sub-watershed	Watershed	Summer 2001 (cfs)[1]	Model Flow (cfs)[2]	4/1/99-9/30/01 Avg Flow (cfs)[3]	Summer WWTP Flows (cfs)	Dry Weather Pipe Discharges (cfs)
12447	14	Addicks	-[5]	0.089	0.131	0.108	
11523	15	Addicks	1.439	1.257	1.245	1.209	
11682	15	Addicks	-[5]	0.767	0.813	0.758	
11836	15	Addicks	-[5]	0.494	0.438	0.480	
11935	15	Addicks	0.224	0.112	0.130	0.113	
12124	15	Addicks	-[5]	0.419	0.421	0.441	
13778	15	Addicks	-[5]	0.0018	0.002	0.002	
12223	16	Addicks	0.843	0.122	0.220	0.206	
12726	16	Addicks	0.273	0.275	0.413	0.427	
01402-000	16	Addicks	-[5]	0.152	-[4]	-[4]	
11486	18	Addicks	-[5]	0.888	0.813	0.805	
11906	19	Addicks	0.487	0.351	0.396	0.409	
13921	20	Addicks	0.016	-[4]	-[4]	-[4]	
11792	21	Addicks	0.419	0.131	-[4]	-[4]	
11991	22	Addicks	-[5]	0.146	0.159	0.165	
12209	22	Addicks	-[5]	0.237	0.296	0.302	
12834	22	Addicks	0.007	0.042	0.086	0.070	
12841	22	Addicks	-[5]	0.023	0.048	0.047	
12949	22	Addicks	0.009	-[4]	-[4]	-[4]	
11917	23	Addicks	0.567	0.260	0.365	0.327	
11696	29	Addicks	0.448	0.138	0.139	0.132	
12516	29	Addicks	-[5]	0.001	0.001	0.001	
3153	31	Addicks	0.047	0.014	-[4]	-[4]	
3994	31	Addicks	0.003	-[4]	-[4]	-[4]	
13484	31	Addicks	0.066	0.039	0.046	0.040	
10932	32	Addicks	-[5]	0.013	0.022	0.021	
11290	32	Addicks	-[5]	3.190	3.716	4.032	
11414	32	Addicks	0.019	0.028	0.052	0.052	
11472	32	Addicks	0.820	0.504	0.449	0.469	
11947	32	Addicks	-[5]	2.681	2.685	2.682	
12128	32	Addicks	0.948	0.815	0.806	0.812	
12304	32	Addicks	0.937	0.485	0.463	0.490	
12310	32	Addicks	0.011	0.010	0.024	0.015	
12685	32	Addicks	0.137	0.061	0.106	0.101	
12355	56	Addicks	-[5]	0.0002	0.0005	0.000	
12830	56	Addicks	-[5]	0.0012	0.002	0.003	
11284	57	Addicks	1.028	0.584	0.854	0.888	
11969	57	Addicks	0.115	0.911	0.973	0.967	
11989	57	Addicks	0.584	0.358	0.337	0.340	
12110	57	Addicks	0.250	0.047	0.065	0.057	
12140	57	Addicks	0.246	0.122	0.166	0.186	
12189	57	Addicks	-[5]	0.039	0.063	0.066	
12247	57	Addicks	0.009	0.214	0.236	0.240	
12802	57	Addicks	0.155	0.207	0.226	0.224	
12346	35	Barker	0.289	0.251	0.294	0.309	
12406	35	Barker	-[5]	0.002	0.002	0.002	
12427	35	Barker	0.017	0.000	0.000	0.000	
12682	35	Barker	0.068	0.011	0.022	0.026	
13021	35	Barker	-[5]	0.070	0.156	0.165	
13228	35	Barker	-[5]	0.024	0.046	0.052	
10495-135	35	Barker	1.683	0.516	0.810	0.845	
11152	58	Barker	-[5]	2.408	2.548	2.468	
11598	58	Barker	1.177	1.132	1.043	1.072	
11632	58	Barker	-[5]	0.032	0.045	0.036	
11883	58	Barker	0.835	0.711	0.732	0.750	
12289	58	Barker	3.263	0.763	0.800	0.754	
12479	58	Barker	-[5]	0.560	0.618	0.609	
12356	59	Barker	0.176	0.076	0.215	0.211	
11893	60	Barker	-[5]	1.868	1.931	1.905	
12858	60	Barker	-[5]	0.010	0.004	0.003	
13245	60	Barker	-[5]	0.026	0.035	0.031	
13558	60	Barker	-[5]	0.771	1.007	1.044	
13172-002	60	Barker	-[5]	0.182	0.404	0.430	
10706	61	Barker	-[5]	1.554	1.772	2.220	
12370	61	Barker	-[5]	0.138	0.168	0.186	
12412	61	Barker	0.0007	0.001	0.002	0.002	
12805	61	Barker	-[5]	0.032	0.042	0.031	
13775	61	Barker	-[5]	0.030	0.079	0.078	
12298	62	Barker	0.056	0.096	0.088	0.083	
10495-030	33	BB	-[5]	14.275	14.799	14.8898	
10495-109	55	BB	-[5]	5.465	6.934	6.966	
	Total to West Belt Gage:			**47.232**	**52.002**	**52.855**	**0.422**
	Median Bayou Flow:				**80.95**	**75.96**	
12233	44	BB	-[5]	0.0012	0.0011	0.0010	
10584	53	BB	-[5]	3.479	3.459	3.470	
	Cumulative Total to Shepherd Gage:			**50.712**	**55.462**	**56.326**	**2.013**
	Median Bayou Flow:				**150.814**	**123.561**	

[1] Sampled by UH during Summer 2001
[3] Flows based on 5-year average from TCEQ database.
[3] Flows from avg TCEQ Data for model period: 4/1/99 to 9/30/01
[4] Facilities sampled by UH but not found in TCEQ Self-Reporting Database
[5] Facilities located in the model boundaries that were not sampled by UH

Abbreviations:
WWTP: Wastewater treatment plant
MGD: Million gallons per day
BB: Buffalo Bayou
Whiteoak Bayou: Whiteoak Bayou

Table 5.17A (Continued)
Whiteoak Bayou Dry Weather Pipe Discharge and Point Source Flow Summary

Sample ID	Sub-watershed	Watershed	Summer 2001 (cfs)[1]	Model Flow (cfs)[2]	4/1/99-9/30/01 Avg Flow (cfs)[3]	Summer WWTP Flows (cfs)	Dry Weather Pipe Discharges (cfs)
10495-139	1	WO B	1.454	0.608	0.691	0.846	
11193	2	WO B	0.050	0.470	0.752	0.856	
12139	2	WO B	0.005	0.030	0.029	0.026	
12222	2	WO B	4.394	0.036	0.108	0.119	
10495-076	2	WO B	-[5]	13.550	12.059	14.00	
11051	4	WO B	0.045	0.024	0.029	0.031	
11188	4	WO B	0.590	0.408	0.367	0.376	
11273	4	WO B	0.330	0.635	0.642	0.655	
11375	4	WO B	0.207	0.153	0.257	0.150	
11389	4	WO B	0.016	0.027	0.019	0.015	
11485	4	WO B	0.572	0.697	0.685	0.701	
11538	4	WO B	-[5]	1.569	1.531	1.614	
11670	4	WO B	0.617	0.529	0.568	0.566	
12342	4	WO B	0.026	0.021	0.025	0.026	
12443	4	WO B	0.002	0.0013	0.0014	0.0013	
12466	4	WO B	0.010	0.0020	0.0013	0.0014	
12552	4	WO B	-[5]	0.008	0.004	0.004	
13433	4	WO B	0.002	-[4]	-[4]	-[4]	
13509	4	WO B	0.004	0.008	0.028	0.031	
13578	4	WO B	0.005	0.0057	0.0069	0.0067	
13623	4	WO B	0.565	0.091	0.197	0.211	
13689	4	WO B	0.292	0.336	0.502	0.608	
13727	4	WO B	0.019	0.0111	0.0095	0.0094	
13807	4	WO B	0.004	0.0014	0.0014	0.0015	
13939	4	WO B	-[5]	0.002	0.003	0.006	
13983	4	WO B	-[5]	0.0014	0.0014	0.0013	
03014-000	4	WO B	-[5]	0.012	0.014	0.013	
12552-002	4	WO B	-[5]	0.004	0.004	0.004	
10495-099	7	WO B	-[5]	2.168	2.406	2.514	
11153	9	WO B	-[5]	2.059	2.082	2.106	
11651	9	WO B	-[5]	0.024	0.027	0.023	
11797	9	WO B	-[5]	0.014	0.015	0.015	
12573	9	WO B	0.015	0.009	0.007	0.008	
12714	9	WO B	0.274	0.197	0.227	0.242	
13912	9	WO B	0.003	-[4]	-[4]	-[4]	
01899-000	9	WO B	-[5]	0.017	0.028	0.024	
11563	10	WO B	1.051	0.970	0.937	1.028	
11979	10	WO B	0.388	0.285	0.285	0.294	
12397	10	WO B	-[5]	0.006	0.006	0.008	
12574	10	WO B	0.237	0.072	0.103	0.119	
12681	10	WO B	-[5]	0.118	0.396	0.309	
14072	10	WO B	2.182	-[4]	-[4]	-[4]	
12121	11	WO B	1.702	1.399	1.411	1.470	
12795	11	WO B	0.244	0.135	0.230	0.230	
12465	13	WO B	0.006	0.0076	0.0076	0.0075	
10876-001	13	WO B	1.944	1.520	1.328	1.344	
10876-002	13	WO B	1.393	1.105	1.161	0.088	
11005	17	WO B	0.242	0.190	0.178	0.170	
12132	40	WO B	0.029	0.058	0.063	0.062	
13764	42	WO B	0.685	0.043	0.088	0.101	
			Cumulative Total to Heights Gage:	**29.636**	**29.519**	**31.046**	**0.758**
			Median Bayou Flow:		**40.180**	**44.440**	

[1] Sampled by UH during Summer 2001
[2] Flows based on 5-year average from TCEQ database.
[3] Flows from avg TCEQ Data for model period: 4/1/99 to 9/30/01
[4] Facilities sampled by UH but not found in TCEQ Self-Reporting Database
[5] Facilities located in the model boundaries that were not sampled by UH

Abbreviations:
WWTP: Wastewater treatment plant
MGD: Million gallons per day
BB: Buffalo Bayou
Whiteoak Bayou: Whiteoak Bayou

reattachment of detached sediment, atmospheric deposition, scour, deposition, decay, particle settling and shear stress on the stream bed.

While many parameters involved in sediment simulation are unknowns and are treated as calibration parameters, several key parameter values were developed from data collected during the monitoring effort in the summer of 2001. These parameters include sediment particle size (Table 5.18), density, concentration of EC in sediment and EC decay rates in sediment (discussed in section 5.1.5.4).

Bed stresses for cohesive sediments were initially calculated using a typical shear stress formula (Chow, 1969). This shear stress formula involves the multiplication of the specific weight of water, hydraulic radius and slope. Using the same slope values provided by HCFCD for the hydrologic portions of the models, shear stress can be calculated for a given hydraulic radius. The hydraulic radius can be considered similar to water depth for a wide, rectangular channel. Based on the HEC-2 results discussed in the hydrologic sections of this report and listed in the FTABLES section of the UCI files, an initial selection of water depths corresponding to flows of about 100 cfs in BB and 50 cfs in WOB were used to calculate shear stresses for each of the model reaches. It is assumed that scouring or deposition of sediment would occur when the shear stress calculated by the model is above or below the input shear stress values. Table 5.20 shows the calculated shear stress values for reaches in both BB and WO Bayous. These values, ranging from 0 to 1.727 lb/ft^2, were adjusted when necessary during the calibration process, to minimize sediment accumulation in the bed of the bayous.

TABLE 5.18
SEDIMENT PARTICLE SIZES DISTRIBUTION

Bayou	Reach ID	Sampling Date	Location	Specific Gravity	Percent of			Particle Size (in)		
					Sand	Silt	Clay	D50	D15	D10
BB	35	8/15/01	SH 6	2.63	91.5	8.6	-0.1	0.00654	0.00435	0.00345
BB	39	8/15/01	Kirkwood	2.63	61.6	36.9	1.5	0.00339	0.00192	0.00156
BB	39	8/15/01	Wilcrest	2.63	81.6	13.6	1.1	0.00976	0.00307	0.00207
BB	39	8/06/01	West Belt	2.63	85.4	13.4	0.2	0.00862	0.00326	0.00223
BB	45	8/06/01	Shepherd	2.63	77.2	21.6	1.2	0.00551	0.00227	0.00180
BB	50	8/06/01	IH 610	2.63	93.1	8.2	-1.3	0.00898	0.00590	0.00458
BB	53	8/06/01	Westcott	2.63	87.7	13.6	-1.3	0.00508	0.00326	0.00268
BB	53	8/06/01	Piney Point	2.63	76.0	23.6		0.00528	0.00227	0.00191
BB	53	8/06/01	VOSS	2.63	90.4	9.6		0.00673	0.00430	0.00308
BB	55	8/15/01	Eldridge	2.63	63.8	31.7	4.5	0.00453	0.00144	0.00057
BB	60	8/15/01	Fry	2.63	9.4	55.7	34.9	0.00047	0.00000	0.00000
BB	60	8/15/01	Westheimer	2.63	31.8	47.5	19.3	0.00177	0.00011	0.00007
CC	2	8/13/01	Deihl	2.63	84.5	14.0	1.3	0.00441	0.00293	0.00214
WO	4	8/13/01	West Belt	2.63	79.7	4.5	0.9	0.00976	0.00742	0.00638
WO	7	8/13/01	W Little York	2.63	46.1	41.2	12.7	0.00268	0.00040	0.00014
WO	8	8/13/01	Tidwell	2.63	77.4	5.5	0.9	0.04138	0.01419	0.00816
WO	46	8/13/01	Houston	2.63	88.2	13.2	-1.4	0.00776	0.00371	0.00257

Note: Sand (0.075-4.75 mm)
Silt (0.002-0.075 mm)
Clay (< 0.002 mm)

Adjustments to the calculated shear stress were made according to the method suggested in the Application Guide for Hydrological Simulation Program - FORTRAN published by the EPA (Donigian *et al.*, 1984). The process described the Donigian *et al.* (1984) involves looking at the critical bed stress during a time when the model simulates the hydrology well. The values for the deposition and shear critical bed stress are then chosen to bracket the modeled critical bed stress. According to the HPSF Application Guide, the proper values for the critical shear and deposition stresses result in scour during periods of increased flow and deposition during less turbulent portions of the simulation period. During the majority of the flow record, though, no bed shear or deposition should be occurring on the reach beds (Donigian *et al.*, 1984). The calibrated shear stress values are presented in Table 5.19.

From the 2001 sampling data, the geometric mean EC levels in sediments of BB and WO Bayous were 56,371 and 53,677 MPN/dL, respectively. These values translate into 0.214 and 0.204 MPN/mg, respectively, which were input to the HSPF models as initial EC concentrations in sediments.

5.1.5.2.3 Buildup and Stormwater Wash-off

The HSPF Model allows users to enter wash-off coefficients for the simulation of EC wash-off by rain and by surface flow on pervious or impervious land segments. A constant EC accumulation rate in MPN per acre per day can be input to simulate bacteria buildup during dry weather. The model is provided with asymptotic maximum storage coefficients associated with surface buildup (SQO). These accumulated EC loads are washed off based upon specified and

TABLE 5.19
CALCULATED SHEAR STRESS FOR SEDIMENT SIMULATION

Bayou	Reach ID	Slope (ft/ft)	Water Depth (ft) When Q ~ 100 cfs		D15	Calculated Shear Stress (lb/ft2)		Calibrated Shear Stress (lb/ft2)	
			Deposition	Scouring	(in)	Deposition	Scouring	Deposition	Scouring
BB	26	0.00245	3.00	4.00	0.00287	0.458	0.611	0.128	0.130
BB	27	0.00271	3.00	4.00	0.00287	0.507	0.676	0.128	0.130
BB	28	0.00305			0.00287	0.000	0.000	0.000	0.000
BB	33	0.00075	1.50	2.00	0.00287	0.071	0.094	0.135	0.150
BB	34	0.00085			0.00287	0.000	0.000	0.000	0.000
BB	35	0.00013			0.00435	0.000	0.000	0.000	0.000
BB	37	0.00064	15.75	15.76	0.00287	0.626	0.627	0.095	0.100
BB	38	0.00025	12.25	12.26	0.00287	0.193	0.193	0.095	0.100
BB	39	0.00050	4.00	5.00	0.00275	0.125	0.156	0.125	0.156
BB	44	0.00079	3.00	4.00	0.00287	0.149	0.198	0.128	0.130
BB	45	0.00033	11.06	11.07	0.00227	0.225	0.225	0.128	0.130
BB	47	0.00124	22.25	22.26	0.00287	1.726	1.727	0.095	0.100
BB	50	0.00033	2.00	3.00	0.00590	0.041	0.061	0.128	0.130
BB	51	0.00053	3.00	4.00	0.00287	0.100	0.133	0.128	0.130
BB	52	0.00037	4.00	5.00	0.00287	0.091	0.114	0.128	0.130
BB	53	0.00046	7.00	8.00	0.00327	0.201	0.229	0.135	0.150
BB	54	0.00052	5.00	6.00	0.00287	0.164	0.196	0.135	0.150
WO	1	0.00131	1.50	2.00	0.00643	0.123	0.164	0.100	0.110
WO	2	0.00104	2.50	3.00	0.00293	0.163	0.195	0.000	0.100
WO	3	0.00093	2.00	2.50	0.00643	0.117	0.146	0.000	0.100
WO	4	0.00097	2.10	2.20	0.00742	0.128	0.134	0.100	0.110
WO	5	0.00173	2.50	3.00	0.00643	0.269	0.323	0.000	0.0001
WO	6	0.00186	1.50	2.00	0.00643	0.174	0.232	0.100	0.110
WO	7	0.00062	0.75	1.00	0.00040	0.029	0.038	0.040	0.052
WO	8	0.00192	2.00	2.50	0.01419	0.239	0.299	0.000	0.111
WO	9	0.00117	2.00	3.00	0.00643	0.147	0.220	0.000	0.0001
WO	10	0.00094	3.50	4.00	0.00643	0.206	0.235	0.000	0.0001
WO	11	0.00102	1.50	2.00	0.00643	0.095	0.127	0.000	0.0001
WO	12	0.00074	1.50	2.00	0.00643	0.069	0.093	0.000	0.0001
WO	13	0.00058	1.50	2.00	0.00643	0.054	0.073	0.000	0.0001
WO	17	0.00124	2.00	3.00	0.00643	0.155	0.233	0.000	0.100
WO	40	0.00090	15.21	15.21	0.00643	0.853	0.853	0.300	0.310
WO	41	0.00085	6.35	6.37	0.00643	0.338	0.339	0.100	0.150
WO	42	0.00119	2.50	3.00	0.00643	0.186	0.224	0.100	0.150
WO	43	0.00087	1.50	2.00	0.00643	0.082	0.109	0.000	0.100
WO	46	0.00073	20.34	20.34	0.00371	0.930	0.930	0.290	0.300
WO	48	0.00183	2.30	2.40	0.00643	0.262	0.274	0.000	0.100
WO	49	0.00142	4.00	4.50	0.00643	0.353	0.397	0.000	0.0001

Notes:
1. Critical bed shear stress for deposition represented by TAUCD model parameter
2. Critical bed shear stress for scour is represented by TAUCS model parameter

washoff coefficient (WSQOP) specified in the model. Given that no data are available to specify these buildup and wash-off parameters, they were treated as calibration parameters.

5.1.5.4 Decay, Adsorption and Transfer Rates

The 2001 monitoring effort confirmed that bacteria die-off and regrowth in the water are common phenomena in BB and WO Bayous (See Section 3.3). While these processes are complicated, the TMDL HSPF models represent them as first-order decay processes. The test chamber studies conducted in 2001 yielded net decay (die-off minus regrowth) coefficients in water ranging from about 1 to 5 per day. Additionally, literature values of *in situ* rates summarized in an EPA document (1985) range from 0.192 day^{-1} to 15.12 day^{-1}, with a median rate of 0.96 day^{-1}. The modeled rate was therefore treated as a calibration parameter. The calibrated values could not always be kept within the measured range, but were kept within the range of literature values.

In addition to EC decay in the water, fate and transport of EC associated with the sediment was also modeled. The simulation of EC in sediment is controlled by several input parameters, e.g.. decay of EC in sediment, adsorption of EC onto sediment, transfer of EC between adsorbed and desorbed states, and initial concentration of EC in sediment. Data from the 2001 sampling effort provided values for some of these parameters. As listed in Table 5.20, the calculated average EC first-order decay rates in sediments for BB was 0.113 and 0.108/day for Whiteoak Bayou. Through the process of calibrating Whiteoak Bayou, it was found that a lower sediment decay rate of 0.01/day provided a much better fit to the in-stream observed WQ data.

TABLE 5.20
DECAY OF EC IN SEDIMENT

SampleType	EC in Sediment (cfu/dL)					
Sediment Collection Sites	BB@ Shepherd	BB@ Piney Pt.	BB@ Westheimer	WO@ Houston	WO@ Little York	Cole Ck. @Deihl
Date	8/6/2001	8/6/2001	8/15/2001	8/13/2001	8/13/2001	8/13/2001
1.0 mL Sediment	41,060	155,307	41,060	241,917	77,010	98,040
0.5 mL Sediment	15,360	52,040	29,100	223,970	22,600	65,640
0.01 mL Sediment	697,000	152,000	31,000	231,000	41,000	52,000
Geometric Mean	76,035	107,100	33,334	232,179	41,478	69,426
Date	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001	8/27/2001
10 mL Sediment						
1.0 mL Sediment	11,300	4,160	9,590	92,080	5,200	17,230
0.5 mL Sediment	10,580	4,180	8,500	137,340	7,080	10,560
0.01 mL Sediment	< 10,000	10,000	10,000	31,000	10,000	
Geometric Mean	10,613	5,582	9,341	73,188	7,167	13,489
1st-order Decay Coef. (1/day)	0.094	0.141	0.106	0.082	0.125	0.117
Average Decay Coef. (1/day)	0.113			0.108		

5.2 HYDROLOGY CALIBRATION

The calibration of the HSPF models involved adjusting model parameters (within a reasonable range) until model output matched observed data as closely as possible. Flow was calibrated first, followed by the water quality calibration. In addition, sensitivity analyses were completed with both the flow and water quality components of the model to understand model response to changes in input parameters. This section describes the flow calibration.

During the calibration process, the modeled flows were compared with the actual data. Model parameters were adjusted as necessary throughout the calibration process to improve the match with observed data. The availability of reliable observations was therefore critical to the calibration process as will be seen in the next few sections.

5.2.1 Flow Measurements Used for Calibration

The hydrologic calibration of HSPF models was conducted using hourly flow data provided by USGS at the following gage locations:

For Buffalo Bayou:

08073600 Buffalo Bayou at West Belt

08073700 Buffalo Bayou at Piney Point

08074000 Buffalo Bayou at Houston, Texas (at Shepherd)

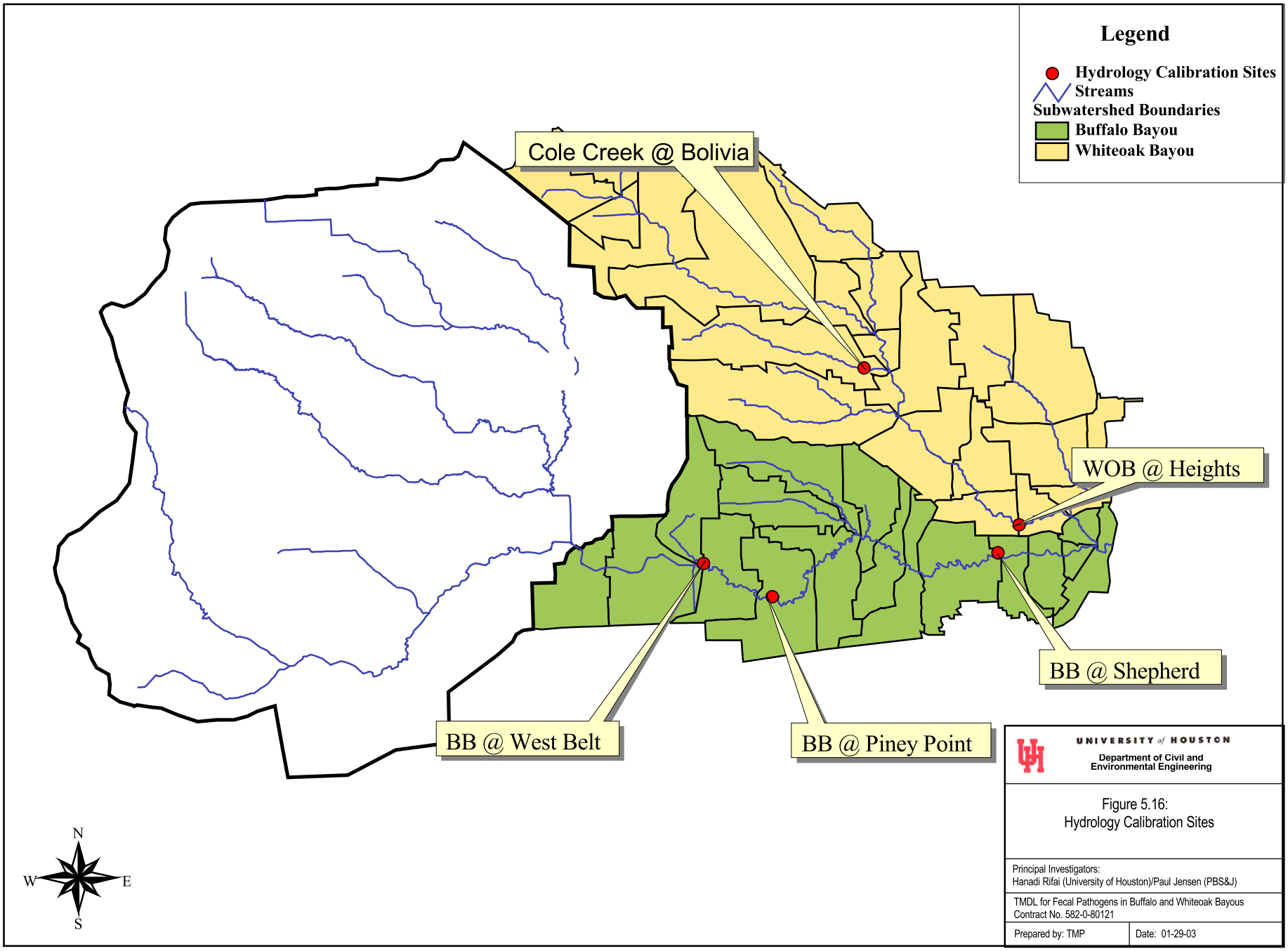
For White Oak Bayou:

08074150 Cole Creek at Deihl Road (Whiteoak Bayou)

08074500 White Oak Bayou at Houston, Texas (at Height)

Figure 5.16 shows the location of these stations. The calibration time period extended from April 1, 1999 through September 30, 2001. These gages were the primary data used for flow calibration. Using an hourly time step, each gage dataset yielded approximately 22,000 hourly data points in the time series.

The quality of these observations was reported by the USGS to be good (United States Geological Survey 2001). Buffalo Bayou at Shepherd is a flood-hydrograph partial-record station, which means that discharge data produced above 2,000 cfs are computed using a stage-discharge relation and flows below 1,000 cfs are estimated following designated storm periods only. The records for the gage at Heights in Whiteoak Bayou are considered fair, but the Cole Creek at Deihl Road records are poor (United States Geological Survey 2001). The Cole Creek gage, similar to the Shepherd location, is a flood-hydrograph partial-record station, and therefore may exhibit backwater influence from Whiteoak Bayou during periods of non-storm flow. These issues with the observed data quality have significant implications on HSPF model development as will be seen in subsequent sections.


Legend
Hydrology Calibration Sites
Streams
Subwatershed Boundaries
Buffalo Bayou
Whiteoak Bayou
Cole Creek @ Bolivia
WOB @ Heights
BB @ Shepherd
BB @ West Belt
BB @ Piney Point
N
W
E
S
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 5.16:
Hydrology Calibration Sites
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121
Prepared by: TMP
Date: 01-29-03

5.2.2 Flow Calibration Results

The Buffalo and Whiteoak Bayou HSPF flow models were calibrated using several different means of estimating error. Plots of the observed flow and the modeled flow were visually inspected to qualitatively evaluate the fit of the data. The root mean square (RMS) value was used to guide parameter selection but other additional measures were used to evaluate overall goodness of fit. The RMS error was calculated as follows:

$$RMS = sqr[\Sigma(Observed - Modeled)^2] \quad (5\text{-}4)$$

Statistical indicators, such as the mean flow, 90th, 50th and 10th percentile flows and storm volume were also examined to see how well the model matched observed flows. Finally, the normalized error was computed for these comparisons as follows:

$$Error = [(Modeled\text{-}Observed)/Observed]*100\% \quad (5\text{-}5)$$

Each hydrologic calibration model run involved the process of comparing model output against the observed calibration flow time series for each gage in Buffalo and Whiteoak Bayou.

The parameters that were adjusted during the hydrologic calibration as well as the final hydrologic parameters for Buffalo Bayou model are shown in Appendix B. The calibrated model parameters are within the ranges specified in the HSPF user's manual (Bicknell 1996).

5.2.2.1 Buffalo Bayou

A summary and assessment of model performance for Buffalo Bayou hydrology is presented in Table 5.21. It is clear from this table that the fit of the model is quite good, but in

Table 5.21 Hydrology Summary and Model Performance for Buffalo Bayou

Data Source	Location	Total Volume	90th Percentile Flow	10th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	West Belt	4.84E+05	72.60	3.80	9.7898E+04	1.19E+05
	Piney Point	5.19E+05	75.38	4.84	1.0458E+05	1.32E+05
	Shepherd [4]	4.69E+05	207.63	93.39	1.0783E+05	1.15E+05
Modeled	West Belt	4.34E+05	64.90	2.78	8.6335E+04	1.04E+05
	Piney Point	4.91E+05	71.60	4.01	9.6238E+04	1.20E+05
	Shepherd [4]	3.58E+05	174.90	65.00	8.53E+04	1.57E+05
Error[3]	West Belt	-10%	-11%	-27%	-12%	-13%
	Piney Point	-5%	-5%	-17%	-8%	-10%
	Shepherd [4]	-24%	-16%	-30%	-21%	37%

Notes:

[1] Volumes are in acre-ft/hr

[2] Storm values calculated as total flow following the storms (from the first precipitation to when the flow returns to pre-storm conditions):
07/17/1999 12/08/1999 01/08/2000 01/27/2000 02/07/2000 04/02/2000 07/23/2000
09/12/2000 11/05/2000 12/12/2000 03/14/2001 04/16/2001 05/26/2001 07/26/2001 08/06/2001

[3] Error percentage calcualted as (Model Value - USGS Value) / USGS Value, 0% indicates perfect match

[4] Flow statistics compiled for Shepherd gage only when observed flow available.

general, the flows are somewhat underestimated for all three calibration sites. The West Belt site shows the overall best fit, while Shepherd shows the poorest fit. The model is underpredicting by about 20-30% for the lowest flows at all sites. The only overestimation of flow occurs at the Shepherd site for flow during summer months, which were considered to be June through August. The errors that are found between the observed and modeled values at West Belt and Piney Point are well within acceptable ranges for water quality modeling. The errors at Shepherd, while lower than the other two gages, are considered acceptable because the USGS gage at Shepherd only records flow values around 100 cfs or higher. Therefore the observed data are discontinuous, with only higher flows available for comparison and calibration validation.

Several different plots were prepared to assess the fit of the modeled flows to the observed flows. The cumulative probability distribution function for flow is presented for all three Buffalo Bayou calibration sites in Figure 5.17. These figures show that overall, the model is under predicting during low flows, matching very well at the middle range flows, and under estimating at the very high flows. Figure 5.18 presents a plot of the simulated flow versus the observed flow. Overall, the fits are very good with the R^2 at West Belt and Piney Point being greater than 0.90. The plot for Shepherd only contains values from the model where an observed value was also available. The R^2 at Shepherd is lower, only 0.61, but this is still considered a good fit since some of the observed values at lower flows are estimated and not measured.

Figure 5.17. Cumulative flow frequency curves for simulated and observed flows in Buffalo Bayou

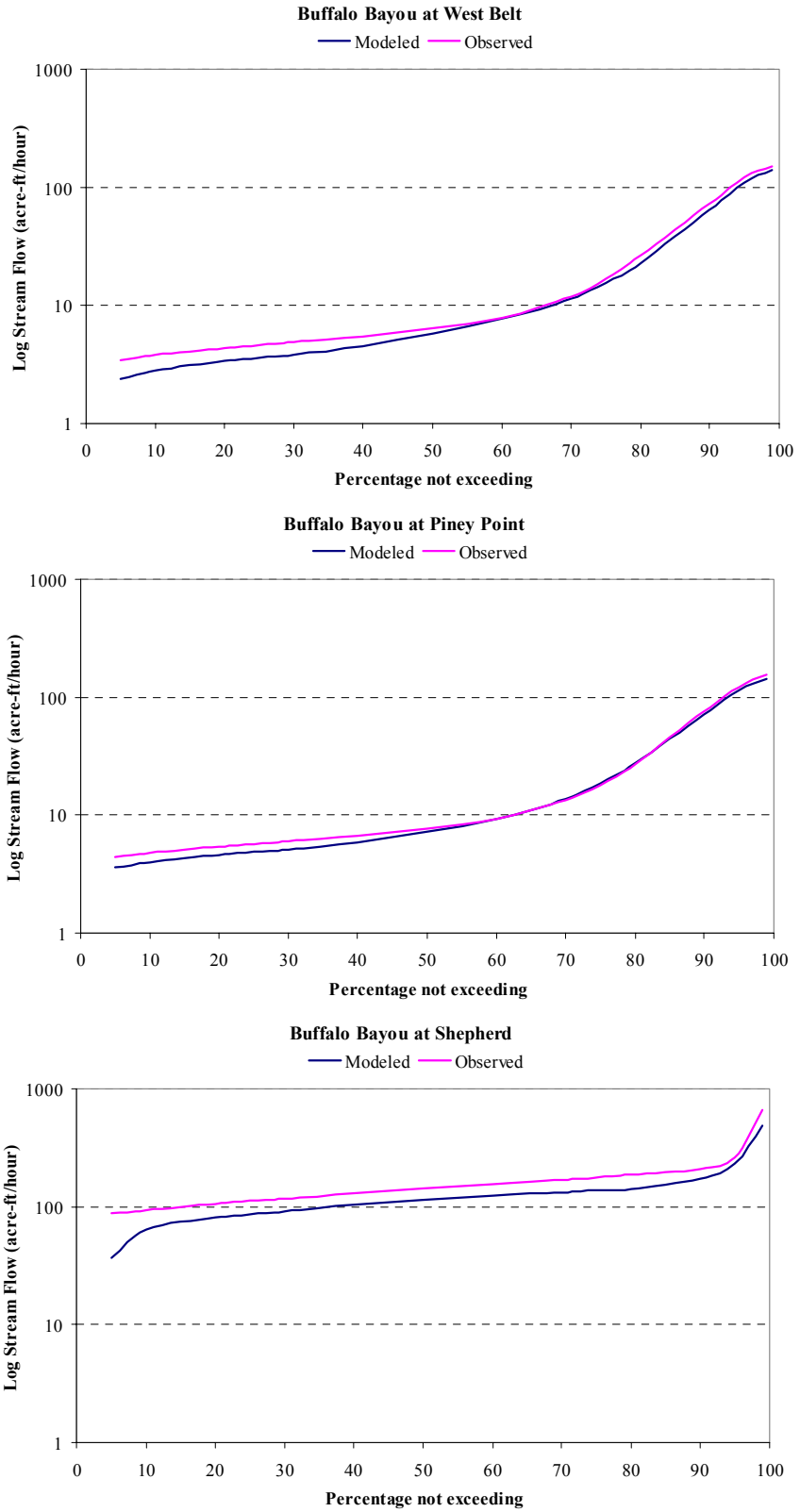


Figure 5.18 Correlation between observed and simulated flow in Buffalo Bayou.

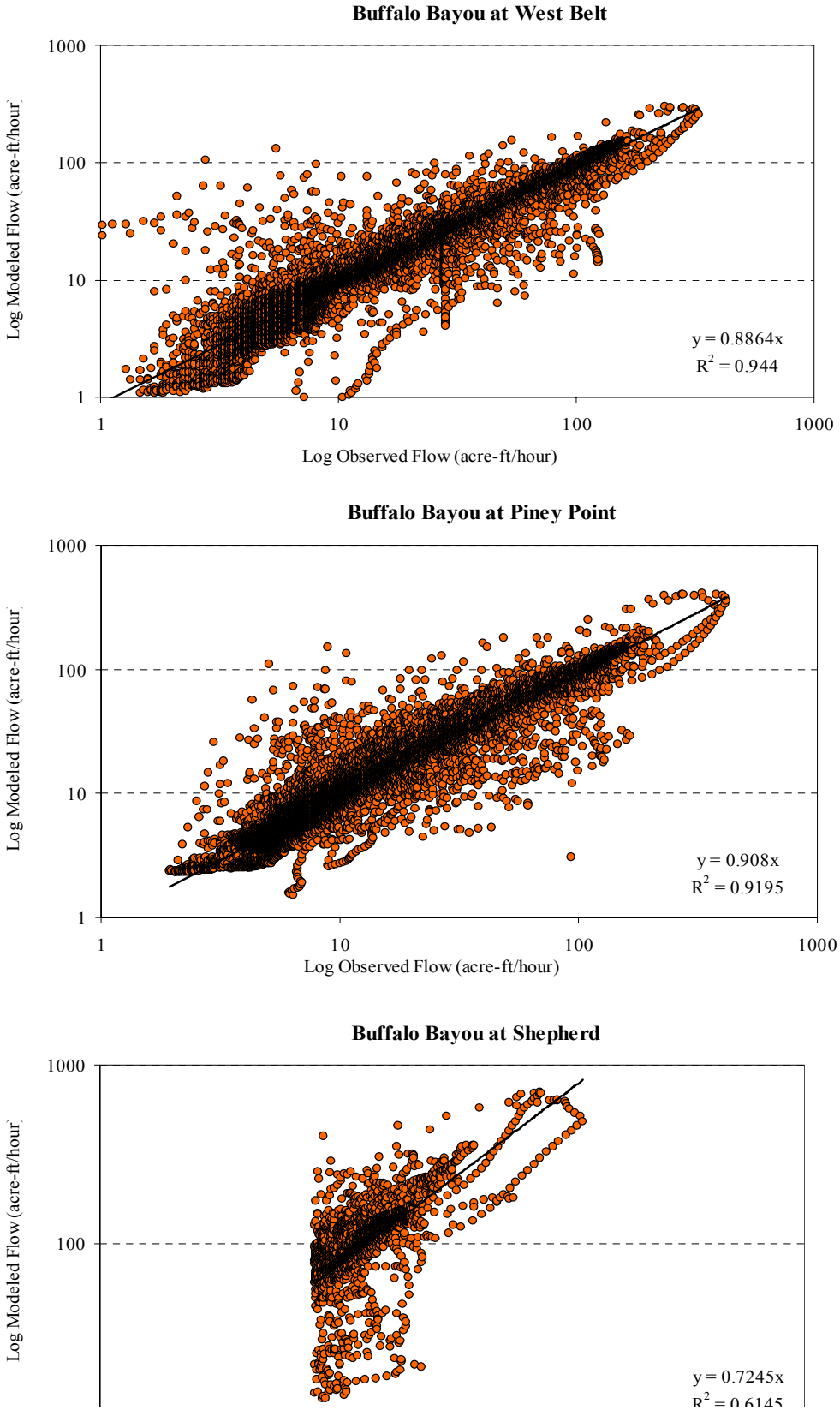
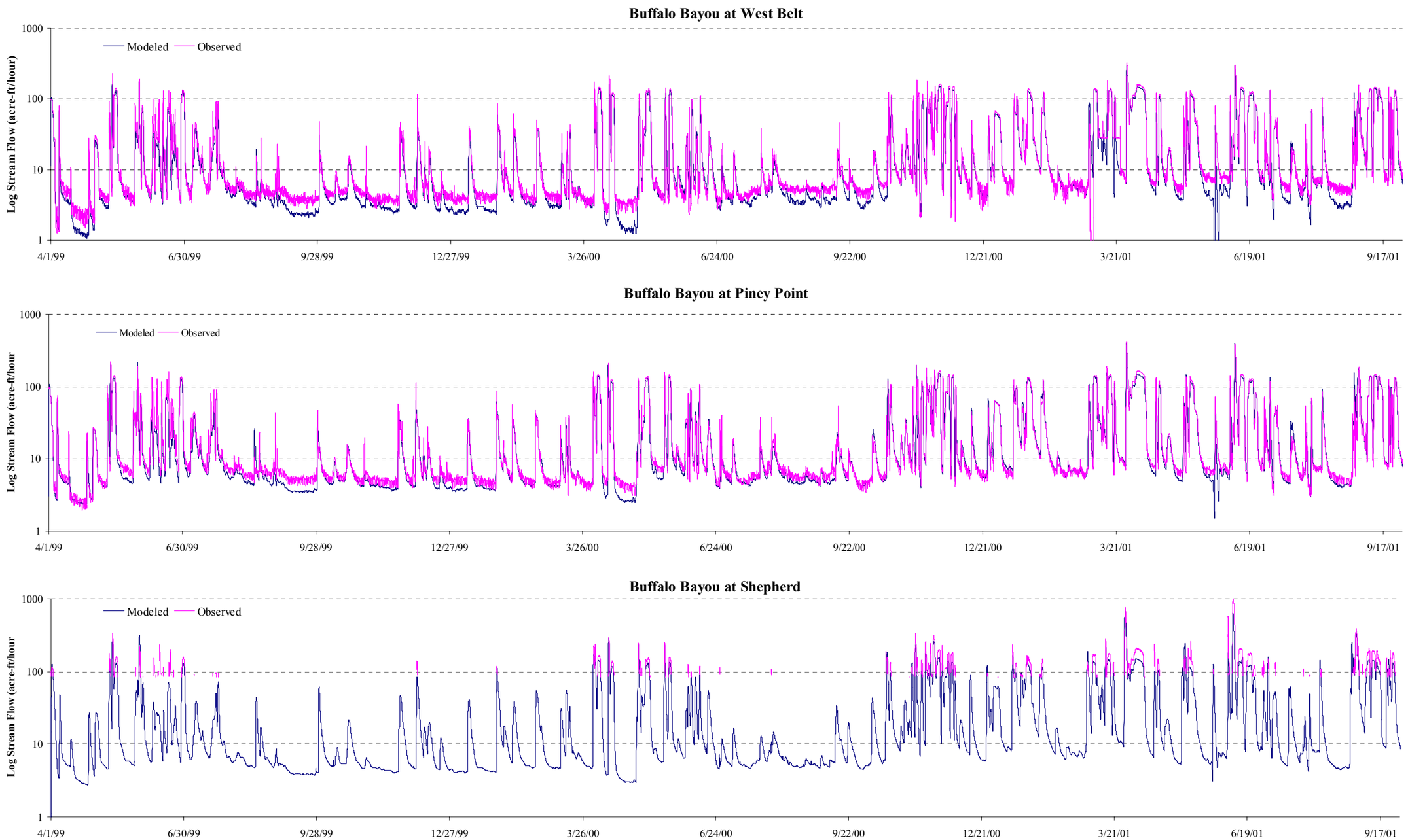


Figure 5.19. Comparison of simulated and observed flow for Buffalo Bayou.



A graph of the model output at each of the three calibration points in Buffalo Bayou are shown in Figure 5.19 for the entire model period of the model. As previously mentioned, the flows at the Shepherd station below 1,000 cfs are only estimated during designated storm periods and therefore the data are quite sparse. These figures show that overall the model is predicting relatively well at the flow calibration points. The graphs confirm that the model is under predicting at the lower flows, while the high flows seem to match better.

5.2.2.2 Whiteoak Bayou

Table 5.22 presents a summary and assessment of model performance for Whiteoak Bayou hydrology. The total volume at the Heights gauge is overestimated by 13%, which is an acceptable amount of error. The highest flows are overestimated at Heights again by 13%, while the lowest flows are matching the observed data exactly. The storm flows are being overestimated at Heights, however, improving this particular statistic meant using unrealistic model parameters.

The Cole Creek modeled flows are much higher than the USGS observed flows. Like the Shepherd gauge, the Cole Creek USGS gauge is a partial-flood hydrograph station, which can cuase discontinuities in the flow record. Another reason for the overestimation is that the USGS gauge is not located at the very end of the subbasin as shown in Figure 5.20 and a large city of Houston plant is located downstream of the USGS gauge with a daily flow of 8.78 MGD (1.11 acre-ft/hr).

Table 5.22 Hydrology Summary and Model Performance for Whiteoak Bayou

Data Source	Location	Total Volume	90th Percentile Flow	10th Percentile Flow	Storm Volume[2]	Summer Volume
Observed	Heights	3.10E+05	19.30	2.72	2.9216E+04	1.30E+05
	Cole Creek	2.24E+04	2.47	0.15	1.9947E+03	9.13E+03
	Cole Creek with WWTP[4]	3.82E+04	3.58	1.26	2.9226E+03	1.44E+04
Modeled	Heights	3.50E+05	21.90	2.72	4.1561E+04	1.15E+05
	Cole Creek	4.65E+04	3.92	1.16	4.65E+03	1.55E+04
Error[3]	Heights	13%	13%	0%	42%	-11%
	Cole Creek	108%	59%	676%	133%	70%
	Cole Creek with WWTP[4]	22%	9%	-8%	59%	8%

Notes:

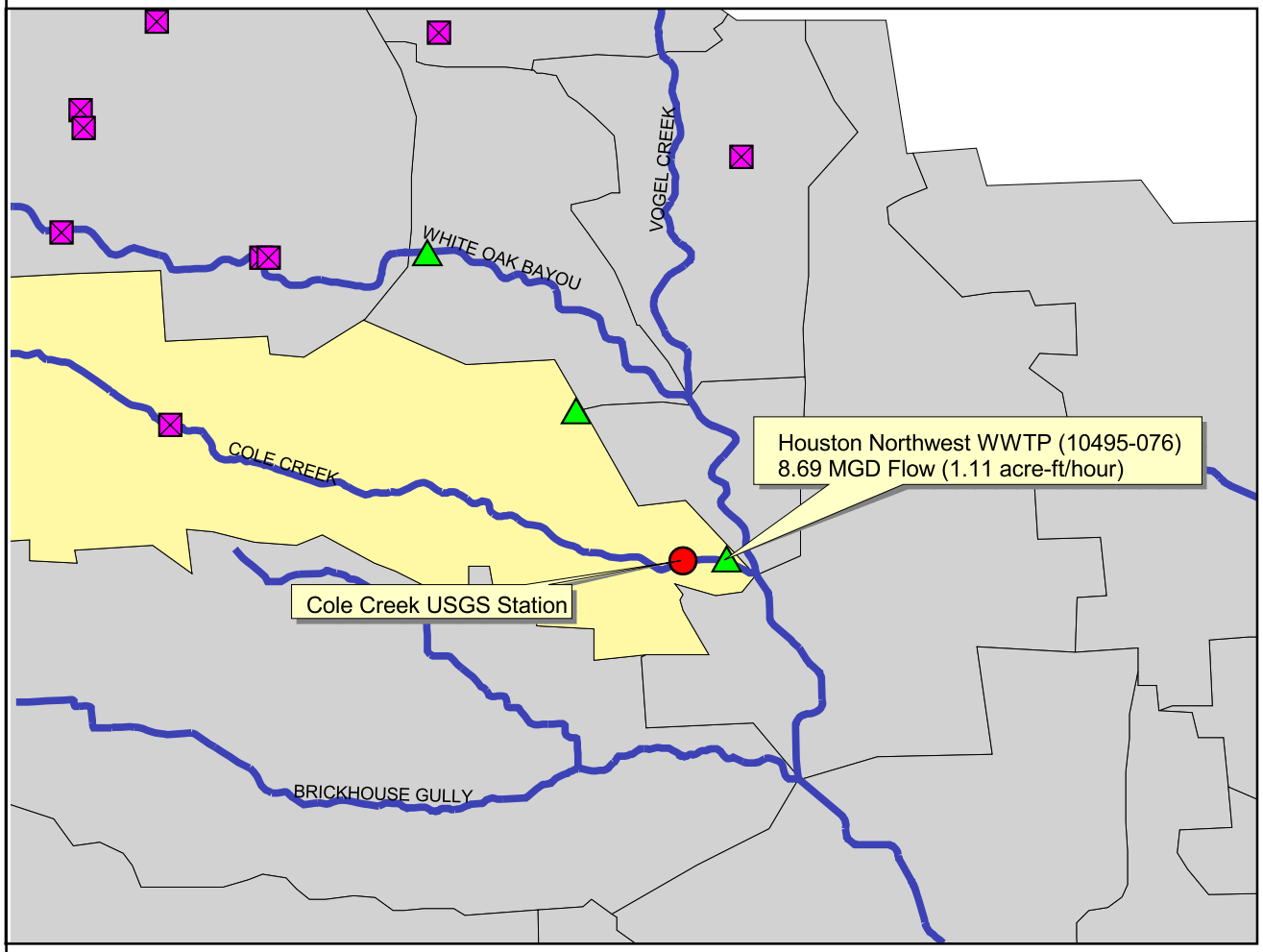
[1] Volumes are in acre-ft/hr

[2] Storm values

07/8/1999 12/04/1999 6/9/2000 6/26/2000 7/4/2000 10/6/2000
11/23/2000 12/24/2000 1/16/01 03/14/2001 8/29/01 9/9/01

[3] Error percentage calcualted as (Model Value - USGS Value) / USGS Value, 0% indicates perfect match

[4] Cole Creek observed volumes include 1.11 acre-ft/hour to compensate for the WWTP located downstream of the USGS station.



Legend

Wastewater Treatment Plants
- Actual Flow Data Used
- Geometric Means Used
- WWTP in Reservoir

- Hydrology Calibration Sites
- Streams

Subwatershed Boundaries
- 2
- 1, 3 - 55

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FIgure 5.20. Detail of Cole Creek and Wastewater Treatment Locations.

Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)

TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121

Prepared by: TMP | Date: 01-23-03

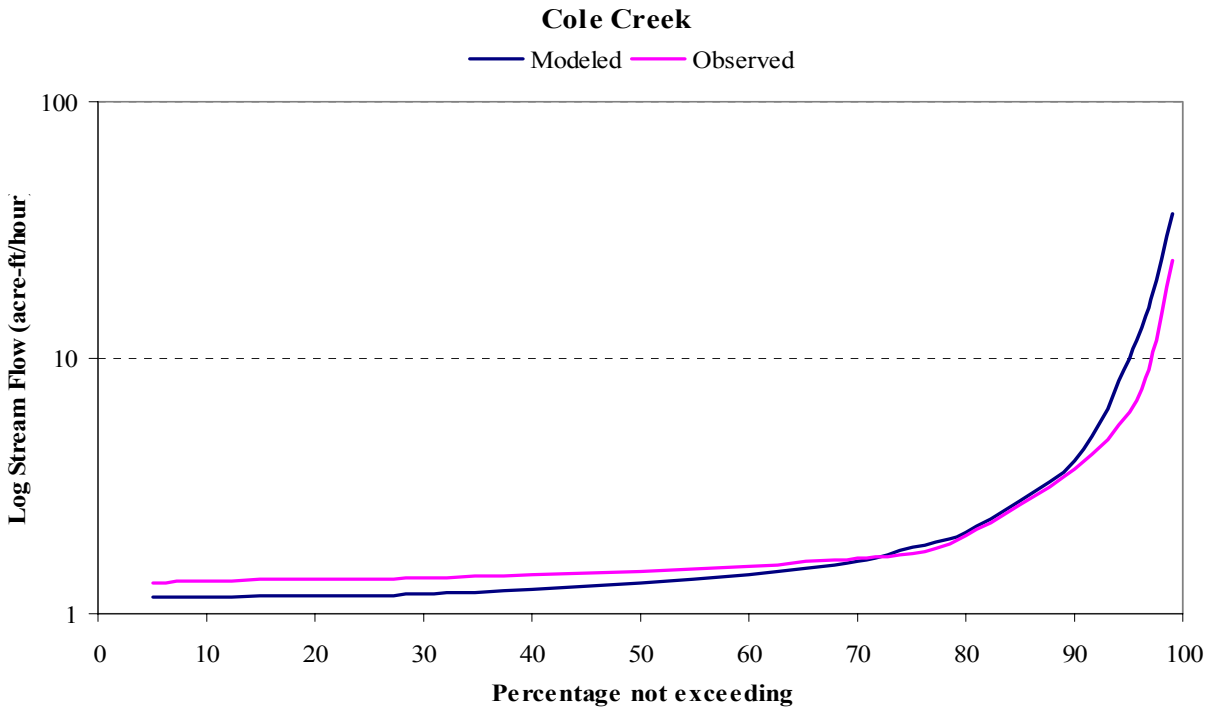
To provide an estimation of the actual flow reaching the end of the subbasin, the constant wastewater treatment plant flow in acre-ft/hour was added to the hourly USGS flows. Since the hourly flows at a wastewater treatment plant fluctuate greatly over the course of the day, the new volumes are only estimates of the wastewater treatment plant impacts on overall flow in Cole Creek. Table 5.22 shows that when the WWTP flow is accounted for, the error between modeled and measured flow decreases from 108% to 22% for total volume.

The cumulative probability distribution function for flow is presented for both the Cole Creek and Heights calibration sites in Figure 5.21. These figures show that overall, the model at Heights is predicting very well, with slight overestimation at low flows. The Cole Creek curve shows a much poorer calibration with the lower percentiles not matching the observed values well. The poor fit may, in part, be due to problems with the observed data at Cole Creek. The calibration does improve at the higher percentile flows (i.e. greater than 70th percentile).

Figure 5.22 presents a plot of the simulated flows versus the observed flows. Overall, the fits are very good with the R^2 at Heights being 0.7069 and Cole Creek being 0.6272. Again, these plots indicate that the model fit is adequate but not as good as the fit in Buffalo Bayou.

A graph of the model output at the 2 calibration points in Whiteoak Bayou is shown in Figure 5.23. The flow graphs for Heights show that both the high and low flows are being matched relatively well. The low flow and summer graphs for Heights are also showing a

Figure 5.21. Cumulative flow frequency curves for simulated and observed flows in Whiteoak Bayou



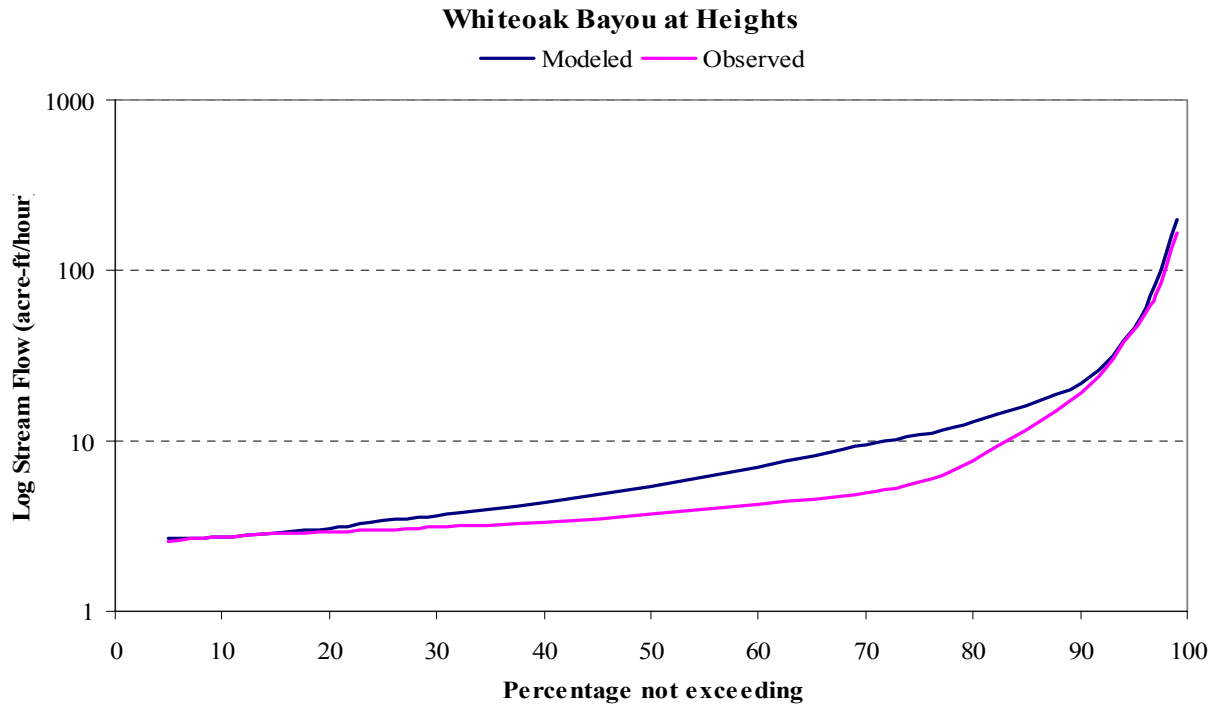
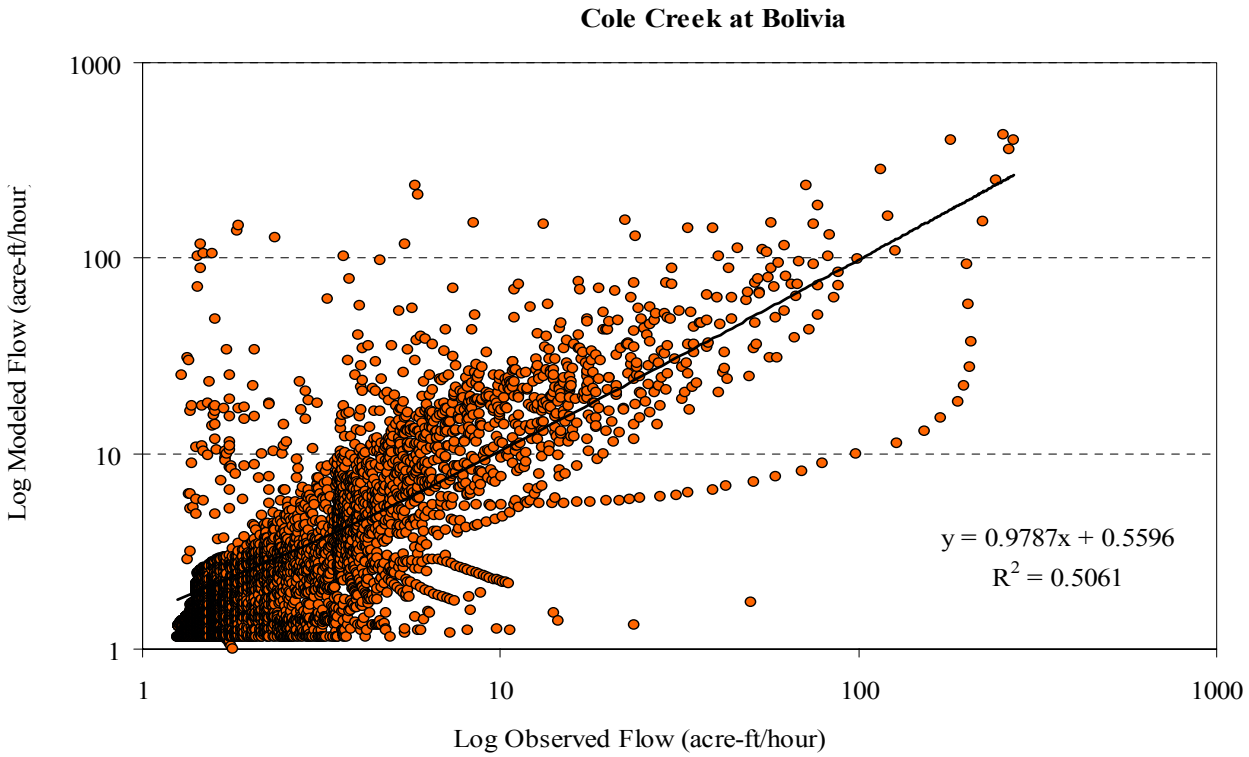


Figure 5.22 Correlation between observed and simulated flow in Whiteoak Bayou.



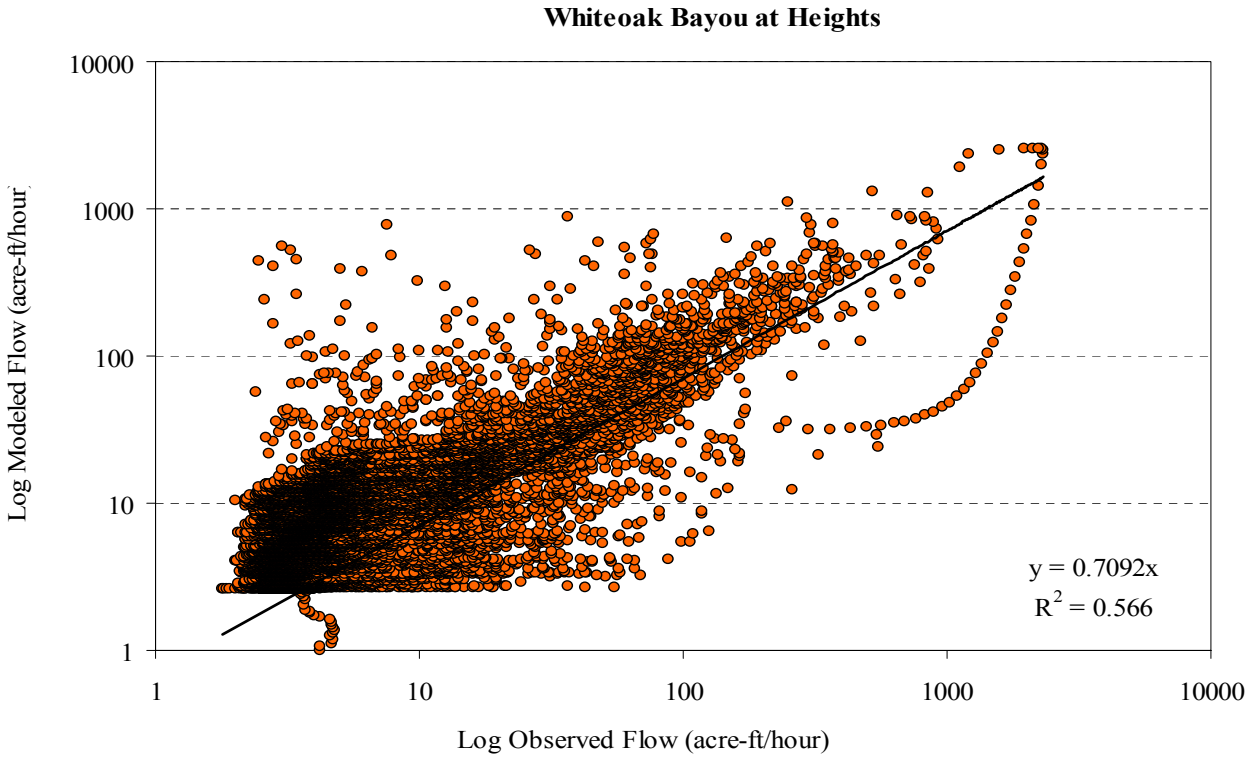
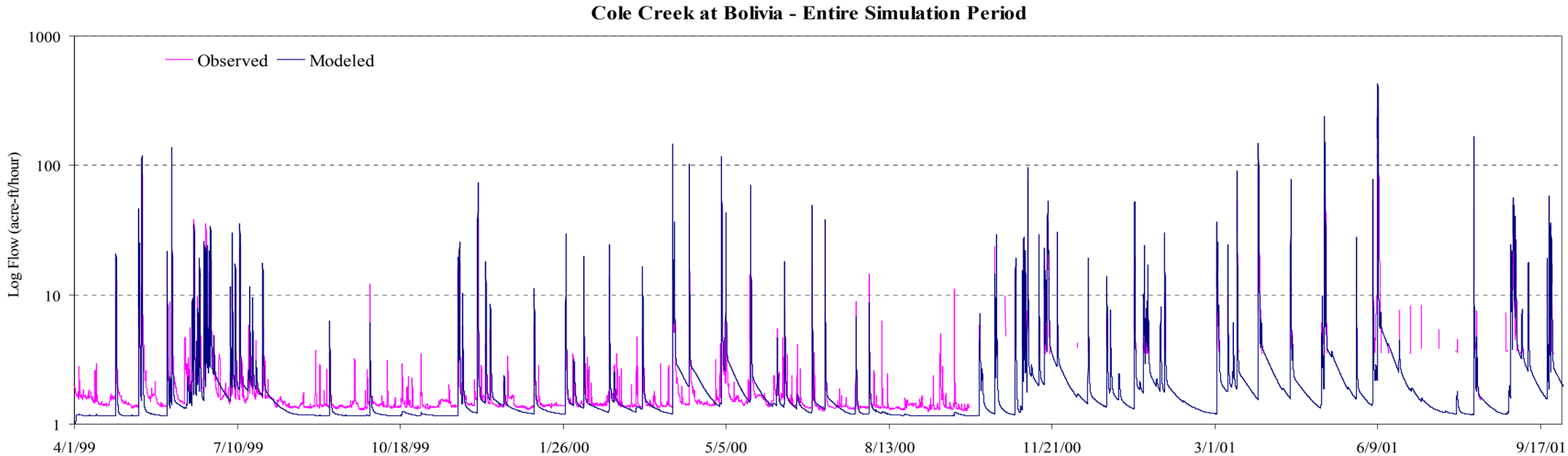
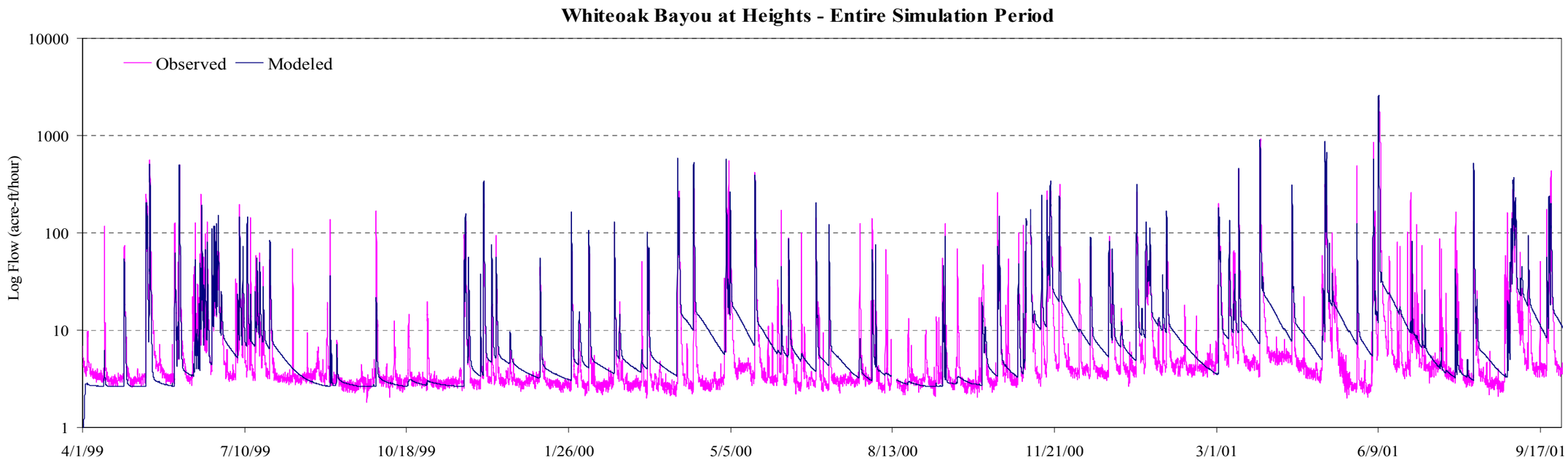


Figure 5.23. Comparison of simulated and observed flow for Cole Creek and Whiteoak Bayou.





good fit. The observed data show some spikes where the model does not, the reasons for which are not clear at this time. Since Houston has a very good distribution of rain gages, gage records in the watershed other than those included in the model were examined to see if rainfall occurred during those spikes and thus the model precipitation gage network was inadequate. No rainfall was recorded and therefore these spikes may be a result of the poor quality observed data at the Heights. The Cole Creek data are very sparse since it is a partial hydrograph station, and thus the calibration cannot be adequately evaluated.

5.3 WATER QUALITY CALIBRATION

The calibration of water quality parameters is quite different from calibrating simulated stream flows. Complications are encountered for several reasons. One of the primary reasons is that the underlying processes that affect stream flow are better understood than those that are associated with EC concentrations. Additionally, with the exception of the Summer 2001 data, there is little information on EC sources in these watersheds.

In the past, FC has been used as an indicator of fecal contamination in surface waters. More recently, the EPA has recommended the use of EC as a more specific indicator of human pollution. The TCEQ has adopted the use of EC as the primary indicator bacteria for the State of Texas, and therefore, this model was developed to output EC concentrations in cfu/dL/hour.

The historical data consist primarily of FC values, with a number of EC samples that were collected in 2001 by the TCEQ and in this project. The FC data were converted to EC data using the ratio of the water quality standards. The conversion was found to be a sufficient method of

EC concentration estimation since a similar ratio was actually used to develop FC water quality standards (from total coliform standards) (US EPA 1986).

There are, however, limitations to this methodology that should be mentioned. There is no clear evidence that EC exist in any particular ratio to FC. Data collected in this project seem to suggest a single ratio of EC to FC would be difficult to quantify. In fact, it has been found that ratios of EC to FC differ from source to source (Yakub et al., 2002).

The following locations were selected to provide water quality calibration data based on the amount of available historical data:

For Buffalo Bayou:

R-39 Buffalo Bayou at West Belt

R-54 Buffalo Bayou at Briar Forest

R-53 Buffalo Bayou at VOSS

R-45 Buffalo Bayou at Shepherd

For White Oak Bayou:

R-41 White Oak Bayou at Height

R-2 Cole Creek at Bolivia

R-48 Little White Oak Bayou at White Oak Drive

R-3 West 43rd

where R-xx represents a reach number in the models. Figure 5.24 presents the locations of the water quality calibration sites.

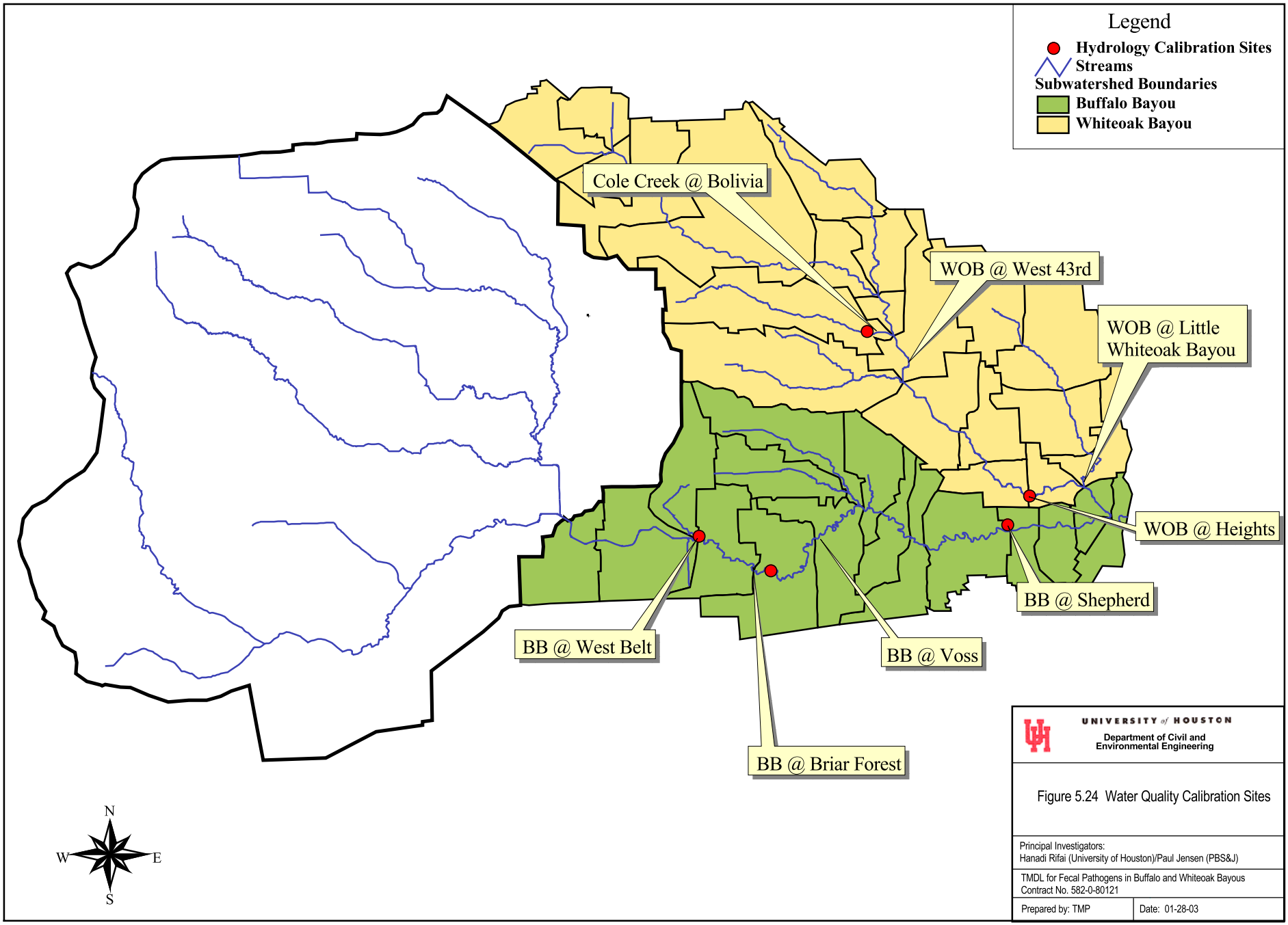
Within the simulation period (4/1/1999-9/30/2001), the numbers of available bacteria data

at these locations are shown in Table 5.23 below. It is noted that each model run generated approximately 22,000 WQ data points at each gage compared to the 30-115 observed data points shown in Table 5.23. It is obvious that the water quality calibration will be impacted by the limited number of water quality observations at the seven gages.

Table 5.23. Number of FC/EC observations at Water Quality Calibration Gages

Buffalo Bayou		Whiteoak Bayou	
Site	Number of Data	Site	Number of Data
R-39	112	R-2	81
R-45	111	R-42	97
R-53	85	R-48	82
R-54	48	R-3	29

Similarly to the hydrologic calibration, a systematic approach was developed to facilitate the calibration in an efficient manner using RMS errors. The following is a step-by-step approach for the calibration process:


Legend
Hydrology Calibration Sites
Streams
Subwatershed Boundaries
Buffalo Bayou
Whiteoak Bayou
Cole Creek @ Bolivia
WOB @ West 43rd
WOB @ Little Whiteoak Bayou
WOB @ Heights
BB @ Shepherd
BB @ West Belt
BB @ Voss
BB @ Briar Forest
N
W
E
S
UNIVERSITY of HOUSTON
Department of Civil and Environmental Engineering
Figure 5.24 Water Quality Calibration Sites
Principal Investigators:
Hanadi Rifai (University of Houston)/Paul Jensen (PBS&J)
TMDL for Fecal Pathogens in Buffalo and Whiteoak Bayous
Contract No. 582-0-80121
Prepared by: TMP
Date: 01-28-03

1. Identify a list of parameters that impact the bacteria simulation;
2. Adjust one parameter at a time and run model to obtain EC time series at the selected calibration locations;
3. Compare model output against observed data by calculating a Root Mean Square (RMS) error, loading (when observed flow data available), concentration (when flow not available), and examining plots of concentrations at each of the selected locations (four locations for Buffalo Bayou and four in White Oak Bayou). The model output was compared only at time steps where observed data were available;
4. Repeat steps 2 and 3 until the fit within each watershed approaches the point where no additional benefit is seen in the goodness-of-fit statistics and plots; and
5. Repeat steps 2-4 until all identified parameters have been investigated.

Steps 2-5 were first conducted on a global basis, i.e. the same values were applied to all subwatersheds. After looking at the global parameters, the individual subwatersheds was examined. Appropriate parameters were further adjusted by repeating steps 2-5 on a subwatershed level.

5.3.1 Calibration Results

5.3.1.1 Buffalo Bayou

The model output was compared to observed values and the results are shown in Table 5.24. Both the loads (when a USGS station is present to provide observed flows) and

Table 5.24. Water Quality Summary and Model Performance for Buffalo Bayou.

Comparison of Hourly Bacteria Loading in Buffalo Bayou.[1]						
	West Belt			Briar Forest		
	Modeled	Observed	Error	Modeled	Observed	Error
Overall Load	2.48E+14	4.16E+15	-94%	2.15E+14	4.89E+15	-96%
High Flow Load[2]	2.31E+14	3.37E+15	-93%	2.05E+14	2.17E+13	845%
Low Flow Load[3]	2.19E+12	1.73E+14	-99%	7.50E+11	4.89E+15	-100%

	Shepherd		
	Modeled	Observed	Error
Overall Load	8.62E+14	1.46E+16	-94%
High Flow Load[2]	8.11E+14	1.28E+16	-94%
Low Flow Load[3]	3.14E+12	4.89E+14	-99%

Comparison of Geomean Concentrations in Buffalo Bayou.[1]						
	West Belt			Briar Forest		
	Modeled	Observed	Error	Modeled	Observed	Error
Overall GM	1645.93	1556.81	6%	2027.88	1419.75	43%
High Flow GM[2]	13959.87	3322.98	320%	9273.95	2601.32	257%
Low Flow GM[3]	670.45	703.00	-5%	663.32	394.95	68%

	Shepherd			Voss		
	Modeled	Observed	Error	Modeled	Observed	Error
Overall GM	3080.52	2479.88	24%	977.41	1186.39	-18%
High Flow GM[2]	7735.08	15644.47	-51%	6613.18	1170.43	465%
Low Flow GM[3]	2135.61	745.14	187%	482.11	728.86	-34%

[1] Modeled values calculated only when an observed data point available.

[2] High flow was considered to be greater than approximately the 80th percentile of the modeled data.

[3] Low flow was considered to be less than approximately the median of the modeled data.

concentrations (for all gages) are presented to summarize the model simulation of water quality in Buffalo Bayou. The overall EC loads are underestimated on the order of 90% throughout Buffalo Bayou. This may be due to the underestimation of the flow that is generally occurring along the bayou. The concentrations, however, show a much better fit with absolute errors ranging from 6% at West Belt to 43% at Briar Forest.

Figure 5.25 shows the log observed EC concentration versus log simulated EC concentration in Buffalo Bayou. The presented plots demonstrate that there is no bias in the model output, since approximately half the data lie above and below the line of equality.

Figure 5.26 shows observed EC grab samples together with the continuous (hourly) model output for the most upstream (West Belt) and most downstream (Shepherd) calibration sites in Buffalo Bayou. This figure shows that the range of observed values is simulated well by the model. The runoff events sampled for this project are also matched well. This can be seen more clearly in Figure 5.27, which shows the summer of 2001. These plots demosntrate that the model is matching the runoff samples very well at West Belt, Briar Forest, Voss and Shepherd.

5.3.1.2 Whiteoak Bayou

Results from the EC calibration are presented in Table 5.25. This table shows that the EC loads are being over predicted in general at Heights, while the low flows are being under predicted. The model is matching the observed loads very well for Cole Creek, with the overall load being underestimated by only 7%.

Figure 5.25. Simulated EC versus Observed EC for Buffalo Bayou.

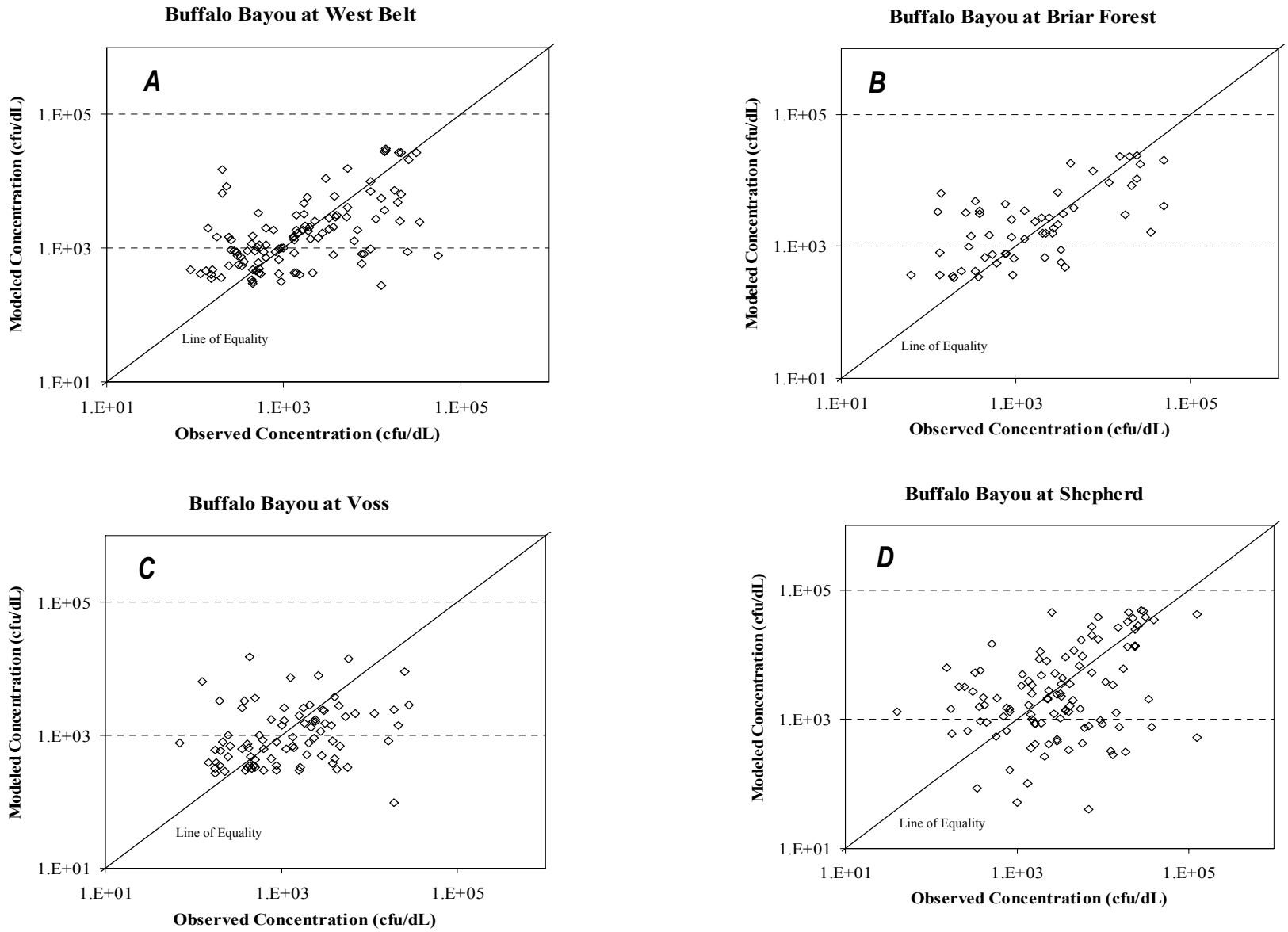
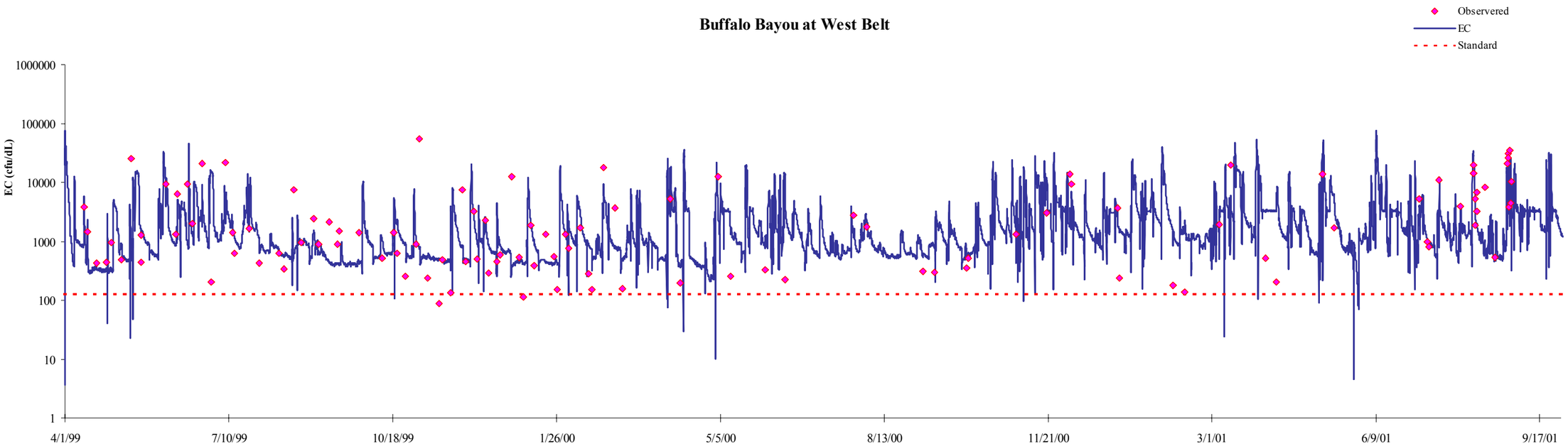


FIGURE 5.26 EC CALIBRATION IN BUFFALO BAYOU, WEST BELT AND SHEPHERD



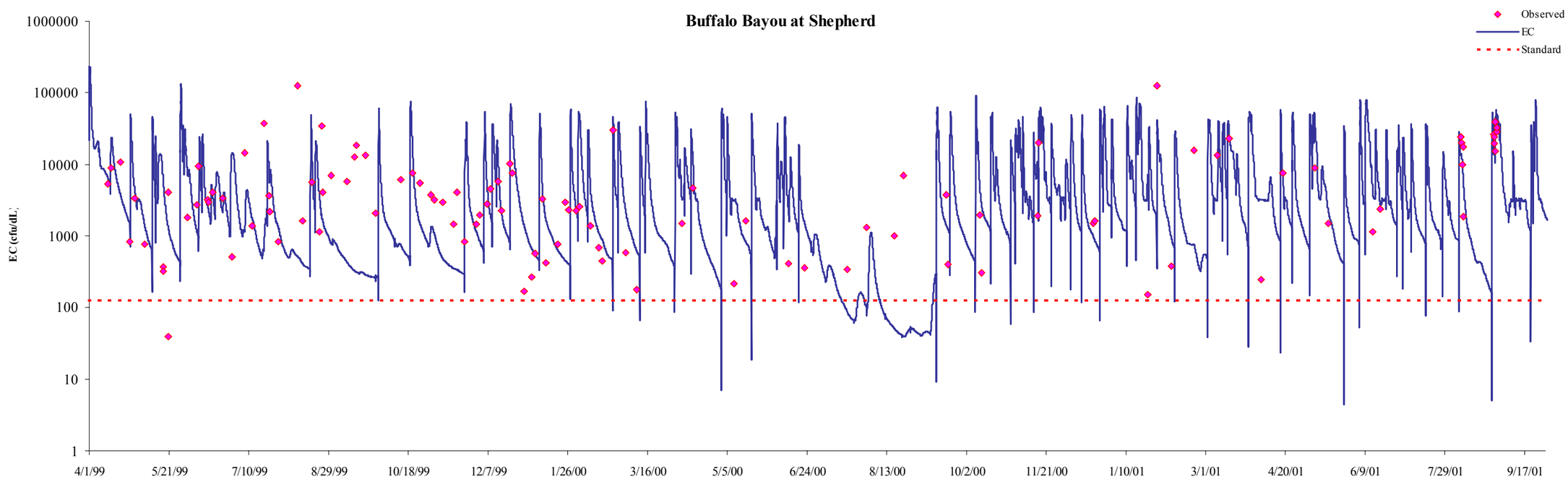


FIGURE 5.27 EC CALIBRATION IN BUFFALO BAYOU FOR SUMMER 2001 RUNOFF EVENTS.

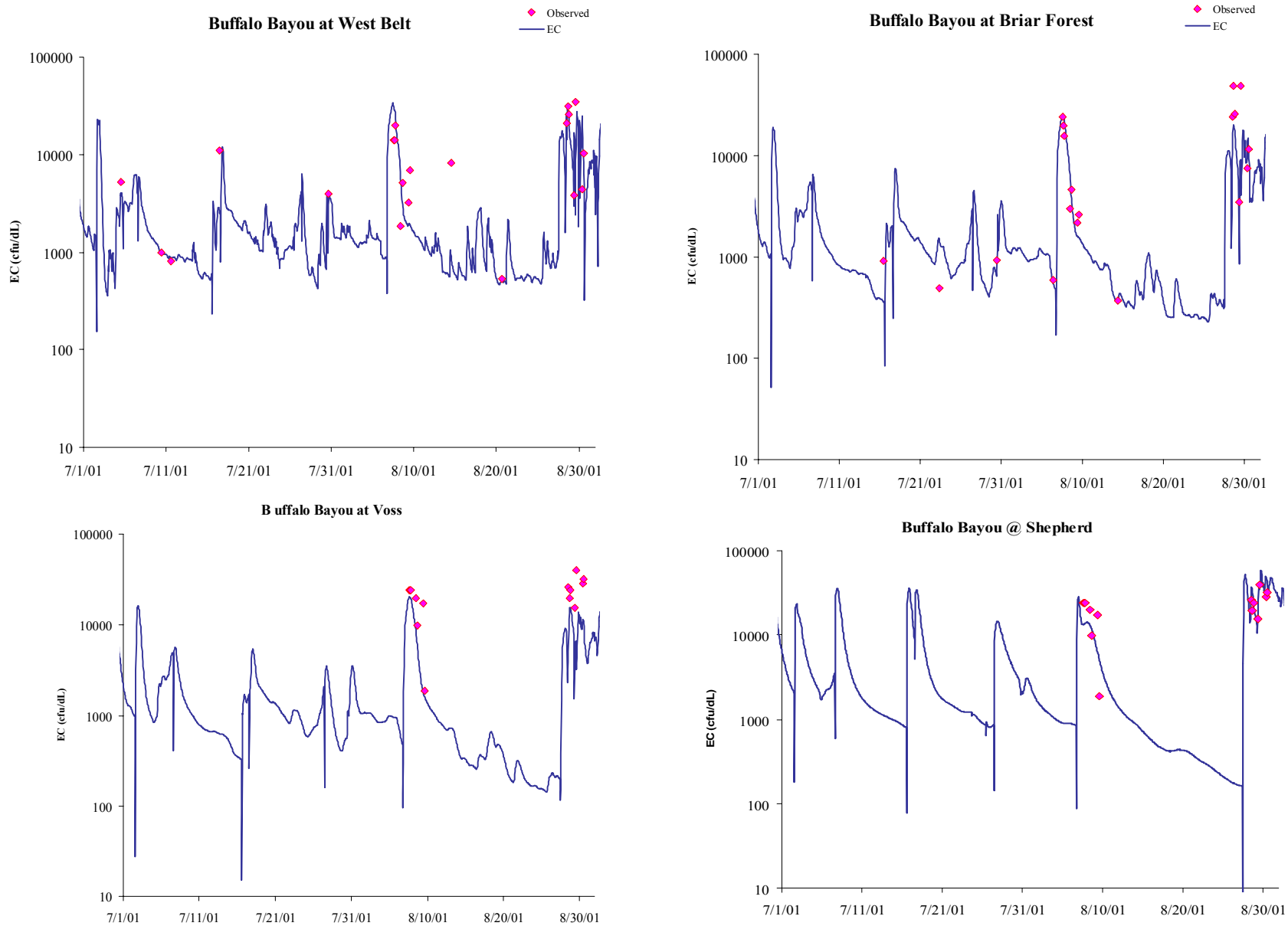


Table 5.25. Water Quality Summary and Model Performance for Whiteoak Bayou.

Comparison of Hourly Bacteria Loading in Whiteoak Bayou. [1]						
	Heights			Cole Creek		
	Modeled	Observed	Error	Modeled	Observed	Error
Overall Load	1.04E+15	2.98E+14	250%	9.07E+12	9.71E+12	-7%
High Flow Load [2]	1.03E+15	2.32E+14	341%	8.40E+12	1.03E+13	-18%
Low Flow Load [3]	2.16E+12	2.08E+13	-90%	2.96E+11	2.16E+11	37%

Comparison of Geomean Concentrations in Whiteoak Bayou. [1]						
	West 43rd			Little Whiteoak		
	Modeled	Observed	Error	Modeled	Observed	Error
Overall GM	926.82	757.26	22%	2834.94	4042.04	-30%
High Flow GM [2]	3908.69	2302.17	70%	29420.33	24241.11	21%
Low Flow GM [3]	336.16	2302.17	-85%	503.79	2639.53	-81%

	Heights			Cole Creek		
	Modeled	Observed	Error	Modeled	Observed	Error
Overall GM	863.64	2955.78	-71%	200.21	1846.02	-89%
High Flow GM [2]	13399.74	9822.83	36%	5057.25	22040.50	-77%
Low Flow GM [3]	192.53	1733.99	-89%	65.48	773.08	-92%

[1] Modeled values calculated only when an observed data point available.

[2] High flow was considered to be greater than approximately the 80th percentile of the modeled data.

[3] Low flow was considered to be less than approximately the median of the modeled data.

Geomean concentration results are also presented in Table 5.25. The concentrations at West 43rd match the overall geometric mean concentration fairly well, with 22% error. The high flow concentrations are overestimated and the low flow concentrations are underestimated by the model. This same pattern is seen at the Heights and Little Whiteoak Bayou stations. The overestimation of the storm flows could be a result of the hydrologic calibration, which overestimates the storm runoff volumes. The concentration data at Cole Creek are more plentiful than the other three stations. Because flow data were available at Cole Creek, emphasis was placed upon matching the bacteria loads, rather than bacteria concentrations, at this station. An effort was made to minimize the amount of underestimation of the low flow, while maintaining a reasonable amount of overestimation of the high flow concentrations.

A plot of log observed concentrations versus log modeled concentrations is presented in Figure 5.28. These plots demonstrate that the West 43rd and Little Whiteoak Bayou stations are matching the overall distribution of the concentrations well, with an even number of points above and below the line of equality. The Whiteoak Bayou at Heights and Cole Creek data, on the other hand, display a tendency to cluster below the line of equality, indicating that the concentrations are generally underestimated.

Time series plots for the entire model simulation period of West 43rd, the most upstream calibration point in Whiteoak Bayou, and Heights Blvd, the most downstream main stem calibration point in Whiteoak Bayou, are presented in Figure 5.29. The plot of Heights shows that the model does underestimate the concentrations in Fall 1999 and Summer 2000. The plot

Figure 5.28. Simulated EC versus Observed EC for Whiteoak Bayou.

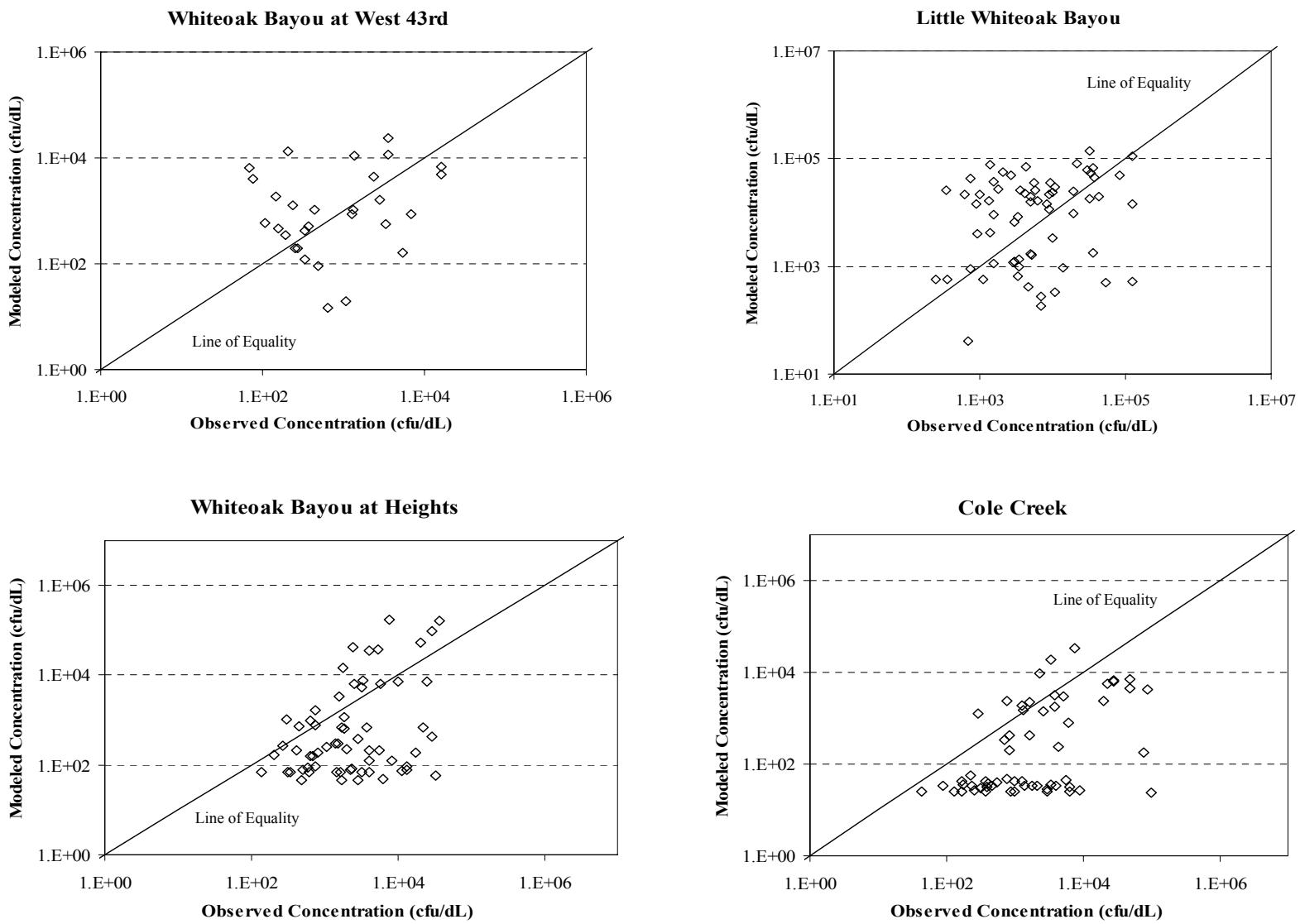
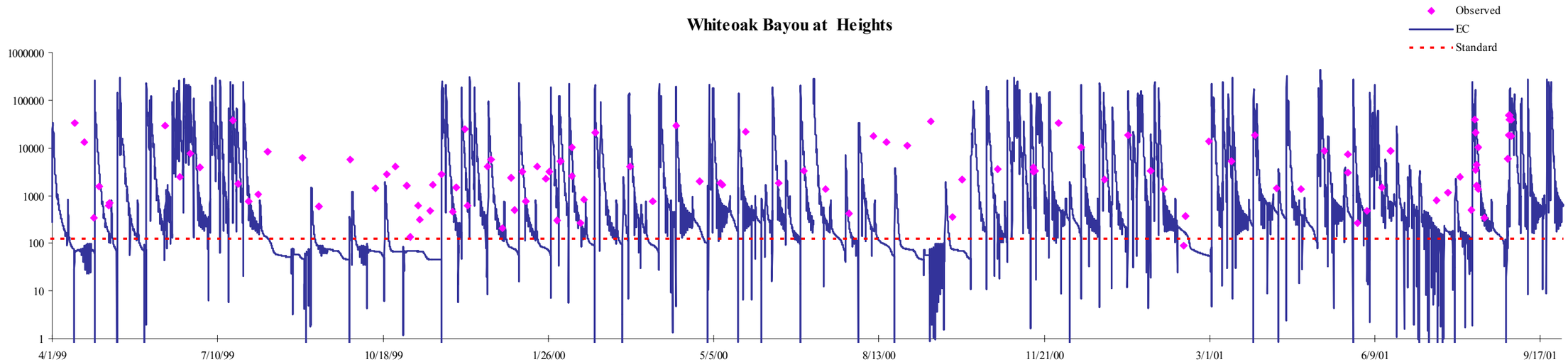
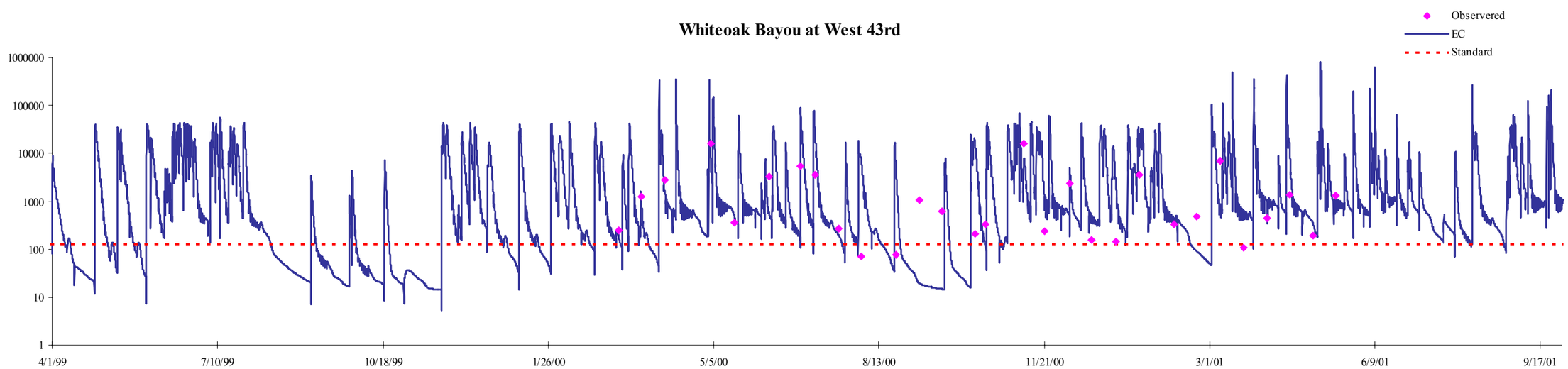


FIGURE 5.29 EC CALIBRATION IN WHITEOAK BAYOU, HEIGHTS AND WEST 43rd

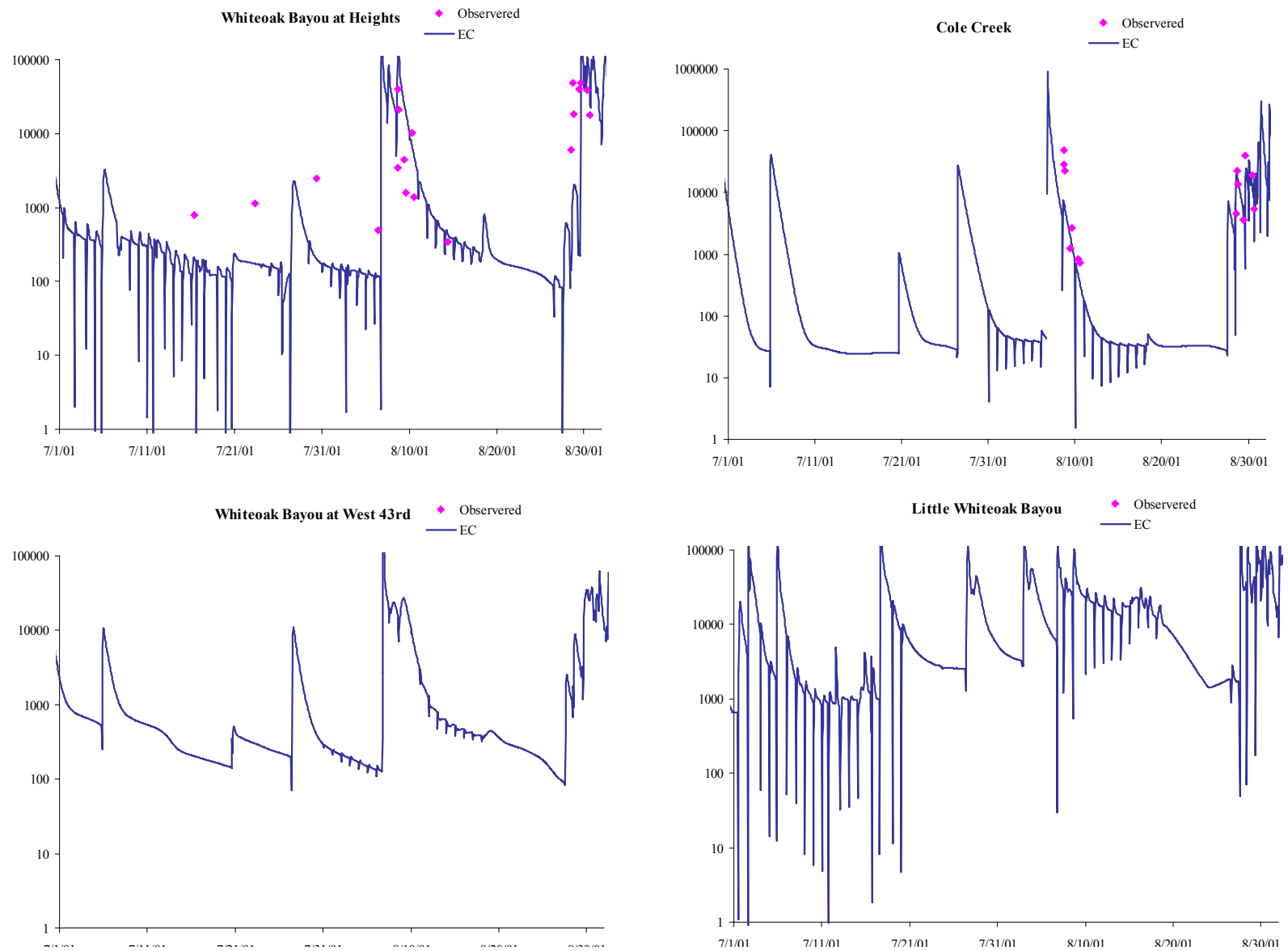




of West 43rd model concentrations demonstrates that the model achieves the range of concentrations seen in the observed data and does a reasonably good job of fitting the data.

Plots of the bacterial concentrations in Summer 2001 are presented in Figure 5.30. Data were only available at Heights and Cole Creek during this time period, but data from West 43rd and Little Whiteoak Bayou are presented for consistency. As in Buffalo Bayou, the Whiteoak Bayou model predicts the Summer 2001 data quite well, matching the fall of the concentrations that was sampled during the runoff component of this project at Heights and Cole Creek.

FIGURE 5.30 EC CALIBRATION IN WHITEOAK BAYOU FOR SUMMER 2001 RUNOFF EVENTS.



CHAPTER 6

TMDL ALLOCATION ANALYSIS

6.1 TMDL ALLOCATION SCENARIOS

6.1.1 Identification of Water Quality Target and Critical Conditions

Establishing the in-stream water quality target is an important step in developing a TMDL. The water quality target, or endpoint, is the maximum allowable concentration that permits the designated use of a water body to be maintained. Buffalo and Whiteoak Bayous were placed on the Clean Water Act 303(d) list for frequent violations of Texas water quality standards for contact recreation indicator bacteria. Therefore, the applicable target values are taken directly from the Texas water quality standards.

The two numeric water quality targets considered for this project are a 30-day geometric mean and daily value for *E. coli*. The models developed for this project provide hourly output of *E. coli* concentrations; therefore, the 30-day geometric mean and the daily maximum value were used to calculate exceedances of the standards. As set forth in the regulations, the water quality was considered impaired if the 30-day geometric mean exceeded 126 MPN/100 mL and the daily maximum exceeded 394 MPN/100 mL. This approach, however, may require further refinement during load allocation analysis since contact recreation, which is full body immersion, is more likely to occur during low flow conditions.

6.1.2 Scenario Development

The scenarios evaluated included the following major groups:

1. Elimination of the bacteria component of wastewater point source discharges,
2. Elimination of the flow and bacterial component of dry weather inflows via storm sewers,
3. Elimination of the bacteria component of upstream inflows (BB only),
4. Removing the non-point source load
5. All sources (1-4) inactivated

These scenarios were developed following the identification of major bacteria sources, i.e. the wastewater discharge, dry weather storm sewer discharge, upstream input from Addicks and Barker reservoirs and non-point sources. The dry weather storm sewer discharges were treated as a point source parameter, since they are an "end-of-pipe" discharge and thus are not considered in the non-point source scenarios. The non-point source (NPS) scenarios were simulated by reducing the bacterial accumulation on the pervious and impervious land. Although other non-point sources exist in the model, such as sediment build up and runoff, and sediment resuspension, these are not currently considered in the non-point source reduction scenarios.

The scenarios involved the complete elimination of the source, while maintaining the other active sources. All considered sources were inactivated for scenario number 5. The elimination of point source and dry weather storm sewer flows were considered together as one source. This is due to the model becoming unstable in Whiteoak Bayou when the dry weather storm sewer loads and flows are inactivated separately. To maintain consistency, the point source and dry weather storm sewer sources were combined together for both Buffalo and Whiteoak

Bayous.

Many of the scenarios require the generation of new WDM files containing new time series of point source, storm sewer, non-point sources or upstream inflow data. Significant data processing was involved. In addition, one UCI file per scenario per bayou was created so that the correct WDM files could be called during the simulations. Both the WDM and UCI files were thoroughly checked for accuracy before executing the scenario runs.

The scenarios reduced bacterial concentrations from wastewater or reservoir release flows, but not the flows. This assumption results in a TMDL implementation for WWTP and reservoir releases that involves only improved treatment, but no flow reduction.

To assess the outcomes of the scenarios, the following criteria were developed. These data are presented in a longitudinal plot, moving the most upstream portion of the bayou to the most downstream portion of the bayou.

1. Number of hours with maximum hourly EC > 394 MPN/dL,
2. Number of months with geometric mean > 126 MPN/dL,
3. Long-term geometric mean of all EC concentrations in the hourly time series (4/1/1999 – 9/30/2001),
4. Total EC load.

The results of these calculations were then compared against the calibration case using the identified water quality targets.

The following sections provide a detailed discussion of the results of scenario runs and the comparisons between these results and the calibrated models.

6.1.3 Source Contributions

The modeled loads for Buffalo and Whiteoak Bayous were determined by eliminating all but one of the identified sources in the model and then comparing that load to the calibrated laod at each subwatershed outlet.

Table 6.1 presents the percentage of the total loads associated with each identified source for all subwatersheds in Buffalo Bayou. In Buffalo Bayou, the point sources and dry weather storm sewer discharges (as modeled) exert no noticeable effect on the overall loading in the bayou. The upstream input clearly impacts the most upstream locations, such as West Belt and Briar Forest, but its importance declines at Shepherd to about 22% of the total loading. The significance of nonpoint sources increases downstream where it comprises 78% of the total loading. Finally, the sediment and other non-point sources contribute the remaining portion of the total load (less than 1%).

Table 6.1. Estimation of Source contribution to EC Loading in Buffalo and Whiteoak Bayous

Buffalo Bayou

Subwatershed	NPS	WWTP and Dry Weather Flows	Upstream
55 (Dairy Ashford)	0.00%	0.00%	100.00%
39 (West Belt)	0.00%	16.63%	83.33%
54 (Briar Forest)	0.24%	25.14%	74.11%
53 (Voss)	0.21%	31.35%	67.70%
52	0.22%	48.39%	50.63%
51	0.13%	68.81%	30.37%
50	0.12%	70.78%	28.38%
44	0.11%	73.25%	25.96%
45 (Shepherd)	0.09%	77.64%	21.58%
38	0.09%	77.85%	21.35%
37	0.08%	78.04%	21.14%
47	0.08%	78.16%	21.01%

Whiteoak Bayou

Subwatershed	NPS	WWTP and Dry Weather Flows
13	99.24%	0.00%
11	99.34%	0.00%
4	97.57%	0.02%
7	97.48%	0.02%
8	97.71%	0.01%
3 (West 43rd)	99.39%	0.01%
43	99.68%	0.04%
42	99.68%	0.04%
41 (Heights)	99.73%	0.03%
40	99.87%	0.01%
46	99.93%	0.00%

[2] Percentage of Total Load was calcluated by Total EC Load of Source / Total EC Load at location

Loading in Whiteoak Bayou is dominated by nonpoint sources, which account for a full 99% of the total loading at all subwatershed outlets, as shown in Table 6.1. Similarly to Buffalo Bayou, the point source and dry-weather inflows (as modeled) and other sources (sediment) contribute very little to the overall loading, in comparison with the nonpoint sources.

6.1.4 Buffalo Bayou Scenario Predictions

6.1.4.1 Impact of Scenarios on Long-Term Geometric Means

Figure 6.1 compares the effects of each of the load reduction scenario using the long-term geometric mean of all the modeled data at each subwatershed outlet along Buffalo Bayou. The observed geometric mean for the model period is also shown on the figure. The criterion for contact recreation is a long-term geometric mean EC level of 126 MPN/dL, which is exceeded for most scenarios and stations. Only two scenarios, no upstream EC loading and no sources, result in any part of the modeled long-term geometric means meeting the standard. Even then, the geometric mean exceeds the water quality standard around river kilometer 20 (downstream of Briar Forest), which is in between subwatersheds 52 and 53. Eliminating the wastewater treatment and dry weather storm sewer discharge component in the model makes a small difference in the results, although it is not discernable in the figure.

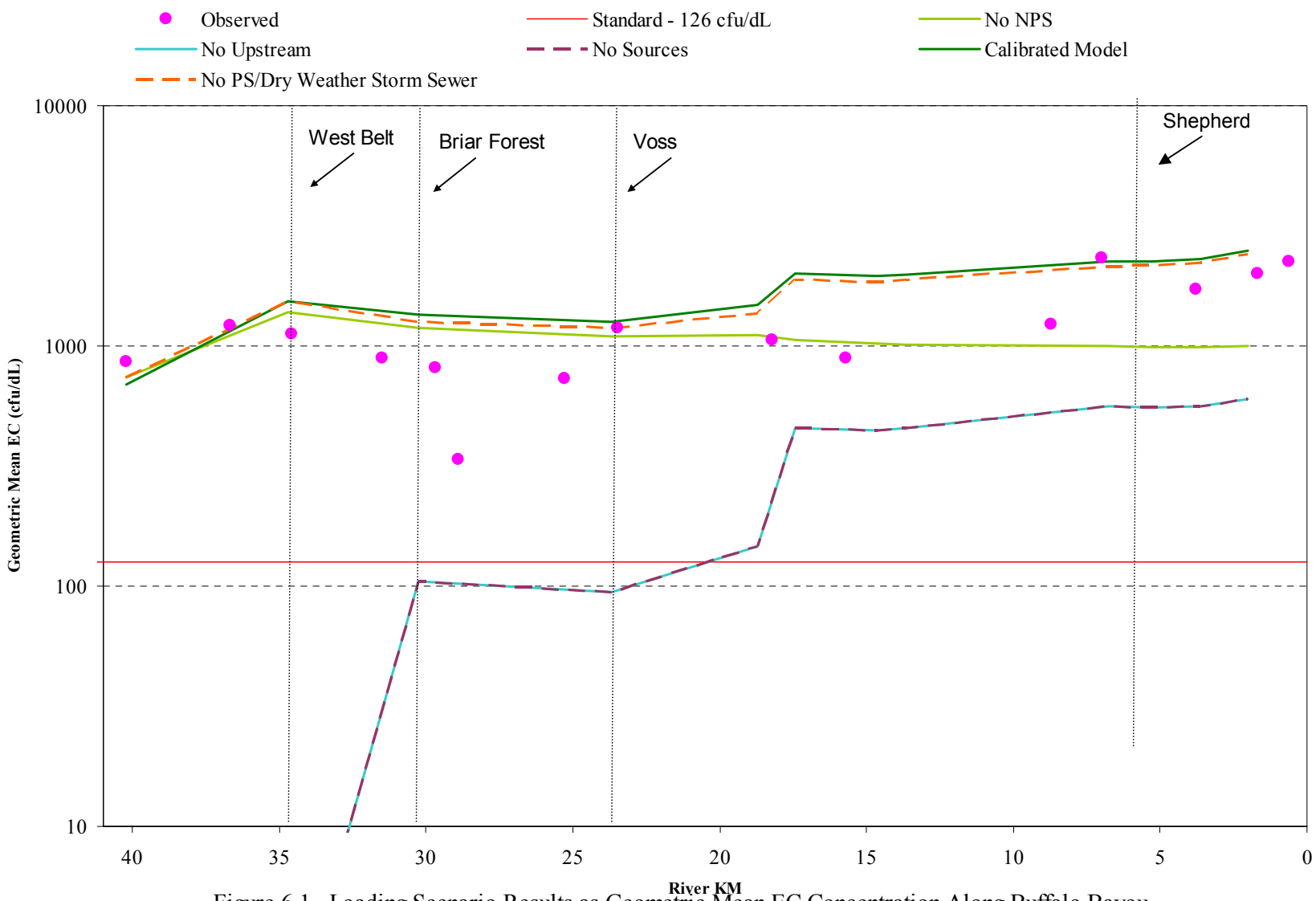


Figure 6.1. Loading Scenario Results as Geometric Mean EC Concentration Along Buffalo Bayou

6.1.4.2 Impact of Scenarios on Total Loads

Figure 6.2 summarizes model results on the basis of the total EC loads to Buffalo Bayou. Bacteria loads predicted by the model are on the order of $1x10^{17}$ bacteria/hour/model simulation time period. Trends are similar to those noted in Figure 6.1. The loads are fairly constant across the bayou for all scenarios except the no upstream EC loading and the removal of all the sources.

6.1.4.3 Impact of Scenarios on Daily Criteria of 126 CFU/dL

Figure 6.3 summarizes model results as evaluated by the number of days when the maximum hourly value within each day exceeds the single sample "not to exceed" value of 126 cfu/dL. The calibrated model has a total of 914 days over the simulation period. The reduction of the point sources, dry weather storm sewer discharges and non-point source accumulation does very little in the way of reducing the number of days the 126 cfu/dL standard is exceeded. Only when the upstream EC loading is removed, does Buffalo Bayou begin to approach the standard and the days that exceed begin to decrease. Even with the complete removal of all the sources in the model, there are over 700 days out of the 914 that exceed 126 cfu/dL at Shepherd.

6.1.4.4 Impact of Scenarios on Single Sample Criteria of 394 CFU/dL

Figure 6.4 summarizes model results as evaluated by the number of hours when the concentration exceeds the single sample "not to exceed" value of 394 cfu/dL. The calibrated model has 21,934 hours during the simulation time period (the first two hours of the model run were excluded to avoid including the sometimes large values output by

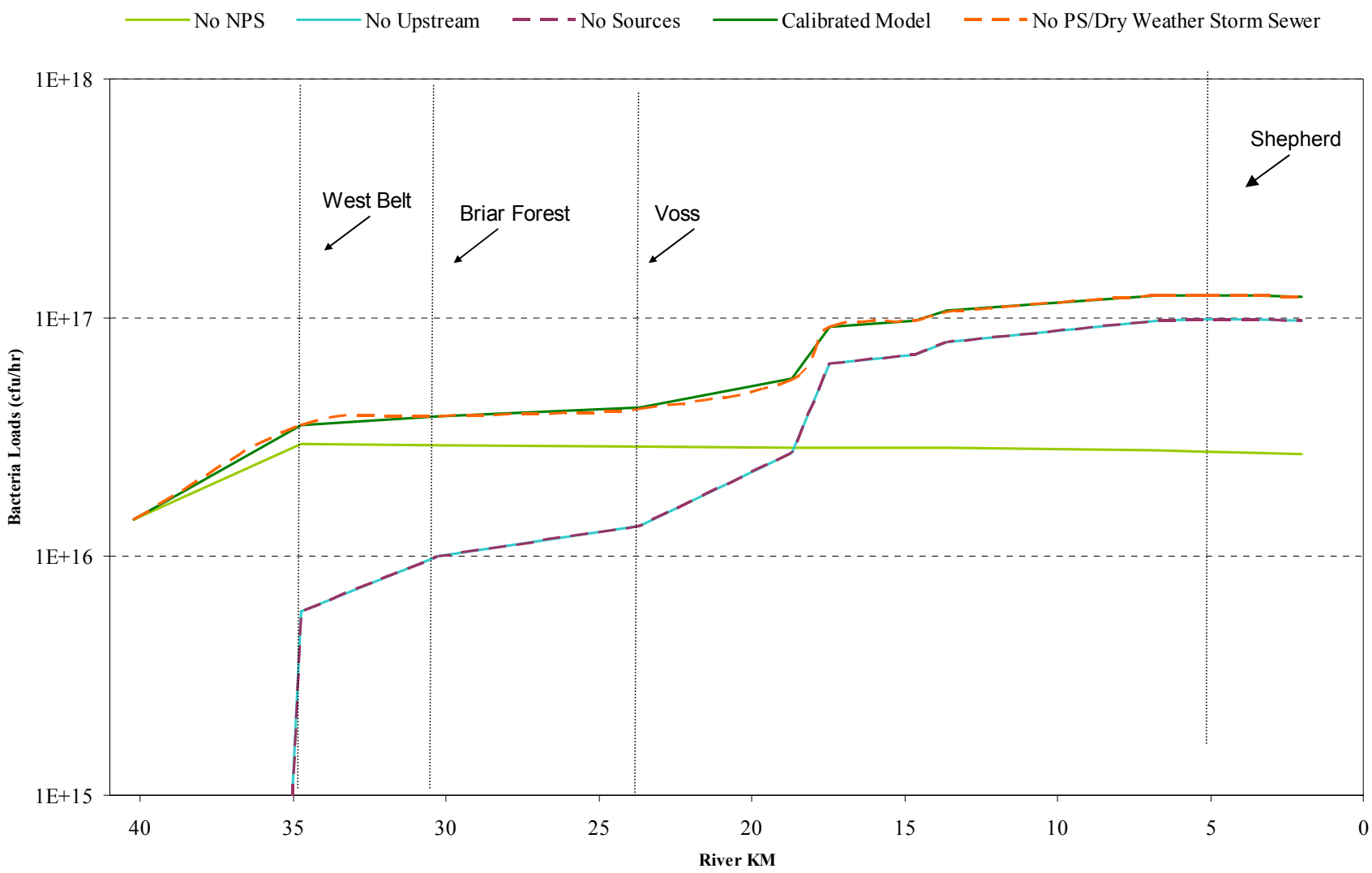


Figure 6.2. Bacteria Loads presented Longitudinally Along Buffalo Bayou

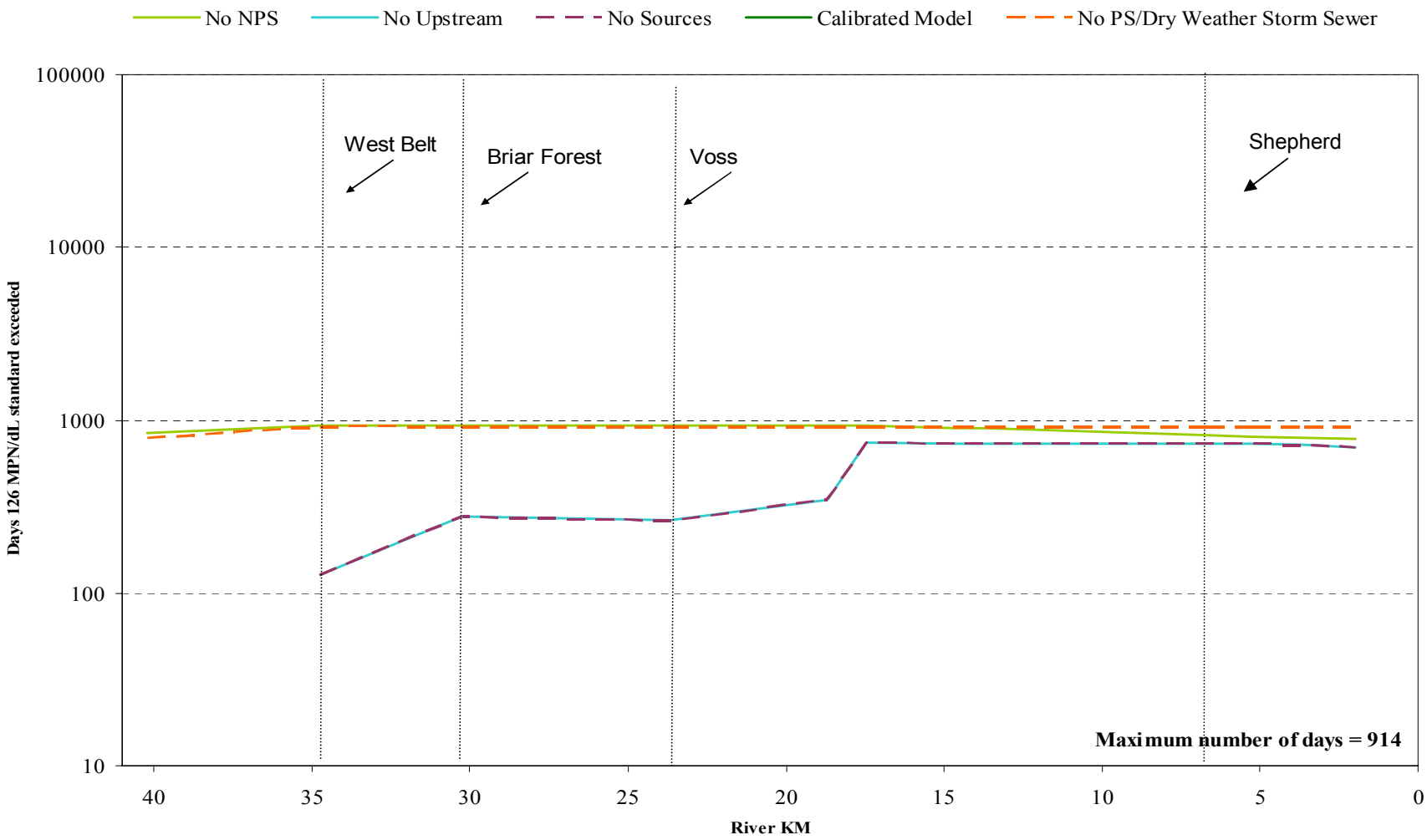


Figure 6.3. Number of Days Daily Geomean Exceeds 126 MPN/dL Standard @ BB

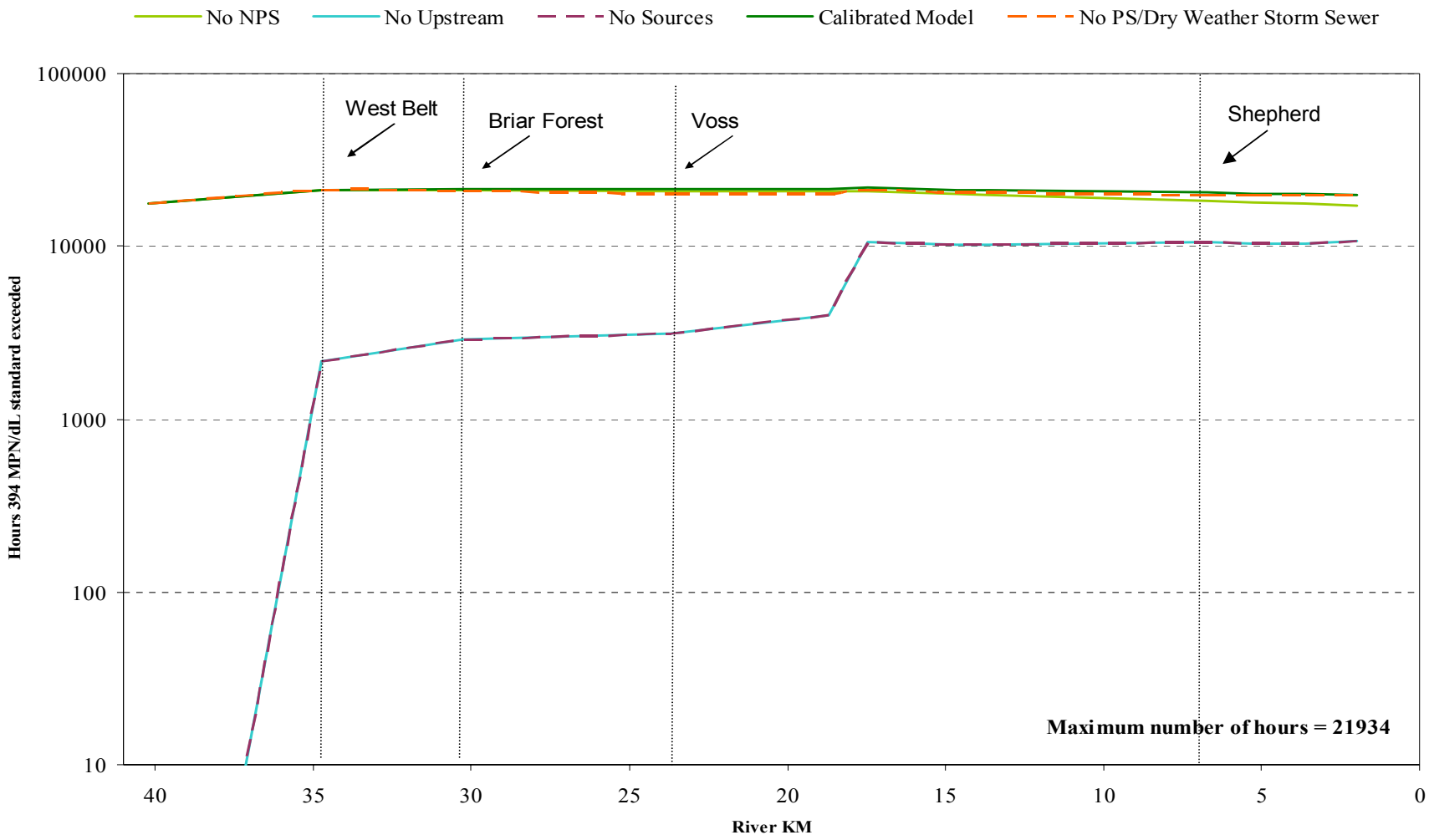


Figure 6.4. Number of Hours Hourly Concentration exceeds 394 MPN/dL Standard @ BB

HSPF at the beginning of the runs). Similarly to the other plots, the only significant differnece in the model results is made when the upstream EC loading is removed. Even with no sources, though, the model quickly approaches over 10,000 hours (about half the time) where the 394 cfu/dL standard is exceeded out of the 21, 934.

6.1.5 White Oak Bayou Scenario Predictions

6.1.5.1 Impact of Scenarios on Long-Term Geometric Means

Figure 6.5 presents Whiteoak Bayou scenario results, using the long-term geometric mean at along the bayou to evaluate the scenarios. The criterion for contact recreation is a long-term geometric mean EC level of 126 MPN/dL. The long-term geometric mean at downstream locations in Whiteoak Bayou begins to approach the standard when the non-point source bacteria accumulation is eliminated, and is even closer when all sources are removed. A substantial improvement is seen in the long-term geometric means when the point source and dry weather storm sewer discharges are eliminated, but this improvement is not adequate to achieve the standard.

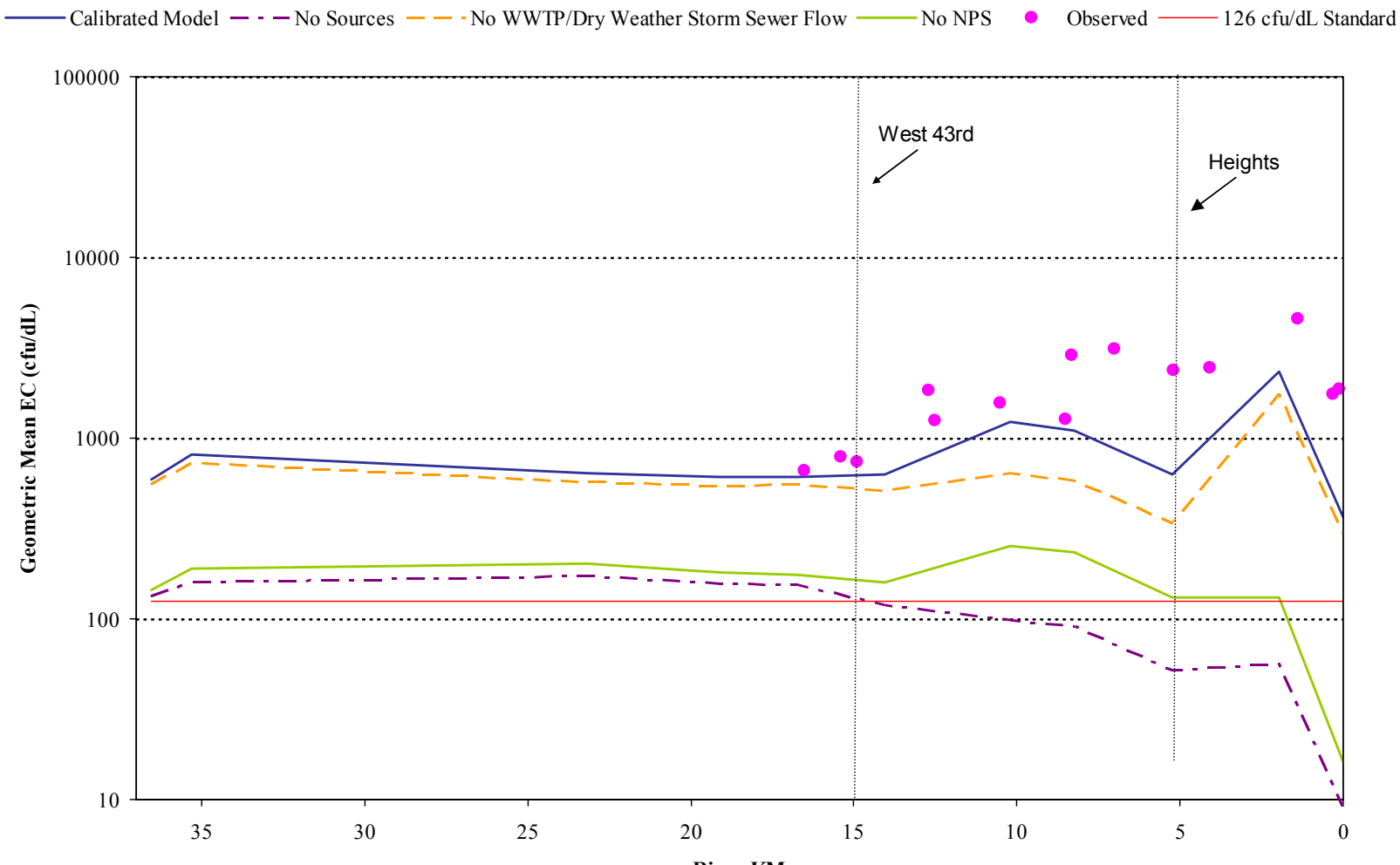


Figure 6.5. Loading Scenario Results Presented as Geometric Means along Whiteoak Bayou

6.1.5.2 Impact of Scenarios on Total Loads

The total EC loads for the model simulation in Whiteoak Bayou are presented in Figure 6.6. Bacteria loads predicted by the model are on the order of $1x10^{14}$ bacteria/hour/model simulation time period when the non-point source bacteria accumulation is eliminated, and approximately $1x10^{17}$ bacteria/hour/model simulation time period during the other scenarios. An increase in the load is observed when the non-point source is present in the model, but the loads are fairly constant across the bayou for the scenarios without non-point source.

6.1.5.3 Impact of Scenarios on Daily Criteria of 126 CFU/dL

The model results as evaluated by the number of days when the maximum hourly value within each day exceeds the single sample "not to exceed" value of 126 cfu/dL are presented in Figure 6.7. The number of days this standard is exceeded stays constant regardless of the inactivated source, but the scenario with all sources eliminated clearly produces the fewest number of exceedances.

6.1.5.4 Impact of Scenarios on Single Sample Criteria of 394 CFU/dL

Figure 6.8 presents the model results as evaluated by the number of hours when the concentration exceeds the single sample value of 394 cfu/dL. A trend similar to that seen in Figure 6.7 is present in Figure 6.8. It is clear that a reduction in point source and dry weather storm sewer flows does provide some reduction in the number of exceedances, as does the elimination of non-point sources.

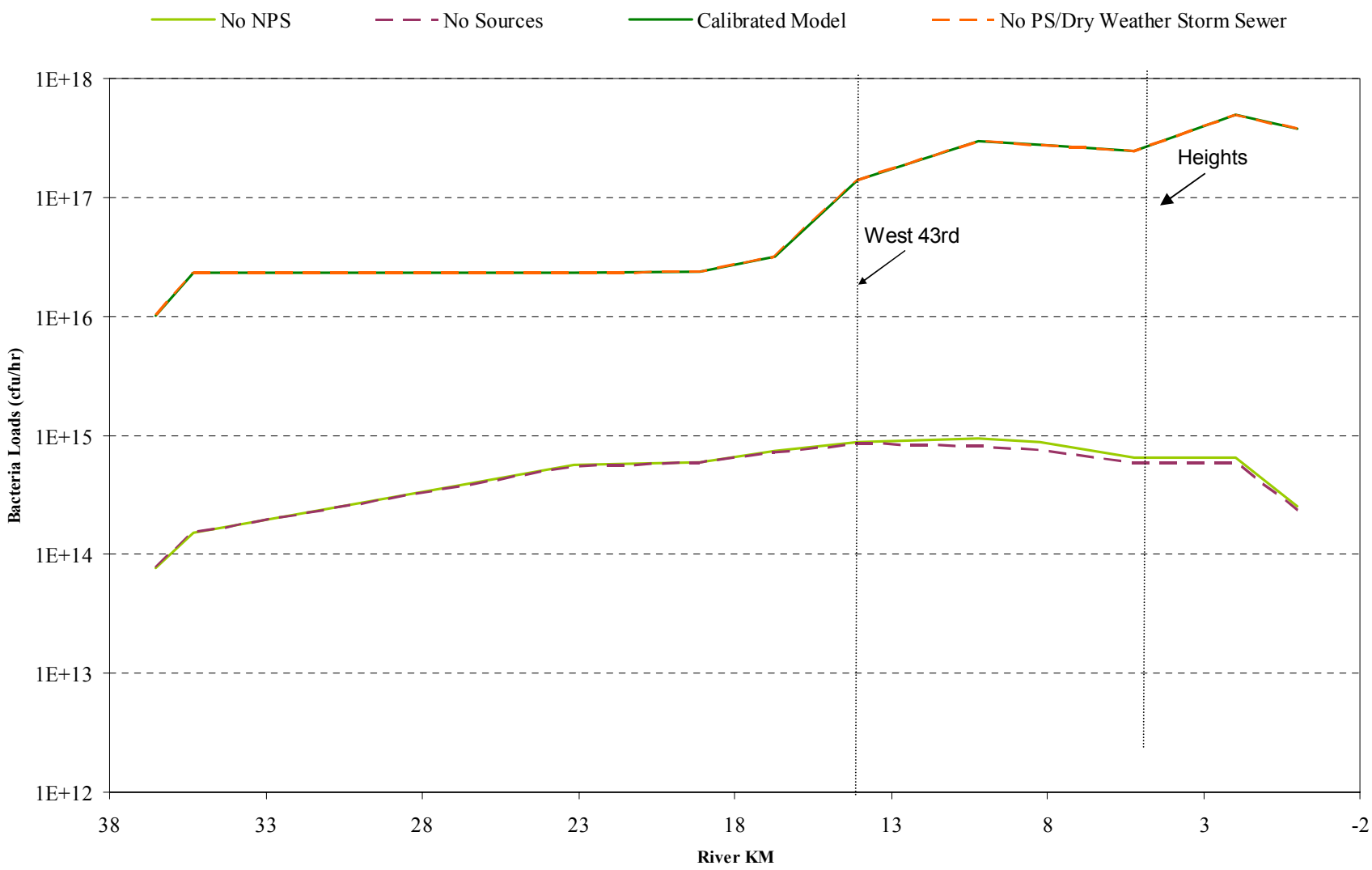


Figure 6.6. Bacteria Loads presented Longitudinally Along Whiteoak Bayou

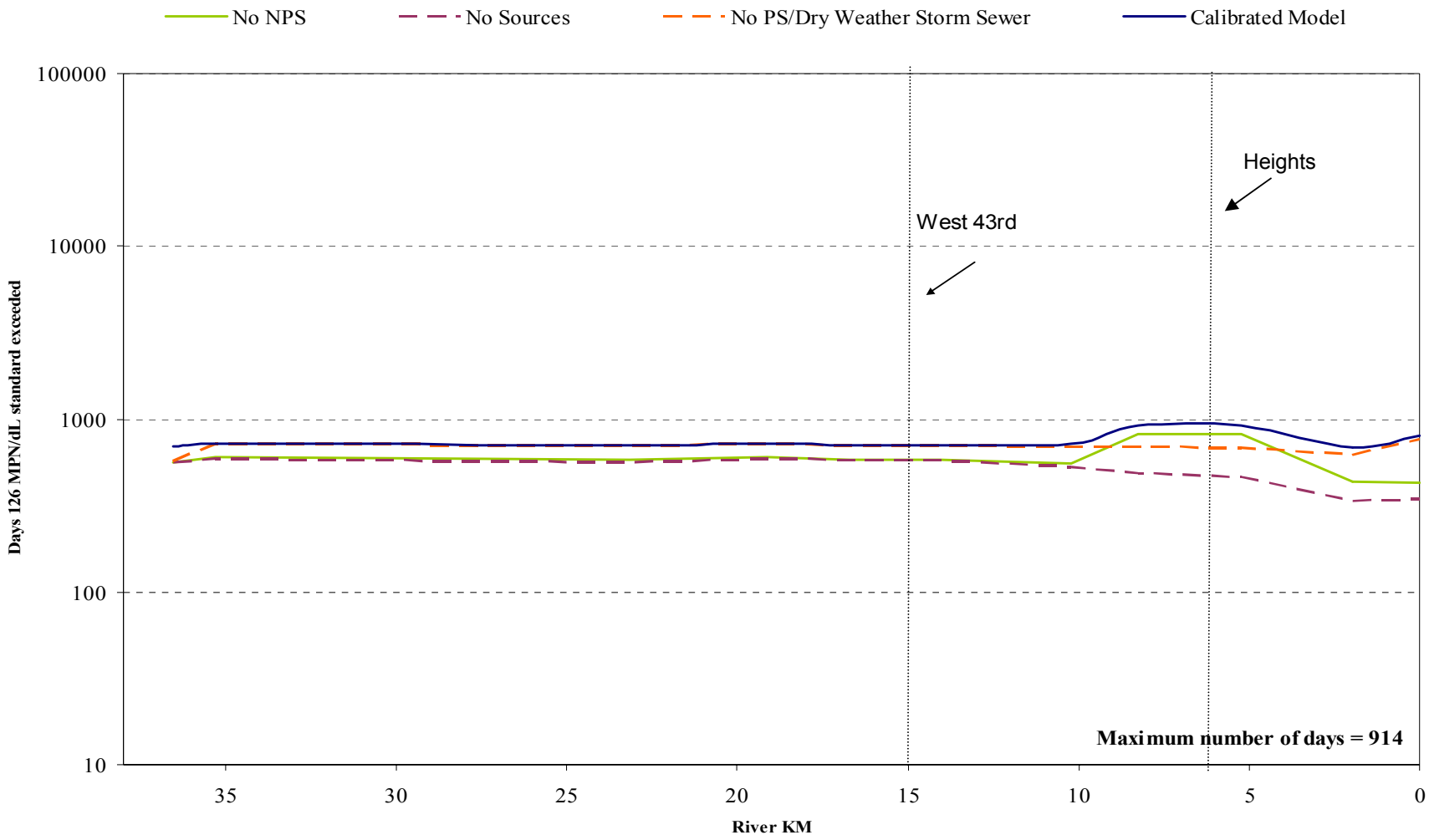


Figure 6.7. Number of Days Daily Geomean Exceeds 126 MPN/dL Standard

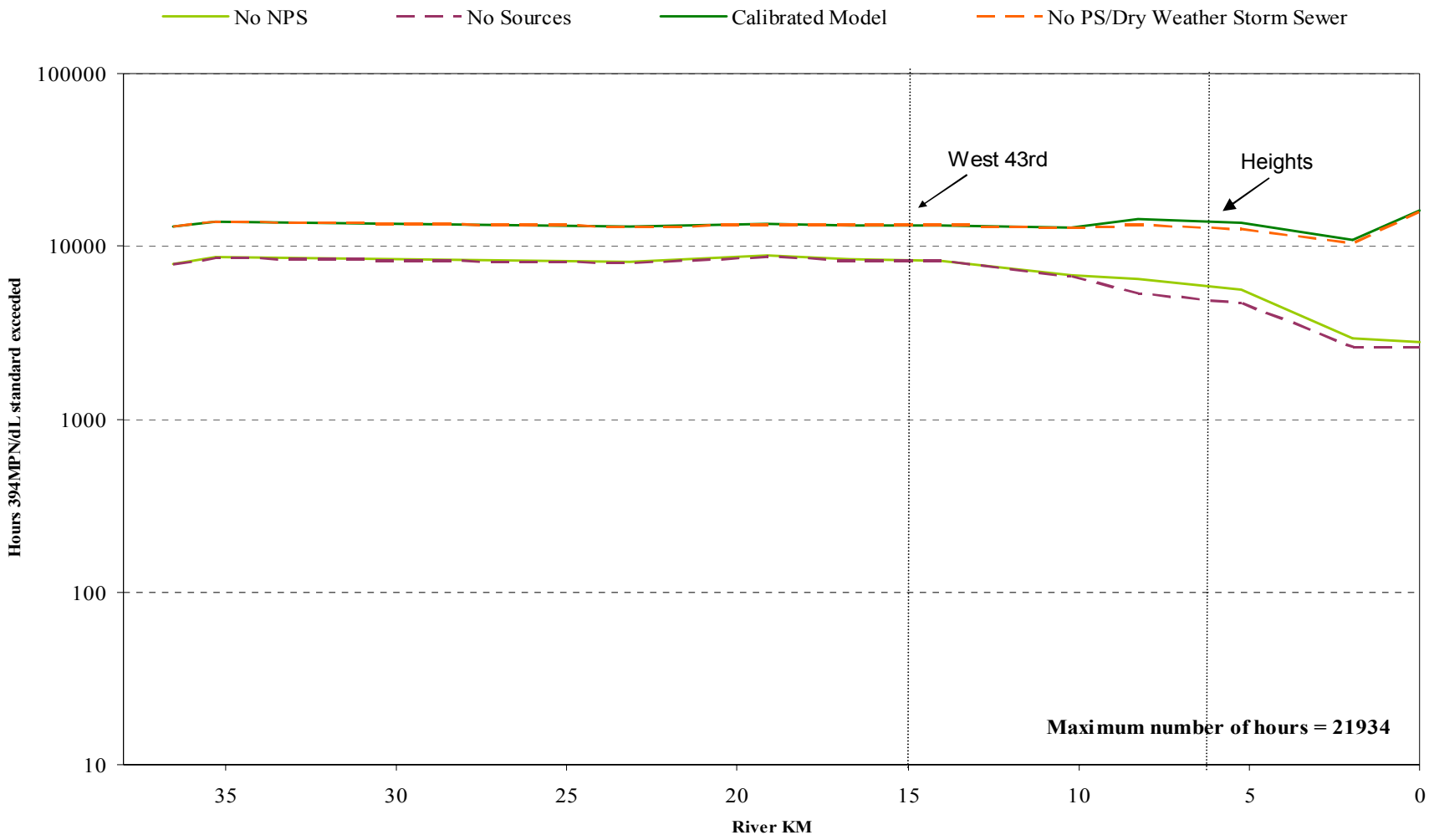


Figure 6.8. Number of Hours Hourly Concentration exceeds 394 MPN/dL Standard

6.2 MODEL LIMITATIONS

Water quality models are intended to simulate observed conditions in surface water bodies. Even with very thorough and complete calibrations, there is still uncertainty inherent in modeling results. It is important to note the limitations associated with the Buffalo and Whiteoak Bayou models that have been developed in this project.

As previously described, a ratio of water quality standards was used to convert historical FC data to EC data for use in the model. The model, therefore, is calibrated to the converted EC data, not actual observed EC data. The model appears to be adequately predicting converted EC concentrations, but there is no way of judging its accuracy until more EC data are available for the water quality calibration.

Another limitation of the model is due to the use of some parameters as strictly calibration parameters. Over the course of the calibration, some of the model parameters were adjusted beyond literature reported values to achieve a better fit to the observed data. The values of these parameters, therefore, may not be physically meaningful. Infiltration is one such parameter that is outside the reported range, even though soil data suggest that it should be lower.

Source representation is limited to only four identified sources: wastewater treatment discharges, dry weather storm sewer discharges, upstream sources in Buffalo Bayou and non-point sources. Other sources including solids discharges, overflows and bypasses were not included. First order decay rates were calculated under Work Order 1, but the deposition of EC onto pervious, impervious and bayou reaches has not been studied in these watersheds. In fact, very little data are available for the urban characterization of accumulation of EC in watersheds.

Because of the lack of data, the accumulation parameters were used as calibration parameters. The justification and reasonableness of these data is difficult to quantify. Additionally, the data most likely vary on a monthly, if not more frequent, basis but the periodicity is not currently known.

While sediment loading is an important parameter, very little data (except for Summer 2001) are available on this source. Similarly, the input from the reservoirs is important but is not well characterized based on available data.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The following activities were conducted to complete the tasks listed in the Work Plan for Work Order No. 582-0-80121-02 for the Bacteria Project: assessment of current levels of fecal pathogens in Buffalo and Whiteoak bayous, assessment of major sources of indicator bacteria to the project area, assessment of levels and trends of fecal coliform in the Buffalo and Whiteoak Bayous, development of an HSPF model for indicator bacteria in the study area, estimation of load allocations, and participation in stakeholder/public outreach activities.

Early in the monitoring program, it was well known that high bacteria levels were the norm, but there was little definitive information available as to the reasons for the high levels. Moreover, there was little quantitative information available to support a modeling effort needed to quantify sources and address reductions. Accordingly, an intensive program of field efforts was conducted. This section summarizes our current understanding of the processes and findings based on field data and modeling results.

7.1 RUNOFF AND DYNAMICS

As presented in Chapter 3, bayou bacteria concentrations were observed to respond to runoff events in what appears to be a very direct manner. Experimental data show that runoff exhibits high concentrations of EC and TC. EC concentrations varied between 1,724 and > 48,384 MPN/100 mL in Buffalo Bayou and between 1,366 and > 48,384 MPN/100 mL in Whiteoak

Bayou.

Perhaps the major finding of the in-stream dynamics studies was the important role played by settling of particulate matter. The light/dark test chamber studies revealed high first order die-off rates, with no systematic relation to light intensity. Regrowth of bacteria discharged from point sources exists, but may not be a major process based on the results obtained. While it may not be large for EC test results in mixed stream and effluent samples, regrowth was stronger for TC data in the disinfected effluent. This suggests that substantial regrowth occurs for organisms other than e-coli that are accounted for in the TC test.

7.2 SEDIMENTS

A major factor affecting bacteria levels in the bayous appears to be the level of bacteria that is supported in the unconsolidated sediments. Sampling results demonstrate that bayou sediments have a high bacteria content. Bacteria from sediments can be easily resuspended when bayou flows increase. The test chamber studies revealed an overall high rate of decrease in EC levels under conditions where settling is possible. The rate of decrease, ranging from 1 to as much as 4/day, is high by literature standards. It is expected that if these die-off rates are used in the model without considering the settling process, the model would yield results that would not be representative. Accordingly, the model incorporates sediment settling and resuspension to the extent possible with the limited data that were available.

7.3 POINT SOURCES

At low flows, point sources dominate the flow. Earlier studies had suggested that disinfection of WWTP effluent was not always complete so that the flows could be a significant

load to the system. Monitoring by the Harris County Pollution Control Department from March 1998 to February 2001 showed that 25 out of 29 measurements (for a total of 18 small plants in the Buffalo and Whiteoak Bayous) exceeded the limit of 200 cfu/dL for FC, with 14 samples showing FC levels higher than 10,000 cfu/dL[4] . Consequently, sampling of small WWTPs (flow < 1 MGD) was conducted to quantify the load of EC and FC to the bayous from these sources.

Results from the WWTP monitoring component in this study show that 11 out of 76 WWTPs exceeded the EC quality criterion of 126 MPN/100 mL. Regarding FC counts, only 3 plants exceeded the 200 cfu/100 mL limit. The estimated loads of EC to Buffalo and Whiteoak Bayous are 3.0×10^{12} and 7.6×10^{14} MPN/yr, respectively. On the other hand, the FC loads are 9.5×10^{11} for Buffalo Bayou and 7.6×10^{12} cfu/yr for Whiteoak Bayou[5].

A total of 84 pipes discharging into the bayous during dry-weather conditions were sampled as part of the dry-weather inflows to Buffalo and Whiteoak Bayous monitoring component. In general, these samples exhibited high EC levels with 16 out of 92 samples exhibiting EC counts in excess of 5,000 MPN/100 mL. Overall, bacterial levels in samples for this component exceeded those for the WWTP monitoring.

7.4 NON-POINT SOURCES

Data from Summer 2001 sampling were used for the development of point source data.

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[4]Although FC data are available only for 18 facilities, sampling was conducted at many more plants, and because for the majority of these measurements the residual chlorine criterion was met, FC was not sampled.

[5]EC was analyzed using the IDEXX method, which is based in the most probable number technique, while FC were analyzed using membrane filtration. The MPN technique usually yield values higher than those obtained using the membrane filtration technique.

Non point sources included in the model included dry-weather storm sewer discharges (using Summer 2001 data), sediment scour and deposition, and build up and stormwater wash off.

7.5 BACTERIA MODELING

Bacteria HSPF models have been developed to investigate the fate and transport of bacteria. These models simulate fate and transport of bacteria for both in-stream and sediment concentrations. The model is used to understand the different sources of bacteria in the bayous and estimate the contributions of each source. The effects of modifying the sources can also be studied to determine the best approaches for improving the water quality in the bayous.

7.5.1 Model Calibration

Employing both the large pool of routine monitoring data and data collected specifically to support modeling, the HSPF hydrologic and water quality parts of the models were calibrated. The calibrated models appear to generate reasonable results. The calibrated models simulate flow and water quality relatively well. The Buffalo Bayou model underestimates the flow at all points, while the Whiteoak Bayou model is slightly overestimating the flows. Water quality simulations in Buffalo Bayou were evaluated at four different sites, with all four locations underestimating the EC loading and generally overestimating the geometric means. EC geometric means of data collected under high flow conditions are overestimated by a large percentage, while the EC geometric means of low flow data are sometimes underestimated. The Whiteoak Bayou model is generally overestimating the EC load and underestimating the overall geometric mean. The high flow EC geometric means are overestimated in Whiteoak Bayou and the low flow geometric means are underestimated.

7.5.2 Model Results

The HSPF models were employed to evaluate a wide range of options that might be taken to reduce bacterial inputs. These scenarios include reductions in wastewater, dry weather storm sewer discharges, upstream EC inputs, and non point sources. It was found that even with no EC loading results from wastewater treatment plants and complete elimination of dry weather inflows, bacteria levels remain well in excess of criteria. The only measures that proved effective (using the calibrated HSPF models) were those involving removal non point sources in Buffalo and Whiteoak Bayou and the elimination of the upstream bacteria load entering Buffalo Bayou from the reservoirs. Even then, the overall bacteria levels would generally still exceed criteria because of other nonpoint sources, including sediment accumulation on land surfaces not associated with bacterial accumulation, sediment build up and runoff, and sediment resuspension.

The HSPF models indicate that actions to control wastewater effluents and dry-weather stormsewer flows may not be sufficient to attain the contact recreation standard in the bayous. However, it is noted that for public safety reasons and since the contact recreation use is only feasible in these bayous during low flow conditions, actions to minimize collection system leaks would be important, even if no major sources were observed during dry weather field surveys conducted with this project. Accordingly, it is recommended that efforts in this direction be continued and enhanced.

The results of scenario simulations indicate that exceedances of the contact recreation criterion, either based on both the 126 MPN/dL geometric mean and the 394 MPN/dL single value criterion, would be minimized if the upstream sources of EC were eliminated in

Buffalo Bayou. Significant exceedances of the standard, however, would still occur at the downstream locations in the bayou even if all identified controllable sources modeled with HSPF have been eliminated. In Whiteoak Bayou, significant improvements to the water quality would be made if all the identified sources of bacteria were eliminated and the standard would be almost achieved throughout the watershed.

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APPENDIX A

SLIDES PRESENTED AT STAKEHOLDER MEETINGS

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

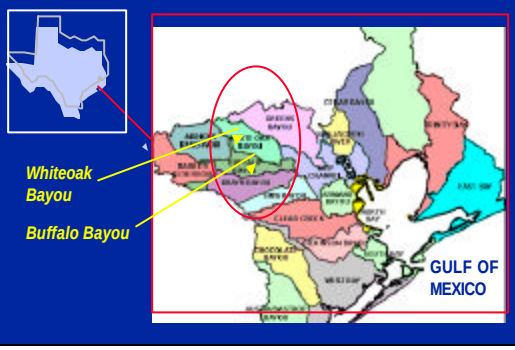
Technical Presentation at March 7,2002 Stakeholder Meeting

University of Houston
PBS&J

Major tasks

- Stakeholder/Public education and involvement
- Assess current levels and trends of bacterial indicators of fecal pathogens in the bayous
- Assess major sources, transport, and fate of bacterial indicators of fecal contamination
- Apply models to elucidate the sources and major processes controlling observed levels of FC
- TMDL allocation analysis

Buffalo and Whiteoak Bayous

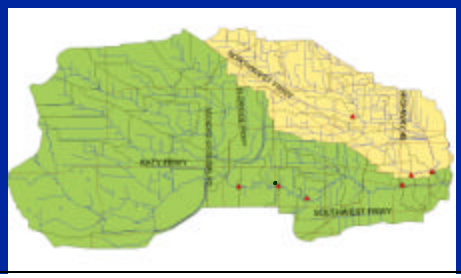


Assess current levels and trends of indicator bacteria in BB and WO

1. Assess bacteria levels resulting from moderate rainfall runoff events
2. Assess dynamics of bacteria within the bayous

Bacteria from rainfall runoff events

- Two runoff events: Aug 7-9 & Aug 28-30, 2001
- 4 BB stations, 2 WO locations, & 1 WO tributary



Rain and flow gage locations

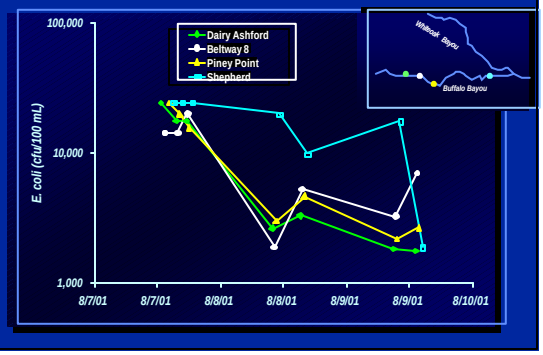
Daily rainfall data

	Date	RG15	RG30	RG31	RG34
Event 1	8/6/01	0.84	1.28	0.65	0.00
	8/7/01	0.11	0.00	0.02	0.28
	8/8/01	0.13	0.00	0.00	0.35
	8/9/01	0.05	0.00	0.00	0.00
Event 2	8/27/01	0.12	0.59	0.34	0.63
	8/28/01	0.16	1.74	0.39	0.51
	8/29/01	1.00	1.00	1.12	0.75
	8/30/01	1.36	1.12	1.09	1.76
	8/31/01	2.15	2.00	2.37	2.29

24 hr-rainfall data (inches)

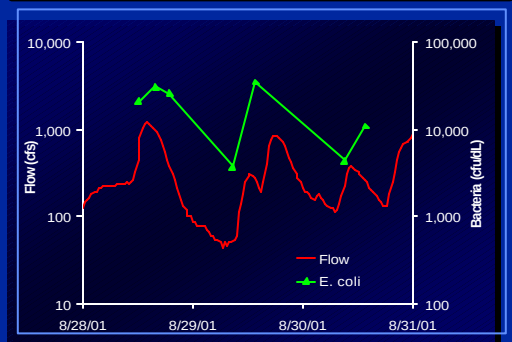
Relating City of Houston rain gages to sampling sites: RG15 (Cole Creek); RG30 (BB@Dairy Ashford); RG31 (BB@Beltway 8 & Piney Point); RG34 (BB@Shepherd and WO@Heights & Houston)

EC data in BB from 7-9 Aug, 2001 event

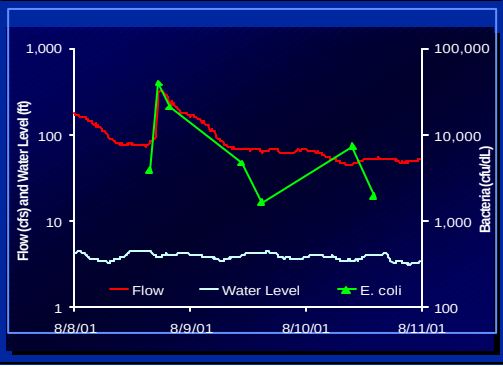


Runoff study – BB at Dairy Ashford

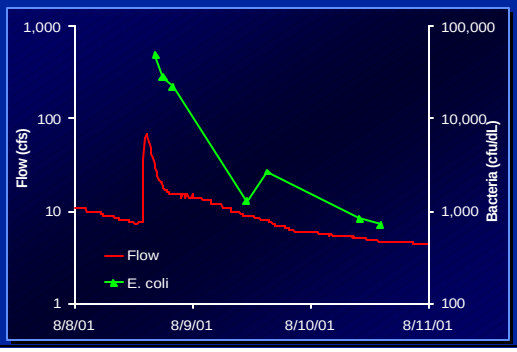
Runoff study – BB at Beltway 8



Runoff study – WO at Houston



Runoff study – Cole Creek at Deihl



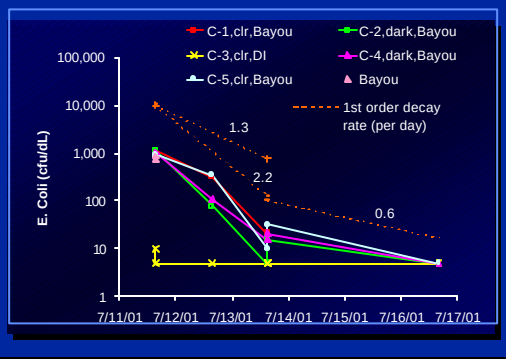
Dynamics studies

- Population change (light/dark chambers)
- Regrowth
- Resupply

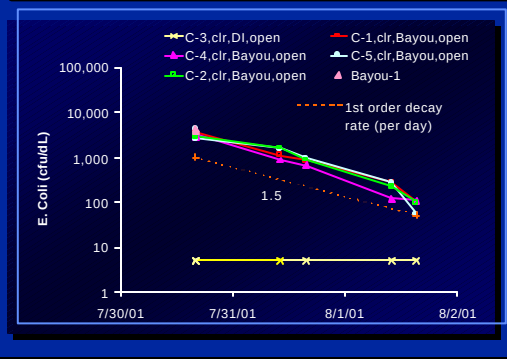
Light/dark dynamics results

	Initial EC (cfu/dL)	EC die-off rates (1/day) Covered clear	Covered dark	Open
BB – 7/11-16 (Beltway 8)	836-1145	1.3	2.2	
BB – 7/30-8/1 (Beltway 8)	2897-4082	1.4	1.4	1.5
WO – 8/1-3 (IH 610)	190-352	3.0	3.0	4.0
BB – 8/14-16 (Wilcrest)	426-565	1.6	1.6	
WO – 8/14-16 (IH 610)	379-452	1.6	1.6	

Light/dark effects, Buffalo Bayou



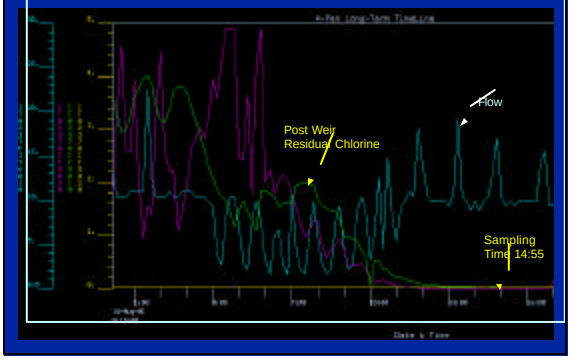
Light/dark Effects, BB, open chambers



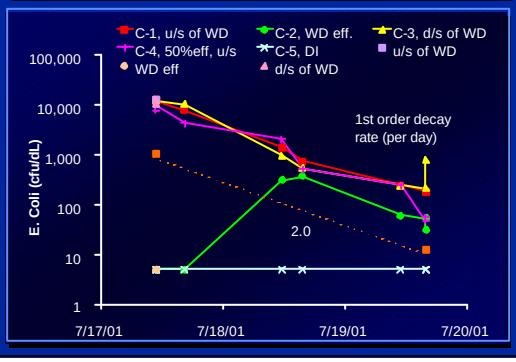
Regrowth results

WWTP	Initial EC (cfu/dL)	K (1/day)	EC regrowth
West District *(Buffalo B., 7/17-19/01)*	ND	2.0	yes
Turkey Creek *(Buffalo B., 7/17-19/01)*	ND	1.0	slight
Northwest *(Cole Creek, 7/24-26/01)*	5	1.4	yes
White Oak *(WO B., 7/17-19/01)*	15	1.4	neutral
West District *(Buffalo B., 8/14-16/01)*	19,863	0.9/4.5	no

West District WWTP on 8/14/01



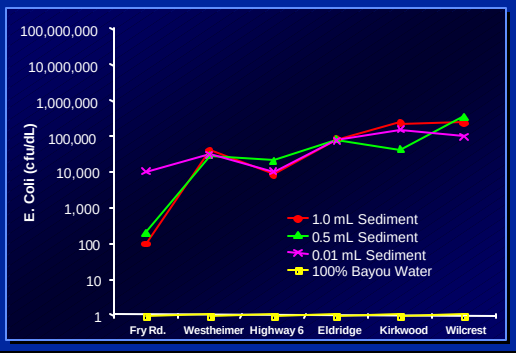
Regrowth – West District WWTP



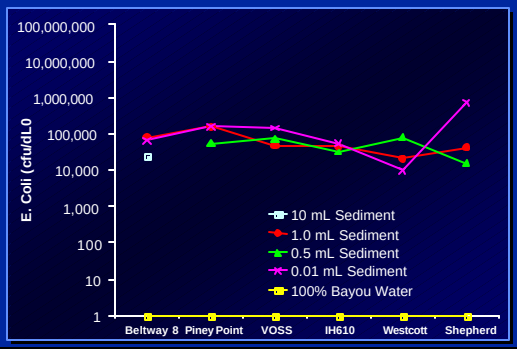
Sediment resupply

- Bacteria conc in sediments
- Resupply

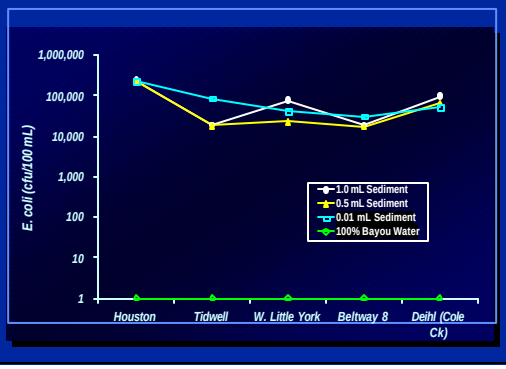
EC in BB sediments



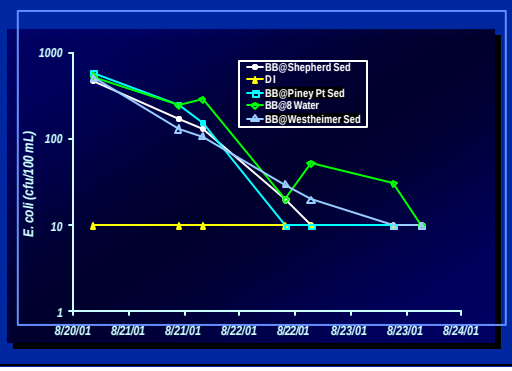
EC in BB sediments (cont'd)



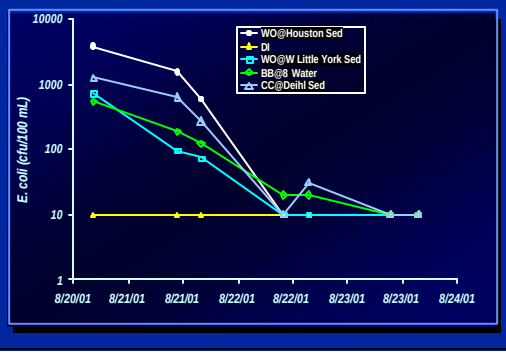
EC in WO sediments



BB sediment resupply



WO sediment resupply

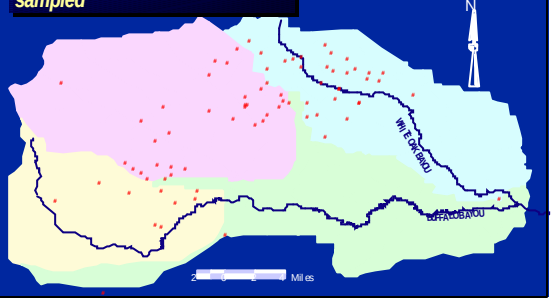


Assess major sources of bacteria in BB and WO

1. Sample point source discharges during low flow conditions
2. Monitor storm sewers discharging to bayous during dry weather conditions to assess potential illicit discharges

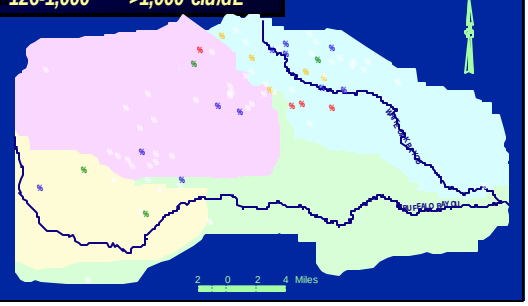
Point source sampling

A total of 76 WWTPs were sampled



EC data from point source sampling

< 10 10-50 50-126 126-1,000 >1,000 cfu/dL

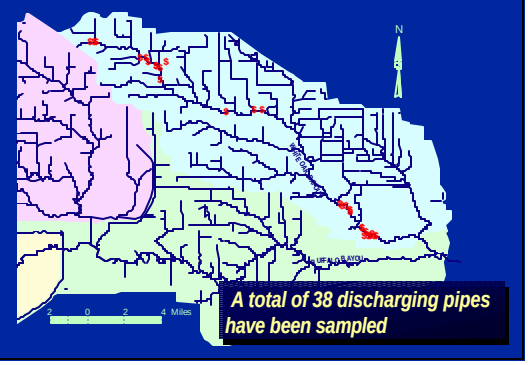


Summary of point source sampling

	All samples		Peak flow samples		Off-peak flow samples	
	EC	FC	EC	FC	EC	FC
Geomean	2.7	0.5	3.2	0.7	2.3	0.3
Range	0-2,347	0-5,000	0-2,347	0-5,000	0-759	0-150
% >std[1]	7.2%	2.0%	8.8%	3.8%	5.6%	0%

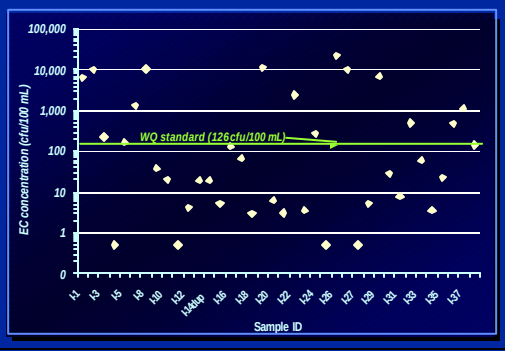
[1] regulatory limits: 126 cfu/dL for EC and 200 cfu/dL for FC
All the values given in cfu/dL

Storm sewer sampling



A total of 38 discharging pipes have been sampled

EC data from storm sewer sampling



Summary of storm sewer sampling

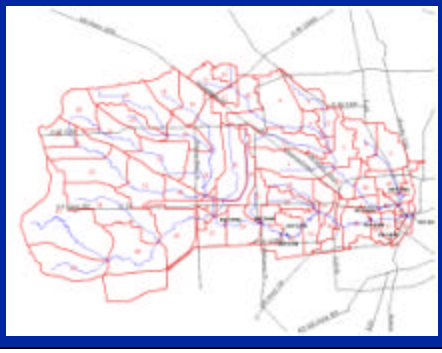
	EC (cfu/dL)	FC (cfu/dL)
Number samples	38	30
Geomean	73	16
Range	0-22,027	0-5,600
% Exceeding WQ criterion[1]	44.7%	26.7%

[1] regulatory limits: 126 cfu/dL for EC and 200 cfu/dL for FC

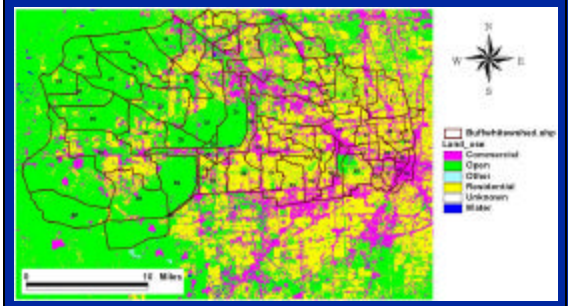
Modeling activities

1. Delineation of subwatersheds
2. Data preparation and compilation
3. Modeling calibration
4. Sensitivity analysis
5. Model runs ? load allocations

Subwatershed definition for modeling

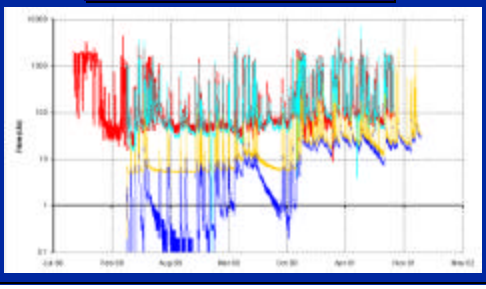


Compilation of input data



Preliminary model output - BB flow @ West Beltway

___ USGS Gage ___ HSPF no PS, no U/S
___ HSPF w/PS, no U/S ___ HSPF w/PS, w/U/S



Summary of Findings

Sources

- Point sources: 11 out of 76 plants exceeded EC criterion while 3 out of 76 exceeded FC limit
- Storm sewer sampling showed higher EC and FC levels than WWTP monitoring

Summary of Findings cont'd

Current levels

- Runoff exhibited high concentrations of EC
- Runoff concentrations appear to track with variations in flow

Summary of Findings cont'd

Dynamics

- High first-order die-off rates with no relation to light intensity
- Regrowth exists but may not be a major process
- Sediment resuspension when bayou flows increase may play significant role
- Quiescent conditions reduce EC levels rapidly

Future Tasks

- Complete HSPF modeling of bayou bacteria levels
- Apply the model to analyze alternatives
- Load allocations

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

Technical Presentation at June 26,2002 Stakeholder Meeting

University of Houston
PBS&J

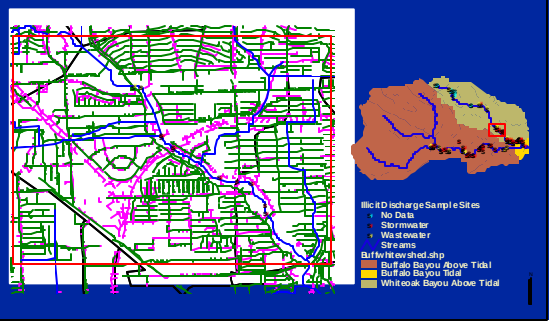
Major Tasks

- Stakeholder/Public education and involvement
- Assess current levels and trends of bacterial indicators of fecal pathogens in the bayous
- Assess major sources, transport, and fate of bacterial indicators of fecal contamination
- Apply models to elucidate the sources and major processes controlling observed levels of FC
- TMDL allocation analysis

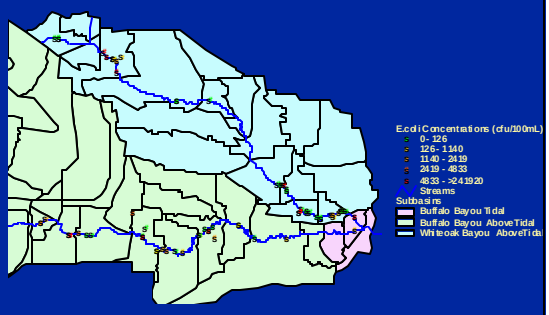
Progress to Date

- Quarterly Report completed and submitted – 6/11/02
- Storm sewer sampling mostly completed
- HSPF model developed for both bayous

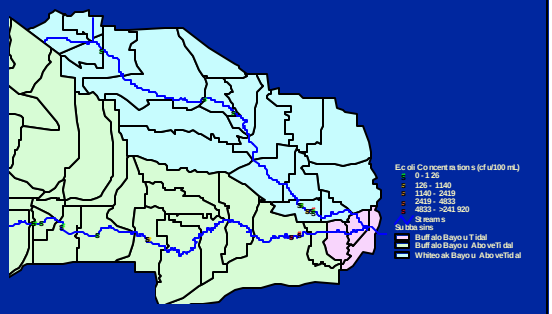
Storm and Wastewater Sewer Sampling Locations



EC concentrations in Storm Sewers



EC concentrations in Wastewater Sewers



Summary of Storm Sewer Sampling

	All samples		Wastewater Sewers		Stormwater Sewers	
	EC	FC	EC	FC	EC	FC
Geomean	161	62.9	191.2	30.8	153.8	76.5
Range	0-241,920	0-26,000	0-241,920	0-20,000	0-241,920	0-26,000
% >std[1]	52.9%	42.9%	55.6%	33.3%	58.2%	44.8%

[1] regulatory limits: 126 MPN/dL for EC and 200 cfu/dL for FC
EC values given in MPN/dL; FC values give in cfu/dL

Storm Sewer Sampling Summary by Watershed

	Buffalo Bayou		Whiteoak Bayou	
	EC	FC	EC	FC
Wastewater	73.9	18.9	408.9	45.3
Stormwater	261.1	307.9	100.1	23.9

EC values in MPN/dL; FC values in cfu/dL. Values presented are geometric means.

E. coli load for Point Source and Illicit Discharges

	Point Sources (MPN/yr)	Illicit Discharges (MPN/yr)
Buffalo Bayou	1.82E+12	7.89E+13
Whiteoak Bayou	5.83E+14	7.24E+13
Total	6.09E+14	2.31E+14

HSPF Modeling

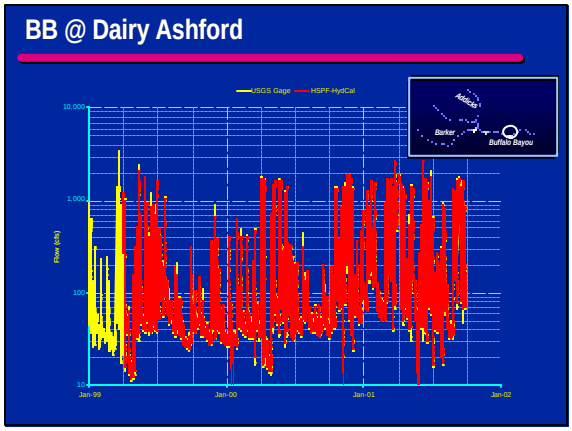
- Hydraulic calibration and sensitivity analysis completed for both Buffalo and Whiteoak Bayous
- Bacteria calibration and sensitivity analysis ongoing

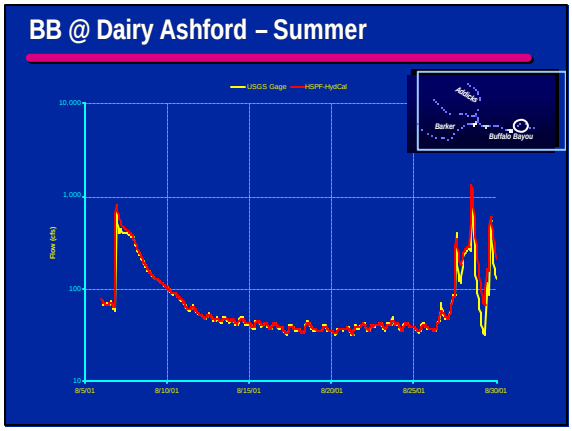
Hydraulic Calibration & Sensitivity Analysis

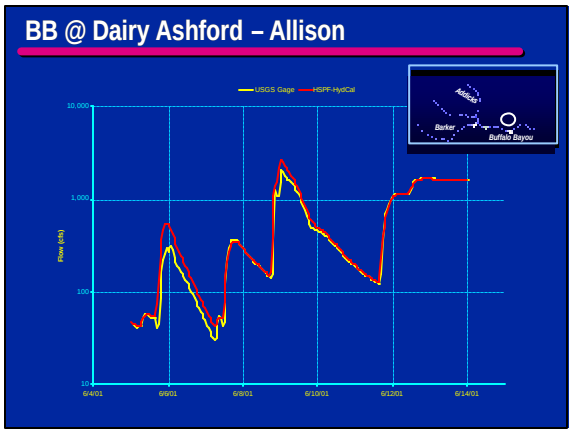
- Change hydraulic parameters one by one
- Calculate Root Mean Square difference between model output and USGS gaged flow data
- Calibration points: BB @ Dairy Ashford, West Belt, Piney Point and Shepherd; WO @ Heights; CC @ Deihl

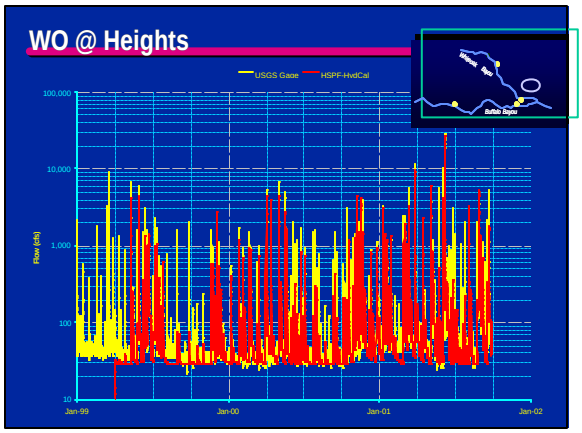
Hydraulic Calibration & Sensitivity Analysis (cont'd)

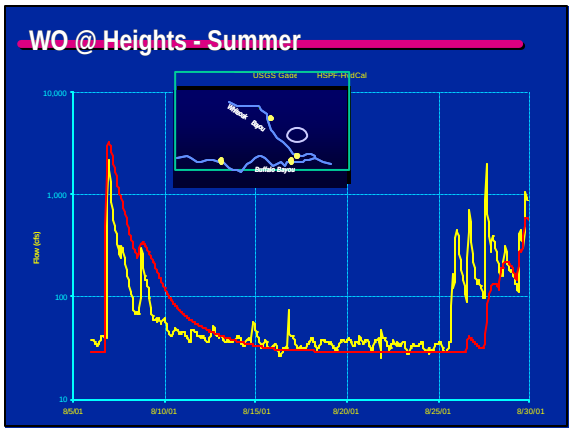
- "Best match" values (minimizing total RMS) of parameters within reasonable range selected
- Number of simulations conducted:
  - BB: 51; WO: 41

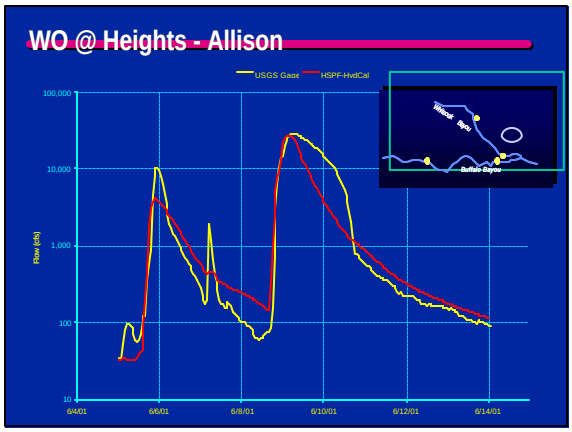

BB @ Dairy Ashford
USGS Gage
HSPF-HydCal
Flow (cfs)
10,000
1,000
100
10
Jan-99
Jan-00
Jan-01
Jan-02
Allison
Barker
Buffalo Bayou


BB @ Dairy Ashford – Summer
USGS Gage
HSPF-HydCal
Flow (cfs)
10,000
1,000
100
10
8/5/01
8/10/01
8/15/01
8/20/01
8/25/01
8/30/01
Allison
Barker
Buffalo Bayou

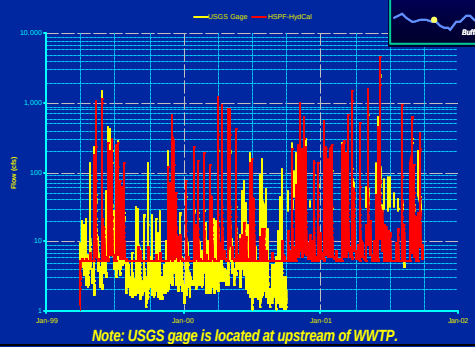

BB @ Dairy Ashford – Allison
USGS Gage
HSPF-HydCal
Flow (cfs)
10,000
1,000
100
10
6/4/01
6/6/01
6/8/01
6/10/01
6/12/01
6/14/01
Allison
Barker
Buffalo Bayou


WO @ Heights
USGS Gage
HSPF-HydCal
Flow (cfs)
100,000
10,000
1,000
100
10
Jan-99
Jan-00
Jan-01
Jan-02
Buffalo Bayou


WO @ Heights - Summer
USGS Gage
HSPF-HydCal
Flow (cfs)
10,000
1,000
100
10
8/5/01
8/10/01
8/15/01
8/20/01
8/25/01
8/30/01
Buffalo Bayou

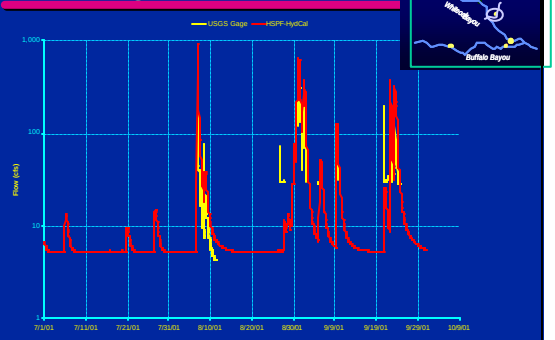

WO @ Heights - Allison
USGS Gage
HSPF-HydCal
Flow (cfs)
100,000
10,000
1,000
100
10
6/4/01
6/6/01
6/8/01
6/10/01
6/12/01
6/14/01
Buffalo Bayou

Cole Creek @ Deihl



Note: USGS gage is located at upstream of WWTP.

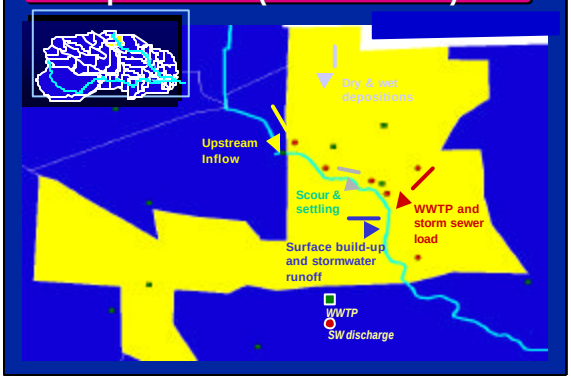
Cole Creek @ Deihl - Summer



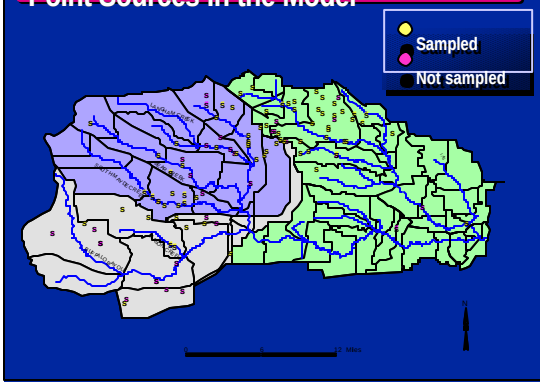
Bacteria Modeling

- Sources and sinks of bacteria
  - Point sources
  - Storm Sewers
  - Dry and wet deposition
  - Sediments (Scour, erosion and settling)
    Stormwater Runoff (Build-up & Wash-off)
  - Upstream inflows
- Fate and transport
  - Net decay (die-off minus regrowth)
- Calibration against historical data

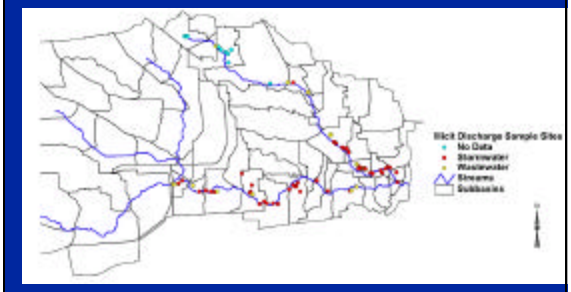
Conceptual Model (Subwatershed 10)



Point Sources in the Model



Illicit Discharge Data in the Model



WWTP and Storm Sewers

- WWTP Flow Data:
  - DMR data from 1995 to 2000 provided by TNRCC
  - Average flow for each WWTP
  - Total WWTP per subwatershed
- WWTP Effluent Concentrations (this project)
- Storm Sewer Flows & Conc (this project)
- Assign Average Values to Unsampled Subwatersheds
- Combine WWTP & Storm Sewer Values (Add flows, Calc flow-weighted concs)
- Assume Constant Over Time

Dry and Wet Deposition

- Sources:
  - Bird droppings
  - Pet wastes
  - Wastes of other animals
  - Other bacteria loadings on surface
- Modeled as Loading Rates
  - In cfu/acre/month
  - Subwatershed specific
  - Season specific
- Treated as calibration parameters

Sediment Source and Sink

- Sediment Simulations
  - Soil detachment from pervious lands
  - Atm Deposition of Sediment (lb/ac/d)
  - Build-up and wash-off
  - Scouring based on Shear Stress (lb/ft^2)
  - Settling based on particle size, density, settling velocity & shear stress (summer 01 data)
  - Bacteria adsorbed to sediment
  - Transfer rates (1/day) between adsorbed and desorbed states
  - Most are calibration parameters

Storm Water Runoff and Upstream Inflow

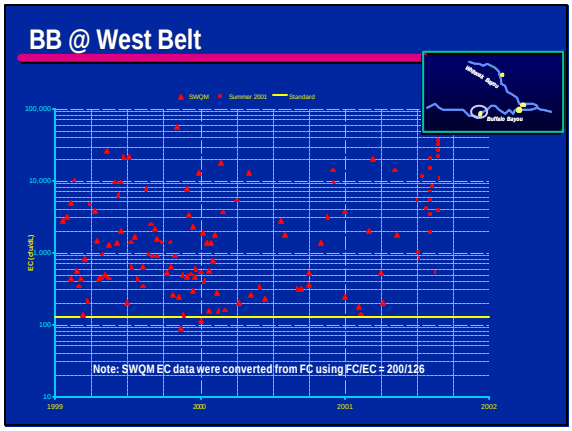
- Bacteria Buildup and Wash-off
  - Accumulation rate (cfu/ac/day)
  - Wash-off potency
  - Runoff rate for removing 90% of surface storage
- Inflow from Upstream Subwatershed
  - Flow
  - Dissolved Conc
  - Conc in Sediment

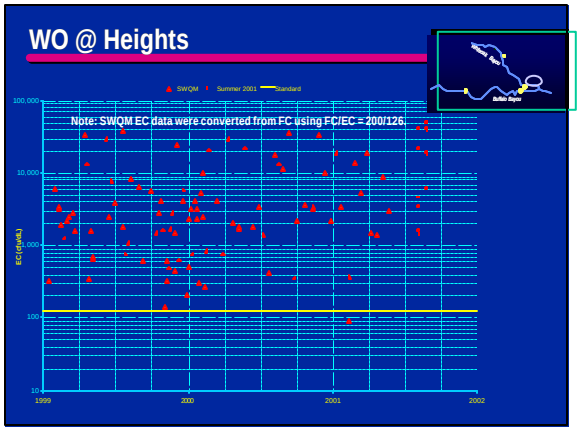
Fate and Transport

- First-Order Decay Rates
  - Decay in water
  - Decay in sediment
  - Based on Summer 01 data

Bacteria Calibration

- Compare output against historical data
- Buffalo Bayou:
  - R-45-BB@Shepherd
  - R-53-BB@VOSS
  - R-39-BB@West Belt
  - R-55-BB@Dairy Ashford
  - R-54-BB@Briar Forest
- White Oak Bayou:
  - R-41-WO@Height
  - R-2-CC@Bolivia
  - R-48-Little WO@WO Dr
- Assume FC/EC = 200/126


BB @ West Belt
SWQM
Summer 2001
Standard
100,000
10,000
1,000
100
10
EC(cfu/dL)
Note: SWQM EC data were converted from FC using FC/EC = 200/126
1999
2000
2001
2002
Mission Bay
Buffalo Bayou


WO @ Heights
SWQM
Summer 2001
Standard
100,000
10,000
1,000
100
10
EC(cfu/dL)
Note: SWQM EC data were converted from FC using FC/EC = 200/126
1999
2000
2001
2002
Mission Bay
Buffalo Bayou

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

Responses to Comments from Last Meeting

University of Houston
PBS&J

Comment 1

RELATIONSHIP OF FERTILIZERS AND LEVELS OF BACTERIA IN THE BAYOUS

Comment 2

SOURCE TRACKING SHOWING SOURCES OF NON-HUMAN ORIGIN

Methods

- DNA
  - Polymerase Chain Reaction
  - Pulsed -field gel electrophoresis
  - Ribotyping
- BIOCHEMICAL
  - Antibiotic resistance
- CHEMICAL
  - Caffeine or optical brighteners

Active Efforts

- TAMU, TAMU-CC, UT ++
- USGS
- USDA
- Others

Key Points

- Most methods require large fingerprint database
- Utility of database appears to decrease with distance
- Full characterization of sources would be significant undertaking

Comment 3

CONTRIBUTION OF BACTERIA FROM SEDIMENT ON STREAM BANKS

Bank Sediments

- Heat-tolerant bacteria exist in natural environment, including soils, vegetation, etc.
- Collected two soil samples on 6/13/02 from Buffalo Bayou at West Belt from under and away from the bridge
- Samples analyzed by City of Houston PW&E WW Operation QC Lab

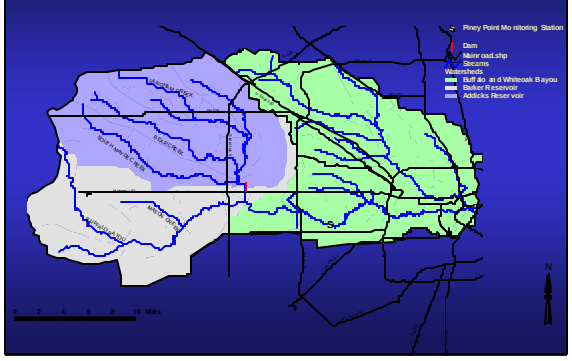
Bank Sediments (cont'd)

- Resulting FC Levels (MPN/g dry wt):
  - Under bridge: 760
  - Away from bridge: 820
- Assuming 80% moisture content and 2.63 g/cm ^{3} soil density, then
  - 800 MPN/g dry wt = 42,080 MPN/dL wet wt
- Within the range of results obtained last summer using bottom sediments (24,192 to 77,000 MPN/dL wet wt)

Comment 4

CONTRIBUTION FROM UPSTREAM OF BARKER AND ADDICKS

Barker and Addicks Reservoirs

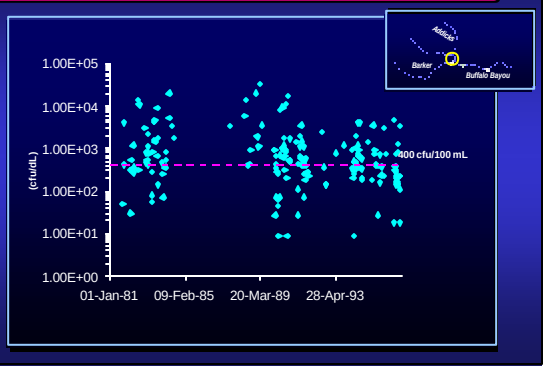


Reservoir Historical Data – USGS

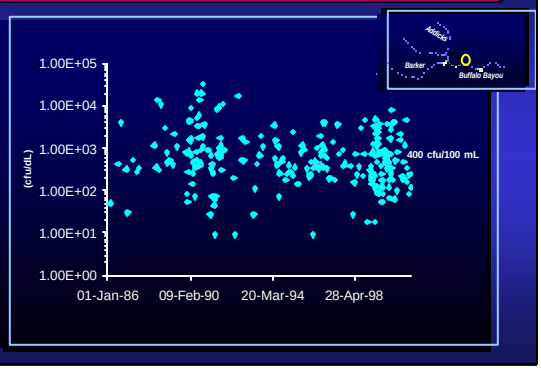
Reservoir	*Location*	*Mean FC (cfu/dL)*
Addicks	Tributaries	6307
	Reservoir	1090
	Discharge	737
Barker	Tributaries	3220
	Reservoir	763
	Discharge	663

Source: USGS WRI 86-4356, 1987. Samples collected from 1978-1981.

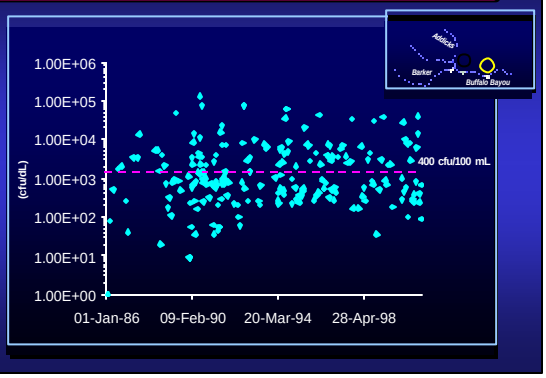
Time Series of FC Data at Barker Dam



Time Series of FC Data at Hwy 6



Time Series of FC Data at Dairy Ashford

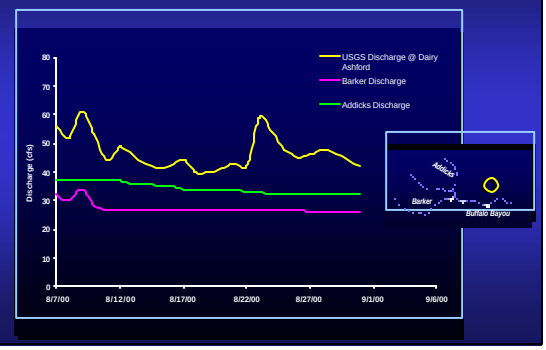


Downstream Monitoring Stations

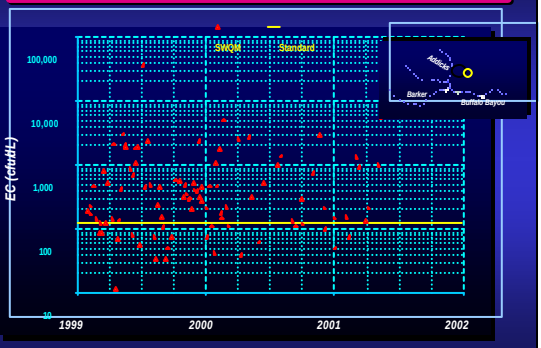
	Range	N	Geo Mean	% > Std [1]
Barker Dam	9 – 58,000	122	899	71%
Highway 6	9 – 58,000	232	579	59%
Dairy Ashford	9 – 130,000	185	1,263	72%

[1] regulatory limits: 400 cfu/dL for FC. All the values given as FC in cfu/dL. Data from 1990 onward.

Dry weather Reservoir and Dairy Ashford Hydrograph



BB @ State Highway 6



Note: SWQM EC data were converted from FC using FC/EC = 200/126.

Reservoir Summary

- Historically high levels of fecal coliform are observed within and downstream of the reservoirs
- Reservoirs are attenuating the bacteria levels
- During dry weather conditions, most of the upstream bayou flow originates from the reservoirs
- Reservoirs will be treated as a single input in the TMDL

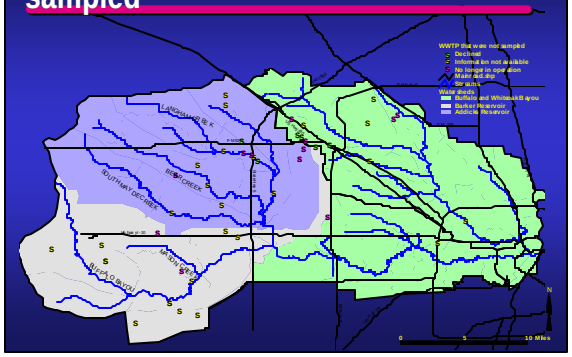
Comment 5

CONTRIBUTION OF 45 WWTPs NOT SAMPLED

Reasons that WWTPs were not sampled

	# of Plants
Facility no longer in operation	14
Request to collect samples was declined	6
Information from TNRCC database regarding location and/or operator incorrect or operator non-responsive.	25

Distribution of plants that were not sampled



Significance of unsampled WWTPs

- Geometric mean of *E. coli* at WWTPs is 3.4 cfu/100 mL
- For plants that we have not sampled, we will assign an EC value based on the flow-weighted geometric mean of the subwatershed
- Resources shifted to illicit discharge sampling

Comment 6

POSSIBLE MODIFICATIONS TO STANDARDS IN NEXT REVISIONS

APPENDIX B

SUMMARY OF MODEL PARAMETERS

AND INPUT FILES

TABLE B-1. HSPF INPUT PARAMETERS

Parameter	Units	Model Type		Description
PWAT-PARM2				**Second Group of PWATER Parameters**
FOREST	none	Hydrology	Pervious	the fraction of the PLS which is covered by forest, and which will therefore continue to transpire in winter. This is only relevant if snow is being considered (i.e., CSNOFG = 1)
LZSN	inches	Hydrology	Pervious	the lower zone nominal storage
INFILT	inches/hour	Hydrology	Pervious	an index to the infiltration capacity of the soil
LSUR	feet	Hydrology	Pervious	length of the assumed overland flow plane
SLSUR		Hydrology	Pervious	slope of the overland flow plane
KVARY	1/inches	Hydrology	Pervious	parameter which affects the behavior of groundwater recession flow, enabling it to be non-exponential in its decay with time
AGWRC	1/day	Hydrology	Pervious	basic groundwater recession rate if KVARY is zero and there is no inflow to groundwater; AGWRC is defined as the rate of flow today divided by the rate of flow yesterday
PWAT-PARM3				**Third Group of PWATER Parameters**
PETMAX	deg F	Hydrology	Pervious	air temperate below which E-T will arbitrarily be reduced below the value obtained from the input time series
PETMIN	deg F	Hydrology	Pervious	temperature below which E-T will be zero regardless of the value in the input time series
INFEXP	none	Hydrology	Pervious	exponent in the infiltration equation
INFILD	none	Hydrology	Pervious	ratio between the maximum and mean infiltration capacities over the PLS
DEEPFR	none	Hydrology	Pervious	fraction of groundwater inflow which will enter deep (inactive) groundwater, and, thus, be lost from the system as it is defined in HSPF
BASETP	none	Hydrology	Pervious	fraction of remaining potential E-T which can be satisfied from baseflow (groundwater outflow), if enough is available
AGWETP	none	Hydrology	Pervious	fraction of remaining potential E-T which can be satisfied from active groundwater storage if enough is available
PWAT-PARM4				**Fourth Group of PWATER Parameters**
CEPSC	inches	Hydrology	Pervious	interception storage capacity
UZSN	inches	Hydrology	Pervious	upper zone nominal storage
NSUR	complex	Hydrology	Pervious	Manning's n for the assumed overland flow plane
INTFW	none	Hydrology	Pervious	interflow inflow parameter
IRC	1/day	Hydrology	Pervious	interflow recession parameter. Under zero inflow, this is the ratio of today's interflow outflow rate to yesterday's rate.
LZETP	none	Hydrology	Pervious	lower zone E-T parameter. It is an index to the density of deep-rooted vegetatior

TABLE B-1. HSPF INPUT PARAMETERS

Parameter	Units	Model Type		Description
PWAT-PARM5				**Fifth Group of PWATER Parameters**
FZG	/inches	Hydrology	Pervious	parameter that adjusts for the effect of ice in the snow pack on infiltration when IFFCFG is 1. It is not used if IFFCFG is 2.
FZGL	none	Hydrology	Pervious	lower limit of INFFAC as adjusted by ice in the snow pack when IFFCFG is 1. If IFFCFG is 2, FZGL is the value of INFFAC when the lower layer temperature is at or below freezing
PWAT-STATE1				**PWATER Initial State Variables**
CEPS	inches	Hydrology	Pervious	initial interception storage
SURS	inches	Hydrology	Pervious	initial surface (overland flow) storage
UZS	inches	Hydrology	Pervious	initial upper zone storage
IFWS	inches	Hydrology	Pervious	initial interflow storage
LZS	inches	Hydrology	Pervious	initial lower zone storage
AGWS	inches	Hydrology	Pervious	initial active groundwater storage
GWVS	inches	Hydrology	Pervious	initial index to groundwater slope; it is a measure of antecedent active groundwater flow
SED-PARM1		Sediment	Pervious	**First Group of SEDMNT Parameters**
CRV/CRVFG		Sediment	Pervious	if CRVFG is 1, erosion-related cover may vary throughout the year. Values are supplied in Table-type MON-COVER
VSIV/VSIVFG		Sediment	Pervious	if VSIVFG is 1, the rate of net vertical sediment input may vary throughout the year. If VSIVFG is 2, the vertical sediment input is added to the detached sediment storage only on days when no rainfall occurred during the previous day. Values are supplied in Table type MON-NVSI
SDOP/SDOPFG		Sediment	Pervious	flag that determines the algorithm used to simulate removal of sediment from the land surface. If SDOPFG is 1, sediment removal will be simulated with the algorithm used in the predecessor models, ARM and NPS. If is is 0, a different algorithm will be used (see the Functional Description for details)

TABLE B-1. HSPF INPUT PARAMETERS

Parameter	Units	Model Type		Description
SED-PARM2				**Second Group of SEDMNT Parameters**
SMPF	none	Sediment	Pervious	"supporting management practice factor." It is used to simulate the reduction in erosion achieved by use of erosion control practices
KRER	complex	Sediment	Pervious	coefficient in the soil detachment equation
JRER	complex	Sediment	Pervious	exponent in the soil detachment equation
AFFIX	/day	Sediment	Pervious	fraction by which detached sediment storage decreases each day as a result of soil compaction
COVER	none	Sediment	Pervious	fraction of land surface which is shielded from rainfall erosion (not considering snow cover, which is handled by the program)
NVSI	pounds/acre/day	Sediment	Pervious	rate at which sediment enters detached storage from the atmosphere. A negative value can be supplied, for example, to simulate removal by human activity or wind.
SED-PARM3				**Third Group of SEDMNT Parameters**
KSER	complex	Sediment	Pervious	coefficient in the detached sediment washoff equation
JSER	complex	Sediment	Pervious	exponent in the detached sediment washoff equation
KGER	complex	Sediment	Pervious	coefficient in the matrix soil scour equation, which simulated gully erosion
JGER	complex	Sediment	Pervious	exponent in the matrix soil scour equation, which simulates gully erosion
SED-STOR				**Initial Storage of Detached Sediment**
DETS	tons/acre	Sediment	Pervious	initial storage of detached sediment
QUAL-INPUT				**Nonseasonal PQUAL Parameters**
SQO	quantity/acre	Bacteria	Pervious	initial storage of QUALOF on the surface of the PLS
POTFW	quantity/ton	Bacteria	Pervious	the washoff potency factor
POTFS	quantity/ton	Bacteria	Pervious	the scour potency factor
ACQOP	quantity/acre/day	Bacteria	Pervious	rate of accumulation of QUALOF
SQOLIM	quantity/acre	Bacteria	Pervious	maximum storage of QUALOF
WSQOP	inches/hour	Bacteria	Pervious	rate of surface runoff which will remove 90 percent of stored QUALOF per hour
IOQC	quantity/feet^3	Bacteria	Pervious	concentration of the constituent in interflow outflow; it is meaningful only if this QUAL is a QUALIF
AOQC	quantity/feet^3	Bacteria	Pervious	concentration of the constituent in active groundwater outflow; it is meaningful only if this QUAL is QUALGW
IWAT-PARM2				**Second Group of IWATER Parameters**
LSUR	feet	Hydrology	Impervious	length of the assumed overland flow plane
SLSUR	none	Hydrology	Impervious	slope of the overland flow plane
NSUR		Hydrology	Impervious	Manning's n for the assumed overland flow plane
RETSC	feet	Hydrology	Impervious	retention (interception) storage capacity of the surface

TABLE B-1. HSPF INPUT PARAMETERS

Parameter	Units	Model Type		Description
IWAT-PARM3				**Third Group of IWATER Parameters**
PETMAX	deg F	Hydrology	Impervious	air temperature below which E-T will arbitrarily be reduced below the value obtained from the input time series
PETMIN	deg F	Hydrology	Impervious	temperature below which E-T will be zero regardless of the value in the input time series. These values are only used if snow is being considered (i.e., CSNOFG = 1 in Table-type IWAT-PARM1)
IWAT-STATE1				**IWATER Initial State Variables**
RETS	inches	Hydrology	Impervious	initial retention storage
SURS	inches	Hydrology	Impervious	initial surface (overland flow) storage
SLD-PARM2				**Second Group of SOLIDS Parameters**
KEIM	complex	Sediment	Impervious	coefficient in the solids washoff equation
JEIM	complex	Sediment	Impervious	exponent in the solids washoff equation
ACCSDP	tons/acre/day	Sediment	Impervious	rate at which solids accumulate on the land surface
REMSDP	/day	Sediment	Impervious	fraction of solids storage which is removed each day when there is no runoff, for example, because of street sweeping
SLD-STOR				**Initial Solids Storage**
SLDS	tons/acre	Sediment	Impervious	initial storage of solids on the impervious surface
QUAL-INPUT				**Surface Storage of qual and Nonseasonal Parameters**
SQO	quantity/acre	Bacteria	Impervious	initial storage of QUALOF on the surface of the ILS
POTFW	quantity/ton	Bacteria	Impervious	washoff potency factor
ACQOP	quantity/acre/day	Bacteria	Impervious	rate of accumulation of QUALOF on the surface
SQOLIM	quantity/acre	Bacteria	Impervious	maximum storage of QUALOF on the surface
WSQOP	inches/hour	Bacteria	Impervious	rate of surface runoff that will remove 90 percent of stored QUALOF per hour
HYDR-PARM2				**Parameters for HYDR Section**
LEN	miles	Hydrology	Reaches	length of the RCHRES
DELTH	feet	Hydrology	Reaches	drop in water elevation from the upstream to the downstream extremities of the RCHRES. (It is used if section OXRX is active and reaeration is being computed using the Tsivoglou-Wallace equation; or if section SEDTRN is active and sandload transport capacity is being computed using either the Toffaleti or Colby method)
STCOR	feet	Hydrology	Reaches	correction to the RCHRES depth to calculate stage
KS	none	Hydrology	Reaches	weighting factor for hydraulic routing
DB15/DB50	inches	Hydrology	Reaches	median diameter of the bed sediment (assumed constant throughout the run)

TABLE B-1. HSPF INPUT PARAMETERS

Parameter	Units	Model Type		Description
SED-GENPARM				
BEDWID	feet	Sediment	Reaches	width of the cross-section over which HSPF will assume bed sediment is deposited (regardless of stage, top-width, etc); BEDWID is constant. It is used to estimate the depth of bed sediment
BEDWRN	feet	Sediment	Reaches	bed depth which, if exceeded (e.g., through deposition) will cause a warning message to be printed in the echo file (MESSU)
POR	none	Sediment	Reaches	porosity of the bed (volume voids/total volume). It is used to estimate bed depth
SAND-PM				**General Sediment Related Paramters**
D	inches	Sediment	Reaches	effective diameter of the transported sand particles
W	inches/second	Sediment	Reaches	fall velocity in still water for D sand particles
RHO	grams/centimeter^3	Sediment	Reaches	density of the sand particles
KSAND	complex	Sediment	Reaches	coefficient in the sandload power function formula
EXPSND	complex	Sediment	Reaches	exponent in the sandload power function formula
SILT-CLAY-PM				**Parameters for Silt or Clay**
D	inches	Sediment	Reaches	effective diameter of the transported particles
W	inches/second	Sediment	Reaches	fall velocity in still water for D particles
RHO	grams/centimeter^3	Sediment	Reaches	density of the particles
TAUCD	pounds/feet^2	Sediment	Reaches	critical bed shear stress for deposition. Above this stress, there will be no deposition; as the stress drops below this value to zero, deposition will gradually increase to the value implied by the fall velocity instill water
TAUCS	pounds/feet^2	Sediment	Reaches	critical bed shear stress for scour. Below this value, there will be no scour; above it, scour will steadily increase
SSED-INIT				**Initial Concentration of Suspended Sediment**
Sand	milligrams/liter	Sediment	Reaches	initial concentration of suspended sand
Silt	milligrams/liter	Sediment	Reaches	initial concentration of silt
Clay	milligrams/liter	Sediment	Reaches	initial concentration of clay
BED-INIT				**Initial Content of Bed Sediment**
BEDDEP	feet	Sediment	Reaches	initial total depth (thickness) of the bed
GQ-GENDECAY				**Parameters for "General" Decay of qual**
FSTDEC	/day	Bacteria	Reaches	first-order decay rate for qual
THFST	none	Bacteria	Reaches	temperature correction coefficient for first-order decay of qual

TABLE B-1. HSPF INPUT PARAMETERS

Parameter	Units	Model Type		Description
GQ-SEDDECAY				**Parameters for Decay of Contaminant Adsorbed to Sediment**
KSUSP		Bacteria	Reaches	decay rate for contaminant adsorbed to suspended sedimen
THSUSP		Bacteria	Reaches	temperature correction coefficient for contaminant adsorbed to suspended sedimen
KBED		Bacteria	Reaches	decay rate for contaminant adsorbed to bed sediment
THBED		Bacteria	Reaches	temperature correction coefficient for contaminant adsorbed to bed sediment
GQ-KD				**Adsorption Coefficients of qual**
ADPM1	liters/milligram	Bacteria	Reaches	distribution coefficient for qual with suspended sand
ADPM2	liters/milligram	Bacteria	Reaches	distribution coefficient for qual with suspended silt
ADPM3	liters/milligram	Bacteria	Reaches	distribution coefficient for qual with suspended clay
ADPM4	liters/milligram	Bacteria	Reaches	distribution coefficient for qual with bed sand
ADPM5	liters/milligram	Bacteria	Reaches	distribution coefficient for qual with bed silt
ADPM6	liters/milligram	Bacteria	Reaches	distribution coefficient for qual with bed clay
GQ-ADRATE				**Adsorption/Desorption Rate Parameters**
ADPM1	/day	Bacteria	Reaches	Transfer rates between adsorbed and desorbed state of qual with suspended sand
ADPM2	/day	Bacteria	Reaches	Transfer rates between adsorbed and desorbed state of qual with suspended sil
ADPM3	/day	Bacteria	Reaches	Transfer rates between adsorbed and desorbed state of qual with suspended clay
ADPM4	/day	Bacteria	Reaches	Transfer rates between adsorbed and desorbed state of qual with bed sand
ADPM5	/day	Bacteria	Reaches	Transfer rates between adsorbed and desorbed state of qual with bed sil
ADPM6	/day	Bacteria	Reaches	Transfer rates between adsorbed and desorbed state of qual with bed clay

```
RUN

GLOBAL
  UCI for Buffalo Bayou Segments 1014 and 1013
  START       1999/04/01 00:00  END    2001/09/30 23:00
  RUN INTERP OUTPT LEVELS    3    0
  RESUME     0 RUN     1                          UNITS      1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
MESSU      24   BBS3EC-2.ech
           91   BBS3EC-2.out
WDM1       25   BBS3ECO2.WDM
WDM2       26   COHRAIN.WDM
WDM3       27   WWSW1202.WDM
WDM4       28   GSDAc03.WDM
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND     155
      IMPLND     255
      PERLND     133
      IMPLND     233
      PERLND     139
      IMPLND     239
      PERLND     154
      IMPLND     254
      PERLND     153
      IMPLND     253
      PERLND     152
      IMPLND     252
      PERLND     126
      IMPLND     226
      PERLND     127
      IMPLND     227
      PERLND     151
      IMPLND     251
      PERLND     150
      IMPLND     250
      PERLND     144
      IMPLND     244
      PERLND     145
      IMPLND     245
      PERLND     138
      IMPLND     238
      PERLND     137
      IMPLND     237
      PERLND     147
      IMPLND     247
      RCHRES      55
      RCHRES      33
      RCHRES      39
      RCHRES      54
      RCHRES      53
      RCHRES      52
      RCHRES      26
      RCHRES      27
      RCHRES      51
      RCHRES      50
      RCHRES      44
      RCHRES      45
      RCHRES      38
      RCHRES      37
      RCHRES      47
    END INGRP
END OPN SEQUENCE
```

```
PERLND
  ACTIVITY
*** <PLS >               Active Sections                              ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  126  154   0    0    1    1    0    0    1    0    0    0    0    0
  155  155   0    0    1    0    0    0    0    0    0    0    0    0
***  155  155   0    0    1    1    0    0    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** < PLS>                       Print-flags                          PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  126  155    4    4    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***             Name                  Unit-systems   Printer
*** <PLS >                                t-series Engl Metr
*** x -  x                                 in  out
  126  155Pervious lands-open               1    1    0    0
  END GEN-INFO

  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
  126  154    0    1    1    1    0    0    0    0    1    0    0    0
  155  155    0    1    1    1    0    0    0    0    1    0    0    0
  END PWAT-PARM1

  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x                (in)   (in/hr)      (ft)               (1/in)   (1/day)
*** Upstream of Dairy Ashford
  155  155        1.       20.      0.90      300.    0.0010        0.     0.100
*** Btw DA and West Belt
  139  139        1.        6.      0.90      300.    0.0010        0.     0.250
*** Btw WB and Piney Point
  133  133        1.        6.      0.90      300.    0.0010        0.     0.250
  154  154        1.        6.      0.90      300.    0.0010        0.     0.250
*** Btw PP and Shepherd
  126  127        1.        6.      0.90      300.    0.0010        0.     0.100
  144  145        1.        6.      0.90      300.    0.0010        0.     0.100
  150  153        1.        6.      0.90      300.    0.0010        0.     0.100
*** Dpwnstream of Shepherd
  137  138        1.        6.      0.90      300.    0.0010        0.     0.250
  147  147        1.        6.      0.90      300.    0.0010        0.     0.250
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
*** Upstream of Dairy Ashford
  155  155       40.       35.       2.0        2.      0.01      0.01        0.
*** Btw DA and West Belt
  139  139       40.       35.       2.0        2.      0.01      0.01        0.
*** Btw WB and Piney Point
  133  133       40.       35.       2.0        2.      0.01      0.01        0.
  154  154       40.       35.       2.0        2.      0.01      0.01        0.
*** Btw PP and Shepherd
  126  127       40.       35.       2.0        2.      0.01      0.01        0.
  144  145       40.       35.       2.0        2.      0.01      0.01        0.
  150  153       40.       35.       2.0        2.      0.01      0.01        0.
*** Dpwnstream of Shepherd
  137  138       40.       35.       2.0        2.      0.01      0.01        0.
  147  147       40.       35.       2.0        2.      0.01      0.01        0.
  END PWAT-PARM3
```

```
  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                        (1/day)
*** Upstream of Dairy Ashford
  155  155      0.01     2.500      0.35      1.50     0.999      0.01
*** Btw DA and West Belt
  139  139      0.01     0.050      0.35      1.50     0.100      0.01
*** Btw WB and Piney Point
  133  133      0.01     0.500      0.35      1.50     0.100      0.01
  154  154      0.01     0.500      0.35      1.50     0.100      0.01
*** Btw PP and Shepherd
  126  127      0.01     0.500      0.35      1.50     0.100      0.01
  144  145      0.01     0.500      0.35      1.50     0.100      0.01
  150  153      0.01     0.500      0.35      1.50     0.100      0.01
*** Dpwnstream of Shepherd
  137  138      0.01     0.500      0.35      1.50     0.100      0.01
  147  147      0.01     0.500      0.35      1.50     0.100      0.01
  END PWAT-PARM4

  PWAT-PARM5
*** <PLS >       FZG      FZGL
*** x -  x
  126  155        1.       0.1
  END PWAT-PARM5

  PWAT-PARM6
*** <PLS >     MELEV      BELV    GWDATM       PCW       PGW      UPGW
*** x -  x      (ft)      (ft)      (ft)
  126  155        0.        1.        1.      0.01      0.01      0.01
  END PWAT-PARM6

  PWAT-PARM7
*** < PLS>    STABNO      SRRC     SREXP     IFWSC     DELTA    UELFAC    LELFAC
*** x  - x               (/hr)                (in)      (in)
  126  155        0.       0.1        1.        1.     0.001        4.       2.5
  END PWAT-PARM7

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  126  155      0.01      1.00       0.5       0.5       1.5      1.00      0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  126  155   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1   .1
  END MON-INTERCEP

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  126  155   .2   .2   .3   .3   .4   .4   .4   .4   .4   .3   .2   .2
  END MON-LZETPARM

  SED-PARM1
*** <PLS >       CRV      VSIV      SDOP
*** x -  x     COVER   ATM DEP    ALGORITHM
  126  155        0.        0.        1.
  END SED-PARM1

  SED-PARM2
*** <PLS >  Sediment parameter 2
*** Soil Detachment equation
***             BMP       Coef      Expo    Reattach  Fraction  Atm Deposition
*** <PLS >      SMPF      KRER      JRER     AFFIX     COVER      NVSI
*** x -  x                                   (/day)            (lb/ac-day)
  126  154        1.      0.32       1.7      0.10        0.       0.0
```

```
  155  155        0.      0.00       0.0      0.00        0.       0.0
  END SED-PARM2

  SED-PARM3
*** <PLS >  Sediment parameter 3
*** Washoff Coefficients
***   Sediment- Coef      Expo      Coef      Expo -Matrix Soil Scouring
*** x -  x      KSER      JSER      KGER      JGER
  155  155       0.0       0.0       0.0       0.0
  126  154      0.05       0.0      0.05       0.0
  END SED-PARM3

  SED-STOR
*** <PLS >  Initial storage of detached sediment
*** x -  x      DETS (tons/ac)
  126  154       0.0
  155  155       0.0
  END SED-STOR

  NQUALS
*** <PLS >  NUMBER OF CONSTITUENTS
*** x -  xNQUAL
  126  155    1
  END NQUALS

  PQL-AD-FLAGS
*** <PLS >  ATMOSPHERIC DEPOSITION FLAGS
***         E COLI TSS-NOT USED
*** x -  x  QUAL1  QUAL2
***        <D><W> <D><W>
  126  154   0  0   0  0
  155  155   0  0   0  0
  END PQL-AD-FLAGS

***  QUAL-INPUT
*** <PLS >  Storage on surface and nonseasonal parameters***
*** x -  x     SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
***  126  155     0.0     0.0     0.0      0.     5.0     1.5       0       0
***  END QUAL-INPUT

  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  126  154    E coli       cfu    1    0    0    1    0    1    0    0    0
  155  155    E coli       cfu    1    0    0    1    0    1    0    0    0
  END QUAL-PROPS

  QUAL-INPUT
*** <PLS >  Storage on surface and nonseasonal parameters***
*** x -  x     SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
***        (cfu/ac)    (cfu/ton) (cfu/ac/d)(cfu/ac) (in/h)  (cfu/cf)
  126  127       0 7.3e+10 7.3e+10 1.0E+06 1.0E+10    0.0199999999      0.
  129  132       0 7.3e+08 7.3e+08 1.0E+0299999999    0.0199999999      0.
  133  133       0 7.3e+08 7.3e+08 1.0E+0499999999    0.0199999999      0.
  136  138       0 7.3e+08 7.3e+08 1.0E+0299999999    0.0199999999      0.
  139  139       0 7.3e+08 7.3e+08 1.0E+0299999999    0.0199999999      0.
  140  143       0 7.3e+08 7.3e+08 1.0E+0699999999    0.0199999999      0.
  144  152       0 7.3e+10 7.3e+10 1.0E+06 1.0E+10    0.0199999999      0.
  153  153       0 7.3e+08 7.3e+08 1.0E+0299999999    0.0199999999      0.
  154  154       0 7.3e+08 7.3e+08 1.0E+0499999999    0.0199999999      0.
  128  128      0.      0.      0.      0.       0    10.0      0.       0
  134  135      0.      0.      0.      0.       0    10.0      0.       0
  155  155      0.      0.      0.      0.       0    10.0      0.       0
  END QUAL-INPUT

END PERLND

IMPLND
```

```
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  226  254    0    0    1    1    0    1
  255  255    0    0    1    0    0    0
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  226  255    4    4    4    4    4    4    0    1
  END PRINT-INFO

  GEN-INFO
***             Name            Unit-systems   Printer
*** <ILS >                          t-series Engl Metr
*** x -  x                           in  out
  226  255Commercial or paved          1    1    0    0
  END GEN-INFO

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  226  255    0    0    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (ft)
  226         2057.8     0.001    0.250     0.005
  227         1461.7     0.001    0.250     0.005
  233          1472.     0.001    0.250     0.075
  237  238     1992.     0.001    0.250     0.005
  239         1705.8     0.001    0.250     0.005
  244         1113.1     0.001    0.250     0.005
  245         1981.3     0.001    0.250     0.005
  247          1992.     0.001    0.250     0.005
  250         1113.1     0.001    0.250     0.005
  251          350.3     0.001    0.250     0.005
  252         1461.7     0.001    0.250     0.005
  253         1934.3     0.001    0.250     0.005
  254         1317.7     0.001    0.250     0.075
  255          694.4     0.001    0.250     0.100
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  226  255       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  226  255      0.01      0.01
  END IWAT-STATE1

  SLD-PARM2
***             KEIM      JEIM    ACCSDP    REMSDP
*** <ILS >      WASHOFF WASHOFF    tons/      /day
*** x -  x      COEF      EXPO    ac.day
  255  255       0.0       0.0      0.00        0.
  226  254      0.10       5.0      0.05        0.
  END SLD-PARM2

  SLD-STOR
*** <ILS >  Initial solids storage (tons/acre) on impervious surface
*** x -  x      SLDS
```

```
  226  254      0.00
  255  255       0.0
  END SLD-STOR

  NQUALS
*** <ILS >  NUMBER OF CONSTITUENTS
*** x -  xNQUAL
  226  255    1
  END NQUALS

  IQL-AD-FLAGS
*** <ILS >  ATMOSPHERIC DEPOSITION FLAGS
*** Dry deposition from the air onto impervious surface - dirts + birds/pets
***         E COLI TSS-NOT USED
*** x -  x  QUAL1  QUAL2
***        <D><W> <D><W>
  226  254   0  0   0  0
  255  255   0  0   0  0
  END IQL-AD-FLAGS

***  QUAL-INPUT
*** <ILS >    Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW  QSO  VQO
  226  254    E coli       cfu    1    0    1    0
  255  255    E coli       cfu    1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
*** <ILS >  Storage on surface and nonseasonal parameters***
*** x -  x     SQO   POTFW   ACQOP  SQOLIM   WSQOP
  226  227       0 7.3e+10 1.0E+06 1.0E+10    0.01
  229  232       0 7.3e+08 1.0E+0299999999    0.01
  233  233       0 7.3e+08 1.0E+0499999999    0.01
  236  238       0 7.3e+08 1.0E+0299999999    0.01
  239  239       0 7.3e+08 1.0E+0299999999    0.01
  244  252       0 7.3e+10 1.0E+06 1.0E+10    0.01
  253  253       0 7.3e+08 1.0E+0299999999    0.01
  254  254       0 7.3e+08 1.0E+0499999999    0.01
  228  228      0.      0.      0.       1   10.00
  234  235      0.      0.      0.       1   10.00
  255  255      0.      0.      0.       0   10.00
  END QUAL-INPUT

END IMPLND

RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
   26   54    1    1    0    0    1    1    0    0    0    0
   55   55    1    1    0    0    0    1    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
   26   55    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***              Name        Nexits   Unit Systems   Printer
*** RCHRES                             t-series  Engl Metr LKFG
*** x -  x                               in  out
   26     Spring Branch           1         1    1   91    0    0
   27     Trib S of Spring B      1         1    1   91    0    0
   33     Rummel Creek            1         1    1   91    0    0
   37     BB-1206+38-1151+37      1         1    1   91    0    0
   38     BB-1253+69-1206+38      1         1    1   91    0    0
```

```
    39     BB-2351+53-2171+92      1         1    1   91    0    0
    44     BB-1513+43-1480+93      1         1    1   91    0    0
    45     BB-1480+93-1253+69      1         1    1   91    0    0
    47     BB-1151+37-1099+04      1         1    1   91    0    0
    50     BB-1605+13-1513+43      1         1    1   91    0    0
    51     BB-1646+28-1605+13      1         1    1   91    0    0
    52     BB-1809+98-1646+28      1         1    1   91    0    0
    53     BB-2025.38-1809+98      1         1    1   91    0    0
    54     BB-2171+92-2025+38      1         1    1   91    0    0
    55     BB-2433+08-2351+53      1         1    1   91    0    0
  END GEN-INFO

  HYDR-PARM1
***         Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
*** x  - x  FG FG FG FG  possible   exit *** possible   exit     possible   exit
   26   54   0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
   55   55   0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
  END HYDR-PARM1

  HYDR-PARM2
*** RCHRES FTBW FTBU       LEN     DELTH     STCOR        KS      DB15
*** x -  x             (miles)      (ft)      (ft)                (in)
   26        0.  26.      4.11      53.1      20.7      0.10  0.002871
   27        0.  27.      3.38      48.3      28.5      0.10  0.002871
   33        0.  33.      3.39      13.5       37.      0.10  0.002871
   37        0.  37.      1.04       3.5      -6.5      0.10  0.002871
   38        0.  38.       0.9       1.2       -3.      0.10  0.002871
   39        0.  39.       3.4        9.       37.      0.25  0.002750
   44        0.  44.      0.62       2.6       5.6      0.10  0.002871
   45        0.  45.       4.3       7.4      -1.8      0.10  0.002271
   47        0.  47.      0.99       6.5      -13.      0.10  0.002871
   50        0.  50.      1.74        3.       8.2      0.10  0.005904
   51        0.  51.      0.78       2.2      11.2      0.10  0.002871
   52        0.  52.       3.1        6.      13.4      0.10  0.002871
   53        0.  53.      4.08       9.9      19.4      0.10  0.003275
   54        0.  54.      2.78       7.7      29.3      0.10  0.002871
   55        0.  55.      1.54       5.1       46.      0.10  0.001439
  END HYDR-PARM2

  MON-CONVF
*** RCHRES  Monthly f(VOL) adjustment factors
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   26   55 .97  .89  .89  .91  .93  .93  .94  .95  .95  .98  .98  .97
  END MON-CONVF

  HYDR-INIT
***         Initial conditions for HYDR section
***RC HRES       VOL  CAT Initial value  of COLIND     initial  value  of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible exit,ft3
   26   55      1.00       4.2  4.5  4.5  4.5  4.2       2.1  1.2   .5  1.2  1.8
  END HYDR-INIT

SED-GENPARM
*** RCHRES    BEDWID    BEDWRN       POR
*** x -  x      (ft)      (ft)
   26   32       40.      200.      0.50
   33   33       40.      200.      0.50
   34   38       40.      200.      0.50
   39   39        5.      200.      0.50
   40   52       40.      200.      0.50
   53   53       30.      200.      0.50
   54   54       40.      200.      0.50
   55   55       30.      200.      0.50
  END SED-GENPARM

  SAND-PM
*** RCHRES         D         W       RHO     KSAND    EXPSND
```

```
  *** x -  x      (in)  (in/sec)  (gm/cm3)
  *** Duplicating WOB:
     26   54    0.0049    0.5244     2.575       5.0       5.3
     55   55     0.001     0.020      2.63       0.0       0.0
    END SAND-PM

    SILT-CLAY-PM
  *** FOR SILT
  *** RCHRES         D         W       RHO     TAUCD     TAUCS         M
  *** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
     26   54   0.00016 0.0000217       2.3    0.1000    0.1100      0.20
     55   55    0.0000    0.0000      2.63 99999999. 99999999.       0.0
    END SILT-CLAY-PM

    SILT-CLAY-PM
  *** FOR CLAY
  *** RCHRES       D15         W       RHO     TAUCD     TAUCS         M
  *** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
     28   28  0.002871  0.054419      2.63         0         0     12.5
     34   34  0.002871  0.054419      2.63         0         0     12.5
     35   35  0.004345  0.124648      2.63         0         0     12.5
     55   55    0.0000    0.0000      2.63 99999999. 99999999.       0.0
  *** UPSTREAM OF WEST BELT
     39   39  0.002750  0.049930      2.63  0.125000  0.150000     12.5
  *** UPSTREAM OF BRIAR FOREST
     33   33  0.002871  0.054419      2.63  0.135000  0.150000     12.5
     54   54  0.002871  0.054419      2.63  0.135000  0.150000     12.5
  *** UPSTREAM OF VOSS
     53   53  0.003000  0.070798      2.63  0.135000  0.150000     12.5
  *** UPSTREAM OF SHEPHERD
     26   27  0.002871  0.054419      2.63  0.127500  0.130000     12.5
     44   44  0.002871  0.054419      2.63  0.127500  0.130000     12.5
     45   45  0.002271  0.034044      2.63  0.127500  0.130000     12.5
     50   50  0.003000  0.200000      2.63  0.127500  0.130000     12.5
     51   52  0.002871  0.054419      2.63  0.127500  0.130000     12.5
  *** DOWNSTREAM OF SHEPHERD
     37   37  0.002871  0.054419      2.63  0.095000  0.100000     12.5
     38   38  0.002871  0.054419      2.63  0.095000  0.100000     12.5
     47   47  0.002871  0.054419      2.63  0.095000  0.100000     12.5
    END SILT-CLAY-PM

    SSED-INIT
  *** RCHRES Suspended sed concs (mg/L) ***
  *** x -  x      Sand      Silt      Clay ***
     26   54      0.00      25.0      50.0
     55   55      0.00      0.00       0.0
    END SSED-INIT

    BED-INIT
  *** RCHRES    BEDDEP   Initial bed composition ***
  *** x -  x      (ft)      Sand      Silt      Clay ***
     26   54      2.50      0.05      0.55      0.40
     55   55      0.00      0.00      0.00      1.00
    END BED-INIT

    GQ-AD-FLAGS
  *** RCHRES Atmospheric deposition flags ***
  *** Dry Deposition - Bird Droppings into channel
  *** x -  x <F><C>
     26   54   0  0
     55   55   0  0
    END GQ-AD-FLAGS

    GQ-QALDATA
  *** RCHRES                GQID      DQAL    CONCID      CONV     QTYID
  *** x -  x                        concid     (/L)
     26   54 E coli                     0.       cfu 0.0035310       cfu
     55   55 E coli                     0.       cfu 0.0035310       cfu
```

```
  END GQ-QALDATA

  GQ-QALFG
*** RCHRES quality flags ***
*** x -  x HDRL OXID PHOT VOLT BIOD  GEN SDAS***
   26   54    0    0    0    0    0    1    1
   55   55    0    0    0    0    0    1    0
  END GQ-QALFG

  GQ-GENDECAY
*** RCHRES - First-order decay ***
*** x -  x    FSTDEC     THFST ***
***          (1/day)
***   26   54      5.00     1.024
   26   27      1.50     1.024
   29   32      1.50     1.024
   33   33      5.00     1.024
   36   38      1.50     1.024
   39   39      5.00     1.024
   40   52      1.50     1.024
   53   53      3.00     1.024
   54   54      5.00     1.024
   28   28     5.000     1.024
   34   35     5.000     1.024
   55   55     5.000     1.024
  END GQ-GENDECAY

  GQ-SEDDECAY
*** RCHRES - Decay of constituent adsorbed to sediment (1/day) ***
***            Decay in TSS         Decay in Bed Sediment ***
*** x -  x     KSUSP    THSUSP      KBED     THBED ***
   26   27    0.113     1.024     0.113     1.024
   29   33    0.113     1.024     0.113     1.024
   36   54    0.113     1.024     0.113     1.024
***   55   55    0.113     1.024     0.113     1.024
   28   28   10.000     1.024    10.000     1.024
   34   35   10.000     1.024    10.000     1.024
   55   55   10.000     1.024    10.000     1.024
  END GQ-SEDDECAY

  GQ-KD
*** RCHRES - Adsorption coefficients = adsorbed C/dissolved C (L/mg) ***
***         SUS SAND  SUS SILT  SUS CLAY  BED SAND  BED SILT  BED CLAY ***
*** x -  x     ADPM1     ADPM2     ADPM3     ADPM4     ADPM5     ADPM6 ***
***   26   54       10.       10.       10.     0.001     0.001     0.001
   26   27     50000     50000    50000. 0.0000001 0.0000001   0.00001
   29   32     50000     50000    50000. 0.0000001 0.0000001   0.00001
   33   33     50000     50000   500000. 0.0000001 0.0000001   0.00001
   36   38     50000     50000    50000. 0.0000001 0.0000001   0.00001
   39   39     50000     50000500000000. 0.0000001 0.0000001   0.00001
   40   52     50000     50000    50000. 0.0000001 0.0000001   0.00001
   53   53     50000     50000  5000000. 0.0000001 0.0000001   0.00001
   54   54     50000     50000   500000. 0.0000001 0.0000001   0.00001
   28   28 0.0000001 0.0000001 0.0000001 0.0000001 0.0000001 0.0000001
   34   35 0.0000001 0.0000001 0.0000001 0.0000001 0.0000001 0.0000001
   55   55 0.0000001 0.0000001 0.0000001 0.0000001 0.0000001 0.0000001
  END GQ-KD

  GQ-ADRATE
*** RCHRES - Transfer rates between adsorbed and desorbed states (1/DAY) ***
***         SUS SAND  SUS SILT  SUS CLAY  BED SAND  BED SILT  BED CLAY ***
*** x -  x     ADPM1     ADPM2     ADPM3     ADPM4     ADPM5     ADPM6 ***
***   26   54       10.       10.       10.     0.001     0.001     0.001
   26   27   0.00001   0.00001   0.00001   500000.   500000.   500000.
   29   32   0.00001   0.00001   0.00001   500000.   500000.   500000.
   33   33   0.00001   0.00001   0.00001   500000.   500000.   5000.00
   36   38   0.00001   0.00001   0.00001   500000.   500000.   500000.
   39   39   0.00001   0.00001   0.00001   500000.   500000.   500000.
```

```
    40   52   0.00001   0.00001   0.00001   500000.   500000.   500000.
    53   53   0.00001   0.00001   0.00001   500000.   500000.   500000.
    54   54   0.00001   0.00001   0.00001   500000.   500000.   5000.00
    28   28   0.00001   0.00001   0.00001   0.00001   0.00001   0.00001
    34   35   0.00001   0.00001   0.00001   0.00001   0.00001   0.00001
    55   55   0.00001   0.00001   0.00001   0.00001   0.00001   0.00001
***   55   55   0.00001   0.00001   0.00001   0.00001   0.00001   500000.
  END GQ-ADRATE

  GQ-SEDCONC
*** RCHRES - Initial concentrations (cfu/mg) of EC in ***
***         SUS SAND  SUS SILT  SUS CLAY  BED SAND  BED SILT  BED CLAY ***
*** x -  x     SQAL1     SQAL2     SQAL3     SQAL4     SQAL5     SQAL6 ***
    26   27     0.214     0.214     0.214     0.214     0.214     0.214
    29   33     0.214     0.214     0.214     0.214     0.214     0.214
    36   54     0.214     0.214     0.214     0.214     0.214     0.214
***   55   55        0.        0.     0.214        0.        0.     0.214
    28   28        0.        0.     0.000        0.        0.     0.000
    34   35        0.        0.     0.000        0.        0.     0.000
    55   55        0.        0.     0.000        0.        0.     0.000
  END GQ-SEDCONC

END RCHRES

FTABLES

  FTABLE     55
 rows cols                              ***
   12    4
     depth      area    volume  outflow1 ***
        0.        2.        0.        0.
       1.6      2.73      2.45       6.8
      1.75      2.95      2.85       8.4
      4.07      6.08     12.36       68.
      4.52      6.47     14.74       84.
     11.65       16.     82.33      680.
     12.78     18.09    100.47      840.
     28.85     91.46    641.08     6800.
      31.1    289.48   1080.64     8400.
     31.87    351.09   1354.59     9400.
     33.21     429.4   1961.75    11500.
     98.56    714.63  47199.82   115000.
  END FTABLE 55

  FTABLE     33
 rows cols                              ***
   13    4
     depth      area    volume  outflow1 ***
        0.       14.        0.        0.
       0.4     14.52    156.11       2.4
      0.45     14.58    156.79       3.3
      1.14     15.33    166.62      24.3
      1.34      15.5    169.62      33.2
      4.01     18.49    213.21     242.5
      4.76     19.37    226.08     331.7
     14.07     39.31    454.64     2425.
     15.93     73.13    525.94     3317.
      16.6     82.05    556.17     3700.
     18.08    261.98    682.48     4712.
     37.74   1232.25   6691.56    47120.
      100.   1232.25  83411.45   587359.
  END FTABLE 33

  FTABLE     39
 rows cols                              ***
   12    4
     depth      area    volume  outflow1 ***
        0.        9.        0.        0.
```

```
        1.87      9.27      8.74      11.1
        2.07      9.74     10.07      13.9
        5.14     14.08     36.50      111.
        5.72     14.68     43.07      139.
       13.36     36.26    201.65     1110.
       14.67     43.45    253.09     1390.
        30.3    208.52   1676.31    11100.
       33.81    784.06   2928.63    13900.
       35.29    964.07   3899.45    16500.
       37.14   1197.21   5664.68    19800.
      106.87   1439.24 102495.16   198000.
    END FTABLE 39

    FTABLE     54
   rows cols                              ***
     12    4
       depth      area    volume  outflow1 ***
          0.        7.        0.        0.
        2.44      7.48     11.29      12.2
        2.79      8.19     13.55       17.
        5.99     14.48     48.03      122.
         6.8     15.89      58.1      170.
       14.64     38.75    239.27     1220.
       16.51     45.42    306.21     1700.
       32.41    147.41   1680.86    12200.
       36.51    293.67    2496.1    17000.
       37.82    422.66   2970.03    19000.
       39.94    632.62   4014.69    22800.
      113.36   1225.39  89534.32   228000.
    END FTABLE 54

    FTABLE     53
   rows cols                              ***
     12    4
       depth      area    volume  outflow1 ***
          0.       12.        0.        0.
        5.01     12.06     18.55      12.2
        5.29     13.05     21.88       17.
        7.96     21.08     68.12      122.
        8.66     22.95     84.64      170.
       15.64     45.86    331.39     1220.
       17.32      61.2    428.51     1700.
       33.14    251.99   2834.47    12200.
       37.08    349.85    4049.7    17000.
       38.68    417.13   4592.87    19000.
       41.36    641.28   5822.46    22800.
      120.67    993.68  76295.73   228000.
    END FTABLE 53

    FTABLE     52
   rows cols                              ***
     12    4
       depth      area    volume  outflow1 ***
          0.        9.        0.        0.
        2.53      9.16      15.9      14.3
        2.77      9.67      18.2      18.9
        5.24     14.46     52.63      143.
        5.74     15.43     62.02      189.
       12.75     36.78    243.97     1430.
       14.44     49.19    311.85     1890.
       31.54    156.07   2100.41    14300.
       35.75    193.37   2790.79    18900.
       37.76    214.55   3175.64    21300.
       40.77    281.13   3900.07    25600.
      124.59    557.82  48303.98   256000.
    END FTABLE 52

    FTABLE     26
```

```
  rows cols                                ***
    13    4
      depth      area    volume  outflow1 ***
         0.        9.        0.        0.
       1.36      9.13      3.97       7.4
       1.53      9.43      4.58       9.9
       3.23     11.92     14.44      73.5
       3.63     12.36     17.35      99.2
       8.02     17.67     65.28      735.
         9.     19.16     81.85      992.
       18.6     83.64    414.22     7350.
      20.75     138.6     545.7     9920.
      21.61    176.25    620.05    11210.
      23.59    294.87     846.6    14000.
      47.69   1718.49  18026.94   140000.
       100.   1718.49 107921.15  838132.3
   END FTABLE 26

   FTABLE     27
  rows cols                                ***
    13    4
      depth      area    volume  outflow1 ***
         0.       14.        0.        0.
        0.4     14.52    156.11       2.4
       0.45     14.58    156.79       3.3
       1.14     15.33    166.62      24.3
       1.34      15.5    169.62      33.2
       4.01     18.49    213.21     242.5
       4.76     19.37    226.08     331.7
      14.07     39.31    454.64     2425.
      15.93     73.13    525.94     3317.
       16.6     82.05    556.17     3700.
      18.08    261.98    682.48     4712.
      37.74   1232.25   6691.56    47120.
       100.   1232.25  83411.45   587359.
   END FTABLE 27

   FTABLE     51
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.        2.        0.        0.
       1.52      2.97      2.69      14.8
       1.74      3.16      3.16      19.7
        4.4      5.46     13.11      148.
       5.06      5.74     16.23      197.
      12.97     10.79     77.88     1480.
       14.7     12.29     97.67     1970.
      32.28     26.98    475.65    14800.
      36.48     29.81    595.38    19700.
      38.52      33.1    659.62    22300.
      41.56     38.11    767.62    26800.
     125.85    126.15  10921.16   268000.
   END FTABLE 51

   FTABLE     50
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.        7.        0.        0.
       1.13      7.63      13.5      14.8
       1.19      7.86     14.35      19.7
       3.14     10.57     35.33      148.
       3.75     11.34     42.26      197.
      11.16     20.17    158.49     1480.
       12.9     22.92    195.42     1970.
      31.25      94.9   1289.77    14800.
      35.59    109.12   1729.57    19700.
```

```
      37.64    118.68   1964.53    22300.
       40.6    168.84   2405.86    26800.
     125.06    238.85  22454.21   268000.
   END FTABLE 50

   FTABLE     44
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.        3.        0.        0.
       3.66       3.1      6.44      15.1
       3.68      3.11      6.55      20.5
       4.56      3.76      11.7      151.
       4.97        4.     13.75      205.
      11.79       7.3     52.91     1510.
      13.53      8.22     66.46     2050.
      32.31     36.51    415.71    15100.
      36.83     45.23     598.3    20500.
      38.96      48.5     696.5    23200.
      41.77     57.39    840.65    27800.
     127.21    107.51   9742.49   278000.
   END FTABLE 44

   FTABLE     45
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.       45.        0.        0.
      11.04     45.66    264.46      16.3
      11.05     45.67    264.55      21.8
      11.08     46.52    274.05      163.
      11.11     47.02    280.49      218.
      13.18     69.22    540.28     1630.
      14.21     76.09    646.85     2180.
      34.67    319.60   4357.95    16300.
      39.76     379.1   6032.94    21800.
      42.13    425.71    6940.3    24500.
       44.9    499.68   8240.17    29500.
     132.79    981.61  90665.75   295000.
   END FTABLE 45

   FTABLE     38
  rows cols                              ***
    14    4
      depth      area    volume  outflow1 ***
         0.       15.        0.        0.
      12.24     15.84     87.55      16.3
      12.25     15.85     87.56      21.8
      12.27       16.     87.96      163.
      12.28     16.11     88.28      218.
      13.75     18.77    120.94     1630.
      14.59     19.74    139.25     2180.
       35.1     77.75    967.38    16300.
       40.3    108.45   1447.45    21800.
      42.74    125.27   1725.80    24500.
      45.53    156.08   2109.39    29500.
     133.77    222.53  21410.53   295000.
       150.    222.53  25022.19   344762.
      1500.    2225.3  250221.9  3447620.
   END FTABLE 38

   FTABLE     37
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.       18.        0.        0.
      15.74     18.68    138.21      16.3
      15.75     18.69    138.22      21.8
```

```
      15.76     18.71    138.49      163.
      15.77     18.73    138.69      218.
      16.87     22.09    164.19     1630.
      17.58     24.92    182.31     2180.
      38.24     101.1   1491.71    16300.
      43.47    145.91   2132.29    21800.
      45.93    172.71   2517.88    24500.
      48.69    217.56   3069.41    29500.
     137.13    312.15  30208.78   295000.
  END FTABLE 37

  FTABLE     47
 rows cols                              ***
   12    4
      depth      area    volume  outflow1 ***
         0.       21.        0.        0.
      22.24      21.1    246.56      46.6
      22.25     21.11    246.57      61.3
      22.26     21.12    246.81      466.
      22.27     21.13    246.99      613.
      23.19     22.62    269.48     4660.
       23.8     23.02     284.8     6130.
      42.91     76.29   1108.03    46600.
        48.    115.88   1610.44    61300.
      50.55    141.79   1931.62    66500.
       53.7    176.65   2407.59    75000.
      141.7    268.57  25792.91   750000.
  END FTABLE 47
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name> x x ***
*** Met Seg RG30
WDM2    30 PREC     ENGLZERO          SAME PERLND 126 155 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 126 155 EXTNL  PETINP
*** Met Seg RG30
WDM2    30 PREC     ENGLZERO          SAME IMPLND 226 255 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 226 255 EXTNL  PETINP
*** Met Seg RG30
WDM2    30 PREC     ENGLZERO          SAME RCHRES  39     EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  39     EXTNL  POTEV
*** Met Seg RG30
WDM2    30 PREC     ENGLZERO          SAME RCHRES  53  55 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  53  55 EXTNL  POTEV
*** Met Seg RG21
WDM2    21 PREC     ENGLZERO          SAME RCHRES  26  33 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  26  33 EXTNL  POTEV
*** Met Seg RG32
WDM2    32 PREC     ENGLZERO          SAME RCHRES  44  45 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  44  45 EXTNL  POTEV
*** Met Seg RG32
WDM2    32 PREC     ENGLZERO          SAME RCHRES  50  52 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  50  52 EXTNL  POTEV
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME RCHRES  37  38 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  37  38 EXTNL  POTEV
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME RCHRES  47     EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  47     EXTNL  POTEV
*** UPSTREAM (DAIRY ASHFORD) INFLOW AND EC CONC
WDM4    55 FLOW     ENGLZERO          SAME RCHRES  55     EXTNL  IVOL
WDM4   552 CONC     ENGLZERO          SAME RCHRES  55     INFLOW IDQAL
*** POINT SOURCE AND DRY WEATHER SEWER FLOWS
WDM3    33 FLOW     ENGLZERO          SAME RCHRES  33     EXTNL  IVOL
WDM3    39 FLOW     ENGLZERO          SAME RCHRES  39     EXTNL  IVOL
WDM3    44 FLOW     ENGLZERO          SAME RCHRES  44     EXTNL  IVOL
WDM3    45 FLOW     ENGLZERO          SAME RCHRES  45     EXTNL  IVOL
```

```
WDM3    47 FLOW     ENGLZERO          SAME RCHRES  47     EXTNL  IVOL
WDM3    50 FLOW     ENGLZERO          SAME RCHRES  50     EXTNL  IVOL
WDM3    52 FLOW     ENGLZERO          SAME RCHRES  52     EXTNL  IVOL
WDM3    53 FLOW     ENGLZERO          SAME RCHRES  53     EXTNL  IVOL
WDM3    54 FLOW     ENGLZERO          SAME RCHRES  54     EXTNL  IVOL
*** POINT SOURCE AND DRY WEATHER SEWER LOADS
WDM3   133 CONC     ENGLZERO          SAME RCHRES  33     INFLOW IDQAL
WDM3   139 CONC     ENGLZERO          SAME RCHRES  39     INFLOW IDQAL
WDM3   144 CONC     ENGLZERO          SAME RCHRES  44     INFLOW IDQAL
WDM3   145 CONC     ENGLZERO          SAME RCHRES  45     INFLOW IDQAL
WDM3   147 CONC     ENGLZERO          SAME RCHRES  47     INFLOW IDQAL
WDM3   150 CONC     ENGLZERO          SAME RCHRES  50     INFLOW IDQAL
WDM3   152 CONC     ENGLZERO          SAME RCHRES  52     INFLOW IDQAL
WDM3   153 CONC     ENGLZERO          SAME RCHRES  53     INFLOW IDQAL
WDM3   154 CONC     ENGLZERO          SAME RCHRES  54     INFLOW IDQAL

SCHEMATIC
<-Volume->                  <--Area-->     <-Volume->  <ML#> ***       <sb>
<Name>   x                  <-factor->     <Name>   x        ***        x x
PERLND 155                        1684     RCHRES  55      2
IMPLND 255                        1491     RCHRES  55      1
PERLND 133                        1149     RCHRES  33      2
IMPLND 233                        1851     RCHRES  33      1
RCHRES  55                                 RCHRES  39      3
PERLND 139                        2184     RCHRES  39      2
IMPLND 239                        2495     RCHRES  39      1
RCHRES  39                                 RCHRES  54      3
RCHRES  33                                 RCHRES  54      3
PERLND 154                        1441     RCHRES  54      2
IMPLND 254                        1819     RCHRES  54      1
RCHRES  54                                 RCHRES  53      3
PERLND 153                        1964     RCHRES  53      2
IMPLND 253                        2970     RCHRES  53      1
RCHRES  53                                 RCHRES  52      3
PERLND 152                        1373     RCHRES  52      2
IMPLND 252                        2140     RCHRES  52      1
PERLND 126                        1787     RCHRES  26      2
IMPLND 226                        2301     RCHRES  26      1
PERLND 127                        1129     RCHRES  27      2
IMPLND 227                        1736     RCHRES  27      1
RCHRES  52                                 RCHRES  51      3
RCHRES  26                                 RCHRES  51      3
RCHRES  27                                 RCHRES  51      3
PERLND 151                        1014     RCHRES  51      2
IMPLND 251                        1505     RCHRES  51      1
RCHRES  51                                 RCHRES  50      3
PERLND 150                         638     RCHRES  50      2
IMPLND 250                        1365     RCHRES  50      1
RCHRES  50                                 RCHRES  44      3
PERLND 144                         867     RCHRES  44      2
IMPLND 244                        1808     RCHRES  44      1
RCHRES  44                                 RCHRES  45      3
PERLND 145                        2082     RCHRES  45      2
IMPLND 245                        1857     RCHRES  45      1
RCHRES  45                                 RCHRES  38      3
PERLND 138                         497     RCHRES  38      2
IMPLND 238                        1133     RCHRES  38      1
RCHRES  38                                 RCHRES  37      3
PERLND 137                         397     RCHRES  37      2
IMPLND 237                        1171     RCHRES  37      1
RCHRES  37                                 RCHRES  47      3
PERLND 147                           9     RCHRES  47      2
IMPLND 247                         449     RCHRES  47      1
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
```

```
**** FLOW OUTPUT (ACRE-FT/HOUR)
RCHRES  55 HYDR   ROVOL  1 1               WDM1    55 FLOW     ENGL AGGR REPL
RCHRES  39 HYDR   ROVOL  1 1               WDM1    39 FLOW     ENGL AGGR REPL
RCHRES  54 HYDR   ROVOL  1 1               WDM1    54 FLOW     ENGL AGGR REPL
RCHRES  53 HYDR   ROVOL  1 1               WDM1    53 FLOW     ENGL AGGR REPL
RCHRES  45 HYDR   ROVOL  1 1               WDM1    45 FLOW     ENGL AGGR REPL
****  SEDIMENT OUTFLOWS (TON/HOUR)
RCHRES  55 SEDTRN ROSED  1            SAME WDM1   551 CONC     ENGL AGGR REPL
RCHRES  55 SEDTRN ROSED  2            SAME WDM1   552 CONC     ENGL AGGR REPL
RCHRES  55 SEDTRN ROSED  3            SAME WDM1   553 CONC     ENGL AGGR REPL
RCHRES  39 SEDTRN ROSED  1            SAME WDM1   391 CONC     ENGL AGGR REPL
RCHRES  39 SEDTRN ROSED  2            SAME WDM1   392 CONC     ENGL AGGR REPL
RCHRES  39 SEDTRN ROSED  3            SAME WDM1   393 CONC     ENGL AGGR REPL
RCHRES  54 SEDTRN ROSED  1            SAME WDM1   541 CONC     ENGL AGGR REPL
RCHRES  54 SEDTRN ROSED  2            SAME WDM1   542 CONC     ENGL AGGR REPL
RCHRES  54 SEDTRN ROSED  3            SAME WDM1   543 CONC     ENGL AGGR REPL
RCHRES  53 SEDTRN ROSED  1            SAME WDM1   531 CONC     ENGL AGGR REPL
RCHRES  53 SEDTRN ROSED  2            SAME WDM1   532 CONC     ENGL AGGR REPL
RCHRES  53 SEDTRN ROSED  3            SAME WDM1   533 CONC     ENGL AGGR REPL
RCHRES  45 SEDTRN ROSED  1            SAME WDM1   451 CONC     ENGL AGGR REPL
RCHRES  45 SEDTRN ROSED  2            SAME WDM1   452 CONC     ENGL AGGR REPL
RCHRES  45 SEDTRN ROSED  3            SAME WDM1   453 CONC     ENGL AGGR REPL
*** OUTPUT OF EC CONCENTRATIONS IN WATER (CFU/HR) AND IN SAND, SILT AND CLAY (CFU/HR)
RCHRES  55 GQUAL  RODQAL 1     0.001  SAME WDM1   555 CONC     ENGL AGGR REPL
RCHRES  55 GQUAL  ROSQAL 1     0.001  SAME WDM1   556 CONC     ENGL AGGR REPL
RCHRES  55 GQUAL  ROSQAL 2     0.001  SAME WDM1   557 CONC     ENGL AGGR REPL
RCHRES  55 GQUAL  ROSQAL 3     0.001  SAME WDM1   558 CONC     ENGL AGGR REPL
RCHRES  39 GQUAL  RODQAL 1     0.001  SAME WDM1   395 CONC     ENGL AGGR REPL
RCHRES  39 GQUAL  ROSQAL 1     0.001  SAME WDM1   396 CONC     ENGL AGGR REPL
RCHRES  39 GQUAL  ROSQAL 2     0.001  SAME WDM1   397 CONC     ENGL AGGR REPL
RCHRES  39 GQUAL  ROSQAL 3     0.001  SAME WDM1   398 CONC     ENGL AGGR REPL
RCHRES  54 GQUAL  RODQAL 1     0.001  SAME WDM1   545 CONC     ENGL AGGR REPL
RCHRES  54 GQUAL  ROSQAL 1     0.001  SAME WDM1   546 CONC     ENGL AGGR REPL
RCHRES  54 GQUAL  ROSQAL 2     0.001  SAME WDM1   547 CONC     ENGL AGGR REPL
RCHRES  54 GQUAL  ROSQAL 3     0.001  SAME WDM1   548 CONC     ENGL AGGR REPL
RCHRES  53 GQUAL  RODQAL 1     0.001  SAME WDM1   535 CONC     ENGL AGGR REPL
RCHRES  53 GQUAL  ROSQAL 1     0.001  SAME WDM1   536 CONC     ENGL AGGR REPL
RCHRES  53 GQUAL  ROSQAL 2     0.001  SAME WDM1   537 CONC     ENGL AGGR REPL
RCHRES  53 GQUAL  ROSQAL 3     0.001  SAME WDM1   538 CONC     ENGL AGGR REPL
RCHRES  45 GQUAL  RODQAL 1     0.001  SAME WDM1   455 CONC     ENGL AGGR REPL
RCHRES  45 GQUAL  ROSQAL 1     0.001  SAME WDM1   456 CONC     ENGL AGGR REPL
RCHRES  45 GQUAL  ROSQAL 2     0.001  SAME WDM1   457 CONC     ENGL AGGR REPL
RCHRES  45 GQUAL  ROSQAL 3     0.001  SAME WDM1   458 CONC     ENGL AGGR REPL
*** OUTPUT OF BED DEPTHS (FT)
RCHRES  55 SEDTRN BEDDEP 1                 WDM1   554 CONC     ENGL AGGR REPL
RCHRES  39 SEDTRN BEDDEP 1                 WDM1   394 CONC     ENGL AGGR REPL
RCHRES  54 SEDTRN BEDDEP 1                 WDM1   544 CONC     ENGL AGGR REPL
RCHRES  53 SEDTRN BEDDEP 1                 WDM1   534 CONC     ENGL AGGR REPL
RCHRES  45 SEDTRN BEDDEP 1                 WDM1   454 CONC     ENGL AGGR REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
PERLND     PQUAL  SOQUAL 1                 RCHRES         INFLOW IDQAL  1
PERLND     PQUAL  IOQUAL 1                 RCHRES         INFLOW IDQAL  1
PERLND     PQUAL  AOQUAL 1                 RCHRES         INFLOW IDQAL  1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW IDQAL  1
PERLND     PQUAL  SOQS   1                 RCHRES         INFLOW ISQAL  3 1
PERLND     SEDMNT SOSED  1     0.05        RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED  1     0.55        RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED  1     0.40        RCHRES         INFLOW ISED   3
  END MASS-LINK    2

  MASS-LINK        1
```

```
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
IMPLND     IWATER SURO       0.0833333     RCHRES         INFLOW IVOL
IMPLND     IQUAL  SOQUAL 1                 RCHRES         INFLOW IDQAL  1
IMPLND     IQUAL  SOQS   1                 RCHRES         INFLOW ISQAL  3 1
IMPLND     SOLIDS SOSLD  1     0.05        RCHRES         INFLOW ISED   1
IMPLND     SOLIDS SOSLD  1     0.55        RCHRES         INFLOW ISED   2
IMPLND     SOLIDS SOSLD  1     0.40        RCHRES         INFLOW ISED   3
  END MASS-LINK    1

  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
RCHRES     ROFLOW ROVOL  1                 RCHRES         INFLOW IVOL   1
RCHRES     ROFLOW RODQAL 1                 RCHRES         INFLOW IDQAL  1
RCHRES     ROFLOW ROSQAL 1                 RCHRES         INFLOW ISQAL  1
RCHRES     ROFLOW ROSQAL 2                 RCHRES         INFLOW ISQAL  2
RCHRES     ROFLOW ROSQAL 3                 RCHRES         INFLOW ISQAL  3
RCHRES     ROFLOW ROSED  1                 RCHRES         INFLOW ISED   1
RCHRES     ROFLOW ROSED  2                 RCHRES         INFLOW ISED   2
RCHRES     ROFLOW ROSED  3                 RCHRES         INFLOW ISED   3

  END MASS-LINK    3
END MASS-LINK

END RUN
```

```
RUN

GLOBAL
  UCI for Whiteoak Bayou for Segment 1017
  START       1999/04/01 00:00  END    2001/09/30 23:00
  RUN INTERP OUTPT LEVELS    3    0
  RESUME     0 RUN     1                          UNITS      1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------------->
MESSU      24   ncal02.ech
           91   ncal02.out
WDM1       25   bacti-out.wdm
WDM2       26   COHRAIN.WDM
WDM3       27   WWSW1202.WDM
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND     113
      IMPLND     213
      PERLND     112
      IMPLND     212
      PERLND     111
      IMPLND     211
      PERLND     110
      IMPLND     210
      PERLND     104
      IMPLND     204
      PERLND     107
      IMPLND     207
      PERLND     109
      IMPLND     209
      PERLND     117
      IMPLND     217
      PERLND     108
      IMPLND     208
      PERLND     102
      IMPLND     202
      PERLND     103
      IMPLND     203
      PERLND     101
      IMPLND     201
      PERLND     143
      IMPLND     243
      PERLND     142
      IMPLND     242
      PERLND     141
      IMPLND     241
      PERLND     140
      IMPLND     240
      PERLND     106
      IMPLND     206
      PERLND     105
      IMPLND     205
      PERLND     149
      IMPLND     249
      PERLND     148
      IMPLND     248
      PERLND     146
      IMPLND     246
      RCHRES      12
      RCHRES      13
      RCHRES      11
      RCHRES      10
      RCHRES       4
```

```
        RCHRES       7
        RCHRES       9
        RCHRES      17
        RCHRES       8
        RCHRES       2
        RCHRES       3
        RCHRES       1
        RCHRES      43
        RCHRES      42
        RCHRES      41
        RCHRES      40
        RCHRES       6
        RCHRES       5
        RCHRES      49
        RCHRES      48
        RCHRES      46
      END INGRP
END OPN SEQUENCE

PERLND
  ACTIVITY
*** <PLS >               Active Sections                                ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  149    0    0    1    1    0    0    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** < PLS>                       Print-flags                            PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  101  149    4    4    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***             Name                  Unit-systems   Printer BinaryOut
*** <PLS >                                t-series Engl Metr Engl Metr
*** x -  x                                 in  out
  101  149Pervious lands-open               1    1    0    0    0    0
  END GEN-INFO

  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
  101  149    0    1    1    1    0    0    0    0    1    0    0    0
  END PWAT-PARM1

  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  101             1.       10.      0.05      306.      0.01        0.       0.9
  102             1.        6.      0.05      306.      0.01        0.       0.8
  103  149        1.       10.      0.05      306.      0.01        0.       0.9
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
  101            40.       35.        2.        2.        0.      0.02        0.
  102            40.       35.        2.        2.        0.      0.03        0.
  103  149       40.       35.        2.        2.        0.      0.02        0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                        (1/day)
  101            0.1       2.5      0.35        3.       0.9       0.3
  102            0.1       2.5      0.35        8.       0.9       0.1
  103  149       0.1       2.5      0.35        3.       0.9       0.3
```

```
  END PWAT-PARM4

  PWAT-PARM5
*** <PLS >       FZG      FZGL
*** x -  x
  101  149        1.       0.1
  END PWAT-PARM5

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101  149      0.01      0.01       0.3      0.01       1.5      0.01      0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  149  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  END MON-INTERCEP

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101  149  0.2  0.2  0.3  0.3  0.4  0.4  0.4  0.4  0.4  0.3  0.2  0.2
  END MON-LZETPARM

  SED-PARM1
*** <PLS >  Sediment parameters 1
*** x -  x  CRV VSIV SDOP
  101  149    0    0    0
  END SED-PARM1

  SED-PARM2
*** <PLS >      SMPF      KRER      JRER     AFFIX     COVER      NVSI
*** x -  x                                  (/day)           lb/ac-day
  101  149        1.      0.32       1.7       0.1        0.        0.
  END SED-PARM2

  SED-PARM3
*** <PLS >  Sediment parameter 3
*** x -  x      KSER      JSER      KGER      JGER
  101            0.1       0.7       0.1        0.
  102  103       0.1       0.7       0.1        1.
  104            0.1       1.7       0.1        2.
  105            0.1       0.7       0.1        0.
  106            0.1       1.7       0.1        1.
  107            0.1       0.7       0.1        0.
  108            0.1       0.7       0.1        1.
  109            0.1       1.7       0.1        1.
  110  111       0.1       0.7       0.1        0.
  112            0.1       1.7       0.1        1.
  113            0.1       0.7       0.1        0.
  117            0.1       1.7       0.1        2.
  140  142       0.1       0.7       0.1        0.
  143            0.1       2.7       0.1        3.
  146            0.1       2.7       0.1        3.
  148  149       0.1       1.7       0.1        2.
  END SED-PARM3

  SED-STOR
*** <PLS >  Detached sediment storage (tons/acre)
*** x -  x      DETS
  101  149        0.
  END SED-STOR

  NQUALS
*** <PLS >
```

```
  *** x -  xNQUAL
    101  149    1
    END NQUALS

    PQL-AD-FLAGS
  ***                        Atmospheric Deposition Flags
  *** < PLS>  QUAL1  QUAL2  QUAL3  QUAL4  QUAL5  QUAL6  QUAL7  QUAL8  QUAL9 QUAL10
  *** x  - x <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C>
    101  149   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
    END PQL-AD-FLAGS

    QUAL-PROPS
  *** <PLS >  Identifiers and Flags
  *** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
    101  149E coli          cfu     1    0    0    1    0    1    0    0    0
    END QUAL-PROPS

    QUAL-INPUT
  ***         Storage on surface and nonseasonal parameters
  ***            SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
  *** x -  x                           ac.day
    101        1E+11 10000.8     5.8 5.8E+104.64E+10     0.01     0.      0.
    102        1E+11     5.8     5.8 5.8E+126.64E+12     0.5      0       0
    103        1E+11     1e7     5.8 3.8E+072.64E+07     0.01     0.      0.
    104        1E+11     1e7     5.8 1.8E+051.64E+05     0.01     0.      0.
    105  106   1E+11     1e7     5.8 7.8E+097.64E+09     0.01     0.      0.
    107        1E+11     1e7     5.8 8.8E+108.64E+10     0.01     0.      0.
    108        1E+11     1e7     5.8 2.8E+102.64E+10     0.01     0.      0.
    109        1E+11     1e7     5.8 6.8E+096.64E+09     0.01     0.      0.
    110        1E+11     1e7     5.8 6.8E+086.64E+08     0.01     0.      0.
    111  113   1E+11     1e7     5.8 6.8E+106.64E+10     0.01     0.      0.
    114  116   1E+11     1e7     5.8 3.8E+109.64E+10     0.01     0.      0.
    117        1E+11     1e7     5.8 3.8E+099.64E+09     0.01     0.      0.
    118  139   1E+11     1e7     5.8 7.8E+116.64E+12     0.01     0.      0.
    140        1E+11     1e7     9.8 9.8E+127.64E+12     0.5      0.      0.
    141        1E+11     1e3     9.8 1.8E+061.64E+06     0.01     0.      0.
    142        1E+11     1e3     9.8 3.8E+062.64E+06     0.01     0.      0.
    143        1E+11     1e3     9.8 3.8E+033.64E+03     0.5      0.      0.
    144  145   1E+11     1e7     9.8 7.8E+115.64E+11     0.5      0.      0.
    146        1E+11     1e7     9.8 7.8E+115.64E+11     0.01     0.      0.
    148  149   1E+11     1e7     5.8 1.8E+101.64E+10     0.01     0.      0.
    END QUAL-INPUT

  END PERLND

  IMPLND
    ACTIVITY
  *** <ILS >               Active Sections
  *** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
    201  249    0    0    1    1    0    1
    END ACTIVITY

    PRINT-INFO
  *** <ILS > ******** Print-flags ******** PIVL  PYR
  *** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
    201  249    4    4    4    4    4    4    0    1
    END PRINT-INFO

    GEN-INFO
  ***             Name             Unit-systems   Printer BinaryOut
  *** <ILS >                           t-series Engl Metr Engl Metr
  *** x -  x                            in  out
    201  249Commercial or paved          1    1    0    0    0    0
    END GEN-INFO

    IWAT-PARM1
  *** <ILS >        Flags
```

```
*** x -  x CSNO RTOP  VRS  VNN RTLI
  201  249    0    0    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                           (in)
  201           150.     0.001      0.25       0.6
  202           150.     0.001      0.25       0.4
  203  249      150.     0.001      0.25       0.6
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  201  249       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  201  249      0.01      0.01
  END IWAT-STATE1

  SLD-PARM2
***             KEIM      JEIM    ACCSDP    REMSDP
*** <ILS >                         tons/      /day
*** x -  x                        ac.day
  201            2.3       0.7 0.0008677      0.00005
  202            2.3       0.7 0.0007652      0.00005
  203            2.3       0.7 0.0007602      0.00005
  204            0.3       0.7 0.0005394      0.00005
  205            2.3       0.7 0.0011658      0.00005
  206            1.3       0.7 0.0011047      0.00005
  207            2.3       0.7 0.0008757      0.00005
  208            2.3       0.7 0.0009129      0.00005
  209            2.3       0.7 0.0005685      0.00005
  210            2.3       0.7 0.0007177      0.00005
  211            2.3       0.7 0.0005747      0.00005
  212            2.3       0.7 0.0003135      0.00005
  213            2.3       0.7 0.0005774      0.00005
  217            2.3       0.7 0.0009032      0.00005
  240            2.3       0.7 0.0016511      0.00005
  241            2.3       0.7  0.001321      0.00005
  242            2.3       0.7 0.0012641      0.00005
  243            2.3       0.7 0.0011264      0.00005
  246            2.3       0.7 0.0014106      0.00005
  248            2.3       0.7 0.0014106      0.00005
  249            2.3       0.7 0.0003852      0.10005
  END SLD-PARM2

  SLD-STOR
*** <ILS >  Solids storage (tons/acre)
*** x -  x
  201  249        0.
  END SLD-STOR

  NQUALS
*** <ILS >
*** x -  xNQUAL
  201  249    1
  END NQUALS

  IQL-AD-FLAGS
***                        Atmospheric Deposition Flags
*** < ILS>  QUAL1  QUAL2  QUAL3  QUAL4  QUAL5  QUAL6  QUAL7  QUAL8  QUAL9 QUAL10
*** x  - x <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C> <F><C>
```

```
  201  249   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0   0  0
  END IQL-AD-FLAGS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
  201  249E coli          cfu     1    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                   ac.day
  201        1E+10   1e7  8.54E+118.07E+11       0.5
  202        1E+10     5.81.66E+092.53E+09       1.0
  203        1E+10   1e7  8.06E+088.55E+08       0.5
  204        1E+10   1e7  1.63E+061.84E+06       0.5
  205        1E+10   1e7  1.97E+11 1.3E+11       0.5
  206        1E+10   1e7  1.72E+111.12E+11       0.5
  207        1E+10   1e7  5.11E+095.34E+09       0.5
  208        1E+10   1e7  9.35E+108.68E+10       0.5
  209        1E+10   1e7  8.29E+108.63E+10       0.5
  210        1E+10   1e3  1.71E+051.17E+05       0.5
  211        1E+10   1e7  1.35E+111.78E+11       0.5
  212        1E+10   1e7  1.68E+111.27E+11       0.5
  213        1E+10   1e7   1.1E+111.68E+11       0.5
  217        1E+10   1e7  1.42E+081.94E+08       0.5
  240        1E+10   1e7  9.03E+125.13E+12       0.5
  241        1E+10   1e1  2.38E+018.28E+01       0.01
  242        1E+10   1e1  1.26E+019.26E+01       0.01
  243        1E+10   1e3  1.83E+031.63E+03       0.5
  244        1E+10   1e7  1.83E+091.63E+09       0.5
  245        1E+10   1e7  1.83E+091.63E+09       0.5
  246        1E+10   1e7  1.83E+111.63E+11       0.5
  248        1E+10   1e7  1.86E+111.73E+11       0.5
  249        1E+10   1e7  1.18E+11 1.6E+11       0.5
  END QUAL-INPUT

END IMPLND

RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
    1   49    1    1    0    0    1    1    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1   49    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***              Name        Nexits   Unit Systems   Printer
*** RCHRES                               t-series  Engl Metr LKFG
*** x -  x                                 in  out
    1     Brickhouse Gully        1         1    1   91    0    0    0    0
    2     Cole Creek              1         1    1   91    0    0    0    0
    3     WO-555+90-478+85        1         1    1   91    0    0    0    0
    4     WO-1043+96-772+85       1         1    1   91    0    0    0    0
    5    6LWOB                    1         1    1   91    0    0    0    0
    7     WO-772+85-641+50        1         1    1   91    0    0    0    0
    8     VOGEL CREEK             1         1    1   91    0    0    0    0
    9     VOGEL CREEK Up          1         1    1   91    0    0    0    0
   10     WO-1160+15-1043+96      1         1    1   91    0    0    0    0
```

```
    11     WO-1219+95-1160+15      1         1    1   91    0    0    0    0
    12     E132-00-00              1         1    1   91    0    0    0    0
    13     MOST UPSTREAM WOB       1         1    1   91    0    0    0    0
    17     Vogel-12700-0+00        1         1    1   91    0    0    0    0
    40     WO-182+50-75+40         1         1    1   91    0    0    0    0
    41     WOB @ HEIGHTS           1         1    1   91    0    0    0    0
    42     WO-354+85-285+71        1         1    1   91    0    0    0    0
    43     ELLA                    1         1    1   91    0    0    0    0
    46     WO-75+40-1+60           1         1    1   91    0    0    0    0
    48     LWOB OUT                1         1    1   91    0    0    0    0
    49     LWOB                    1         1    1   91    0    0    0    0
  END GEN-INFO

  HYDR-PARM1
***         Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT  for each
*** x  - x  FG FG FG FG  possible   exit *** possible   exit     possible   exit
    1   49   0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1  1  1  1
  END HYDR-PARM1

  HYDR-PARM2
*** RCHRES FTBW FTBU       LEN     DELTH     STCOR        KS      DB50
*** x -  x             (miles)      (ft)      (ft)                 (in)
    1        0.   1.     5.782       40.      47.1       0.1    0.0154
    2        0.   2.     6.703      36.9      54.6       0.1    0.0154
    3        0.   3.     1.459       7.2      36.5       0.1    0.0154
    4        0.   4.     5.135      26.4      68.2       0.1    0.0154
    5        0.   5.     2.042      18.6      33.1       0.1    0.0154
    6        0.   6.     2.296      22.5      52.1       0.1    0.0154
    7        0.   7.     2.488       8.1      60.1       0.1    0.0154
    8        0.   8.     1.621      16.4      43.7       0.1    0.0154
    9        0.   9.     4.046      25.1      74.4       0.1    0.0154
   10        0.  10.      2.21       11.      94.6       0.1    0.0154
   11        0.  11.     1.133       6.1     105.6       0.1    0.0154
   12        0.  12.     1.558       6.1     111.7       0.1    0.0154
   13        0.  13.     1.986       6.1     111.7       0.1    0.0154
   17        0.  17.     2.405      15.8      57.6       0.1    0.0154
   40        0.  40.     2.023       9.6      -0.9       0.1    0.0154
   41        0.  41.     1.955       8.8       8.7       0.1    0.0154
   42        0.  42.       1.3       8.2      17.5       0.1    0.0154
   43        0.  43.     2.349      10.8      25.7       0.1    0.0154
   46        0.  46.     1.396       5.4      -6.3       0.1    0.0154
   48        0.  48.     1.813      17.5      -0.5       0.1    0.0154
   49        0.  49.     2.088      15.6      17.2       0.1    0.0154
*** DB50 is average of WOB data from Table 5.19 in draft final report
  END HYDR-PARM2

  MON-CONVF
*** RCHRES  Monthly f(VOL) adjustment factors
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
    1   49 0.97 0.89 0.89 0.91 0.93 0.93 0.94 0.95 0.95 0.98 0.98 0.97
  END MON-CONVF

  HYDR-INIT
***         Initial conditions for HYDR section
***RC HRES       VOL  CAT Initial value  of COLIND     initial  value  of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible exit,ft3
    1   49        1.       4.2  4.5  4.5  4.5  4.2       2.1  1.2  0.5  1.2  1.8
  END HYDR-INIT

  SANDFG
*** RCHRES
*** x -  x SNDFG
    1   49    3
  END SANDFG

  SED-GENPARM
```

```
  *** RCHRES    BEDWID    BEDWRN       POR
  *** x -  x      (ft)      (ft)
      1   49       10.      100.       0.5
    END SED-GENPARM

    SAND-PM
  *** RCHRES         D         W       RHO     KSAND    EXPSND
  *** x -  x      (in)  (in/sec)  (gm/cm3)
      1    4    0.0049    0.5244     2.575        5.       5.3
      5   12    0.0049    0.5244     2.575        5.       7.3
     13   49    0.0049    0.5244     2.575        5.       5.3
    END SAND-PM

    SILT-CLAY-PM
  *** RCHRES         D         W       RHO     TAUCD     TAUCS         M
  *** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
      1         0.0003 0.0000881       2.2       0.1      0.11       2.7
  *** Cole Creek
      2    3    0.0003 0.0000881       2.2        0.       0.1       2.7
      4         0.0003 0.0000881       2.2       0.1      0.11       2.7
  *** Little WOB
      5         0.0003 0.0000881       2.2        0.    0.0001       2.7
      6         0.0003 0.0000881       2.2       0.1      0.11       2.7
      7         0.0003 0.0000881       2.2    0.0404    0.0521       2.7
  *** Vogel Creek
      8         0.0003 0.0000881       2.2        0.     0.111       2.7
      9   13    0.0003 0.0000881       2.2        0.    0.0001       2.7
     17         0.0003 0.0000881       2.2        0.       0.1       2.7
  *** Below Heights
     40         0.0003 0.0000881       2.2       0.3      0.31       2.7
  *** Above Heights
     41   42    0.0003 0.0000881       2.2       0.1      0.15       2.7
  *** Above Ella
     43         0.0003 0.0000881       2.2        0.       0.1       2.7
     46         0.0003 0.0000881       2.2       0.29       0.3       2.7
     48         0.0003 0.0000881       2.2        0.       0.1       2.7
     49         0.0003 0.0000881       2.2        0.    0.0001       2.7
    END SILT-CLAY-PM

    SILT-CLAY-PM
  *** RCHRES         D         W       RHO     TAUCD     TAUCS         M
  *** x -  x      (in)  (in/sec)    gm/cm3    lb/ft2    lb/ft2  lb/ft2.d
      1         0.0002 0.0000217       2.3       0.1      0.11       2.7
  *** Cole Creek
      2    3    0.0002 0.0000217       2.3        0.       0.1       2.7
      4         0.0002 0.0000217       2.3       0.1      0.11       2.7
  *** Little WOB
      5         0.0002 0.0000217       2.3        0.    0.0001       2.7
      6         0.0002 0.0000217       2.3       0.1      0.11       2.7
      7         0.0002 0.0000217       2.3    0.0404    0.0521       2.7
  *** Vogel Creek
      8         0.0002 0.0000217       2.3        0.     0.111       2.7
      9   13    0.0002 0.0000217       2.3        0.    0.0001       2.7
     17         0.0002 0.0000217       2.3        0.       0.1       2.7
  *** Below Heights
     40         0.0002 0.0000217       2.3       0.3       0.3       2.7
  *** Above Heights
     41   42    0.0002 0.0000217       2.3       0.1       0.1       2.7
  *** Above Ella
     43         0.0002 0.0000217       2.3        0.       0.1       2.7
     46         0.0002 0.0000217       2.3       0.29       0.3       2.7
     48         0.0002 0.0000217       2.3        0.       0.1       2.7
     49         0.0002 0.0000217       2.3        0.    0.0001       2.7
    END SILT-CLAY-PM

    SSED-INIT
  *** RCHRES     Suspended sed concs (mg/l)
```

```
  *** x -  x      Sand      Silt      Clay
      1             0.    228.78    152.52
    END SSED-INIT

    BED-INIT
  *** RCHRES    BEDDEP  Initial bed composition
  *** x -  x      (ft)      Sand      Silt      Clay
      1   49      0.5       0.50      0.25      0.25
    END BED-INIT
  *** changed bed composition from 0.75 sand, 0.16 silt, 0.09 clay to 0.5, 0.25, and 0.25..
  *** this change affected the sediment bed depth

    GQ-AD-FLAGS
  ***        Atmospheric Deposition Flags
  *** RCHRES GQUAL1 GQUAL2 GQUAL3
  *** x -  x <F><C> <F><C> <F><C>
      1   49   0  0   0  0   0  0
    END GQ-AD-FLAGS

    GQ-QALDATA
  *** RCHRES                GQID      DQAL    CONCID      CONV     QTYID
  *** x -  x                        concid
      1   49E coli                      0.      u/dL    0.0035  cfu
    END GQ-QALDATA

    GQ-QALFG
  *** RCHRES HDRL OXID PHOT VOLT BIOD  GEN SDAS
  *** x -  x
      1   49    0    0    0    0    0    1    1
    END GQ-QALFG

    GQ-GENDECAY
  *** RCHRES    FSTDEC     THFST
  *** x -  x    (/day)
      1    1   0.80000     1.024
      2    2   0.80000     1.024
      3    4   0.80000     1.024
      5    6   0.80000     1.024
      7   39   1.80000     1.024
     40        0.80000     1.024
     41   42   8.80000     1.024
     43   43   4.80000     1.024
     44   45   1.80000     1.024
     46        0.80000     1.024
     48   49   0.80000     1.024
    END GQ-GENDECAY

    GQ-SEDDECAY
  *** RCHRES     KSUSP    THSUSP      KBED     THBED
  *** x -  x      /day                /day
      1          0.011     1.024     0.011     1.024
      2          0.011     1.024     0.011     1.024
      3   39     0.051     1.024     0.011     1.024
      40  40     0.011     1.024     0.111     1.024
      41  41     6.151     1.024     0.111     1.024
      42  42     6.151     1.024     0.111     1.024
      43  43     0.151     1.024     0.111     1.024
      44  45     0.051     1.024     0.111     1.024
      46  46     0.011     1.024     0.011     1.024
      47  47     0.051     1.024     0.111     1.024
      48  49     0.011     1.024     0.011     1.024
    END GQ-SEDDECAY


    GQ-KD
  *** RCHRES                  Partition coefficients (l/mg)
  *** x -  x ADPM(1,1) ADPM(2,1) ADPM(3,1) ADPM(4,1) ADPM(5,1) ADPM(6,1)
```

```
      1   39   0.0001    25000.     25000.  0.0001    0.0001      0.0001
      40  47   0.0001    25000.     25000.  0.0001    0.0001      0.0001
      48  49   0.0001    25000.     25000.  0.0001    0.0001      0.0001
    END GQ-KD

    GQ-ADRATE
  *** RCHRES         Adsorption/desorption rate parameters (/day)
  *** x -  x ADPM(1,2) ADPM(2,2) ADPM(3,2) ADPM(4,2) ADPM(5,2) ADPM(6,2)
      1   39   0.0001    0.0001     50000.  0.0001    0.0001      0.0001
      40  47   0.0001    0.0001     50000.  0.0001    0.0001      0.0001
      48  49   0.0001    0.0001     50000.  0.0001    0.0001      0.0001
    END GQ-ADRATE

    GQ-ADTHETA
  *** RCHRES     Adsorption/desorption temp. correction parameters
  *** x -  x ADPM(1,3) ADPM(2,3) ADPM(3,3) ADPM(4,3) ADPM(5,3) ADPM(6,3)
      1   49      1.07      1.07      1.07      1.07      1.07      1.07
    END GQ-ADTHETA

    GQ-SEDCONC
  *** RCHRES  Initial concentrations on sediment (concu/mg)
  *** x -  x     SQAL1     SQAL2     SQAL3     SQAL4     SQAL5     SQAL6
      1   49        0.        0.     0.204        0.        0.     0.204
    END GQ-SEDCONC

  END RCHRES

  FTABLES
    FTABLE     12
   rows cols                              ***
     13    4
       depth      area    volume  outflow1 ***
          0.        9.        0.        0.
        0.25      9.43      1.56      1.67
        0.29      9.47      1.77      2.26
        0.61      9.92      4.74     16.71
        0.72     10.05      5.62     22.59
        2.18     11.83     19.13     167.1
        2.58     12.33     23.33     225.9
        8.71     32.95    107.12     1671.
       10.16     50.03    150.05     2259.
       10.69     57.13    169.81     2598.
       11.53     71.68    192.95     3339.
       38.69   2720.73  55727.55    26712.
        200.  14064.26  288072.2  138082.2
    END FTABLE 12

    FTABLE     13
   rows cols                              ***
     13    4
       depth      area    volume  outflow1 ***
          0.        9.        0.        0.
        0.25      9.43      1.56      1.67
        0.29      9.47      1.77      2.26
        0.61      9.92      4.74     16.71
        0.72     10.05      5.62     22.59
        2.18     11.83     19.13     167.1
        2.58     12.33     23.33     225.9
        8.71     32.95    107.12     1671.
       10.16     50.03    150.05     2259.
       10.69     57.13    169.81     2598.
       11.53     71.68    192.95     3339.
       38.69   2720.73  55727.55    26712.
        200.  14064.25  288072.1  138082.2
    END FTABLE 13

    FTABLE     11
```

```
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.        5.        0.        0.
       0.28       5.1      0.85      4.05
       0.33      5.14        1.      5.49
       0.92      5.82      3.41     40.53
        1.1      5.93      4.11     54.92
       3.44      7.44     15.57     405.3
       4.07      7.86     19.35     549.2
      11.78     15.01    100.19     4053.
      13.23      74.9    149.92     5492.
      13.71     164.1    191.61     6198.
      14.71    424.17    425.37     7915.
      44.67    1893.6   48571.7    63320.
   END FTABLE 11

   FTABLE     10
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.       12.        0.        0.
       1.07     12.02      3.37      6.48
        1.2     12.17      4.09      8.77
       2.86      14.6     13.75     64.75
       3.33     15.27     17.24     87.74
       6.67     24.52     70.75     647.5
       7.34     25.56     86.01     877.4
      15.13    104.37    389.78     6475.
        16.    328.99    646.09     8774.
      16.31    472.46     810.1     9697.
        17.    873.23   1320.89    12302.
       55.4   3069.99 101087.64    98416.
   END FTABLE 10

   FTABLE      4
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.       12.        0.        0.
       1.11     12.94     13.06      9.46
       1.15     13.32     14.16     11.65
       2.04     17.74     38.67     94.58
       2.22     18.78     44.41     116.5
       5.83     89.21    331.45     945.8
       6.47     93.53    407.44     1165.
      18.37   1164.87   2824.98     9458.
      19.43   2011.74   4270.14    11650.
       19.9   2275.96   5081.09    12591.
      20.98   2692.44   6634.07    14883.
      76.92   4016.11 187162.66   119064.
   END FTABLE  4

   FTABLE      7
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.       17.        0.        0.
       0.32     17.03     15.68     11.63
       0.34      17.1     16.35     13.72
       1.01     18.85     33.59    116.31
        1.1     19.12     36.42    137.23
       3.36     33.61    120.03    1163.1
       3.69     52.93     142.3    1372.3
      14.65    393.67   1431.26    11631.
      17.07    848.11   2427.01    13723.
      17.56    994.93   2891.82    14902.
```

```
      18.86   1237.07   4101.19    17399.
      83.48   1706.36 104981.83   139192.
   END FTABLE  7

   FTABLE      9
  rows cols                              ***
    13    4
      depth      area    volume  outflow1 ***
         0.        3.        0.        0.
        0.4      3.89      1.57       1.5
       0.47      4.21      1.84      2.09
       1.32      6.71      5.88       15.
       1.55      7.22       7.3      20.9
       4.06     13.59     30.32      150.
       4.55     15.15     38.35      209.
      10.57    203.95    276.29     1500.
      11.82     334.5    452.45     2090.
       12.4    386.21    523.69     2380.
      13.37    552.71    783.04     3000.
      30.64   1126.23  10732.27    30000.
       200.   7351.38  70053.98  195822.5
   END FTABLE  9

   FTABLE     17
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.        4.        0.        0.
       0.39      4.43      1.98      3.14
       0.46      4.61      2.26      4.12
       1.62      5.87      6.54     31.42
       1.92      6.14      7.77     41.18
       6.36     11.24     32.85     314.2
       7.17     12.42     40.58     411.8
      16.15    241.16    412.06     3142.
      17.92    421.33    839.52     4118.
      18.61    493.96   1136.52     4573.
      19.71    617.06   1619.49     5500.
      31.18     914.1  17558.52    55000.
   END FTABLE 17

   FTABLE      8
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.       10.        0.        0.
       0.93     10.97      6.53     14.84
       1.06     11.02      6.97     18.85
        3.2     20.07     23.61    148.41
        3.4     20.33     26.73    188.45
       6.83      26.3    110.97    1484.1
        7.6     27.16    124.73    1884.5
      23.35     45.47    587.77    14841.
      28.49     263.4   1078.84    18845.
      28.89     303.5   1229.69    19991.
      30.81    442.46   1911.24    23735.
      98.34    920.22  61100.36   189880.
   END FTABLE  8

   FTABLE      2
  rows cols                              ***
    13    4
      depth      area    volume  outflow1 ***
         0.       13.        0.        0.
        0.8     13.92     13.76      3.27
        0.9     14.38     14.86      4.54
       1.96     17.88     27.36     32.68
```

```
        2.28     18.92     31.93     45.43
        5.45     32.66     97.35     326.8
        5.91     35.41    119.64     454.3
       10.83     64.73    422.48     3268.
       12.15    199.46    613.12     4543.
       12.67    603.06    973.83     5107.
       13.77   1409.86   1840.73     6500.
       25.63     3898.  70242.54    65000.
        200.  30417.48  548127.5  507218.1
    END FTABLE  2

    FTABLE      3
   rows cols                              ***
     12    4
       depth      area    volume  outflow1 ***
          0.        2.        0.        0.
        1.21      1.64      1.39     15.78
        1.41      1.73      1.65     20.56
        3.69      8.91     10.76    157.81
        3.95      9.07     12.66    205.62
        8.01     11.72     49.25    1578.1
        9.08     12.38     59.93    2056.2
       26.27     34.82    452.16    15781.
       31.27    202.72     955.3    20562.
       32.29    259.65   1140.03    21923.
       34.51    396.49   1762.69    25507.
      105.03    619.46  44364.18   204056.
    END FTABLE  3

    FTABLE      1
   rows cols                              ***
     13    4
       depth      area    volume  outflow1 ***
          0.        9.        0.        0.
        0.22      9.27      2.48      5.95
        0.27      9.65        3.        8.
        0.92     10.54     10.76      59.5
         1.1     10.59     12.93       80.
        4.02     12.92     45.15      595.
        5.01     15.75     56.81      800.
       13.68     80.37    278.23     5950.
       15.55    580.46   1059.49     8000.
       16.16    898.26   1584.77     8800.
       17.64   1315.46   2426.86    10900.
       31.68   4708.94  113972.5   109000.
        200.  29728.16  719523.6  688131.4
    END FTABLE  1

    FTABLE     43
   rows cols                              ***
     12    4
       depth      area    volume  outflow1 ***
          0.        3.        0.        0.
        1.33      3.64      3.06     22.09
        1.36      5.15      4.03      28.6
        2.88     15.38     21.17    220.92
        3.07     15.76     25.06    286.03
        6.96     20.58     96.01    2209.2
        7.77     21.76    116.25    2860.3
       28.66     58.63    846.17    22092.
       33.24    252.21    1471.7    28603.
       34.28    360.88   1800.46    31709.
       36.65    587.47   2739.26    37858.
      113.77    906.81   68806.7   302864.
    END FTABLE 43

    FTABLE     42
```

```
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.        2.        0.        0.
       2.24      2.01      1.78      22.6
       2.36      2.74      2.22     27.32
        4.2      8.31     12.07    225.96
       4.45      8.46     13.79    273.22
      10.13     11.53     58.53    2259.6
      10.95     12.06      68.1    2732.2
      33.27     34.13    577.12    22596.
      37.71    371.05   1213.71    27322.
      39.33    519.56   1920.03    30203.
      43.19      658.   3944.83    35780.
     121.21    674.75  56382.73   286240.
   END FTABLE 42

   FTABLE     41
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.        8.        0.        0.
       6.31      8.45     16.28     23.09
       6.32      8.65     16.62     27.42
        6.4     11.42     27.23    230.92
       6.44     11.58     29.14    274.23
      10.24     16.69    101.84    2309.2
      11.11     17.51    116.31    2742.3
      31.44     56.56    864.15    23092.
      36.63    174.24   1329.01    27423.
      38.17    294.35   1723.31    29800.
      42.21    646.84   3729.96    35823.
     126.48    871.86  73104.39   286584.
   END FTABLE 41

   FTABLE     40
  rows cols                                ***
    12    4
      depth      area    volume  outflow1 ***
         0.       16.        0.        0.
       15.2     16.82    111.17     22.84
      15.21     16.83    111.18     27.44
      15.22     16.87    111.67    228.36
      15.23     16.89    111.92    274.42
      16.55     22.56    150.03    2283.6
      17.14     25.62      167.    2744.2
      33.35    110.02    1414.4    22836.
      38.23    135.68   1968.19    27442.
      38.64    139.61   2038.01    29680.
      43.64    264.45   3037.11    35837.
      132.4    473.05  43849.74   286696.
   END FTABLE 40

   FTABLE      6
  rows cols                                ***
    13    4
      depth      area    volume  outflow1 ***
         0.       80.        0.        0.
       0.73     88.61    122.66     12.39
       0.86     88.62    122.72      18.5
        0.9     88.65    122.78     20.75
       0.98     88.75    122.95       25.
       3.14     101.8    136.08      185.
       4.07     104.8    140.43      275.
      13.23    411.05    472.07     1850.
      14.19    562.88     744.4     2500.
      14.66    604.62    831.15     2700.
```

```
      15.25    761.94   1379.77     3300.
      50.92   1737.94 125105.94    26400.
       200.   6826.16  491382.2  103692.1
   END FTABLE  6

   FTABLE      5
  rows cols                              ***
    13    4
      depth      area    volume  outflow1 ***
         0.        5.        0.        0.
       1.63      5.37      4.26     42.38
       1.92      5.41      5.34     63.01
       1.93      5.42      5.35     63.26
       2.08      5.44       6.2     75.91
       5.19      6.06     23.17     632.6
       5.85      6.53     29.14    835.01
      23.86    192.24    370.13     6326.
      27.36    420.03    996.72     7591.
       28.7    574.68   1459.51     8130.
      29.89    776.35   2197.11     9800.
      64.22   2232.01  75514.91    78400.
       150.   5213.35 176381.76 183120.52
   END FTABLE  5

   FTABLE     49
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.       10.        0.        0.
       3.29     10.12     12.14     53.16
       3.68     10.61     15.21     77.19
       3.71     10.65     15.47     79.34
       3.91     10.86     17.06       93.
        8.3     13.52     64.16     793.4
      10.03     16.26     82.92     1023.
      23.23     46.02    492.27     7934.
      24.57     99.92     745.8     9300.
       25.1    143.54    872.84    10030.
      26.02    227.36   1102.38    11300.
      52.02   1962.01  37762.74    90400.
   END FTABLE 49

   FTABLE     48
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.        7.        0.        0.
       1.97      7.42     10.39     58.18
       2.27      7.92     13.11     85.53
       2.29      7.94     13.23     86.84
       2.42      8.11     14.59    103.05
       6.26     11.44     54.06     868.4
       7.28     13.91     89.06   1133.55
      27.78      77.6    688.25     8684.
      29.35     89.24    831.72    10305.
      29.84     92.68    875.19    11129.
       30.8     99.24    948.33    12800.
       43.4    506.03  10828.87   102400.
   END FTABLE 48

   FTABLE     46
  rows cols                              ***
    12    4
      depth      area    volume  outflow1 ***
         0.       38.        0.        0.
      20.33     38.61    271.75     29.06
      20.34     38.62    271.76     35.96
```

```
      20.35     38.67    272.04    290.63
      20.36      38.7    272.22    359.57
      20.51     41.84    299.26    2906.3
      20.66     43.05    314.93    3595.7
      30.58     88.16   1286.17    29063.
      35.34    131.13   1877.71    35957.
      36.12    133.26   1929.66    38056.
      39.79    185.52   2744.89    46041.
     133.67    328.36  30964.37   368328.
  END FTABLE 46
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name> x x ***
*** Met Seg RG14
WDM2    14 PREC     ENGLZERO          SAME PERLND 101 104 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 101 104 EXTNL  PETINP
*** Met Seg RG14
WDM2    14 PREC     ENGLZERO          SAME PERLND 106 117 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 106 117 EXTNL  PETINP
*** Met Seg RG32
WDM2    32 PREC     ENGLZERO          SAME PERLND 143     EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 143     EXTNL  PETINP
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME PERLND 105     EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 105     EXTNL  PETINP
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME PERLND 140 142 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 140 142 EXTNL  PETINP
*** Met Seg RG30
WDM2    30 PREC     ENGLZERO          SAME PERLND 146 149 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME PERLND 146 149 EXTNL  PETINP
*** Met Seg RG14
WDM2    14 PREC     ENGLZERO          SAME IMPLND 201 204 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 201 204 EXTNL  PETINP
*** Met Seg RG14
WDM2    14 PREC     ENGLZERO          SAME IMPLND 206 217 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 206 217 EXTNL  PETINP
*** Met Seg RG32
WDM2    32 PREC     ENGLZERO          SAME IMPLND 243     EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 243     EXTNL  PETINP
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME IMPLND 205     EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 205     EXTNL  PETINP
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME IMPLND 240 242 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 240 242 EXTNL  PETINP
*** Met Seg RG30
WDM2    30 PREC     ENGLZERO          SAME IMPLND 246 249 EXTNL  PREC
WDM2    11 PEVT     ENGL              SAME IMPLND 246 249 EXTNL  PETINP
*** Met Seg RG14
WDM2    14 PREC     ENGLZERO          SAME RCHRES   1   4 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES   1   4 EXTNL  POTEV
*** Met Seg RG14
WDM2    14 PREC     ENGLZERO          SAME RCHRES   6  17 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES   6  17 EXTNL  POTEV
*** Met Seg RG32
WDM2    32 PREC     ENGLZERO          SAME RCHRES  43     EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  43     EXTNL  POTEV
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME RCHRES   5     EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES   5     EXTNL  POTEV
*** Met Seg RG34
WDM2    34 PREC     ENGLZERO          SAME RCHRES  40  42 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  40  42 EXTNL  POTEV
*** Met Seg RG30
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```
WDM2    30 PREC     ENGLZERO          SAME RCHRES  46  49 EXTNL  PREC
WDM2    12 EVAP     ENGL              SAME RCHRES  46  49 EXTNL  POTEV
*** WWTP & Dry Weather Storm Sewer Loading
WDM3   113 CONC     ENGLZERO          SAME RCHRES  13     INFLOW IDQAL
WDM3   111 CONC     ENGLZERO          SAME RCHRES  11     INFLOW IDQAL
WDM3   110 CONC     ENGLZERO          SAME RCHRES  10     INFLOW IDQAL
WDM3   104 CONC     ENGLZERO          SAME RCHRES   4     INFLOW IDQAL
WDM3   107 CONC     ENGLZERO          SAME RCHRES   7     INFLOW IDQAL
WDM3   109 CONC     ENGLZERO          SAME RCHRES   9     INFLOW IDQAL
WDM3   117 CONC     ENGLZERO          SAME RCHRES  17     INFLOW IDQAL
WDM3   102 CONC     ENGLZERO          SAME RCHRES   2     INFLOW IDQAL
WDM3   101 CONC     ENGLZERO          SAME RCHRES   1     INFLOW IDQAL
WDM3   143 CONC     ENGLZERO          SAME RCHRES  43     INFLOW IDQAL
WDM3   142 CONC     ENGLZERO          SAME RCHRES  42     INFLOW IDQAL
WDM3   141 CONC     ENGLZERO          SAME RCHRES  41     INFLOW IDQAL
WDM3   140 CONC     ENGLZERO          SAME RCHRES  40     INFLOW IDQAL
*** WWTP & Dry Weather Storm Sewer Flows
WDM3    13 FLOW     ENGLZERO          SAME RCHRES  13     EXTNL  IVOL
WDM3    11 FLOW     ENGLZERO          SAME RCHRES  11     EXTNL  IVOL
WDM3    10 FLOW     ENGLZERO          SAME RCHRES  10     EXTNL  IVOL
WDM3     4 FLOW     ENGLZERO          SAME RCHRES   4     EXTNL  IVOL
WDM3     7 FLOW     ENGLZERO          SAME RCHRES   7     EXTNL  IVOL
WDM3     9 FLOW     ENGLZERO          SAME RCHRES   9     EXTNL  IVOL
WDM3    17 FLOW     ENGLZERO          SAME RCHRES  17     EXTNL  IVOL
WDM3     2 FLOW     ENGLZERO          SAME RCHRES   2     EXTNL  IVOL
WDM3     1 FLOW     ENGLZERO          SAME RCHRES   1     EXTNL  IVOL
WDM3    43 FLOW     ENGLZERO          SAME RCHRES  43     EXTNL  IVOL
WDM3    42 FLOW     ENGLZERO          SAME RCHRES  42     EXTNL  IVOL
WDM3    41 FLOW     ENGLZERO          SAME RCHRES  41     EXTNL  IVOL
WDM3    40 FLOW     ENGLZERO          SAME RCHRES  40     EXTNL  IVOL
END EXT SOURCES

SCHEMATIC
<-Volume->                  <--Area-->     <-Volume->  <ML#> ***       <sb>
<Name>   x                  <-factor->     <Name>   x        ***        x x
PERLND 112                         971     RCHRES  12      2
IMPLND 212                         722     RCHRES  12      1
PERLND 113                        1695     RCHRES  13      2
IMPLND 213                        1219     RCHRES  13      1
RCHRES  13                                 RCHRES  11      3
RCHRES  12                                 RCHRES  11      3
PERLND 111                         663     RCHRES  11      2
IMPLND 211                         836     RCHRES  11      1
RCHRES  11                                 RCHRES  10      3
PERLND 110                        2366     RCHRES  10      2
IMPLND 210                        2259     RCHRES  10      1
RCHRES  10                                 RCHRES   4      3
PERLND 104                        6299     RCHRES   4      2
IMPLND 204                        4836     RCHRES   4      1
RCHRES   4                                 RCHRES   7      3
PERLND 107                         975     RCHRES   7      2
IMPLND 207                         838     RCHRES   7      1
PERLND 109                        1646     RCHRES   9      2
IMPLND 209                        1532     RCHRES   9      1
RCHRES   9                                 RCHRES  17      3
PERLND 117                        1152     RCHRES  17      2
IMPLND 217                         846     RCHRES  17      1
RCHRES   7                                 RCHRES   8      3
RCHRES  17                                 RCHRES   8      3
PERLND 108                         417     RCHRES   8      2
IMPLND 208                         345     RCHRES   8      1
PERLND 102                        2493     RCHRES   2      2
IMPLND 202                        3742     RCHRES   2      1
RCHRES   8                                 RCHRES   3      3
RCHRES   2                                 RCHRES   3      3
PERLND 103                        2568     RCHRES   3      2
IMPLND 203                        1844     RCHRES   3      1
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PERLND 101                        3197     RCHRES   1      2
IMPLND 201                        4489     RCHRES   1      1
RCHRES   3                                 RCHRES  43      3
RCHRES   1                                 RCHRES  43      3
PERLND 143                        1322     RCHRES  43      2
IMPLND 243                        2830     RCHRES  43      1
RCHRES  43                                 RCHRES  42      3
PERLND 142                         853     RCHRES  42      2
IMPLND 242                        1318     RCHRES  42      1
RCHRES  42                                 RCHRES  41      3
PERLND 141                         480     RCHRES  41      2
IMPLND 241                        1215     RCHRES  41      1
RCHRES  41                                 RCHRES  40      3
PERLND 140                         437     RCHRES  40      2
IMPLND 240                         779     RCHRES  40      1
PERLND 106                        1827     RCHRES   6      2
IMPLND 206                        2019     RCHRES   6      1
RCHRES   6                                 RCHRES   5      3
PERLND 105                        2212     RCHRES   5      2
IMPLND 205                        3057     RCHRES   5      1
RCHRES   5                                 RCHRES  49      3
PERLND 149                        1157     RCHRES  49      2
IMPLND 249                        1858     RCHRES  49      1
RCHRES  49                                 RCHRES  48      3
PERLND 148                         906     RCHRES  48      2
IMPLND 248                        1367     RCHRES  48      1
RCHRES  40                                 RCHRES  46      3
RCHRES  48                                 RCHRES  46      3
PERLND 146                         142     RCHRES  46      2
IMPLND 246                         528     RCHRES  46      1
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg strg***
*** OUTPUT OF FLOW (ACRE-FT/HR)
RCHRES  41 HYDR   ROVOL  1 1   1000.       WDM1   101 FLOW     ENGL AGGR REPL
RCHRES  48 HYDR   ROVOL  1 1   1000.       WDM1   201 FLOW     ENGL AGGR REPL
RCHRES  43 HYDR   ROVOL  1 1   1000.       WDM1   301 FLOW     ENGL AGGR REPL
RCHRES   2 HYDR   ROVOL  1 1   1000.       WDM1   401 FLOW     ENGL AGGR REPL
RCHRES   3 HYDR   ROVOL  1 1   1000.       WDM1   501 FLOW     ENGL AGGR REPL
*** OUTPUT OF DISSOLVED EC (CFU/HR)
RCHRES  41 GQUAL  RODQAL 1     0.001  SAME WDM1   102 CONC     ENGL AGGR REPL
RCHRES  48 GQUAL  RODQAL 1     0.001  SAME WDM1   202 CONC     ENGL AGGR REPL
RCHRES  43 GQUAL  RODQAL 1     0.001  SAME WDM1   302 CONC     ENGL AGGR REPL
RCHRES   2 GQUAL  RODQAL 1     0.001  SAME WDM1   402 CONC     ENGL AGGR REPL
RCHRES   3 GQUAL  RODQAL 1     0.001  SAME WDM1   502 CONC     ENGL AGGR REPL
*** OUTPUT OF SEDIMENT ASSOCIATED EC IN ALL SEDIMENT (SAND+SILT+CLAY) (TONS)
RCHRES  41 GQUAL  ROSQAL 4     0.001  SAME WDM1   103 CONC     ENGL AGGR REPL
RCHRES  48 GQUAL  ROSQAL 4     0.001  SAME WDM1   203 CONC     ENGL AGGR REPL
RCHRES  43 GQUAL  ROSQAL 4     0.001  SAME WDM1   303 CONC     ENGL AGGR REPL
RCHRES   2 GQUAL  ROSQAL 4     0.001  SAME WDM1   403 CONC     ENGL AGGR REPL
RCHRES   3 GQUAL  ROSQAL 4     0.001  SAME WDM1   503 CONC     ENGL AGGR REPL
*** CONCENTRATION OF SUSPENDED SEDIMENT (MG/L)
RCHRES  41 SEDTRN SSED   4            AVER WDM1   104 CONC     ENGL AGGR REPL
RCHRES  48 SEDTRN SSED   4            AVER WDM1   204 CONC     ENGL AGGR REPL
RCHRES  43 SEDTRN SSED   4            AVER WDM1   304 CONC     ENGL AGGR REPL
RCHRES   2 SEDTRN SSED   4            AVER WDM1   404 CONC     ENGL AGGR REPL
RCHRES   3 SEDTRN SSED   4            AVER WDM1   504 CONC     ENGL AGGR REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
***Conversion of Runoff from inches to ac-ft = 0.083333
```

```
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
PERLND     PWTGAS PODOXM                   RCHRES         INFLOW OXIF   1
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT  1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW IDQAL  1
PERLND     PEST   POPST  1                 RCHRES         INFLOW IDQAL  1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL  1 1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL  2 1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL  3 1
PERLND     SEDMNT SOSED  1        0.05     RCHRES         INFLOW ISED   1
PERLND     SEDMNT SOSED  1         0.4     RCHRES         INFLOW ISED   2
PERLND     SEDMNT SOSED  1        0.55     RCHRES         INFLOW ISED   3
  END MASS-LINK    2

  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
IMPLND     IWATER SURO       0.0833333     RCHRES         INFLOW IVOL
IMPLND     IWTGAS SODOXM                   RCHRES         INFLOW OXIF   1
IMPLND     IWTGAS SOHT                     RCHRES         INFLOW IHEAT  1
IMPLND     IQUAL  SOQUAL 1                 RCHRES         INFLOW IDQAL  1
IMPLND     SOLIDS SOSLD  1        0.05     RCHRES         INFLOW ISED   1
IMPLND     SOLIDS SOSLD  1         0.4     RCHRES         INFLOW ISED   2
IMPLND     SOLIDS SOSLD  1        0.55     RCHRES         INFLOW ISED   3
  END MASS-LINK    1

  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name> x x  ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    3
END MASS-LINK

END RUN
```

APPENDIX C

RESULTS OF MODEL CALIBRATION

AND LOAD ALLOCATION SCENARIOS

Table C-1. Global Hydrologic Calibration and Sensitivity Analysis for the WO HSPF Model

Cases	Pervious Land Parameters										Impervious Land Parameters			Reaches	Root Mean Square of Flows			Optimal Values			Remarks[1]
	LZSN (in)	INFILT (in/hr)	AGWRC (1/day)	INFEXP	DEEPFR	CEPSC (in)	UZSN (in)	NSUR	INTFW	IRC (1/day)	SLSUR	NSUR	RETSC (ft)	KS	Cole Creek	WOB @ Heights	Sum	Variable	Opt Value	Selectd	
1	6	0.16	0.98	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	14,692.4	92,144.2	106,836.7	LZSN			Base from BASINS
2	1	0.16	0.98	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	15,807.1	96,342.3	112,149.4	LZSN			Global
3	20	0.16	0.98	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,911.7	90,147.5	104,059.2	LZSN	20	20	Global
4	20	0.01	0.98	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	16,640.4	101,286.0	117,926.4	INFILT			Global
5	20	0.9	0.98	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	12,443.5	92,937.5	105,381.0	INFILT	0.16	0.16	Global
6	20	0.16	0.1	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	14,109.5	88,648.4	102,757.9	AGWRC	0.1	0.1	Global
7	20	0.16	0.5	2	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,967.6	88,663.2	102,630.9	AGWRC			Global
8	20	0.16	0.1	0.5	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,684.3	87,416.6	101,100.9	INFEXP	0.5	0.5	Global
9	20	0.16	0.1	3	0.1	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	14,343.9	89,376.7	103,720.6	INFEXP			Global
10	20	0.16	0.1	0.5	0.1	0.01	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,684.3	87,416.6	101,100.9	CEPSC			Global
11	20	0.16	0.1	0.5	0.1	1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,684.3	87,416.6	101,100.9	CEPSC	0.1	0.1	Insensitive
12	20	0.16	0.1	0.5	0.01	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,721.7	87,351.0	101,072.7	DEEPFR	0.01	0.01	Global
13	20	0.16	0.1	0.5	0.5	0.1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,545.3	88,018.4	101,563.7	DEEPFR			Global
14	20	0.16	0.1	0.5	0.01	0.1	0.5	0.2	0.75	0.5	0.001	0.1	0.065	0.5	14,465.5	90,844.3	105,309.8	UZSN			Global
15	20	0.16	0.1	0.5	0.01	0.1	2.5	0.2	0.75	0.5	0.001	0.1	0.065	0.5	13,136.9	86,055.2	99,192.1	UZSN	2.5	2.5	Global
16	20	0.16	0.1	0.5	0.01	0.1	5	0.2	0.75	0.5	0.001	0.1	0.065	0.5	12,775.3	87,583.3	100,358.7	UZSN			Global
17	20	0.16	0.1	0.5	0.01	0.1	2.5	0.1	0.75	0.5	0.001	0.1	0.065	0.5	13,459.3	87,280.4	100,739.7	NSUR			Global
18	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	0.75	0.5	0.001	0.1	0.065	0.5	12,931.1	85,339.4	98,270.5	NSUR	0.35	0.35	Global
19	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	0.05	0.5	0.001	0.1	0.065	0.5	13,190.2	85,720.1	98,910.3	INTFW			Global
20	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	1.5	0.5	0.001	0.1	0.065	0.5	12,660.3	85,020.5	97,680.8	INTFW			Global
21	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.5	0.001	0.1	0.065	0.5	12,347.2	84,953.4	97,300.6	INTFW	5	5	Global
22	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.01	0.001	0.1	0.065	0.5	12,634.1	82,911.2	95,545.4	IRC			Global
23	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.1	0.065	0.5	12,315.1	80,988.8	93,304.0	IRC	0.1	0.1	Global
24	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.999	0.001	0.1	0.065	0.5	12,566.8	93,565.6	106,132.4	IRC			Global
25	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.005	0.1	0.065	0.5	13,644.3	87,726.7	101,371.0	SLSUR	0.001	0.001	Global
26	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.05	0.1	0.065	0.5	14,874.3	95,064.2	109,938.4	SLSUR			Global
27	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.075	0.065	0.5	12,834.5	83,505.9	96,340.3	NSUR			Global
28	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	0.065	0.5	10,299.2	73,166.0	83,465.2	NSUR	0.25	0.25	Global
29	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	0.005	0.5	10,682.7	74,350.0	85,032.7	RETSC			Global
30	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	0.01	0.5	10,635.7	74,183.0	84,818.8	RETSC			Global
31	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	0.1	0.5	10,136.9	72,821.1	82,958.0	RETSC			Global
32	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	0.25	0.5	9,660.5	71,908.5	81,569.0	RETSC			Global
33	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	0.5	0.5	9,145.9	71,326.8	80,472.7	RETSC			Global
34	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	1	0.5	8,687.6	71,105.7	79,793.4	RETSC	1	1	Global
35	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	1	0.1	7,968.1	69,802.4	77,770.5	KS	0.1	0.1	Global
36	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	1	0.25	8,223.3	70,223.6	78,446.9	KS			Global
37	20	0.16	0.1	0.5	0.01	0.1	2.5	0.35	5	0.1	0.001	0.25	1	0.1	7,968.1	69,802.4	77,770.5				Subbasin division
38	20	0.9	0.1	0.5	0.5	0.1	5	0.35	5	0.1	0.001	0.25	1	0.1	8,205.2	70,764.2	78,969.4				Subbasin 02
39	20	0.16	0.1	0.5	0.5	0.1	5	0.35	5	0.1	0.001	0.25	1	0.1	7,823.8	70,189.3	78,013.1				Subbasin 02
40	20	0.16	0.1	0.5	0.01	0.1	5	0.35	5	0.1	0.001	0.25	1	0.1	7,939.6	70,039.6	77,979.1				Subbasin 02
41	20	0.16	0.1	0.5	0.5	0.1	2.5	0.35	5	0.1	0.001	0.25	1	0.1	7,789.9	69,897.3	77,687.2				Subbasin 02

Notes/Abbreviations:

[1] Global means that the calibration variable is adjusted globally, i.e. on all subbasins; Insensitive means that the adjustment of a variable resulted in insignificant change to RMS; and "Sub-xx" means that the bolded variables are adjusted only for subbasin xx

LZSN is alower zone nominal storage (inches) INFILT is an index to the infiltration capacity of the soil (inches/hr) LSUR is the length of the assumed overland flow plane (feet) LSUR is the length of the assumed overland flow plane (feet) SLSUR is the slope of the overland flow

AGWRC is the groundwater recession rate (1/day) INFEXP is the exponent in the infiltration equation (no units) UZSN is the upper zone nominal storage (inches) NSUR is Manning's n for the assumed overland flow plane (complex units) INTFW is the interflow inflow parameter

Table C-2. Global Hydrologic Calibration and Sensitivity Analysis for the BB HSPF Model

Cases	Pervious Land Parameters										Impervious Land Parameters			Reaches	Root Mean Square of Flows					Optimal Values			Remarks[1]
	LZSN (in)	INFILT (in/hr)	LSUR (ft)	SLSUR	AGWRC (1/day)	INFEXP	UZSN (in)	NSUR	INTFW	IRC (1/day)	SLSUR	NSUR	RETSC (ft)	KS	Dairy Ashford	West Belt	Piney Pt.	Shepherd	Sum	Variable	Opt Value	Selectd	
1	1	0.16	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	8,933.3	18,194.7	23,892.3	56,253.7	107,273.9	LZSN			Global
2	6	0.16	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	8,034.6	17,788.2	22,713.6	55,682.6	104,218.9	LZSN			Base from BASINS
3	20	0.16	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,518.4	17,662.7	22,154.3	56,214.7	103,550.1	LZSN	20	36	Global
4	36	0.16	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,200.4	17,653.1	21,914.7	57,221.1	103,989.2	LZSN			Global
5	36	0.01	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	8,778.0	18,357.0	24,173.3	57,220.0	108,528.3	INFILT			Global
6	36	0.9	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,993.5	17,617.8	21,736.2	57,987.2	104,334.8	INFILT			Global
7	36	1.5	300	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,995.2	17,612.9	21,731.6	57,953.5	104,293.2	INFILT	1.5	0.9	Global
8	36	0.9	100	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,993.5	17,617.8	21,736.2	57,986.6	104,334.2	LSUR	100	300	Insensitive
9	36	0.9	1000	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,993.5	17,617.8	21,736.2	57,987.2	104,334.8	LSUR			Global
10	36	0.9	3000	0.001	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,993.5	17,617.8	21,736.2	57,987.2	104,334.8	LSUR			Global
11	36	0.9	300	0.0005	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,993.5	17,617.8	21,736.2	57,987.2	104,334.8	SLSUR			Global
12	36	0.9	300	0.01	0.98	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,993.5	17,617.8	21,736.2	57,986.6	104,334.2	SLSUR	0.01	0.001	Insensitive
13	36	0.9	300	0.001	0.01	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,554.5	17,173.8	21,679.2	55,570.1	101,977.6	AGWRC			Global
14	36	0.9	300	0.001	0.1	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,365.5	17,071.6	21,244.2	55,170.4	100,851.6	AGWRC			Global
15	36	0.9	300	0.001	0.25	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,262.2	17,112.4	21,156.8	55,313.7	100,845.0	AGWRC	0.25	0.25	Global
16	36	0.9	300	0.001	0.5	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,162.7	17,232.4	21,239.1	55,832.2	101,466.5	AGWRC			Global
17	36	0.9	300	0.001	0.999	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	6,972.0	17,724.1	21,868.8	58,610.2	105,175.1	AGWRC			Global
18	6	0.9	300	0.001	0.25	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,729.5	16,349.7	20,475.9	52,244.8	96,799.9	LZSN	6		Global
19	10	0.9	300	0.001	0.25	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,634.7	16,493.5	20,553.5	52,602.4	97,284.0	LZSN			Global
20	20	0.9	300	0.001	0.25	2	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,465.4	16,781.1	20,804.7	53,680.8	98,732.0	LZSN			Global
21	6	0.9	300	0.001	0.25	0.5	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,777.0	16,371.6	20,605.7	52,564.6	97,318.9	INFEXP			Global
22	6	0.9	300	0.001	0.25	1	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,754.2	16,379.6	20,597.1	52,591.0	97,321.9	INFEXP			Global
23	6	0.9	300	0.001	0.25	3	1.128	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,777.9	16,384.4	20,543.4	52,043.7	96,749.4	INFEXP	3	2	Global
24	6	0.9	300	0.001	0.25	2	0.05	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,945.9	16,252.0	20,639.2	52,033.1	96,870.1	UZSN			Global
25	6	0.9	300	0.001	0.25	2	0.5	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,801.7	16,299.0	20,451.8	51,803.7	96,356.1	UZSN	0.5	0.5	Global
26	6	0.9	300	0.001	0.25	2	2.5	0.2	0.75	0.5	0.001	0.1	0.065	0.5	7,676.4	16,476.2	20,688.5	53,192.1	98,033.2	UZSN			Global
27	6	0.9	300	0.001	0.25	2	0.5	0.1	0.75	0.5	0.001	0.1	0.065	0.5	7,834.0	16,328.4	20,533.9	51,877.4	96,573.7	NSUR			Global
28	6	0.9	300	0.001	0.25	2	0.5	0.35	0.75	0.5	0.001	0.1	0.065	0.5	7,785.0	16,274.6	20,388.0	51,760.6	96,208.3	NSUR	0.35	0.35	Global
29	6	0.9	300	0.001	0.25	2	0.5	0.35	0.05	0.5	0.001	0.1	0.065	0.5	7,917.3	16,393.0	20,717.7	51,884.9	96,912.9	INTFW			Global
30	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.5	0.001	0.1	0.065	0.5	7,762.2	16,258.8	20,338.7	51,754.5	96,114.2	INTFW	1.5	1.5	Global
31	6	0.9	300	0.001	0.25	2	0.5	0.35	5	0.5	0.001	0.1	0.065	0.5	7,754.0	16,258.1	20,335.6	51,768.0	96,115.8	INTFW			Global
32	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.01	0.001	0.1	0.065	0.5	7,907.5	16,285.1	20,580.9	51,531.7	96,305.2	IRC			Global
33	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.1	0.065	0.5	7,845.6	16,209.4	20,345.9	51,342.2	95,743.1	IRC	0.1	0.1	Global
34	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.999	0.001	0.1	0.065	0.5	7,693.8	16,408.7	20,565.8	52,835.0	97,503.3	IRC			Global
35	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.005	0.1	0.065	0.5	8,326.8	17,145.1	22,065.0	53,681.1	101,218.0	SLSUR	0.001	0.001	Global
36	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.05	0.1	0.065	0.5	8,800.3	18,365.9	23,943.6	56,345.0	107,454.8	SLSUR			Global
37	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.075	0.065	0.5	8,034.4	16,527.4	20,981.6	52,182.3	97,725.6	NSUR			Global
38	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.15	0.065	0.5	7,564.6	15,843.7	19,492.7	50,237.1	93,138.1	NSUR			Global
39	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.065	0.5	7,189.9	15,566.1	18,565.9	49,233.0	90,555.0	NSUR	0.25	0.25	Global
40	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.5	7,331.8	15,464.7	18,628.2	49,018.7	90,443.5	RETSC	0.005	0.005	Global
41	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.01	0.5	7,317.0	15,476.2	18,618.7	49,067.9	90,479.8	RETSC			Global
42	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.1	0.5	7,130.1	15,612.2	18,558.6	49,372.2	90,673.2	RETSC			Global
43	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.1	6,698.7	15,437.7	18,230.6	49,355.0	89,722.0	KS	0.1	0.1	Global
44	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.25	6,854.6	15,423.7	18,344.9	49,218.9	89,842.1	KS			Global
45	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.75	8,107.4	15,626.9	19,072.9	48,894.1	91,701.2	KS			Global
46	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.1	6,698.7	15,437.7	18,230.6	49,355.0	89,722.0				Subbasin divided
47	**20**	0.9	300	0.001	**0.1**	2	**2.5**	0.35	1.5	**0.999**	0.001	0.25	**0.1**	0.1	6,216.9	15,713.5	18,350.1	49,535.8	89,816.4				Sub-55
48	6	0.9	300	0.001	0.25	2	**0.05**	0.35	1.5	0.1	0.001	0.25	0.005	**0.25**	6,216.9	15,707.8	18,341.9	49,514.7	89,781.4				Sub-39
49	6	0.9	300	0.001	0.25	2	0.5	0.35	1.5	0.1	0.001	0.25	0.075	0.1	6,216.9	15,707.8	18,326.9	49,553.0	89,804.7				Sub-33,54
50	6	**0.15**	300	0.001	**0.1**	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.1	6,216.9	15,707.8	18,326.9	50,326.1	90,577.7				Sub-26,27,44,45,50-53
51	6	0.9	300	0.001	**0.1**	2	0.5	0.35	1.5	0.1	0.001	0.25	0.005	0.1	6,216.9	15,707.8	18,326.9	49,403.0	89,654.7				Sub-26,27,44,45,50-53

Notes/Abbreviations:

The bolded numbers are variables changed during the subbasin calibration

[1] Global means that the calibration variable is adjusted globally, i.e. on all subbasins; Insensitive means that the adjustment of a variable resulted in insignificant change to RMS; and "Sub-xx" means that the bolded variables are adjusted only for subbasin xx

LZSN is alower zone nominal storage (inches) INFILT is an index to the infiltration capacity of the soil (inches/hr) LSUR is the length of the assumed overland flow plane (feet) LSUR is the length of the assumed overland flow plane (feet) SLSUR is the slope of the overland flow plane (no units)

AGWRC is the groundwater recession rate (1/day) INFEXP is the exponent in the infiltration equation (no units) UZSN is the upper zone nominal storage (inches) NSUR is Manning's n for the assumed overland flow plane (complex units) INTFW is the interflow inflow parameter (unitless)

IRC is the interflow recession parameter (1/day) RETSC is the retention (interception) storage capacity of the surface (inches) KS is the weighting factor for hydraulic routing

Table C-3. Model results from Buffalo Bayou Scenarios

Data for Figure 6.1: Geometric Mean of entire simulation period (cfu/dL)

Subwatershed	No Upstream	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	0.00	0.00	743.98	743.98	688.76
39	1.23	1.23	1387.69	1527.93	1528.73
54	104.39	104.39	1188.26	1263.68	1352.62
53	94.91	94.91	1098.24	1191.93	1266.98
52	145.96	145.96	1104.42	1371.72	1484.97
51	454.66	454.66	1054.77	1891.53	1992.41
50	446.03	446.03	1028.18	1854.18	1951.67
44	457.87	457.87	1010.75	1886.07	1984.51
45	561.90	561.90	1004.06	2155.03	2252.46
38	556.75	556.75	992.29	2159.58	2250.96
37	560.56	560.56	986.21	2218.25	2301.82
47	597.82	597.82	995.16	2408.09	2480.88

Data for Figure 6.2: Loads for entire simulation period (cfu/simulation period)

Subwatershed	No Upstream	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	1.17E+01	1.17E+01	1.43E+16	1.43E+16	1.43E+16
39	5.90E+15	5.90E+15	2.95E+16	3.54E+16	3.54E+16
54	1.01E+16	1.01E+16	2.91E+16	3.87E+16	3.88E+16
53	1.35E+16	1.35E+16	2.87E+16	4.17E+16	4.18E+16
52	2.73E+16	2.73E+16	2.86E+16	5.52E+16	5.54E+16
51	6.40E+16	6.40E+16	2.87E+16	9.19E+16	9.20E+16
50	6.99E+16	6.99E+16	2.85E+16	9.75E+16	9.77E+16
44	7.88E+16	7.88E+16	2.85E+16	1.06E+17	1.06E+17
45	9.76E+16	9.76E+16	2.78E+16	1.24E+17	1.24E+17
38	9.80E+16	9.80E+16	2.76E+16	1.24E+17	1.25E+17
37	9.79E+16	9.79E+16	2.73E+16	1.24E+17	1.24E+17
47	9.67E+16	9.67E+16	2.67E+16	1.22E+17	1.22E+17

Note: Simulation period is 21,934 hours

Data for Figure 6.3: Number of Days Daily Geometric Mean exceeds 126 cfu/dL

Subwatershed	No Upstream	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	0	0	848	786	786
39	127	127	937	914	914
54	275	275	931	914	914
53	263	263	925	914	914
52	344	344	930	914	914
51	744	744	931	914	914
50	735	735	901	914	914
44	734	734	893	914	914
45	729	729	823	914	914
38	724	724	807	914	914
37	715	715	796	914	914
47	696	696	775	912	913

Note: Simulation period is 914 days

Data for Figure 6.4: Number of Hours Concentration exceeds 394 cfu/dL

Subwatershed	No Upstream	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	0	0	17681	17681	17623
39	2168	2168	21024	21186	21186
54	2882	2882	21023	20804	21414
53	3115	3115	20842	20053	21360
52	3981	3981	20878	19979	21453
51	10563	10563	20770	21244	21794
50	10266	10266	20019	20539	21239
44	10277	10277	19772	20417	21110
45	10488	10488	18280	19953	20458
38	10428	10428	17929	19848	20204
37	10358	10358	17632	19762	20065
47	10635	10635	17167	19683	19954

Note: Simulation period is 21,934 days

Table C-4. Model results from Whiteoak Bayou Scenarios

Data for Figure 6.1: Geometric Mean of entire simulation period (cfu/dL)

Subwatershed	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
13	132.37	144.93	553.88	590.81
11	159.84	188.61	723.95	818.20
4	173.18	202.06	567.64	637.39
7	155.33	180.21	542.90	605.15
8	152.91	173.72	556.51	609.31
3	118.61	159.18	508.85	626.40
43	97.64	254.29	634.95	1224.37
42	90.50	232.58	577.14	1099.28
41	52.19	131.22	337.19	631.91
40	56.11	130.37	1757.26	2339.03
46	8.97	16.22	295.33	362.95

Data for Figure 6.2: Loads for entire simulation period (cfu/simulation period)

Subwatershed	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	7.67E+13	7.70E+13	1.02E+16	1.02E+16
39	1.51E+14	1.52E+14	2.30E+16	2.30E+16
54	5.55E+14	5.59E+14	2.30E+16	2.30E+16
53	5.92E+14	5.97E+14	2.37E+16	2.37E+16
52	7.26E+14	7.31E+14	3.19E+16	3.20E+16
51	8.50E+14	8.65E+14	1.41E+17	1.41E+17
50	8.18E+14	9.42E+14	2.98E+17	2.98E+17
44	7.63E+14	8.82E+14	2.76E+17	2.76E+17
45	5.89E+14	6.61E+14	2.43E+17	2.43E+17
38	5.86E+14	6.58E+14	5.00E+17	5.00E+17
47	2.37E+14	2.54E+14	3.76E+17	3.76E+17

Note: Simulation period is 21,934 hours

Data for Figure 6.3: Number of Days Daily Geometric Mean exceeds 126 cfu/dL

Subwatershed	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	560	564	570	695
39	589	599	713	715
54	566	578	702	710
53	595	603	713	718
52	578	585	702	705
51	578	584	701	704
44	529	552	696	713
45	484	822	697	908
38	462	817	687	909
37	338	432	621	686
47	346	427	762	799

Note: Simulation period is 914 days

Data for Figure 6.4: Number of Hours Concentration exceeds 394 cfu/dL

Subwatershed	No Sources	No NPS	No PS/Dry Weather Flows	Calibrated Model
55	7889	7924	13038	13064
39	8516	8612	13892	13975
54	8054	8128	12980	13083
53	8732	8821	13223	13353
52	8278	8352	13140	13218
50	8218	8279	13155	13226
44	6649	6778	12747	12866
45	5357	6519	13206	14259
38	4708	5603	12670	13738
37	2611	2941	10433	10898
47	2631	2798	15811	16184

Note: Simulation period is 21,934 days