Little White Oak Bayou and Halls Bayou Sediment Study

Prepared for

City of Houston, Harris County, Harris County Flood Control District, and the Texas Department of Transportation – Houston District

by

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AECOM Project Numbers 60073058
March 2009

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Executive Summary

Sediment and Water samples, under both dry and wet weather conditions, were collected at Little White Oak Bayou (LWO), which receives no WWTP discharges, and Halls Bayou (HB), which receives discharges from a number of WWTPs, at three separate locations on each stream in 2008. Samples were collected twice at each location, one under dry weather, and the other after a storm, representing wet weather conditions. Samples were analyzed for various nutrients and bacteria including fecal coliform, *E. coli*, and enterococci. Additionally, sediment samples were collected upstream and downstream of a stormwater outfall on LWO during both sampling events. Although the nutrient levels in HB are significantly higher than in LWO, there is no significant difference in water column bacteria levels between the two streams during dry weather, indicating that WWTPs do not directly contribute significant bacteria to HB during dry weather. However, HB appears to have noticeably higher bacteria levels in sediment especially under dry weather conditions although the difference is not statistically significant. Further investigation in sediment properties, including sediment nutrient levels and particle size, is needed to determine if the elevated bacteria levels in the sediment of HB is a result of higher nutrient levels. The water column bacteria levels in HB under wet weather conditions were found to be higher than in LWO. Possible reasons include sediment bacteria release and resuspension, additional loading from sanitary systems during wet weather, and different levels of stormwater loading from the watershed. The difference in bacteria levels in sediment collected upstream and downstream of the stormwater outfall is insignificant, but additional investigation of potential bacteria regrowth in the sediment downstream of stormwater outfalls is needed.

Sample Collection

During June 2008, sediment and water samples were collected at LWO and HB at three separate locations on each stream. The two streams were selected in this study because they receive different levels of WWTP discharges. Based on the Texas Commission on Environmental Quality's (TCEQ's) TPDES database, there is no WWTP effluent discharged into the LWO, while HB receives discharges from a number of WWTPs. The field sampling procedures, techniques, and preservation requirements used in this project strictly followed TCEQ's *Surface Water Quality Monitoring Procedures Manual, Volume I* (*TCEQ 2003*). A QAPP was developed before the sampling efforts began. This QAPP details the procedures related to sample collection, handling and analyses in this project. Sediment samples were collected at about 30 cm below the water surface, i.e., the sediment in approximately the top 2 – 4 cm. The sample dates were June 11th and 12th and represented dry weather or pre-storm conditions. The sediment samples were analyzed using SM 9222D for fecal coliform, SM 9223B for *E. coli* and SM 9230C for enterococci. In addition to these bacteria, the water samples were also analyzed for ammonia, nitrate + nitrite, TSS, total phosphorus, and orthophosphate-phosphorus. Streamflow was measured at the time of sampling. Sites were chosen as far away as possible from any wastewater or stormwater outfalls while considering safety and accessibility. Another round of samples was collected on September 25th and 26th representing wet weather or post-storm conditions in both streams. Additionally,

sediment samples were collected upstream and downstream of a stormwater outfall on LWO during both sampling events.

Data Analysis

Table 1 presents the data collected in this study. The in-stream nutrient data and water column and sediment bacteria data collected in LOW and HB are used to compare the differences of nutrient and bacteria levels between the two streams under both dry and wet weather conditions and to investigate how WWTP effluent affects the bacteria levels in both water column and sediment. The bacteria data collected upstream and downstream of the stormwater outfall were used to investigate the impact of stormwater loading on bacteria regrowth in the stream.

Comparison of Nutrient Levels between LOW and HB

The average dry weather concentrations in the water columns of LWO and HB, respectively, are 0.15 mg/l and 6.79 mg/l for nitrite + nitrate, 0.26 mg/l and 3.39 mg/l for total phosphorus, 0.11 mg/l and 3.41 mg/l for orthophosphate-phosphorus, and 0.28 mg/l and 0.63 mg/l for ammonia (*Table 1*). Unpaired student *t*-tests were performed to compare the nutrient levels in the water columns of LWO and HB. The *p*-values from those *t*-tests are presented in *Table 2*. The *p*-values of the *t*-tests for all measured nutrient species except ammonia are less than the threshold of 0.05, indicating that the nutrient levels in the water column of HB are significantly higher than those of LWO under dry weather conditions.

The similar difference in nutrient levels of the two streams is observed under wet weather conditions. The average wet weather concentrations in LWO and HB, respectively, are 0.22 mg/l and 3.53 mg/l for nitrite + nitrate, 0.19 mg/l and 2.33 mg/l for total phosphorus, 0.14 mg/l and 1.12 mg/l for orthophosphate-phosphorus, and 0.12 mg/l and 4.67 mg/l for ammonia (*Table 1*). The *p*-values (*Table 2*) from the unpaired t-student tests for all nutrient species, including ammonia, are less than 0.05, indicating that the nutrient levels in the water column of HB are significantly higher than those in LWO under wet weather conditions.

Comparison of Bacteria Levels in Water Column and Sediment between LOW and HB

Although the in-stream nutrient levels in HB are significantly higher than those in LWO under dry weather conditions, the higher nutrient levels do not result in consistent higher bacteria levels. The geometric means of the bacteria concentration in the water columns of LWO and HB, respectively, under dry weather conditions are 733 cfu/100 ml and 649 cfu/100 ml for fecal coliform (1.13 times higher in LWO), 640 mpn/100 ml and 425 mpn/100 ml for *E. coli* (1.51 times higher in LWO), and 83 cfu/100 ml and 329 cfu/100 ml for enterococci (3.96 times higher in HB). The fecal coliform and *E. coli* levels in the water column of HB are even lower than those of LWO under dry weather conditions.

However, there are some trends of higher bacteria levels in the sediment of HB than those of LWO under dry weather conditions. *Table 1* shows that the geometric means of bacteria concentration in the sediment of LWO and HB, respectively, under dry weather conditions are 67 cfu/g and 153 cfu/g for fecal coliform (2.28 times higher in HB), 47 mpn/g and 129 mpn/g for *E. coli* (2.74 times higher in HB), and 17 cfu/g and 476 cfu/g for enterococci (28.0 times higher in HB). Although there is no statistically significant difference in the bacteria levels between the two streams (*Table 2*), the fecal coliform and *E. coli* levels in the sediment of HB are noticed to be slightly higher than those of LWO, while the geometric mean of enterococci is 28.0 times higher in the sediment of HB. All three types of bacteria in HB are higher than in LWO. It is understood that bacteria concentrations follow a log-normal distribution, meaning they have a greater standard deviation. However, each type of bacteria at each location only has three data points. The statistical results are greatly affected by each data point. More samples need to be collected to support a solid statistical analysis for the bacteria in the two streams.

In contrast to dry weather conditions, it appears that the bacteria levels in the water column of HB are higher than those of LWO under wet weather conditions, although statistics show the difference is not significant (*Table 2*). The geometric means of bacteria concentration in the water column of LWO and HB, respectively, under wet weather conditions are 5,346 cfu/100 ml and 27,525 cfu/100 ml for fecal coliform (5.15 times higher in HB), 2,310 mpn/100 ml and 17,780 mpn/100 ml for *E. coli* (7.70 times higher in HB), and 213 cfu/100 ml and 1,512 cfu/100 ml for enterococci (7.10 times higher in HB). Further bacteria sampling is needed for the statistical analysis.

The geometric means of bacteria concentration in the sediment of LWO and HB, respectively, under wet weather conditions are 1,580 cfu/g and 2,910 cfu/g for fecal coliform (1.84 times higher in HB), 1,307 mpn/g and 1,651 mpn/g for *E. coli* (1.26 times higher in HB), and 35 cfu/g and 110 cfu/g for enterococci (3.14 times higher in HB). The disturbance between the water column and sediment during wet weather may affect the sediment bacteria levels. As a result, the bacteria levels in the sediment of HB are only slightly higher than those of LWO. *Table 2* show the difference between them is not statistically significant.

Although HB and LWO display a significant difference in nutrient levels due to the different levels of WWTP loading, no significant difference in bacteria levels is found in the water columns between them under dry weather conditions. The similarity in bacteria levels may indicate that WWTPs do not directly discharge significant amounts of bacteria into HB during dry weather. In addition, the impact of sediment on water column bacteria levels is minimal during dry weather because the bacteria in the sediment are entrapped in the sediment due to lack of scour. However, the higher bacteria levels in the sediment of HB than those of LWO are noticed especially under dry weather conditions. It is uncertain if the elevated sediment bacteria levels in HB are a result of stronger bacteria survival and regrowth in the sediment due to higher nutrient levels. Further investigations may be needed to investigate sediment nutrient levels in the two streams as well as other sediment properties e.g., particle size. The difference in bacteria levels between the two streams in the water column during wet weather could be a result of the

release and resuspension of bacteria from the sediment due to scour and flow disturbance, additional loading from sanitary systems, such as WWTP bypass and sludge washoff, and sanitary system overflows (SSOs) due to wet weather and/or different levels of stormwater loading from the watershed. Further investigation is needed to determine the reason.

Bacteria Levels in Sediment Upstream and Downstream a Stormwater Outfall

Sediment samples were collected approximately 15 feet upstream and 15 feet downstream from a stormwater outfall in LWO under both dry and wet weather conditions. Note that the wet weather samples were collected during the hurricane season when Hurricane Ike hit the Houston area. These samples represent a severe stormwater condition. One-site condition in the next several days was examined which did not support any sampling activities due to safety issues. Therefore, the samples were collected approximately 13 – 14 days after Hurricane Ike. No flow was observed from the outfall during both dry and wet weather sampling. It is found that 1) the levels of all three types of bacteria in sediment at upstream and downstream sites were similar in dry weather; 2) the bacteria levels of all three types in sediment at upstream and downstream sites were similar in wet weather; and 3) fecal coliform and *E. coli* levels were significantly elevated in wet weather at both upstream and downstream sites while fecal enterococci remained at the same level as that in dry weather. During wet weather conditions, the bacteria levels in the water column of the entire stream are elevated due to tremendous external loads (i.e., MS4 and nonpoint). Some of the bacteria would settle down onto the surface of the sediment along the stream when flowing through the stream, while bacteria entrapped in the sediment could be resuspended and/or released from the stream bottom due to enhanced scour caused by high flow velocity under wet weather conditions. These processes disturb the interface of the water column and the sediment and elevate bacteria levels at the interface. Therefore, the sediment samples collected in wet weather displayed a higher bacteria level than that in dry weather. It is noted that the enterococci level was not elevated in wet weather. The reason for this is unknown. A possibility is that enterococci may have a lower regrowth rate in sediment and the amount of enterococci released from the bottom is limited due to this low rate. Further investigation is needed before any conclusion can be made.

No significant difference is observed for bacteria levels at upstream and downstream sites under both weather conditions. As the bacteria levels in the entire stream are elevated during wet weather, the flow from the upstream reaches already contained elevated bacteria levels. When the flow from upstream reaches mixed with the discharge from the stormwater outfall, the bacteria levels in the mixed flow would not be significantly elevated further as the flow from the outfall was not significant in comparison with the in-stream flow from the upstream reaches. In addition, the two sampling sites are very close to each other (approximately 30 feet apart) and the flow conditions at the two sites should be similar because of the insignificance of outfall inflow in comparison with the in-stream flow. The flow velocities at both sites during wet weather sampling were 4.0 cfs (*Table 1*). The similarity of the bacteria levels and flow conditions would generate

similar bacteria settling and resuspension rates and hence similar bacteria levels in the sediment.

In order to determine if the bacteria in the stormwater discharge can survive and replicate in the sediment after they enter the stream, one should select an outfall which discharges significant flow in wet weather in comparison with the in-stream flow (probably an upstream reach of a small stream with a large outfall). Nutrient and bacteria loads from the outfall should also be measured. In addition, the unattached bacteria loaded from the outfall would flow away and only those attached to particles would settle downstream of the outfall. However, it is uncertain where the majority of these particles would settle as the distance of settling is determined by the flow velocity and the settling rate while the settling rate is a function of particle characteristics. Therefore, the sediment collection site downstream from the outfall may not be exactly where the majority of the bacteria-attached particles settle. A possible improvement includes collecting downstream sediment samples at multiple locations downstream of the outfall with a certain interval between them.

Conclusion

This is a preliminary study of bacteria in stream sediment, investigating the possible bacteria survival, regrowth and replication in stream sediment through the comparison of bacteria in the water column and sediment between two streams which have different nutrient levels due to WWTP discharges, and the bacteria in sediment immediately upstream and downstream of a stormwater outfall. Further investigations are needed to examine more assumptions regarding bacteria regrowth in stream sediment. Based on the limited data, the following conclusions are made:

- HB has higher in-stream nutrient levels than LWO under both dry and wet weather conditions probably due to the impact of WWTP discharges.
- The two streams do not display a significant difference in the water column bacteria level during dry weather, although the nutrient levels are significantly different. This similarity in bacteria levels may suggest that the direct bacteria contribution from WWTP effluent may not be significant during dry weather.
- However, HB has a higher bacteria level in sediment especially under dry weather conditions although the difference is not statistically significant. It appears that the sediment in HB may provide a more favorable environment for bacteria survival and regrowth. The reason for this is uncertain. Further investigation in sediment properties, including sediment nutrient levels and particle size, is needed.
- Higher water column bacteria levels are noted in HB during wet weather, which could be a result of the release and resuspension of bacteria from the sediment due to scour and flow disturbance, additional wet weather loading from sanitary systems (e.g., WWTP bypass, sludge washoff, and SSOs) due to the impact of Hurricane Ike, and/or different levels of stormwater loading from the watershed. Further investigation is needed to determine the dominant reason for this. The bacteria levels in the water columns of the two streams during dry weather are

similar. The higher sediment bacteria levels in HB appear to be entrapped during dry weather due to lack of scour and stream disturbance.

- The insignificant difference in bacteria levels in sediment collected upstream and downstream of the stormwater outfall does not necessarily mean bacteria regrowth is minimal as some adjustments or refinements to the methodology are needed in this investigation.

Reference

Texas Commission on Environmental Quality (TCEQ). 2003. *Surface Water Quality Monitoring Procedures Manual, Volume I* (*December 2003*).

Table 1. Raw Data and Statistics

Date	Site	Time	Flow	Matrix	Fecal Coliform	E. coli	Enterococci	Nitrate + Nitrite	Total Phosphorus	Ortho -phosphate -Phosphorus	TSS	Ammonia
			cfs		cfu/100 ml	mpn/100 ml	cfu/100 ml	mg/L	mg/L	mg/L	mg/L	mg/L
Dry Weather - Water												
6/11/08	LWO1	15:00	0.08	water	60	41	330	0.10	0.54	0.18	16.5	0.1
6/11/08	LWO2	14:00	1.03	water	190	185	< 10	0.17	0.05	< 0.02	2.5	< 0.1
6/11/08	LWO3	10:30	2.94	water	34,600	34,500	350	0.18	0.18	0.15	< 2.5	0.7
				Maximum	34,600	34,500	350	0.18	0.54	0.18	16.5	0.7
				Geo. Mean	733	640	83	0.15	0.17	0.06	3.72	0.15
				Average	11,617	11,575	228	0.15	0.26	0.11	6.75	0.28
				St. Dev.	19,904	19,853	194	0.04	0.25	0.09	8.47	0.36

Dry Weather - Sediment

			cfs		cfu/g	mpn/g	cfu/g
6/11/08	LWO1	15:00	0.08	sediment	< 10	< 10	20
6/11/08	LWO2	14:00	1.03	sediment	20	10	< 10
6/11/08	LWO3	10:30	2.94	sediment	3,000	2,100	50
				Maximum	3,000	2,100	50
				Geo. Mean	67	47	17
				Average	1,008	705	25
				St. Dev.	1,725	1,208	23
6/11/08	SWO down	12:30	0.38	sediment	90	80	70
6/11/08	SWO up	12:40	0.38	sediment	60	30	60

Date	Site	Time	Flow	Matrix	Fecal Coliform	E. coli	Enterococci	Nitrate + Nitrite	Total Phosphorus	Ortho -phosphate -Phosphorus	TSS	Ammonia
			cfs		cfu/100 ml	mpn/100 ml	cfu/100 ml	mg/L	mg/L	mg/L	mg/L	mg/L
Wet Weather - Water												
9/25/08	LWO1	14:30	0.37	water	17,600	22,540	1,600	< 0.05	0.34	0.304	2.5	< 0.1
9/25/08	LWO2	13:35	3.33	water	1,400	983	30	0.19	0.10	0.045	3.4	0.2
9/25/08	LWO3	9:20	6.93	water	6,200	556	200	0.43	0.14	0.080	< 2.5	0.1
				Maximum	17,600	22,540	1,600	0.43	0.34	0.304	3.4	0.2
				Geo. Mean	5,346	2,310	213	0.13	0.17	0.10	2.20	0.10
				Average	8,400	8,026	610	0.22	0.19	0.14	2.38	0.12
				St. Dev.	8,321	12,571	862	0.20	0.13	0.14	1.08	0.08

Wet Weather - Sediment

			cfs		cfu/g	mpn/g	cfu/g
9/25/08	LWO1	14:30	0.37	sediment	980	880	24
9/25/08	LWO2	13:35	3.33	sediment	760	540	19
9/25/08	LWO3	9:20	6.93	sediment	5,300	4,700	98
				Maximum	5,300	4,700	98
				Geo. Mean	1,580	1,307	35
				Average	2,347	2,040	47
				St. Dev.	2,560	2,310	44
9/25/08	SWO down	10:30	4.00	sediment	1,300	1,000	69
9/25/08	SWO up	10:40	4.00	sediment	1,400	1,100	20

Table 1. *Cont.*

Date	Site	Time	Flow	Matrix	Fecal Coliform	E. coli	Enterococci	Nitrate + Nitrite	Total Phosphorus	Ortho -phosphate -Phosphorus	TSS	Ammonia
			cfs		cfu/100 ml	mpn/100 ml	cfu/100 ml	mg/L	mg/L	mg/L	mg/L	mg/L
Dry Weather - Water												
6/12/08	HB1	11:30	1.30	water	4,800	4,352	420	4.74	3.05	2.95	14.1	0.7
6/12/08	HB2	10:40	3.93	water	190	160	100	7.70	3.96	3.99	22.3	0.9
6/12/08	HB3	9:45	5.55	water	300	110	850	7.92	3.16	3.28	19	0.3
				Maximum	4,800	4,352	850	7.92	3.96	3.99	22.3	0.9
				Geo. Mean	649	425	329	6.61	3.37	3.38	18.15	0.57
				Average	1,763	1,541	457	6.79	3.39	3.41	18.47	0.63
				St. Dev.	2,630	2,435	376	1.78	0.50	0.53	4.13	0.31

Dry Weather - Sediment

			cfs		cfu/g	mpn/g	cfu/g
6/12/08	HB1	11:30	1.30	sediment	320	270	260
6/12/08	HB2	10:40	3.93	sediment	140	100	130
6/12/08	HB3	9:45	5.55	sediment	80	80	3,200
				Maximum	320	270	3,200
				Geo. Mean	153	129	476
				Average	180	150	1,197
				St. Dev.	125	104	1,736

Date	Site	Time	Flow	Matrix	Fecal Coliform	E. coli	Enterococci	Nitrate + Nitrite	Total Phosphorus	Ortho -phosphate -Phosphorus	TSS	Ammonia
			cfs		cfu/100 ml	mpn/100 ml	cfu/100 ml	mg/L	mg/L	mg/L	mg/L	mg/L
Wet Weather - Water												
9/26/08	HB1	11:20	1.81	water	980,000	435,200	80,000	2.66	2.29	1.18	4.8	6.5
9/26/08	HB2	10:40	2.55	water	7,600	7,500	240	4.29	3.26	1.36	3.0	5.4
9/26/08	HB3	9:45	7.35	water	2,800	1,722	180	3.64	1.45	0.827	< 2.5	2.1
				Maximum	980,000	435,200	80,000	4.29	3.26	1.36	4.8	6.5
				Geo. Mean	27,525	17,780	1,512	3.46	2.21	1.10	2.62	4.19
				Average	330,133	148,141	26,807	3.53	2.33	1.12	3.02	4.67
				St. Dev.	562,806	248,617	46,067	0.82	0.91	0.27	1.78	2.29

Wet Weather - Sediment

			cfs		cfu/g	mpn/g	cfu/g
9/26/08	HB1	11:20	1.81	sediment	32,000	9,800	600
9/26/08	HB2	10:40	2.55	sediment	5,500	5,100	140
9/26/08	HB3	9:45	7.35	sediment	140	90	16
				Maximum	32,000	9,800	600
				Geo. Mean	2,910	1,651	110
				Average	12,547	4,997	252
				St. Dev.	17,059	4,856	308

Notes:
For the data which are less than the laboratory minimum detection limit, one-half of the limit is used in the statistical analyses.
LWO - Little White Oak Bayou
HB - Halls Bayou

Table 2. *p*-values of Unpaired *t*-tests for Comparison of Nutrient and Bacteria Levels in Little White Oak and Halls Bayous

Dry Weather

Nutrient	Nitrite + Nitrate	Total Phosphorus	Orthophosphate-Phosphorus	Ammonia		
p-Value	0.0029	0.00062	0.00045	0.28		
< 0.05 ?	Yes	Yes	Yes	No		
Significant Different?	Yes	Yes	Yes	No		
Bacteria	Fecal Coliform in Water Column	Fecal Coliform in Sediment	*E. coli* in Water Column	*E. coli* in Sediment	Enterococci in Water Column	Enterococci in Sediment
p-Value	0.4432	0.4534	0.4339	0.4723	0.4030	0.3805
< 0.05 ?	No	No	No	No	No	No
Significant Different?	No	No	No	No	No	No

Wet Weather

Parameter	Nitrite + Nitrate	Total Phosphorus	Orthophosphate-Phosphorus	Ammonia		
p-Value	0.0024	0.015	0.0051	0.027		
< 0.05 ?	Yes	Yes	Yes	Yes		
Significant Different?	Yes	Yes	Yes	Yes		
Bacteria	Fecal Coliform in Water Column	Fecal Coliform in Sediment	*E. coli* in Water Column	*E. coli* in Sediment	Enterococci in Water Column	Enterococci in Sediment
p-Value	0.3782	0.3636	0.3848	0.3948	0.3074	0.3171
< 0.05 ?	No	No	No	No	No	No
Significant Different?	No	No	No	No	No	No