

*Illicit Discharge Elimination Project  
Harris County, Texas*

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**ILLCIT DISCHARGE ELIMINATION PROJECT  
HARRIS COUNTY, TEXAS**

Prepared for:

Harris County Storm Water Quality Section  
9800 Northwest Freeway, Suite 305  
Houston, Texas 77092

Prepared by:

PBS&J  
1250 Wood Branch Park Drive  
Suite 300  
Houston, Texas 77079

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## Executive Summary

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PBS&J was retained by the Harris County Storm Water Quality Section (HCSWQS) to review and document an Illicit Discharge Elimination Project (IDEP). The IDEP was developed and implemented by HCSWQS staff to investigate whether elimination of illicit discharges to urban waterways would measurably reduce instream indicator bacteria levels, and to determine the approximate cost associated with eliminating illicit discharges. Brickhouse Gully and Vogel Creek were selected by HCSWQS for this study.

Brickhouse Gully (Stream Segment 1017A) is a highly urbanized tributary of White Oak Bayou (Stream Segment 1017). Typical low flow in Brickhouse Gully is in the order of 3 to 5 cubic feet per second (cfs). It was estimated that 20–30% of the low flow was wastewater treatment plant (WWTP) effluent. The sampling site was located at the upstream intersection of Brickhouse Gully and U.S. Highway 290.

Vogel Creek is an improved earthen tributary of White Oak Bayou. HCSWQS measured a dry weather flow rate of 1.76 cfs. It appears that in dry weather the flow in Vogel Creek is predominantly WWTP effluent. The sampling site was at the intersection of Vogel Creek and Breen Drive.

Both streams show high levels of indicator bacteria. Brickhouse Gully is on the 2004 303(d) List of impaired water bodies as not supporting contact recreation use due to bacteria. Vogel Creek is not listed apparently because no assessment was done by the State due to lack of data.

The study involved sampling of dry weather discharges, identification of those with high bacteria concentrations and an attempt at elimination of sources. The Brickhouse Gully site was sampled after the attempt to eliminate high bacteria sources. A historical data set collected by the City of Houston provided the baseline condition. The Vogel Creek site was sampled before and after the attempt to eliminate high bacteria sources. An ancillary study was to investigate the quality of discharges from WWTPs into the study streams. Bacteria and residual chlorine data were collected at the Westway WWTP, Willowood WWTP, and Sunset MHP.

A wide variety of the dry weather discharges were found, including water main leaks, lawn irrigation, air conditioner condensate, groundwater, wash water, and sanitary sewer leaks. Identified sources of sewage were found to be a small proportion of dry weather discharges investigated. Both the flow rate and bacteria level at a particular outfalls appear to be highly variable.

Estimates of bacteria loadings from the dry weather discharge measurements show that dry weather discharges appear to be a major contributor to instream bacteria level in Brickhouse Gully, but relatively minor for Vogel Creek.

Statistical tests comparing mean instream bacteria levels in Brickhouse Gully and Vogel Creek before and after the attempt to eliminate high bacteria sources were conducted. These tests showed a statistical difference in Brickhouse Gully but did not show a statistical difference on Vogel Creek. The result for

Brickhouse Gully is not definitive due to the use of different *E. Coli* (EC) test methods by the City and HCSWQS. Whether or not a statistically significant reduction occurred, the bacteria levels after the elimination attempts were still well in excess of criteria. Moreover, even when dry-weather discharges with high bacteria sources are all eliminated, meeting the EC criteria for contact recreation would likely not be achieved based on the findings in the Luce Bayou Background Study.

A comparison between EC data at the weir and at the outfall of two WWTPs indicates that there was no significant increase in EC concentration in the discharge pipe between the weir and the outfall. The EC concentration at the weir appears to be negatively correlated with total residual chlorine concentration.

Efforts to eliminate dry weather discharges with high bacteria sources should first be focused on streams without substantial dry weather WWTP effluent flow. In this study, the elimination of dry weather sources on Brickhouse Gully, with less than 30% WWTP effluent during dry weather, appeared somewhat successful although the stream standard is still exceeded, whereas, reduction efforts in Vogel Creek, which includes a higher proportion of WWTP effluent, did not appear successful. Due to the inherent high variability of bacteria data, it would be desirable to perform “before and after” instream monitoring on one or two other streams to verify the findings of this study.

With regards to data collection, HCSWQS should consider using the IDEXX method to be consistent with the current norm of EC testing so that data collected by HCSWQS can be compared on an equal basis with data collected by other entities.



## 1.0 INTRODUCTION

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PBS&J was retained under Harris County Purchase Order No. PO83016 to review and document two recent projects by the Harris County Storm Water Quality Section (HCSWQS): the Illicit Discharge Elimination Project (IDEP) and the associated Luce Bayou Background Study. The Luce Bayou Background Study is in a separate report. The IDEP was developed and implemented by HCSWQS staff to investigate whether elimination of illicit discharges to urban waterways would measurably reduce instream indicator bacteria levels, and to determine the approximate cost associated with eliminating illicit discharges. PBS&J provided independent professional services to document and comment on the study methods and results.

In 1998 Harris County, the City of Houston, Texas Department of Transportation (TxDOT), and Harris County Flood Control District received a permit from the U.S. Environmental Protection Agency (EPA) to allow the discharge of storm water from the permittees' storm sewer system into waters of the United States. The permit, called a Municipal Separate Storm Sewer System (MS4) Permit, required permittees to develop a program to locate and eliminate illicit discharges into the MS4. To date, these efforts have included "screening" large storm sewer outfalls for illicit discharges and site visits to sectors of commercial facilities which have been known to present a high potential for discharging pollutants into the MS4.

In 2003, the Texas Clean Rivers Program, administered locally by the Houston-Galveston Area Council (H-GAC), commissioned the Small Watershed Study (PBS&J, 2003) on several small waterways that have high bacteria levels. That study examined the number of illicit discharges to the stream and characterized dry weather discharges. One of the streams in the study was Brickhouse Gully. The study identified 223 potential pollutant sources and 61 discharges in this stream. Eight discharges accounted for a very high percentage of the overall level of bacteria in the stream. The Small Watershed Study did not attempt to identify exact sources of discharges or to eliminate illicit discharges (for example, a source was typically given as a discharge pipe or tributary, rather than the exact source, such as a particular business or a point where a sanitary sewer leaked into a storm sewer). HCSWQS intends to build upon these earlier efforts to locate and eliminate illicit discharges in Brickhouse Gully and Vogel Creek.

The work represents efforts by HCSWQS to eliminate, to the extent practical, illicit discharges along two small streams while characterizing the amount of effort involved in eliminating the discharges and the resulting water quality changes. By understanding the natural baseline for water quality, it can be determined to what level water quality in impaired streams could be improved. In understanding the amount of effort needed to clean up waterways through illicit discharge detection and enforcement, better estimates can be prepared for budgetary and staffing requirements needed to improve water quality to a specified level. An ancillary study was to investigate the quality of discharges from wastewater treatment plants (WWTP) into the study streams.

## 2.0 DESCRIPTION OF STREAMS AND SAMPLING SITES

### 2.1 BRICKHOUSE GULLY

Brickhouse Gully (Stream Segment 1017A) is a highly-urbanized tributary of White Oak Bayou (Stream Segment 1017) with a drainage area of 11.6 square miles. The drainage area is shown on Figure 1. The following observations have been made by HCSWQS. Most of the stream is a concrete channel. The flow of the stream is approximately 10 feet wide and 3 inches deep at low flow. The main channel of Brickhouse Gully is approximately 36,600 feet long and has 10 smaller tributaries. Although most of the stream has maintained its major meanders, the water surface itself is generally unshaded. Land use in the contributing drainage area is mostly single-family residential and light industrial (warehousing). Apart from periphyton (small animals and plants that encrust hard substrates), there is little aquatic life in this stream except for occasional pools. In these pools HCSWQS staff reported seeing large numbers of Blue Tilapia (*Oreochromis aureus*). Brickhouse Gully is on the 2004 303(d) List of impaired waterbodies as not supporting contact recreation use due to bacteria.

U.S. Geological Survey (USGS) gaging station 08074250 (Brickhouse Gully at Costa Rica Street) is located near the confluence of Brickhouse Gully with White Oak Bayou. The gage has a drainage area of 11.4 square miles. The gage record starts from September 1, 1964. Unfortunately, there is no discharge record between October 1, 1981 and September 30, 2003 and since February 12, 2004. The following table shows the percentiles of the discharge record for the period between October 1, 2003 and February 11, 2004.

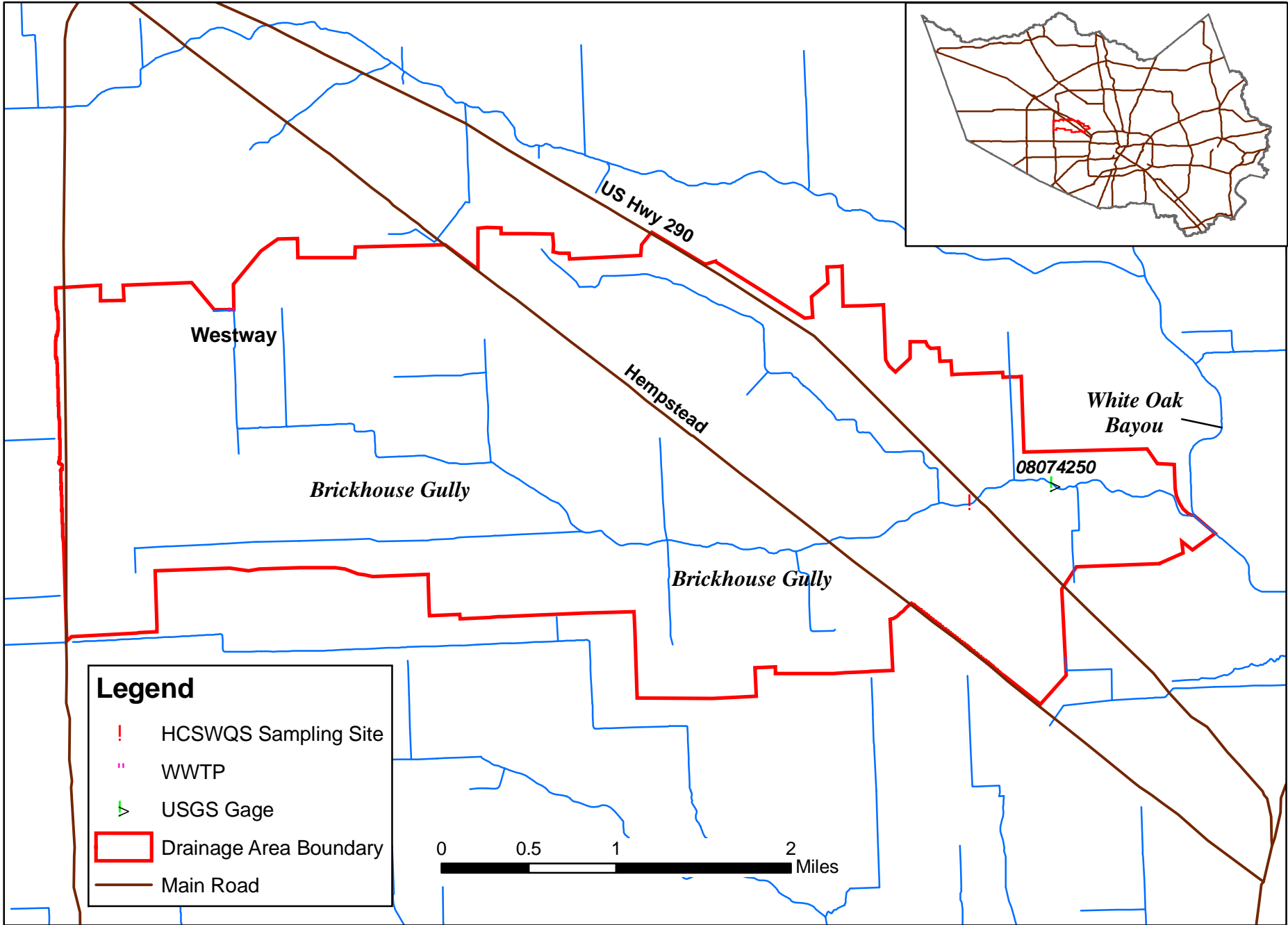
Percentile	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Flow (cfs*)	3.1	3.5	3.9	4.7	5.7	6.5	8.3	13.0	26.8	85.7	2010

cfs = cubic feet per second.

Based on this record, it appears that at low flow, the flow in Brickhouse Gully is in the order of 3 to 5 cfs. The City of Houston Westway Wastewater Treatment Plant is located at the headwater of Brickhouse Gully (TPDES NO. 10495-139, permitted at 0.995 million gallons per day [MGD]). Based on the self-reporting data in the Permit Compliance System (PCS) database (EPA, 2006), between July 2003 and June 2006 the monthly discharges of the plant average about 0.56 MGD (0.87 cfs). Therefore, the effluent of the WWTP is 20–30% of the base flow in Brickhouse Gully.

The sampling site for this study was located at the upstream intersection of Brickhouse Gully and U.S. Highway 290 (29° 49' 35.44" north, -95° 28' 37.28" east). The City of Houston has a well-populated sampling history at this site.

**FIGURE 1**  
**BRICKHOUSE GULLY DRAINAGE AREA**



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## 2.2 VOGEL CREEK

Vogel Creek is an improved earthen tributary of White Oak Bayou, with a drainage area of 8.0 square miles in northwest Harris County, just northwest of the City of Houston corporate limits. The drainage area is shown on Figure 2. The following observations have been made by HCSWQS. The main channel of the study area of Vogel Creek is approximately 25,080 feet long and has four smaller tributaries. The land use for this watershed is predominately residential and commercial, with some undeveloped areas. This stream consists primarily of a wet pilot channel punctuated by plunge pools at street crossings until it accepts treated wastewater effluent from Harris County Water Control & Improvement District #133 (Willowood WWTP, TPDES permit No. WQ11153-001, permitted at 3.0 MGD), at which point the stream becomes much deeper and wider. There are occasional pools and runs downstream of the WWTP. The surface of the stream is generally exposed to sunlight, though there are some reaches in which the creek has riparian foliage. There is a great abundance of fish found at the above-mentioned WWTP outfall. The overwhelming majority of these fish are Sailfin molly (*Poecilia latipinna*), along with (in order of prevalence) Blue tilapia, Rio Grande cichlid (*Cichlasoma cyanoguttatum*), and Western mosquitofish (*Gambusia affinis*). In pools downstream of the WWTP large numbers of South American suckermouth armoured catfish were observed.

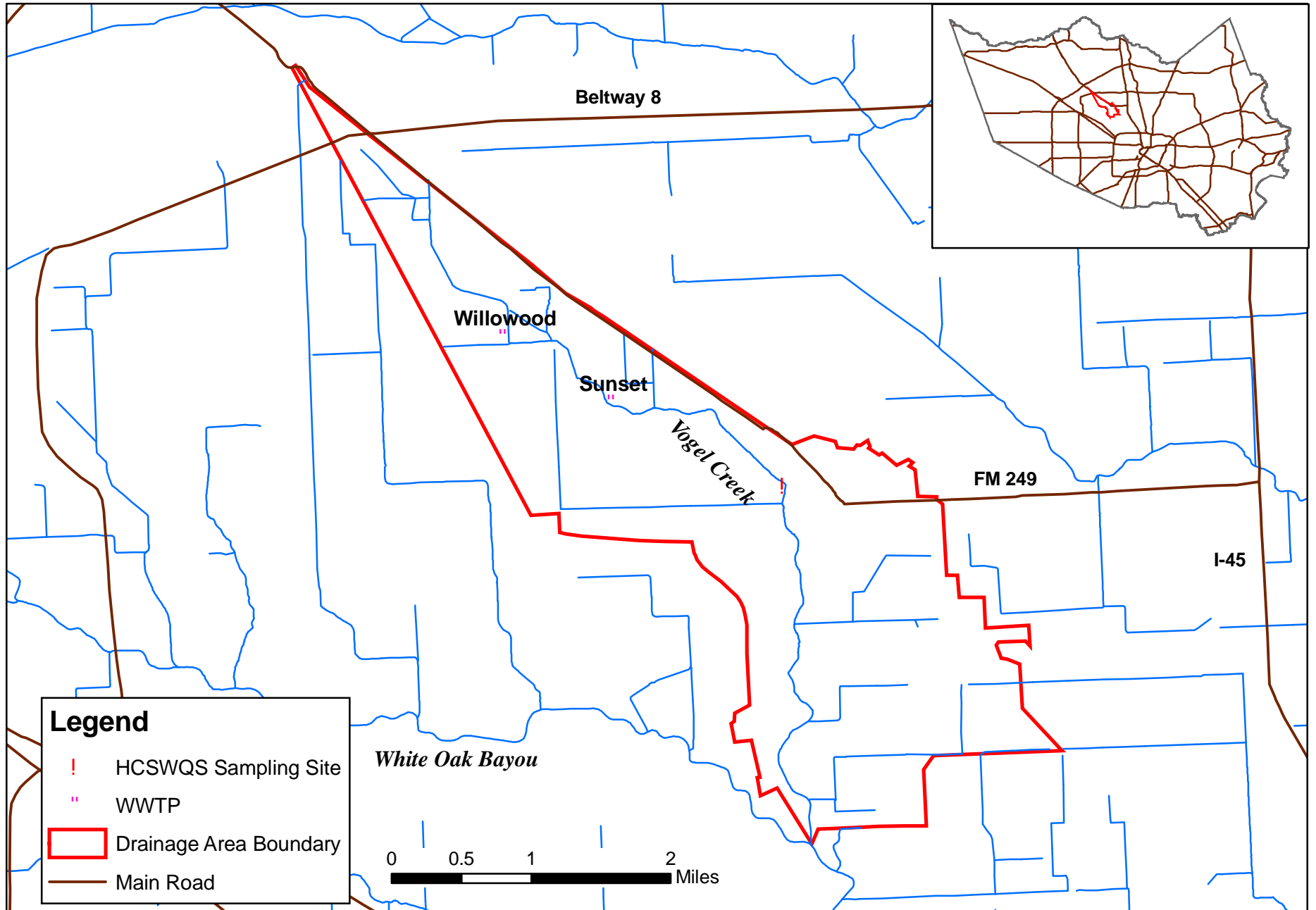
A second, smaller WWTP (William Donald Smith or Sunset MHP, TPDES permit No. WQ14506-001, permitted at 0.012 MGD) discharges directly into Vogel Creek.

Although HCSWQS has observed high levels of indicator bacteria in this study, Vogel Creek is not on the 303(d) List apparently because no assessment was done by the state due to lack of data.

The sampling site for this study was located at the intersection of Vogel Creek and Breen Drive (29° 53' 56.80" north, -95° 28' 7.04" east).

Vogel Creek does not have any flow gaging stations. HCSWQS measured the flow rate at the sampling site on June 5, 2006 during base flow at the time of day when data collection was typically done. That flow measurement was 1.76 cfs. From the PCS database (EPA, 2006) between July 2005 and August 2006, the monthly discharges of the Willowood WWTP average about 1.8 MGD (2.8 cfs). The flow measured on the particular date is less than the typical discharge of the Willowood WWTP. It appears that the base flow of Vogel Creek is predominantly WWTP effluent.

**FIGURE 2  
VOGEL CREEK DRAINAGE AREA**



## **3.0 STUDY APPROACH**

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### **3.1 SAMPLING PROGRAM**

#### **3.1.1 General**

Field sampling for all lab-tested parameters and chain-of-custody procedures were conducted according to procedures described in the TNRCC Water Quality Sampling and Shipping Procedures (2002). Analyses of parameters of interest for instream sampling were reported to follow EPA Standard Methods (40 CFR Part 136). Quality control and quality assurance followed those procedures outlined in TNRCC Surface Water Quality Monitoring Procedures Manual (1999). Laboratory analysis of samples was conducted by an outside contract lab, A & B Laboratories. Other than bacteriological samples, analysis for illicit discharge detection and source identification often consisted of field test kits.

HCSWQS estimated that about 1,000 labor hours have been spent in this study for site reconnaissance, instream monitoring, discharge detection, source tracking, training, and meetings. About one third of the time was used for instream monitoring.

#### **3.1.2 Dry Weather Discharges from Stormwater System**

Following at least 48 hours of antecedent dry period, investigators walked along the banks of the subject streams and any flowing tributaries of the streams. Each discharge into the stream or tributary was sampled and sent to a local lab for enumeration of *E. coli* (EC). Field measurements of the each discharge were taken, which included a qualitative description (odor, clarity, presence of foam or sheen), discharge rate, pH, temperature, total chlorine, and conductivity. Illicit Discharge Detection teams investigated the length of Brickhouse Gully and Vogel Creek twice; i.e., two passes, separated by about 3 to 4 weeks in time.

#### **3.1.3 Wastewater Treatment Plants**

The Willowood WWTP and the Sunset WWTP were sampled 15 times each and the Westway WWTP 14 times. Samples for EC enumeration were taken and total and free chlorine residual measured at the weir and at the outfall pipe to the receiving stream. However, the Westway WWTP had a submerged outfall preventing the collection of end-of-pipe samples. Chlorine residual was measured using HACH test kit CN-66.

#### **3.1.4 Instream Samples**

Base-flow was sampled after a minimum of 3 days antecedent dry period. Frequency of sampling averaged once per week. Field parameters taken were pH, dissolved oxygen (DO), temperature, and conductivity. Laboratory analysis was performed for fecal coliform (FC), *Escherichia coli* (EC), total suspended solids (TSS), total dissolved solids (TDS), ammonia (NH<sub>3</sub>-N), and sulfates. Split samples were

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taken once per month for all parameters except for bacteria (EC and FC). HCSWQS observed a persistent algal bloom beginning in May, 2006 in Brickhouse Gully, and nutrient sampling was added to the original suite of parameters for Brickhouse Gully and Vogel Creek. These additional parameters included total Kjeldahl nitrogen (TKN), nitrate + nitrite ( $\text{NO}_3+\text{NO}_2\text{-N}$ ), total phosphorus, ortho-phosphates, and chlorophyll *a*.

The City of Houston historical data at the Brickhouse Gully sampling site provided the baseline for this stream. There is no known historical baseline water quality data for the study reach of Vogel Creek. HCSWQS sampled the site at Breen Drive 17 times in order to establish a baseline.

Once high bacteria sources were eliminated to the extent practical, 21 and 17 instream water samples were taken at the Brickhouse Gully site and Vogel Creek site, respectively, in order to assess the effects that the high bacteria source elimination might have had on instream water quality.

## **3.2 IDENTIFICATION AND ELIMINATION OF HIGH BACTERIA SOURCES IN STORMWATER SYSTEM**

### **3.2.1 Source Identification**

If a discharge EC level exceeded the 394 cfu/dL single sample criterion (TNRCC, 2000), as determined either through lab or field testing, investigators traced the discharge to its source. Most work included visual observations by opening manhole lids, but dye-tracing was used in some cases.

### **3.2.2 Source Elimination**

Once the source of discharge was determined, and it was confirmed to be an illicit discharge, the source was referred to the appropriate state or local governmental agency for repair or investigation. Discharges of suspected potable water were reported to the owner of the water distribution system, whether or not the discharge exceeded bacteria criteria.

## **3.3 STATISTICAL ANALYSIS APPROACH**

The IDEP sampling protocol specified statistical analysis to test whether there is significant difference between the water quality before and after efforts to eliminate high bacteria sources. The protocol also specified that probability values (p-values) greater than 0.1 are considered insignificant.

The Student's t-Test function in Excel was used to perform the test. The tests were applied to Log(EC) data since the criteria for contact recreation use geometric means.

For comparing bacteria levels before and after efforts to eliminate high bacteria sources, the null hypothesis is that the geometric means of the two data sets are the same. The alternate hypothesis is that the geometric mean after the attempt to eliminate high bacteria sources is lower than before. The one-tailed distribution, two-sample unequal variance test was used.

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For comparing bacteria levels at the weir and the outfall of WWTPs, the null hypothesis is that the geometric means at the two locations are the same, and the alternate hypothesis is that the geometric means are not the same. The two-tailed distribution, paired test was used.

### **3.4 DISCUSSION**

This study employed Standard Method 9222G for EC analysis. In this procedure, EC data are enumerated using a nutrient agar substrate containing 4-methylumbelliferyl- $\beta$ -D-glucuronide (MUG) following the FC test (APHA, 1998). In this procedure, EC are a subset of the FC rather than an independent test. In the Quality Assurance Project Plans (QAPPs) of both the H-GAC's Clean Rivers Program and the Bacteria Total Maximum Daily Load (TMDL) Study for Buffalo and White Oak Bayous, the IDEXX method for EC enumeration is specified. Moreover, in the current Surface Water Quality Monitoring Procedures published by TCEQ (2003), only the IDEXX method is mentioned for the analysis of EC data. Nevertheless, EC data analyzed by the MUG test is still accepted by TCEQ. More discussion will follow in Section 5.



## **4.0 RESULTS**

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### **4.1 DRY WEATHER DISCHARGES**

#### **4.1.1 Characterization of Sources**

The dry weather discharge data for Brickhouse Gully and Vogel Creek are presented in Tables 1 and 2, respectively. In general HCSWQS has used “20,000 cfu/dL” to replace bacteria results that are “too numerous to count” (TNTC). For discharges of domestic sewage, HCSWQS replaced the TNTC with 500,000 cfu/dL.

As mentioned in Section 3.1.2, HCSWQS investigated the length of Brickhouse Gully and Vogel Creek twice. Among the outfalls sampled, 21 of Brickhouse Gully and 5 of Vogel Creek were sampled twice. The results of the two passes are presented side by side in the tables to facilitate comparison. The bacteria loading in the tables will be discussed in Section 5.2.

There is a wide variety of the dry weather discharges, including water main leaks, lawn irrigation, air conditioner condensate, groundwater, wash water, and sewer leaks or overflow. Tables 3 and 4 show the source types of the discharges noted on the field sheets. The flow estimates provided are approximate. The total estimated dry weather flows for Brickhouse Gully are 506.3 and 203 gallons per minute (gpm) (1.1 and 0.45 cfs) for the first and second passes, respectively. For Vogel Creek the dry weather discharge data total only 10.5 and 28.6 gpm (0.02 and 0.06 cfs) for the first and second passes, respectively.

Figure 3 shows the percentage by number of sources counted of each category of source type for discharges that exceeded the EC single sample criterion (394 cfu/dL). When an outfall was sampled twice, the one with the higher bacteria loading was used for this purpose. For both streams, about 40% of the sources counted are irrigation water and about 30% are freshwater, presumed to be from water line leaks. Identified sources of sanitary sewage are a small proportion of the dry weather discharges investigated.

#### **4.1.2 Effects of Effort to Eliminate High Bacteria Sources**

Of the 21 outfalls of Brickhouse Gully that were sampled twice, flow reduction was observed at 9 and EC concentration reduction at 10 of the outfalls. Flow reduction was observed at 2 and EC concentration reduction at 3 of the 5 outfalls of Vogel Creek that were sampled twice.

About half of the outfalls sampled twice did not show an improvement in the discharge. This may be due to multiple sources of discharge observed at a particular outfall and the randomness of the discharges. For example, on one day a sanitary sewer may leak into the storm drain, and on another day that may not flow, but irrigation water from residential lawn watering may enter the same storm drain. Therefore, both the flow rate and bacteria level at a particular outfall appear to be highly variable. In addition, it should be

TABLE 1  
BRICKHOUSE GULLY DRY WEATHER DISCHARGE DATA

Outfall (BG#)	1st Pass			2nd Pass			Bacteria loading (cfu/day)	
	Date	Est. Flow (gpm)	EC (cfu/dL)	Date	Est. Flow (gpm)	EC (cfu/dL)	High Estimate	Low Estimate
8	11/21/2005	0.5	11,600	3/1/2006	2	324	316,179,549	35,324,888
9	11/21/2005	170	1,100				10,194,064,773	10,194,064,773
10	11/21/2005	40	700	3/1/2006	50 <	4	1,526,384,030	5,451,372
21	11/22/2005	1	16				872,219	872,219
32	11/22/2005	2	500	3/1/2006	3	21,100	3,450,718,183	54,513,715
36	11/22/2005	2	4,800	3/1/2006	3	24,800	4,055,820,423	523,331,667
36				3/1/2006	SPLIT	28,500		
69	12/6/2005	40	600				1,308,329,169	1,308,329,169
75	12/6/2005	1	2,600	3/7/2006	1	26,800	1,460,967,572	141,735,660
90				3/7/2006	1	14,400	784,997,501	784,997,501
106	1/5/2006	0.5	208				5,669,426	5,669,426
107	1/5/2006	1	5,000	3/14/2006	3	624	272,568,577	102,049,675
109				3/14/2006	1	16,800	915,830,418	915,830,418
115	1/5/2006	0.1	2,400				13,083,292	13,083,292
117				3/14/2006	15	96	78,499,750	78,499,750
119	1/5/2006	0.1	600	3/14/2006	0.5	8	3,270,823	218,055
122	1/5/2006	0.1	608				3,314,434	3,314,434
125				3/14/2006	3	352	57,566,483	57,566,483
143				3/27/2006	2	5,200	566,942,640	566,942,640
147				3/27/2006	2	500,000	54,513,715,364	54,513,715,364
154	12/1/2005	0.5	114,400				3,118,184,519	3,118,184,519
166	1/31/2006	2	16,200	3/8/2006	1 <	4	1,766,244,378	109,027
167	1/31/2006	1 <	4	3/8/2006	1 <	4	109,027	109,027
169				3/8/2006	1	6,800	370,693,264	370,693,264
171	1/31/2006	2 <	4	3/8/2006	1	8,800	479,720,695	218,055
172	1/31/2006	3.5	280				53,423,441	53,423,441
173	1/31/2006	15 <	4	3/8/2006	2 <	4	1,635,411	218,055
174				3/8/2006	2	224	24,422,144	24,422,144
178				3/8/2006	1	10,200	556,039,897	556,039,897
209	1/19/2006	2	9,200				1,003,052,363	1,003,052,363
210	1/19/2006	0.5	10,800	4/3/2006	2	5,600	610,553,612	294,374,063
225				4/3/2006	1	20,000	1,090,274,307	1,090,274,307
228	2/8/2006	30	1,000	4/3/2006	10	448	1,635,411,461	244,221,445
231	2/8/2006	1	1,200	4/3/2006	7.5	1,200	490,623,438	65,416,458
232	2/8/2006	1.5 <	4				163,541	163,541
235				4/6/2006	5	3,000	817,705,730	817,705,730
235b				4/6/2006	0.5	20,000	545,137,154	545,137,154
237	2/8/2006	30	10,800				17,662,443,778	17,662,443,778
238	2/8/2006	20 <	4	4/6/2006	5	20,000	5,451,371,536	2,180,549
258	2/8/2006	8	1,200	4/6/2006	2	4	523,331,667	436,110
285	11/29/2005	50	2,400	3/15/2006	6	3,800	6,541,645,844	1,242,912,710
286	11/29/2005	60	54,000	3/15/2006	10	1,700	176,624,437,780	926,733,161
299	11/30/2005	0.5	2,300	3/7/2006	5	2,600	708,678,300	62,690,773
300	12/21/2005	10	600	3/7/2006	1.5	500,000	1,635,411,461	40,885,286,523
301	1/31/2006	5	316				86,131,670	86,131,670
302	1/31/2006	5 <	4				545,137	545,137
303	2/8/2006	0.5	3,600	3/1/2006	45 <	4	98,124,688	4,906,234
Bh+Clay(r side)				3/14/2006	2 <	4	218,055	218,055
Sewage #2				3/7/2006	4	500,000	109,027,430,729	109,027,430,729
trib-Gernard				3/15/2006	1	10,200	556,039,897	556,039,897
Total		506.3			203		450,257,874,615	207,389,024,088
Arithmetic Mean			7,619			47,919		
Geometric Mean			570			1,116		
Corresponding instream concentration (cfu/dL) based on 5.0 cfs							3,681	1,695

Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.

TABLE 2  
VOGEL CREEK DRY WEATHER DISCHARGE DATA

Outfall (VC#)	1st Pass			2nd Pass			Bacteria loading (cfu/day)	
	Date	Est. Flow (gpm)	EC (cfu/dL)	Date	Est. Flow (gpm)	EC (cfu/dL)	High Estimate	Low Estimate
12				5/25/2006	3.5	10,400	1,984,299,239	1,984,299,239
15				5/25/2006	0.5	6,300	171,718,203	171,718,203
22	4/20/2006	5	11,200	5/18/2006	4	812	3,052,768,060	177,060,548
26				5/18/2006	0.1	108	588,748	588,748
28	4/20/2006	0.5	13,600				370,693,264	370,693,264
32	4/25/2006	1	108	5/18/2006		12,400	675,970,071	5,887,481
33	4/25/2006	1	4,800	5/18/2006	<	4	261,665,834	109,027
34	4/20/2006	0.5	5,600				152,638,403	152,638,403
36	4/20/2006	0.5	500,000				13,628,428,841	13,628,428,841
37	4/20/2006	1	500,000	5/18/2006	1	500,000	27,256,857,682	27,256,857,682
59				6/8/2006	10	1,700	926,733,161	926,733,161
60				6/8/2006	8	19,800	8,634,972,514	8,634,972,514
64	4/25/2006	1	8,800	5/25/2006	0.5	6,400	479,720,695	174,443,889
64				5/25/2006	1	11,200	610,553,612	610,553,612
Total		10.5			28.6		58,207,608,328	54,094,984,614
Arithmetic Mean			130,514			51,738		
Geometric Mean			13,289			2,992		
Corresponding instream concentration (cfu/dL) based on 1.76 cfs							1,352	1,256

## Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.

TABLE 3  
SOURCES OF DRY WEATHER DISCHARGES FOR BRICKHOUSE GULLY

Outfall (BG#)	Date	Est. Flow (gpm)	EC (cfu/dL)	Number of Sources							Total
				WA	GW	AC	FW	IW	IL	SW	
<b>1st Pass</b>											
8	11/21/2005	0.5	11,600				1				1
9	11/21/2005	170	1,100				1				1
10	11/21/2005	40	700				1				1
21	11/22/2005	1	16							1	1
32	11/22/2005	2	500			1		1			2
36	11/22/2005	2	4,800	1	1						2
285	11/29/2005	50	2,400			1	3				4
286	11/29/2005	60	54,000							1	1
299	11/30/2005	0.5	2,300		1						1
154	12/1/2005	0.5	114,400							1	1
69	12/6/2005	40	600				1				1
75	12/6/2005	1	2,600		1						1
300	12/21/2005	10	600				1				1
106	1/5/2006	0.5	208							1	1
107	1/5/2006	1	5,000				1				1
115	1/5/2006	0.1	2,400			1					1
119	1/5/2006	0.1	600						1		1
122	1/5/2006	0.1	608				1				1
209	1/19/2006	2	9,200				1				1
210	1/19/2006	0.5	10,800		1						1
166	1/31/2006	2	16,200					1			1
167	1/31/2006	1 <	4							1	1
171	1/31/2006	2 <	4							1	1
172	1/31/2006	3.5	280							1	1
173	1/31/2006	15 <	4							1	1
301	1/31/2006	5	316							1	1
302	1/31/2006	5 <	4	1							1
228	2/8/2006	30	1,000				2				2
231	2/8/2006	1	1,200	1							1
232	2/8/2006	1.5 <	4			1					1
237	2/8/2006	30	10,800				1				1
238	2/8/2006	20 <	4							1	1
258	2/8/2006	8	1,200					1			1
303	2/8/2006	0.5	3,600		1						1
<b>2nd Pass</b>											
8	3/1/2006	2	324							1	1
10	3/1/2006	50 <	4							1	1
32	3/1/2006	3	21,100		1			1			2
36	3/1/2006	3	24,800	1			1				2
303	3/1/2006	45 <	4							1	1
75	3/7/2006	1	26,800				1				1
90	3/7/2006	1	14,400			1	1	5			7
299	3/7/2006	5	2,600		1						1
300	3/7/2006	1.5	500,000							1	1
Sewage #2	3/7/2006	4	500,000							2	2
166	3/8/2006	1 <	4							1	1
167	3/8/2006	1 <	4							1	1
169	3/8/2006	1	6,800					1			1
171	3/8/2006	1	8,800							1	1
173	3/8/2006	2 <	4							1	1
174	3/8/2006	2	224							1	1
178	3/8/2006	1	10,200					1			1
107	3/14/2006	3	624				1				1
109	3/14/2006	1	16,800		1						1
117	3/14/2006	15	96						1	1	2
119	3/14/2006	0.5	8						1		1
125	3/14/2006	3	352							1	1
BG & Clay (right side)	3/14/2006	2 <	4							1	1
285	3/15/2006	6	3,800			3	1	1			5
286	3/15/2006	10	1,700				1				1
Trib-Genard	3/15/2006	1	10,200				1	4			5
143	3/27/2006	2	5,200	1			2				3
147	3/27/2006	2	500,000							1	1
210	4/3/2006	2	5,600							1	1
225	4/3/2006	1	20,000							1	1
228	4/3/2006	10	448				2				2
231	4/3/2006	7.5	1,200	2			3	4			9
235	4/6/2006	5	3,000					4			4
238	4/6/2006	5	20,000				1	6			7
258	4/6/2006	2	4					1			1
235-B	4/6/2006	0.5	20,000			1		2			3

Notes:  
Washwater WA  
Groundwater GW  
AC Condensate AC  
Freshwater FW  
Irrigation Water IW  
Illicit Washwater IL  
Sewage SW  
Source type not determined NO

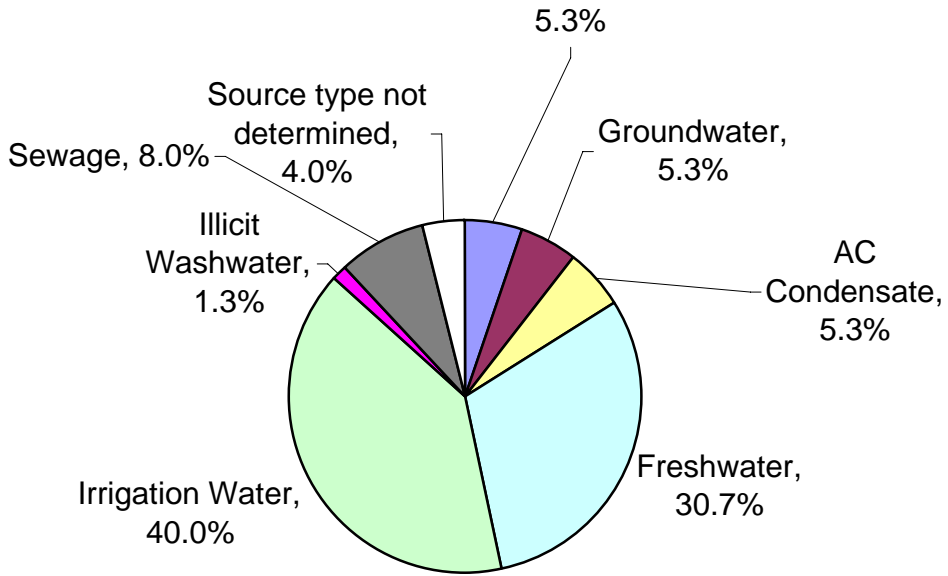
TABLE 4  
SOURCES OF DRY WEATHER DISCHARGES FOR VOGEL CREEK

Outfall (VC#)	Date	Est. Flow (gpm)	EC (cfu/dL)	Number of Sources						
				WA	GW	AC	FW	IW	SW	Total
<b>1st Pass</b>										
22	4/20/06	5	11,200				1			1
28	4/20/06	0.5	13,600					1		1
34	4/20/06	0.5	5,600						1	1
36	4/20/06	0.5	500,000						1	1
37	4/20/06	1	500,000						1	1
32	4/25/06	1	108				1			1
33	4/25/06	1	4,800	1						1
64	4/25/06	1	8,800				1			1
<b>2nd Pass</b>										
22	5/18/06	4	812				1			1
26	5/18/06	0.1	108					1		1
32	5/18/06		12,400				1			1
33	5/18/06	<	4	1						1
37	5/18/06	1	500,000						1	1
12	5/25/06	3.5	10,400				1	2		3
15	5/25/06	0.5	6,300				1			1
64	5/25/06	0.5	6,400				2			2
64 (plant nursery)	5/25/06	1	11,200					1		1
59	6/8/06	10	1,700				1	1	1	3
60	6/8/06	8	19,800					3		3

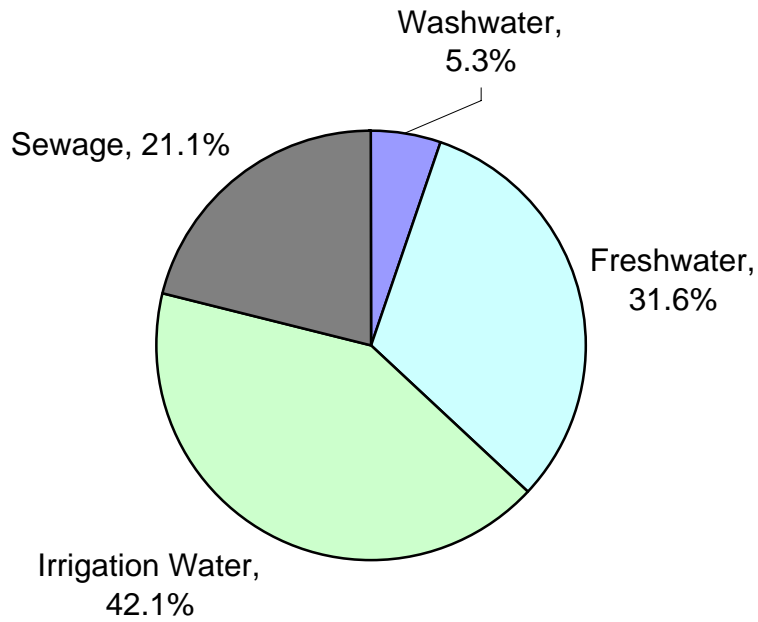
Notes:

Washwater	WA
Groundwater	GW
AC Condensate	AC
Freshwater	FW
Irrigation Water	IW
Sewage	SW

**FIGURE 3**  
**SOURCES OF DRY WEATHER DISCHARGES**  
**THAT EXCEEDED EC SINGLE SAMPLE CRITERION**  
 (Percentages based on number of sources counted)



**Brickhouse Gully**



**Vogel Creek**

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recognized that the identification and quantification of the sources must be an estimate and is not always precise.

## **4.2 WASTEWATER TREATMENT PLANTS**

The data collected at the three WWTPs are presented in Tables 5 to 7. The geometric means of the EC data have been calculated and also presented in the tables. Despite disinfection by chlorine, there are some high EC values at the weir or outfall during the sampling period. It should also be noted that Willowood is required to dechlorinate and had a somewhat higher EC geometric mean than the two smaller plants that do not dechlorinate. However, the EC geometric means of the effluent of all three plants were below the contact recreation geometric mean criterion of 126 cfu/dL (TNRCC, 2000) and also well below the ambient levels in the streams.

## **4.3 INSTREAM – BRICKHOUSE GULLY**

### **4.3.1 Before Attempt to Eliminate High Bacteria Sources**

As mentioned in Section 3.1.4, the historical data collected by the City provided the baseline for this stream. The data collection effort by the City was not targeted towards low flow conditions. Based on rain data from the Harris County Homeland Security & Emergency Management website (<http://www.hcoem.org/>), HCSWQS identified sampling events with more than 0.1 inch rainfall in the 48 hours prior to the sampling events. These events are excluded so that the remaining data represent relatively dry conditions. The data were collected between November 2002 and October 2005 and are presented in Table 8. The EC geometric mean is 1,430 MPN/dL (IDEXX Method used), and there are 19 samples out of 23 that exceed the single sample criterion of 394 cfu/dL.

### **4.3.2 After Attempt to Eliminate High Bacteria Sources**

The effort to eliminate high bacteria sources was completed in April 2006. The Brickhouse Gully site was sampled from May to October 2006, and the data are presented in Table 9. The FC and EC geometric means are 448 and 324 cfu/dL, respectively. Both are higher than the criteria. For both bacteria indicator, 11 samples out of 21 exceed the single sample “not to exceed” criterion. The single sample criterion for FC is 400 cfu/dL (TNRCC, 2000). While Brickhouse Gully instream concentrations did not drop below the bacteria water quality criteria after attempts to eliminate high bacteria sources, the geometric mean of EC data was lower. This can be viewed as a positive outcome, but it must be tempered with the knowledge that the sampling periods were not the same, and different methods were used for EC enumeration. Other factors contributing to differences are discussed in Section 5.1.

TABLE 5  
WESTWAY WWTP DATA

DATE	Total Cl at weir (mg/L)	Free Cl at weir (mg/L)	Total Cl at outfall (mg/L)	Free Cl at outfall (mg/L)	EC @ weir (cfu/dL)	EC @ Outfall (cfu/dL)	Flow (MGD)
30-Nov-05	1.0	0.5	1.0	0.5	4	200	1.34
7-Dec-05	1.7	1.5	1.5	1.2	< 4	< 4	0.76
21-Dec-05	1	0.5	not taken	not taken	< 4	not taken	
4-Jan-06	0.5	0.1	not taken	not taken	288	not taken	0.17
1-Feb-06	0	0	not taken	not taken	24	not taken	0.73
6-Feb-06	2.0	1.5	not taken	not taken	< 4	not taken	0.57
9-Feb-06	2.0	1.5	not taken	not taken	< 4	not taken	0.55
15-Feb-06	2.0	1.5	not taken	not taken	< 4	not taken	0.84
20-Feb-06	1.6	0.6	not taken	not taken	< 4	not taken	0.64
2-Mar-06	1.5	0.4	not taken	not taken	128	not taken	0.19
6-Mar-06 >	3.5	2.1	not taken	not taken	< 4	not taken	0.71
9-Mar-06	3.5	1.5	not taken	not taken	< 4	not taken	0.68
13-Mar-06	0.6	0.1	not taken	not taken	16	not taken	1.00
16-Mar-06	2.0	0.8	not taken	not taken	< 4	not taken	0.80
Arithmetic Mean					34		0.69
Geometric Mean					6		

Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.



TABLE 6  
WILLOWOOD WWTP DATA

DATE	Total Cl above weir (mg/L)	Free Cl above weir (mg/L)	Total Cl below weir (mg/L)	Free Cl below weir (mg/L)	Total Cl at Outfall (mg/L)	Free Cl at Outfall (mg/L)	EC @ weir (cfu/dL)	EC @ Outfall (cfu/dL)	FC @ weir (cfu/dL)	FC @ Outfall (cfu/dL)	Flow (MGD)
7-Nov-05	1.2	0.5	0	0	0	0	4	9	not taken	not taken	
17-Nov-05	0.65	0.2	0	0	0	0	68	32	104	84	
30-Nov-05	0.5	0.2	0	0	0	0	152	4,100	not taken	not taken	
7-Dec-05	1.5	0.1	0	0	0	0	< 4	308	not taken	not taken	
21-Dec-05	1.0	0.1	0	0	0	0	< 4	64	not taken	not taken	
4-Jan-06	1.6	1.3	0	0	0	0	80	100	not taken	not taken	1.57
1-Feb-06	1.0	0.4	0	0	0	0	28	4	not taken	not taken	1.25
6-Feb-06	0.7	0.6	0	0	0	0	2,200	152	not taken	not taken	1.9
9-Feb-06	1.1	0.8	0	0	0	0	< 4	108	not taken	not taken	1.61
15-Feb-06	0.8	0.1	0	0	0	0	328	724	not taken	not taken	2.1
20-Feb-06	1.3	0.8	0	0	0	0	< 4	< 4	not taken	not taken	1.7
23-Feb-06	1	0.4	0	0	0	0	2,700	10,400	not taken	not taken	2.05
2-Mar-06	0.7	0.3	not taken	not taken	0	0	176	224	not taken	not taken	1.82
6-Mar-06	1	0.1	0	0	0	0	224	< 4	not taken	not taken	1.99
9-Mar-06	1.1	0.8	0	0	0	0	< 4	< 4	not taken	not taken	2.31
Arithmetic Mean							398	1,082			1.83
Geometric Mean							36	66			

## Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.

460935/070002

TABLE 7  
SUNSET MHP DATA

DATE	Total Cl above weir (mg/L)	Free Cl above weir (mg/L)	Total Cl at Outfall (mg/L)	Free Cl at Outfall (mg/L)	EC @ weir (cfu/dL)	EC @ Outfall (cfu/dL)	FC @ weir (cfu/dL)	FC @ outfall (cfu/dL)	Flow (MGD)
7-Nov-05	0.6	0.0	0.7	0.0	89	2	not taken	not taken	
17-Nov-05	2.8	1.9	2.9	2.0	< 4	< 4	4	4	
30-Nov-05	1.5	0.6	1.5	1.0	420	12	not taken	not taken	
30-Nov-05	Duplicate				< 4				
7-Dec-05	3.0	0.2	3.0	0.0	80	52	not taken	not taken	
21-Dec-05	0.5	0.1	0.5	0.1	168	88	not taken	not taken	
4-Jan-06	0.1	0.0	0.1	0.0	1,000	500	not taken	not taken	
1-Feb-06	0.6	0.1	0.7	0.2	8	32	not taken	not taken	0.008
6-Feb-06	0.5	0.3	0.5	0.2	< 4	< 4	not taken	not taken	not taken
9-Feb-06	2.2	0.7	1.5	2.0	< 4	< 4	not taken	not taken	0.011
15-Feb-06	2.5	1.5	2.5	1.5	< 4	< 4	not taken	not taken	0.008
20-Feb-06	0.5	0.3	0.5	0.2	< 4	< 4	not taken	not taken	0.0004
23-Feb-06	2.2	1.2	2.2	1.1	16,800	3,200	not taken	not taken	0.008
2-Mar-06	1.5	1.0	2.1	0.8	592	432	not taken	not taken	0.0191
6-Mar-06	0.1	0.0	0.1	0.0	16,800	14,400	not taken	not taken	0.011
9-Mar-06	0.7	0.2	0.8	0.2	< 4	< 4	not taken	not taken	0.011
Arithmetic Mean					2,398	1,249	0.0096		
Geometric Mean					51	27			

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## Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.
2. Duplicate sample not included in analysis.

TABLE 8  
BRICKHOUSE GULLY INSTREAM DATA (BEFORE ATTEMPT TO ELIMINATE HIGH BACTERIA SOURCES)

Date	Time	Temp (deg F)	DO (mg/L)	EC (MPN/dL)	pH (SU)	TSS (mg/L)	TDS (mg/L)	NH3-N (mg/L)	SO4 (mg/L)	Cond (mS/cm)	NO3-N (mg/L)	Ortho-PO4 (mg/L)	Total P (mg/L)
7-Nov-02	9:40	58.2	13.27	1,800	7.92	8	331	0.03	14.8	0.51			
26-Dec-02	10:35	50.1	19.09	11,000	8.04	4.0	393	0.03	19.1	0.71			
23-Jan-03	10:15	44.3	21.87	760	8.30	2.0	471	0.03	22.67	0.80			
25-Mar-03	10:55	74.2	18.66	1,200	8.75	6.0	440	0.03	21.6	0.73			
28-Apr-03	11:50	77.0	19.56	6,600	9.25	6.0	416	0.03	18.7	0.62			
20-May-03	11:25	87.4	19.79	470	9.24	4.0	480	0.03	21.7	0.77			
25-Sep-03	12:35	86.8	17.17	430	9.40	13.0	334	0.03	23.1	0.52	2.88	0.30	0.37
29-Oct-03	13:05	75.6	12.15	2,100	8.92	9.0	387	0.03	25.4	0.60	3.58	0.43	0.46
25-Nov-03	11:15	56.2	13.08	58,000	8.14	6.0	354	0.213	26.6	0.59	3.07		0.74
27-Jan-04	10:55	49.4	16.27	65,000	8.20	9.0	305	0.158	17.1	0.49	1.34	0.28	0.32
23-Mar-04	11:30	71.7	17.7	2,200	8.84	9.0	428	0.03	34	0.66	1.70	0.24	0.29
29-Jun-04	11:55	88.6	15.4	5,000	8.88	4.0	340	0.03	23.7	0.50	0.84	0.12	0.14
19-Aug-04	12:50	91.0	20.79	31	10.60	18.0	379	0.03	56.2	0.59	2.19	0.12	0.44
30-Sep-04	10:51	77.6	12.74	1,500	8.99	5.0	314	0.02	44.9	0.52	2.64	0.06	0.11
19-Jan-05	12:45	62.2	19.93	3,100	9.10	4.0	409	0.1	44.8	0.65	5.29	0.58	0.73
21-Feb-05	10:50	71.1	17.78	2,600	8.88	4.0	452	0.05	38.3	0.69	3.20		0.43
22-Mar-05	10:30	72.4	20.24	1,100	9.17	4.0	355	0.03	25.5	0.57	1.01	0.14	0.21
21-Apr-05	13:45	81.7	19.58	4,200	9.60	5.0	401	0.072	38.0	0.62	2.89		0.41
25-May-05	12:30	90.6	17.91	10	10.84	34.0	419	0.04	57.2	0.68	2.46		0.60
24-Jun-05	11:20	89.4	22.32	10	10.20	37	465	0.03	31.5	0.69	2.61		1.44
12-Jul-05	10:30	86.5	11.81	15,000	8.76	5	215	0.099	13.7	0.34	0.45	0.31	0.39
8-Sep-05	11:35	86.5	15.82	380	9.68	6	448	0.03	57.4	0.68	6.51	0.17	0.32
19-Oct-05	11:50	77.8	16.19	1,800	9.35	9	459	0.03	58.1	0.74	6.33		1.07
Mean		74.2	17.35	8013	9.09	9.2	391	0.052	31.9	0.62	2.88	0.25	0.50
Geometric Mean				1,430									
Number of single sample exceedance				19									

## Notes:

1. Single sample criteria for EC is 394 MPN/dL.

TABLE 9  
BRICKHOUSE GULLY INSTREAM DATA (AFTER ATTEMPT TO ELIMINATE HIGH BACTERIA SOURCES)

Date	Time	Temp (deg F)	DO (mg/L)	FC (cfu/dL)	EC (cfu/dL)	pH (SU)	TSS (mg/L)	TDS (mg/L)	NH3-N (mg/L)	SO4 (mg/L)	Cond (mS/cm)	NO2+NO3- N (mg/L)	Ortho-PO4 (mg/L)	Total P (mg/L)	TKN (mg/L)	Chlorophyll a (mg/L)	Number of days since last precip
3-May-06	13:40	89.5	20.93	< 4	< 4	10.52	24.9	370	< 0.1	67.3	0.90						>2
11-May-06	12:39	87.7	28.55	88	4	10.58	12.0	232	0.1	33.9	0.60						>4
18-May-06	12:10	88.2	21.34	1,100	1,100	10.01	9.8	242	< 0.1	42.3	0.50						>2
25-May-06	12:25	98.6	20.60	900	448	10.54	10.4	224	< 0.1	21.7	0.50						
25-May-06	SPLIT			416	416				< 0.1								
8-Jun-06	11:10	94.1	21.07	< 4	< 4	10.06	45.1	1032	< 0.1	61.5	0.60						>2
15-Jun-06	12:10	94.1	22.04	12	12	10.10	60.3	426	0.1	60.0	0.80						>10
29-Jun-06	10:45	88.2	25.20	552	552	9.72	< 2.5	382	0.1	39.1	0.50						>2
13-Jul-06	12:05	97.1	15.81	8,300	8,300	9.44	3.9	342	0.1	27.9	0.50	5.40	0.38	0.58	<	0.035	4
17-Jul-06	10:20	87.4	19.07	248	248	9.27	4.6	362	< 0.1	39.4	0.60	6.70	0.48	0.50	<	0.035	>2
20-Jul-06	12:05	95.7	25.56	268	268	10.05	73.5	294	< 0.1	35.9	0.60	0.81	0.20	0.26	<	0.07	>2
7-Aug-06	9:05	83.8	14.05	4,400	2,700	8.54	4.7	318	< 0.1	43.3	0.50	0.15	0.11	0.12		not taken	>3
14-Aug-06	11:00	91.8	19.02	1,900	1,600	9.52	6.6	294	0.1	32.0	0.50	0.90	0.20	0.20		not taken	4
17-Aug-06	12:34	98.2	16.95	140	140	9.94	17.2	282	0.1	47.2	0.60	1.00	0.10	0.20		not taken	7
22-Aug-06	10:45	86.2	16.38	3,600	3,100	9.36	< 2.5	298	< 0.1	46.0	0.50	0.92	0.13	0.19	< 0.5	not taken	3
31-Aug-06	12:12	93.4	20.23	80	24	10.08	< 2.5	330	0.1	58.6	0.60	1.15	0.13	0.17	< 0.5	not taken	4
5-Sep-06	12:22	83.1	25.96	352	352	10.03	11.5	382	0.2	68.2	not taken	0.90	0.06	0.14	< 0.5	not taken	
14-Sep-06	11:19	85.8	12.01	352	172	9.06	5.1	222	0.3	57.5	0.50	1.00	0.18	0.20	< 0.5	not taken	3
21-Sep-06	10:52	81.1	13.91	4,500	4,500	8.95	not taken	not taken	0.1	not taken	0.50	2.16	0.03	0.08	< 0.5	not taken	
27-Sep-06	10:48	76.3	18.92	20,000	20,000	9.21	not taken	not taken	0.2	not taken	0.50	1.29	0.06	0.06	< 0.5	not taken	4
2-Oct-06	11:20	82.0	17.24	2,600	2,400	9.86	not taken	not taken	0.2	not taken	0.50	3.20	0.03	0.12	< 0.5	not taken	6
5-Oct-06	10:24	77.9	18.74	3,900	3,100	9.28	not taken	not taken	0.2	not taken	0.60	1.56	0.02	< 0.05	< 0.5	not taken	9
Mean		88.6	19.69	2537.9	2334	9.72	17.3	355	0.11	46.0	0.57	1.94	0.15	0.20	< 0.5		
Geometric Mean				448	324												
Number of single sample exceedance				11	11												

## Notes:

- For results below detection limit, 50% of the reporting limit is used in the calculation.
- Single sample criteria for FC and EC are 400 cfu/dL and 394 cfu/dL respectively.
- Split samples not included in analysis.

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## **4.4 INSTREAM – VOGEL CREEK**

### **4.4.1 Before Attempt to Eliminate High Bacteria Sources**

The Vogel Creek site was sampled between November 2005 and March 2006 before the effort to eliminate high bacteria sources. The data are presented in Table 10. The sample collected on November 17, 2005 was likely affected by runoff condition and was therefore excluded from the analysis. Moreover, the EC concentration of the March 2, 2006 event is substantially greater than the FC concentration. The data appear questionable and are also excluded from the analysis. The FC and EC geometric means are 4,626 and 3,867 cfu/dL, respectively. Both are much higher than the criteria. For both bacteria indicators, 14 samples out of 15 exceed the single sample criterion.

### **4.4.2 After Attempt to Eliminate High Bacteria Sources**

The effort to eliminate high bacteria sources was completed in early June 2006. The Vogel Creek site was sampled from late June to October 2006, and the data are presented in Table 11. The FC and EC geometric means are 3,554 and 2,225 cfu/dL, respectively. These are lower than the “before” sampling, but both are still much higher than the criteria. The numbers of samples exceeding the single sample criterion are 17 for FC and 16 for EC, out of a total of 17 samples.

TABLE 10  
VOGEL CREEK INSTREAM DATA (BEFORE ATTEMPT TO ELIMINATE HIGH BACTERIA SOURCES)

Date	Time	Temp (deg F)	DO (mg/L)	FC (cfu/dL)	EC (cfu/dL)	pH (SU)	TSS (mg/L)	TDS (mg/L)	NH3-N (mg/L)	SO4 (mg/L)	Cond (mS/cm)	Number of days since last precip
7-Nov-05	11:34	81.4	3.00	> 200	> 200	7.48	6.3	482	1	34.9	0.90	7
17-Nov-05	10:04	60.2	5.49	7,200	5,700	7.50	7	302	0.1	27.4	0.60	1.5
30-Nov-05	11:08	62.8	6.05	10,900	5,600	7.72	6.7	476	0.3	45.7	0.80	2.5
30-Nov-05	11:08	SPLIT		2,700	2,700		8.3	480	0.1	48.8		
7-Dec-05	9:57	59.2	5.55	3,700	2,800	7.52	5.1	410	1.2	36.2	0.80	4
21-Dec-05	10:58	58.6	7.08	3,300	1,500	7.67	3	692	0.8	39.5	0.90	
21-Dec-05	10:58	SPLIT		7,900	7,000		< 2.5	486	0.9	41.9		
4-Jan-06	11:15	68.2	3.69	2,000	1,600	7.50	< 2.5	508	1.4	35.6	0.90	>2
1-Feb-06	10:20	65.1	3.11	14,300	10,800	7.54	15.6	450	6.3	36.3	0.90	4
6-Feb-06	10:45	67.0	0.56	8,400	8,100	7.60	4.8	478	9.3	32.6	1.00	>2
6-Feb-06	10:45	SPLIT		10,400	9,600		4.7	472	9.3	29.5		
9-Feb-06	10:05	64.2	3.80	3,800	3,800	7.58	13.6	506	2.6	41.7	1.00	
15-Feb-06	9:43	67.8	3.29	4,400	3,600	7.48	6.0	500	1.2	39.5	0.90	5
20-Feb-06	10:12	53.1	4.97	1,300	1,300	7.56	7.7	502	1.2	34.3	1.00	>5
23-Feb-06	8:51	69.1	3.01	20,000	20,000	7.60	12.7	498	0.77	45.1	0.90	>8
2-Mar-06	10:28	73.3	4.00	3,600	21,500	7.61	18.9	504	0.4	32.9	0.90	5
2-Mar-06	10:28	SPLIT		10,000	900		20.5	474	0.4	34.4		
6-Mar-06	10:45	73.6	3.35	7,200	7,200	7.47	15.6	474	1.6	35.2	0.90	9
9-Mar-06	8:49	72.9	3.52	19,700	19,700	7.60	15.2	464	0.5	36.8	0.90	12
13-Mar-06	8:51	74.3	2.54	26,800	21,600	7.34	14.1	468	1.4	34.6	0.90	12
16-Mar-06	9:15	69.4	5.51	900	900	7.76	12.7	472	0.2	37.7	0.80	>2
Mean		67.1	3.94	8,460	7,247	7.56	10.0	492	1.98	37.7	0.90	
Geometric Mean				4,626	3,867							
Number of single sample exceedance				14	14							

## Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.
2. Single sample criteria for FC and EC are 400 cfu/dL and 394 cfu/dL respectively.
3. Split samples not included in analysis.
4. 3/2/06 bacteria data questionable (EC substantially larger than FC), not used in analysis.
5. 11/17/05 data likely affected by runoff condition, not used in analysis.

TABLE 11  
VOGEL CREEK INSTREAM DATA (AFTER ATTEMPT TO ELIMINATE HIGH BACTERIA SOURCES)

Date	Time	Temp (deg F)	DO (mg/L)	FC (cfu/dL)	EC (cfu/dL)	pH (SU)	TSS (mg/L)	TDS (mg/L)	NH3-N (mg/L)	SO4 (mg/L)	Cond (mS/cm)	NO2+NO3-N (mg/L)	Ortho-PO4 (mg/L)	Total P (mg/L)	TKN (mg/L)	Chlorophyll a (mg/L)	Number of days since last precip
26-Jun-06	8:29	83.7	4.19	2,700	2,700	7.46	8.2	574	0.2	28.8	1.10						4
29-Jun-06	10:15	83.6	5.83	3,200	3,200	7.81	6.0	506	0.2	36.9	0.90						>2
13-Jul-06	10:30	84.5	4.42	4,300	4,300	7.50	6.8	430	0.2	37.1	0.80	6.2	0.48	0.68		< 0.018	4
13-Jul-06	SPLIT						7.3	430	0.1	36.3		6.0	0.48	0.61		< 0.018	
17-Jul-06	10:40	86.9	4.73	2,700	2,700	7.76	10.6	436	0.2	35.4	0.80	9.8	0.45	0.46		< 0.018	>2
20-Jul-06	10:30	85.5	4.77	2,700	2,700	7.77	8.0	426	0.1	28.6	0.80	1.34	0.50	0.50		< 0.007	>2
7-Aug-06	9:53	85.3	4.81	4,300	3,300	7.66	10.1	500	0.1	40.1	0.90	1.52	1.62	1.34		not taken	>3
14-Aug-06	10:28	85.6	4.91	6,000	4,700	7.67	5.1	482	0.2	30.1	0.90	1.7	2.5	2.7		not taken	4
14-Aug-06	SPLIT						7.5	498	0.2	31.7		1.6	2.6	2.6		not taken	
17-Aug-06	13:50	88.7	6.05	2,600	2,200	7.88	7.5	456	0.2	41.6	0.80	1.0	1.6	1.8		not taken	7
22-Aug-06	9:49	86.0	3.05	10,400	9,700	7.31	6.2	406	0.1	31.8	0.80	1.3	1.1	1.1	0.7	not taken	3
28-Aug-06	9:22	83.7	3.26	6,200	5,400	7.13	14.9	348	0.6	22.2	0.70	3.7	1.26	1.49	2.3	not taken	>2
31-Aug-06	13:17	84.2	5.53	1,300	< 4	7.74	4.0	454	0.1	31.2	0.80	3.0	2.3	2.3	< 0.5	not taken	7
5-Sep-06	11:18	82.2	4.81	2,400	2,400	7.69	6.7	434	0.3	38.4	not taken	5.1	2.4	2.1	< 0.5	not taken	
14-Sep-06	10:50	80.6	5.00	6,200	6,200	7.77	12.3	508	0.2	38.4	1.00	4.3	2.2	2.2	< 0.5	not taken	3
14-Sep-06	SPLIT						9.0	460	0.2	33.0		4.6	2.3	2.2	1.0	not taken	
21-Sep-06	10:24	77.4	5.33	4,300	4,300	7.54	15.2	442	0.1	33.1	0.80	4.43	1.40	1.74	< 0.5	not taken	
27-Sep-06	10:13	75.6	5.40	3,800	3,400	7.65	12.5	444	0.3	33.3	0.80	2.97	1.4	1.51	< 0.5	not taken	4
2-Oct-06	11:56	81.3	5.63	2,300	2,000	7.83	8.2	398	0.1	34.6	0.80	1.88	0.95	1.12	< 0.5	not taken	6
5-Oct-06	9:40	80.4	5.73	2700	1,900	7.95	11.0	346	0.2	31.8	0.80	1.94	1.31	1.33	< 0.5	not taken	9
Mean		83.2	4.91	4,006	3,594	7.65	9.0	446	0.20	33.7	0.84	3.35	1.43	1.49	0.58		
Geometric Mean				3,554	2,225												
Number of single sample exceedance				17	16												

## Notes:

1. For results below detection limit, 50% of the reporting limit is used in the calculation.
2. Single sample criteria for FC and EC are 400 cfu/dL and 394 cfu/dL respectively.
3. Split samples not included in analysis.

## 5.0 DISCUSSION OF RESULTS

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### 5.1 INSTREAM WATER QUALITY BEFORE AND AFTER ATTEMPT TO ELIMINATE HIGH BACTERIA SOURCES

In both streams, the FC and EC geometric means of the data after the attempt to eliminate high bacteria sources are lower than those before the attempt. A statistical analysis was performed to test the significance of the differences. The p-values for Brickhouse Gully and Vogel Creek are 0.03 and 0.17, respectively. Therefore the null hypothesis is rejected for Brickhouse Gully but not for Vogel Creek. In other words, the bacteria level was significantly lower for Brickhouse Gully after the attempt to eliminate high bacteria sources but not for Vogel Creek.

A couple of factors need to be considered in interpreting these results. As discussed in Section 2.2, under low flow conditions, the flow in Vogel Creek is predominantly WWTP effluent. On the other hand, WWTP effluent is only about 20–30% of the base flow in Brickhouse Gully. The fact that nonwastewater flow represents the majority of Brickhouse Gully dry weather flow (a relatively unusual condition in Harris County) is consistent with the result that efforts to reduce nonwastewater, dry weather flows to the stream yield a positive difference.

However, an important factor is the different test methods used to enumerate EC in the before and after data sets. Jensen and Lee (2005) have compared parallel FC and EC data collected in different parts of the state for different reasons. The data include both freshwater, saline water, and waters with varying degrees of wastewater input. The EC data are results of the IDEXX method. One of their findings is that the EC/FC ratio tends to be close to the ratio of the criteria values (126/200 or 0.63) when there is little wastewater present. When there is a high degree of wastewater influence, the ratio tends to be on the order of 3 or more. EC data from the MUG test should always give EC/FC ratio less than one because with that method, EC is a subset of FC positive results. It appears that the more wastewater influence a waterbody is subjected to, the more likely the two EC test methods would give different results, and the IDEXX method is likely to give higher results. The city's EC data for Brickhouse Gully are IDEXX results. If IDEXX had been used by HCSWQS, the EC level would likely have been higher and the difference between the two sets of data smaller.

As presented in Section 4.1.1, many of the high bacteria sources are actually allowable nonstormwater discharges, e.g. irrigation water. These sources would still exist even after an effort to eliminate illicit discharges. This suggests that better approaches to address the human health risk than indicator bacteria may be needed.

It should also be noted that even after the effort to eliminate high bacteria sources, the FC and EC geometric means are still substantially higher than criteria. Moreover, over half of the samples in Brickhouse Gully exceed the single sample criterion and almost all the samples in Vogel Creek exceed the single sample criterion. Besides discharges from high bacteria sources, there are other factors



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affecting bacteria levels in an urban stream. One is the potential regrowth of bacteria from WWTP effluent. Moreover, urban streams are often channelized and lack pool areas that would promote settling of particulate matter with associated bacteria.

The bacteria community in a stream is a very dynamic system. For example, bacteria can be sustained or regrow in nutrient-rich waters, and elevated DO and pH levels are potentially deleterious for a facultative anaerobe like EC. An algal bloom in Brickhouse Gully was observed by HCSWQS during post-treatment sampling with extremely elevated oxygen and pH levels. These conditions might have contributed to the reduction in bacteria from the baseline.

## **5.2 COMPARISON OF DRY WEATHER DISCHARGE BACTERIA INPUTS TO MEASURED INSTREAM LEVELS—A CONSISTENCY CHECK**

The bacteria loading can be calculated based on the estimated flow rates and bacteria concentrations measured at the dry weather discharges and compared to measured instream values. Since there were two passes of the dry weather discharge sampling, a “high” estimate was calculated using the higher loading if an outfall had been sampled twice. Conversely, a “low” estimate was calculated using the lower loading. Nevertheless, as mentioned in Section 4.1.2, the flow rates are very hard to determine and bacteria levels of the dry weather discharges are highly variable. Therefore, these bacteria loading estimates should be regarded as “ball park” estimates. The loadings are then put into context of the typical base flows in the stream. The calculations are shown in Tables 1 and 2.

The bacteria input to Brickhouse Gully, due to dry weather discharges, translate to an instream concentration of 1,695 to 3,681 cfu/dL. The EC geometric mean of the baseline condition is 1,430 cfu/dL. These concentrations are obtained by dividing the load by a stream flow of 5 cfs. It appears that dry weather discharges are both a major contributor to instream flow and the high bacteria level in Brickhouse Gully. Note that the calculations in Table 1 do not account for the estimated total stream flow of 5 cfs. The biggest dry weather flow (506 gpm or 1.1 cfs), together with the Westway WWTP measured flow of 0.69 MGD or 1.07 cfs, total to only 2.17 cfs. If the 2.17 cfs flow were used as the stream flow, the calculated concentrations would be more than doubled. This suggests that the dry weather flows from the storm sewers contribute the great majority of the instream bacteria. The WWTP discharge, with a geometric mean bacteria concentration of 6 cfu/dL makes up a small percentage of the instream bacteria load.

Vogel Creek appears to be different. The bacteria input, due to dry weather discharges translates to an instream concentration of 1,256 to 1,352 cfu/dL, assuming the instream flow is only 1.76 cfs. The actual EC geometric mean of the baseline condition is 3,867 cfu/dL. Even using the high estimate, the dry weather discharges only contribute about 35% of the instream bacteria level. If the bacteria load is calculated using the average wastewater and dry weather flows to represent the stream flow, the dry weather flows account for 44% of the bacteria load while the WWTPs account for about 3% of the

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bacteria load. This study does not identify a source for the remainder of the load indicated from the ambient concentrations and estimated flows. Possible sources would appear to be regrowth following disinfection, additional sources to the stream such as birds and bats, sediment resuspension, and the sustained and channelized flows that do not allow settling that is normally a major removal mechanism. It is noted that HCSWQS staff have visually inspected all bridges and found no bat colonies or significant bird populations.

The above results appear to be consistent with the findings in Section 5.1 that the bacteria level was significantly lower for Brickhouse Gully after the attempt to eliminate high bacteria sources, but not for Vogel Creek. With Vogel Creek the dry weather flows are a small portion of the total flow, and efforts to reduce these flows have little effect since the bulk of the bacteria in the stream are coming from unidentified sources.

### **5.3 COST OF ELIMINATING HIGH BACTERIA SOURCES**

Unit costs are estimated that may be used for budgeting purpose of similar effort. The study has used 667 labor hours, excluding the effort for instream monitoring. Using a rate of \$25 per hour and the county's multiplier of 0.3534 for overhead (holiday, vacation, sick leave, benefits), the total labor cost is \$22,568 for site reconnaissance, discharge detection, source tracking, training, and meetings. There are 71 outfall samples for Brickhouse Gully and 19 for Vogel Creek. With a lab test fee of \$35 for EC, the lab test cost is \$3,150; therefore, the total cost is \$25,718. The stream lengths of Brickhouse Gully and Vogel Creek at the sampling sites are 28,100 and 23,300 feet, respectively. The drainage areas at the sampling sites are 6,600 ac and 1,500 acres, respectively, for Brickhouse Gully and Vogel Creek. The cost per foot of stream is \$0.5, and the cost per acre of drainage area is \$3.2. Since there is considerable variability among watersheds, cost estimates based on these unit costs should be regarded as order-of-magnitude estimates only.

### **5.4 EC TO FC RATIO**

The older FC criterion for contact recreation had a geometric mean 200 cfu/dL; for EC the geometric mean criterion is 126 cfu/dL. In some cases, such as the work done at the Buffalo Bayou and White Oak Bayou TMDLs (UH, 2005), all FC data obtained before 2001 was simply converted to EC based on the 126:200 ratio, i.e., 0.63. In this study, the ratios of EC geometric mean to FC geometric mean were found to be 0.84, 0.63, and 0.92 for the "Vogel Before," "Vogel After," and "Brickhouse After" data sets, respectively. However, as discussed in Section 5.1, if the IDEXX method had been used for EC enumeration, the EC/FC ratio would likely to have been much higher since these streams have significant wastewater influence.

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## **5.5 WASTEWATER TREATMENT PLANTS**

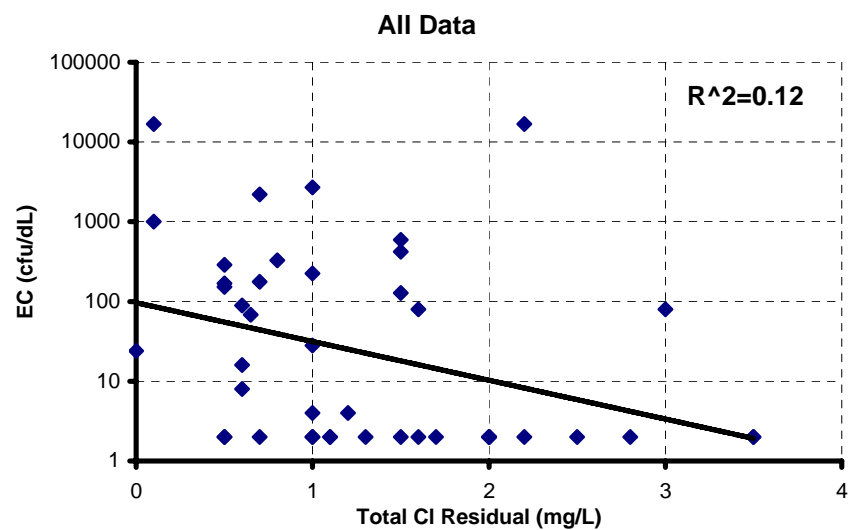
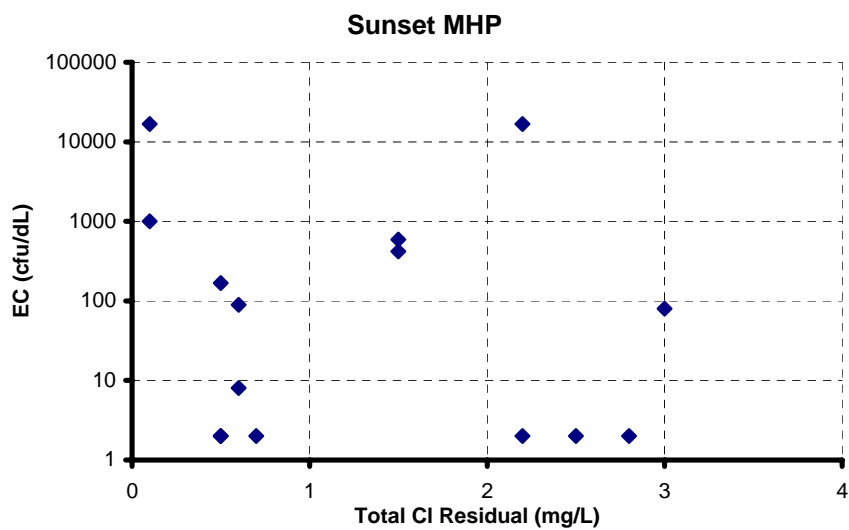
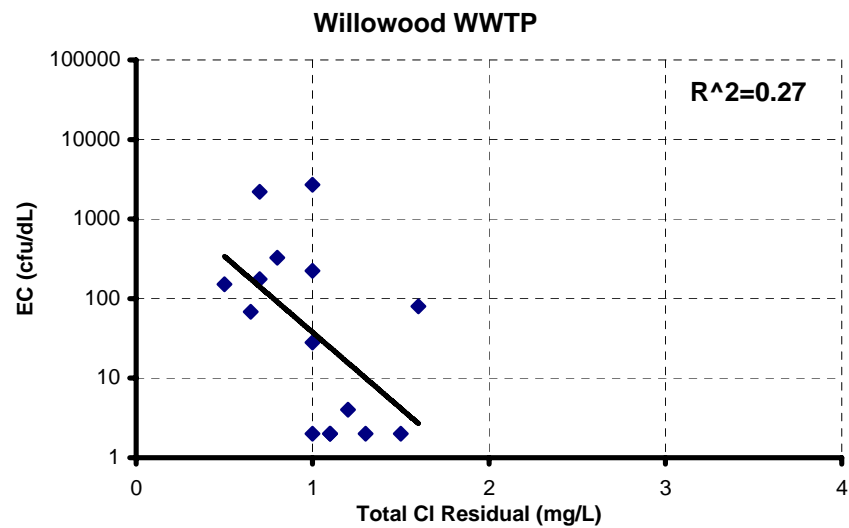
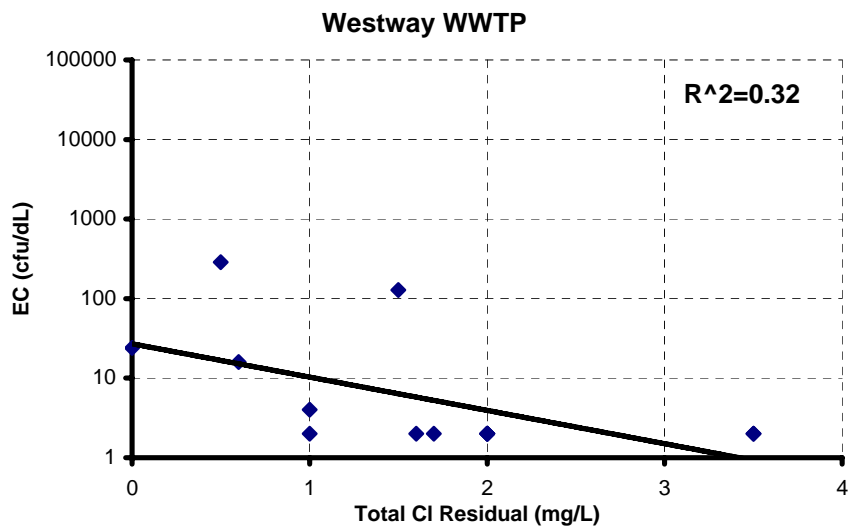
### **5.5.1 Comparison of Bacteria Concentrations at Weir and Outfall**

The question addressed here is whether there is significant regrowth of bacteria in the discharge pipe, particularly in plants where dechlorination is performed. To evaluate this topic, a statistical test was performed to compare the bacteria level at the weir and at the outfall. The calculations were performed for the Willowood WWTP and the Sunset MHP. The Westway WWTP does not have a data set at the outfall because the outfall was submerged preventing the collection of representative samples. The p-values for Willowood and Sunset are 0.38 and 0.09, respectively; therefore, the null hypothesis is not rejected for Willowood but rejected for Sunset. Although the geometric mean bacteria concentration at the Willowood outfall is higher than that at the Willowood weir, the difference is not significant. For Sunset MHP, the geometric mean at the outfall is lower than that at the weir, and the difference is significant. Since this WWTP does not dechlorinate, it appears that disinfection continued to occur between the weir and the outfall. It appears that the data from these two plants does not indicate that regrowth in the discharge pipe is a significant influence on instream bacteria concentrations.

### **5.5.2 Relationship between Effluent EC and Residual Chlorine**

The EC data at the weir are plotted against total residual chlorine for each of the WWTPs on Figure 4. The fourth plot shows all the data together. A linear regression between  $\text{Log}(\text{EC})$  and total residual chlorine shows significant slope at the 95% confidence level for Westway, Willowood, and all the data together. The slope for Sunset is not significant. It appears from these data that EC concentration at WWTP is somewhat negatively correlated with total residual chlorine concentration; higher total residual chlorine levels yield lower EC concentrations.

**FIGURE 4**  
**RELATIONSHIP BETWEEN EC AND TOTAL RESIDUAL CHLORINE AT WEIR FOR PLANTS SAMPLED**



## 6.0 CONCLUSIONS AND RECOMMENDATIONS

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It appears that where dry-weather discharges (excluding WWTP effluent) are a large part of the stream flow, efforts to fix problems in these inputs can have a positive effect. One might also expect a positive effect in other streams that are more dominated by WWTP effluent, but those effects might not be statistically significant.

While there is some evidence of improvement, this evidence is not conclusive due to the use of different EC test methods. The improved bacteria levels are still substantially higher than the contact recreation criteria (established based on swimming conditions). Even when dry-weather discharges with high bacteria sources are all eliminated, meeting the EC criteria for contact recreation would likely not be achieved based on the findings in the Luce Bayou Background Study.

A comparison between EC data at the weir and at the outfall of two WWTPs indicates that there was no significant increase in EC concentration in the discharge pipe between the weir and the outfall. The EC concentration at the weir appears to be negatively correlated with total residual chlorine concentration; higher total residual chlorine levels yield lower EC concentrations.

Efforts to eliminate dry weather discharges with high bacteria sources should first be focused on streams without substantial dry weather WWTP effluent flow. In this study, the elimination of dry weather sources on Brickhouse Gully, with less than 30% WWTP effluent during dry weather produced lower concentrations, which must be tempered by the different methods used and harsh environmental conditions during the sampling period, whereas reduction efforts in Vogel Creek includes a higher proportion of WWTP effluent but did use the same testing method, did not show a significant difference.

As documented in this study, the labor hours for instream monitoring are about one third of the total hours invested in the study. It would be a substantial cost to perform “before and after” instream monitoring for each stream. However, due to the inherent high variability of bacteria data, it would be desirable to perform “before and after” instream monitoring on one or two other streams to verify the findings of this study.

While WWTP effluents contribute relatively little bacteria load directly, the more heavily effluent-dominated streams appear to have higher concentrations. Among the possible reasons are regrowth following disinfection, additional sources to the stream such as birds, bats, and sediment resuspension, and the sustained and channelized flows that do not allow settling that is normally a major removal mechanism. More research on these mechanisms is needed if we are ever to have a mechanistic understanding of the factors that support the very high bacteria levels under low flow conditions.

With regards to data collection, HCSWQS should consider using the IDEXX method to be consistent with the current norm of EC testing so that data collected by HCSWQS can be compared on an equal basis with data collected by other entities. Moreover, since wastewater effluent has substantial influence

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on the study streams, in particular Vogel Creek, it is expected that higher EC values would be obtained if the IDEXX method is used. The instrument reading scale should be adjusted for conductivity data to provide more resolution. The reporting limit for ammonia data should be lowered for the results to be useful for nutrient analysis.

## 7.0 REFERENCES

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