Time of Travel Study at Mason Park

Final Report

Prepared in cooperation with the Harris County Flood Control District
Project ID: Z100-00-00-Y053

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Environmental Institute of Houston
University of Houston - Clear Lake

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Executive Summary

The Harris County Flood Control District (HCFCD) is interested in evaluating the treatment efficiency of the Mason Park treatment wetlands in terms of indicator bacteria and other related pollutants. However, due to complex wetland topography and lack of historical gaged flows it has been difficult to estimate residence and travel time of stormwater through the wetland complex. This lack of physical and hydrological data made it difficult to estimate the timing of appropriate water quality sample collections and locations to insure the same parcel of water is being monitored as it moves through the system.

A research project was initiated by HCFCD with the Environmental Institute of Houston (EIH) to investigate the hydraulic residence and transit time of stormwater within the Mason Park Constructed Wetland System using defined dye tracer methods scoped by EIH. Background information, funding, and two YSI datasondes were provided by HCFCD for this study. Residence time information is needed to design an effective water quality monitoring program to evaluate treatment efficiency for common water quality variables including indicator bacteria, suspended sediment, and nutrients.

In 2011, Texas experienced an extreme drought of national significance. Despite numerous attempts, EIH was not able to effectively conduct a dye tracer study to estimate time of travel and residence time within the wetland. Consequently EIH conducted a review of historical rainfall data as well as stream flow data for Brays Bayou (HCFCD Unit D100-00-00) in an attempt to model rainfall-runoff scenarios that would exist under non-drought conditions.

Based on the analysis of historical hydrological data that exists within the Brays Bayou watershed, EIH was able to determine the conditions and likelihood of effectively treating stormwater runoff from the 22 acre contributing watershed to the treatment wetland complex according to the designed hydrology of the site. Our main findings include the following:

1. A review of 10 years of rainfall data showed that the Mason Park wetland site may have been flooded by Brays Bayou on an average rate of 3 overbank flood events per year. Consequently, the wetland site is subject to complicated hydrology and during overbank flood events, the stormwater treatment capability of the wetland may not be functioning as it was designed. The evaluation of empirical stream elevations confirmed these observations.

2. The Mason Park Created wetland site may improve water quality in the case of localized rainfall events of 2 inches within 24 hours. However, it should be recognized that similar rainfall events at the larger Brays Bayou watershed scale may lead to overbank flooding by the bayou. EIH found for example, that most of the precipitation data from rain gages in the watershed were highly correlated to the nearby Lawndale site. This suggests that most significant (significant is an event which causes a measurable rise and fall in the water level of the waterbody) rain events affect a large portion of the Brays Bayou watershed, which would lead to high water levels and possible overbank flooding at the site, or backup of bayou water into the Tidal Marsh (pond 3) inhibiting downstream flow through the wetland system. In either case this would reduce downstream movement of water from the 22 acre

drainage area through the wetland, effectively reducing measureable stormwater treatment efficiency. To identify the range of these events, more monitoring of the water level in pond 1 is needed.

3. In the case of drought conditions, the water at the ponds is more likely to stay static and the site hydrology will not function as it was designed due to the lack of water flow through the system. Any water quality testing during such droughts should be avoided as these tests would likely yield inconclusive results.

4. The hydrological design of the wetland site should be examined closely especially in the case of extreme rainfall events and possible overbank flooding from Brays Bayou. Also, the observed increase in specific conductance suggests that alternate pathways such as groundwater seepage or backflow due to tidal influence may be occurring at the wetland site. Further investigations are needed to develop an accurate hydrological flow pattern at the site during both wet weather and dry weather events.

To better understand the complex hydrology of the Mason Park wetland system, EIH recommends that additional monitoring be conducted during non-drought conditions that utilizes 1) automated water quality monitors, 2) photographic evidence, 3) additional gage sites and measurements, 4) analysis of regional rainfall and runoff patterns 5) investigate the effects of the adjustable Agridrain weir structures to better manage the hydrology regime of the wetland site, and 6) if feasible, new renewed attempts to conduct flourometric dye tracer studies. This will lead to a better understanding of the hydrology within this system, allowing for proper water quality monitoring planning so that the appropriate conditions under which treatment efficiency for pollutants can be measured.

Introduction

Problem Statement

The Harris County Flood Control District (HCFCD) in partnership with the U.S. Army Corps of Engineers (USACE) started a major flood damage reduction project called "Project Brays" in 1998. Project Brays (or the Brays Bayou Flood Damage Reduction Project) is a 15 year, $413 million project that was designed to reduce the risks associated with flooding in the Brays Bayou watershed. The Brays Project encompasses more than 70 individual projects, one of which was the creation of a stormwater treatment wetland at Mason Park adjacent to Brays Bayou (HCFCD Unit D100-00-00).

The types and amounts of pollutants in stormwater vary widely with the land uses in the contributing watershed. Generally, higher pollutant concentrations are associated with more intensive development and increased surface imperviousness (Kadlec et al. 2000). The water quality of stormwater also varies widely with frequency and intensity of rainfall. Stormwater wetlands when properly designed have been shown to provide effective removal of multiple pollutants including suspended solids, microorganisms, nutrients, and heavy metals (Cappiela et al. 2008). The predominant processes that determine removal and treatment efficiency include sedimentation, filtration, adsorption, chemical precipitation, microbial transformation and biological uptake. These processes are controlled by various factors including hydraulic loading, plant density and the size of the wetland treatment system. Hydraulic loading including peak flows affects both residence time and time of travel through the system (Kadlec et al. 2000). In general reduced flows enhance treatment processes whereas fast flowing water receives less treatment.

The HCFCD is interested in evaluating the treatment efficiency of the Mason Park created wetlands in terms of indicator bacteria and other related pollutants. However, due to complex wetland topography and lack of historical gaged flows it has been difficult to estimate residence and travel time of stormwater through the wetland complex. This lack of physical and hydrological data makes it difficult to estimate the timing of appropriate sample collections and locations to insure the same parcel of water is being monitored as it moves through the system. Information is needed on precipitation induced and influenced surface water inflow rates and residence time within the wetland system. The use of Rhodamine dye as a tracer is an effective way to estimate these parameters (Leibundgut et. al. 2009).

A research project was initiated by HCFCD with the Environmental Institute of Houston (EIH) to investigate the hydraulic residence and transit time of stormwater within the Mason Park Constructed Wetland System using defined dye tracer methods scoped by EIH. Background information, funding, and two YSI datasondes were provided by HCFCD for this study. Residence time information is needed to design an effective water quality monitoring program to evaluate treatment efficiency for common water quality variables including indicator bacteria, suspended sediment, and nutrients.

Background

Study Area

The Brays Bayou watershed is located in southwest Harris County and portions of Ft. Bend County (Figure 1). Brays Bayou watershed covers approximately 127 square miles and there are about 121 miles of streams within the watershed (Harris County Flood Control District 2012). The main channel of Brays Bayou (HCFCD Unit D100-00-00) is about 31 miles long. The bayou flows eastward from Fort Bend County to its confluence with the Houston Ship Channel in Harris County. The watershed includes three primary streams: Brays Bayou, and the tributaries Keegans Bayou and Willow Waterhole Bayou. The Mason Park project site is located directly adjacent to Brays Bayou at the downstream end of the watershed (Figure 1).

Mason Park is located two miles north of the IH-610 and IH-45 interchange in southeast Houston, TX. In 2006 the wetland treatment system designed by Dr. Robert Knight of Wetland Solutions, Inc. was constructed. The contributing watershed to the treatment wetlands is approximately 22 acres, and consists primarily of a portion of the adjacent residential subdivision (Figure 2). The treatment wetland complex consists of three separate ponds, including a wet pond which was designed to receive direct stormwater flow, then a shallow freshwater treatment marsh followed by a tidal marsh which discharges into Brays Bayou (Figure 3). Two Agridrain inline water level control structures™ were installed between each discrete treatment area. Agridrain box number 1 is between the wet pond (WP) and the downstream shallow treatment wetland (TW). Agridrain box number 2 is located between the TW and the final downstream tidal marsh (TM). The Agridrain structures are designed to regulate flow and water level in the system. Agridrain box number two is designed to control tidal backflow into the wetland pond system during periods of high tide in the adjacent Brays Bayou (Wetland Solutions, Inc. 2002).

Drought Conditions

In 2011 Texas experienced an extreme drought of national significance. As a result investigators throughout the state found it very difficult or impossible to conduct field data collection for “stormwater” or wet weather studies. The majority of the state had been designated with the highest rating of “exceptional drought” at some point in 2011. Climatologists stated that this was the worst one-year drought since 1895 (Huber 2012). Consequently EIH also conducted a review of historical rainfall data as well as stream flow data for Brays Bayou in an attempt to model rainfall-runoff scenarios that would exist under non-drought conditions.

Figure 1. Brays Bayou and study area located in Harris County, TX. The Mason Park study site ( ) is located at the furthest most downstream point of the Brays Bayou Watershed.

Mason Park Wetlands Contributing Watershed

Figure 2. Map of the contributing watershed to the treatment wetlands complex located at Mason Park in Houston, TX.

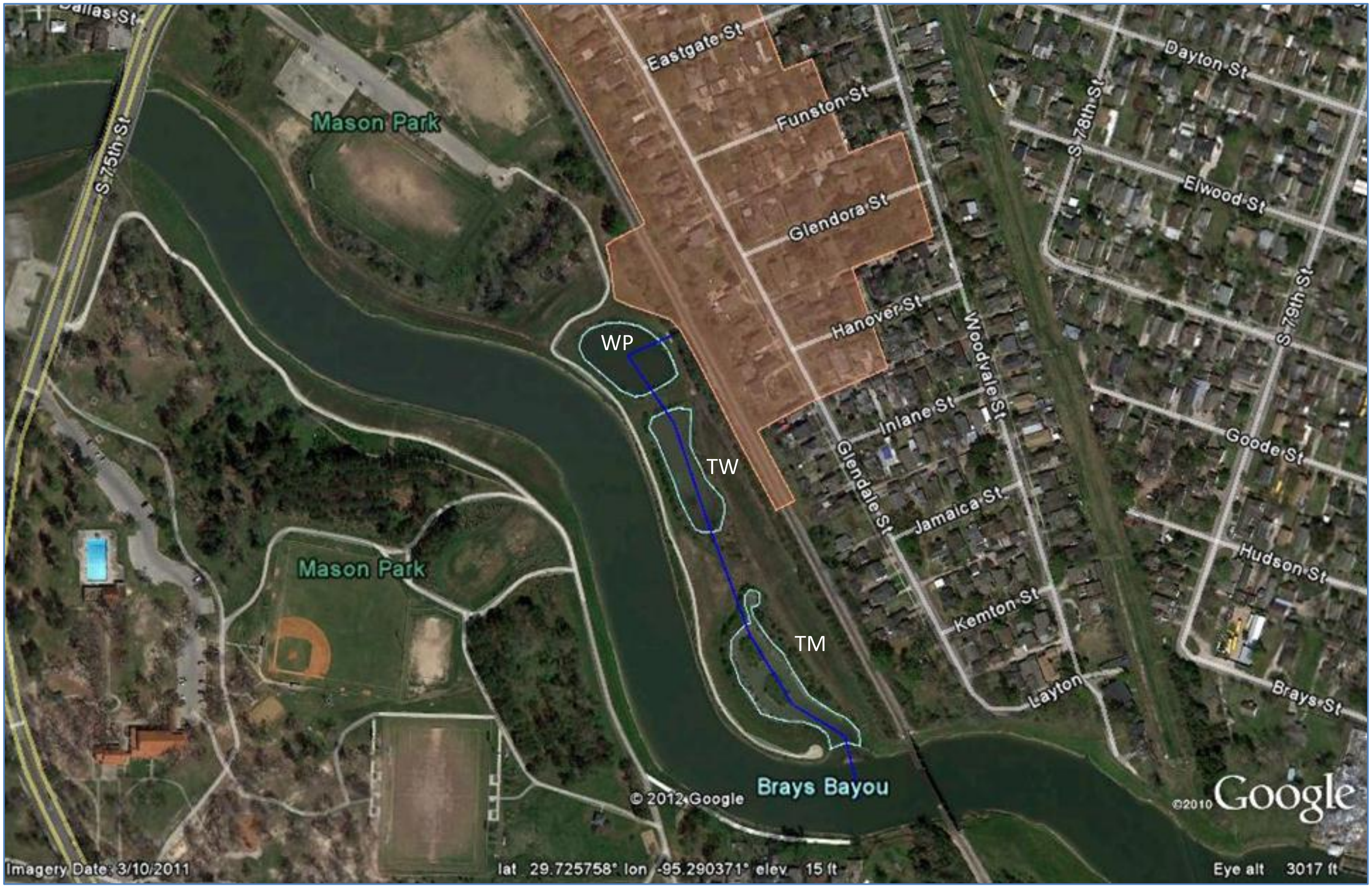

Figure 3. Field survey site locations at Mason Park wetland complex in Houston, TX (wet pond - WP, treatment wetland - TW, tidal marsh TM).

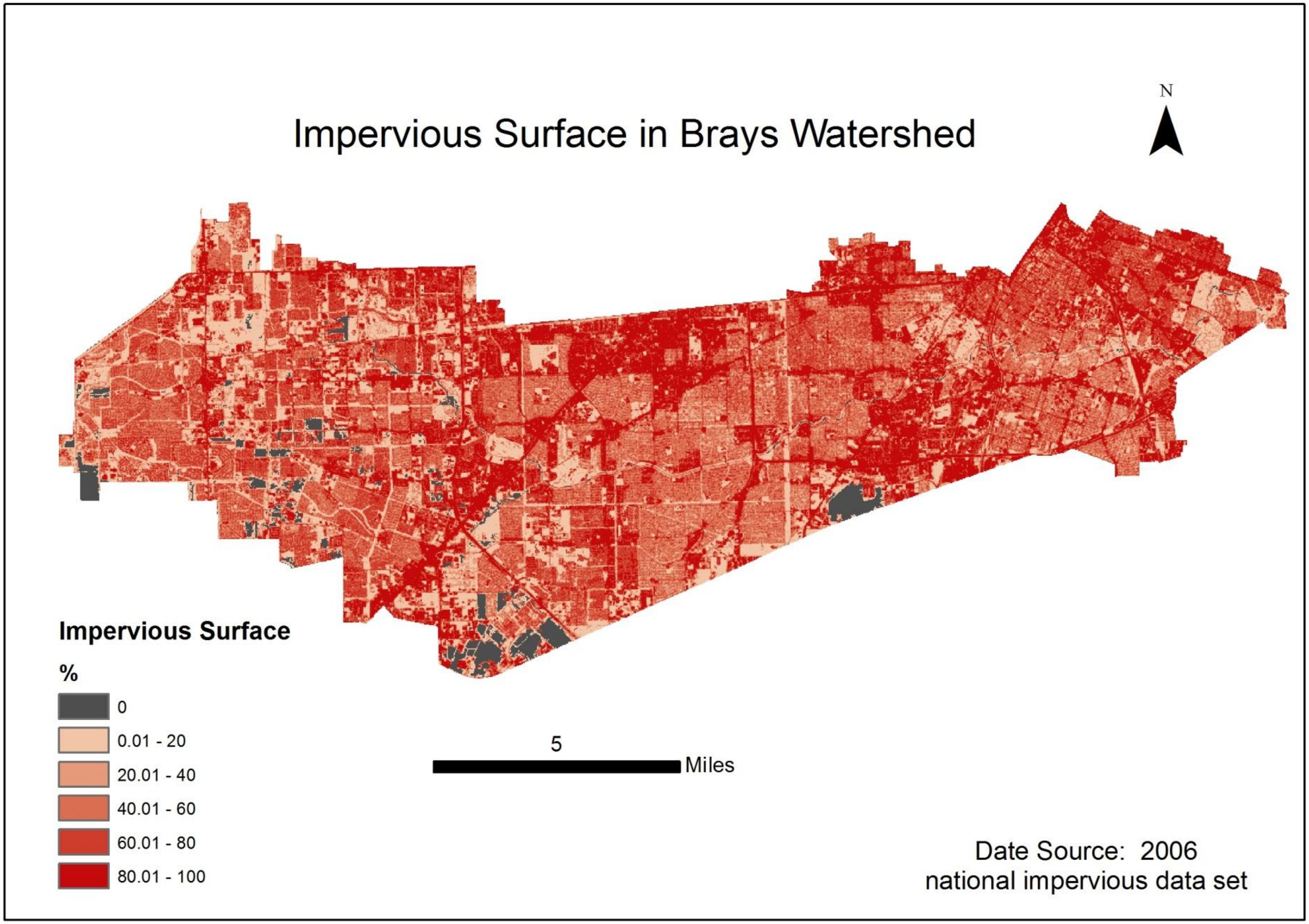

Figure 4. Impervious surface area within the Brays Bayou Watershed, Harris County, TX. The Mason Park study site is located at the furthest most downstream point of the Brays Bayou Watershed.

Study Objective

The original primary objective of this project was to estimate the residence and transit time of stormwater within the Mason Park constructed wetland system. Rhodamine dye studies are an effective way to estimate these parameters (Kilpatrick and Wilson Jr. 1989; Leibundgut et al. 2009). This information is needed to develop an effective water quality monitoring program to evaluate treatment efficiency for common water quality variables including indicator bacteria, suspended sediment, and nutrients. The objective was to release dye at the most upstream point of the system, and record the exact time the dye was released. EIH's deployed datasondes can then monitor continuously at critical points throughout the entire wetland system, and record at what time exactly the dyed water passes through these critical points in the system. By monitoring and determining the average transit time, investigators can determine when to sample "upstream" and "downstream" within the wetland system to insure the same parcel of water is being monitored.

The second objective of this study was to conduct limited concurrent monitoring of *E. coli* bacteria to evaluate treatment efficiency of the wetland under ambient stormwater runoff conditions. However, due to the drought there was a very low probability of having a qualifying event consisting of sustained precipitation within the contributing watershed to the treatment wetlands that would generate sufficient runoff to transport water through the system.

Due to the unforeseen drought conditions, EIH later incorporated supplementary tertiary objectives and methods to determine whether there is sufficient runoff during storm events to transport water through the wetland complex during average precipitation scenarios. Due to the small watershed size (~22 acres) EIH hypothesized that high rainfall events occurring primarily in the contributing watershed to the treatment wetlands, without concurrent high precipitation in the larger upstream Brays Bayou watershed, is most likely a rare event. In addition, during these high rainfall events, Brays Bayou would likely experience high stream flows causing flows within the wetland complex to reverse or even detour over the berm between the wetland complex and the bayou during overbank flood events. Overbank flood events occurring due to high river flows in Brays Bayou effectively short circuit the expected flow pathway through the wetland. Consequently an investigation of recent historical (10 year) rainfall patterns and associated gage heights were assessed, as well as runoff modeling for the Brays Bayou watershed and the much smaller residential 22 acre contributing watershed to the Mason Park created wetland system.

Methods

Site Selection and Descriptions

Three sampling locations were established for this project (

Table 1, Figure 5 and Figure 6). Field survey site 1 was located at the inlet to the northern side of the wet pond (WP). This was the site identified for dye release and flow measurements. Field survey site 2 was located at the outlet of the wet pond in the north Agridrain box 1, where it enters the shallow treatment wetland (TW). Field survey site 3 was located at the outlet of the shallow treatment wetland in the South Agridrain Box 2, where it enters the tidal marsh system (TM). Datasondes were deployed at field survey sites 2 and 3, and flow measurements in total discharge (cfs) and velocity (f/s) were taken during each site visit as applicable.

Table 1. Hydraulic residence time field survey sites.

Site #	Site Description	Latitude	Longitude	Notes
1	Inlet of Wet Pond	29.726482	-95.290504	Dye Release Site
2	North Agridrain Box	29.726030	-95.290598	Long-Term Datasonde Site
3	South Agridrain Box	29.724841	-95.289990	Long-Term Datasonde Site

Figure 5. Location of Mason Park field survey sites.

Figure 6. Mason Park field survey site photographs (1 – inlet to wet pond; 2 – North Agridrain box; 3 – South Agridrain box).

Sampling Methods

Per the contract, EIH field team was to sample three (3) storm events defined as a minimum of 1 inch rainfall occurring within a 24hr period, preceded by 72 hours of no rainfall in the watershed. This sampling included monitoring of rainfall and stream elevation data collected from the Harris County Flood Warning System site 410: D100 Brays Bayou at Lawndale Street (at: http://www.harriscountyfws.org/). Upon observed rainfall within the Mason Park area a field team was deployed to Mason Park Wetland complex to conduct field observations such as flow and water level and release the rhodamine dye at site 1. Dye Release was attempted by EIH field crew a total of six times (Table 2). However, sufficient inflow and flow water within the wetland complex were never visually observed, thus the rhodamine dye was never released. Based upon repeated unsuccessful attempts to conduct the study as scoped, the third objective was defined to determine when and if a rain event would produce the flow patterns necessary to conduct a dye release and subsequent water quality monitoring methodology. An investigation of the general flow patterns of the wetland complex was also conducted.

Table 2. Dates and activities performed at Mason Park Site visits. Rain event activity were attempts to release dye, however the conditions were not conducive, thus no dye was released. Deploy and retrieve activities were site visits that consisted of deployment and retrieval of YSI datasondes at field survey sites 1 and 2.

Date	Activity	Time	Days Since Rain
12/8/2010	Recon	9:45	36
2/15/2011	Deploy	10:50	10
2/28/2011	Retrieve	10:47	19
3/2/2011	Deploy	10:21	21
3/8/2011	Rain Event	11:35	<1
4/5/2011	Retrieve	11:21	22
4/6/2011	Deploy	9:55	23
4/26/2011	Retrieve	11:04	46
4/27/2011	Deploy	14:19	47
5/19/2011	Retrieve	10:43	7
6/22/2011	Rain Event	14:30	<1
10/10/2011	Rain Event	11:15	<1
11/9/2011	Rain Event	12:30	<1
11/14/2011	Deploy	13:46	5
11/15/2011	Rain Event	16:38	<1
12/5/2011	Rain Event	11:00	<1

Rainfall and Runoff Estimations

A total of 34 precipitation gage sites (Table 3 and **Error! Reference source not found.**) were identified within the Brays Bayou watershed. Daily rainfall data was downloaded from the Harris County Flood Warning System website for all 34 gages for the past ten years (2/1/2002-1/30/2012). In addition, hourly rainfall data was downloaded for the study period (1/1/2011-12/31/2011)

Table 3. Rainfall Gage Sites used for runoff analysis and modeling within the Brays Bayou Watershed.

Gage Site ID	Gage Site Location	Latitude	Longitude	Agency	Sensor Number
340	C100 Sims Bayou @ Telephone Road	29.67396	-95.28925	HCFCD	59
360	C100 Sims Bayou @ Martin Luther King Road	29.64518	-95.33695	HCFCD	61
400	D109 Harris Gully @ South McGregor Way	29.70780	-95.39216	HCFCD	66
410	D100 Brays Bayou @ Lawndale Street	29.72249	-95.30507	HCFCD	68
420	D100 Brays Bayou @ South Main Street	29.69741	-95.41209	HCFCD	71
430	D100 Brays Bayou @ Stella Link Road	29.69063	-95.44003	HCFCD	73
435	D100 Willow Water Hole @ Willowbend Boulevard	29.66433	-95.45984	HCFCD	74
440	D100 Brays Bayou @ Rice Avenue	29.67883	-95.46788	HCFCD	76
460	D100 Brays Bayou @ Gessner Road	29.67278	-95.52817	HCFCD	79
465	D100 Brays Bayou @ Beltway 8	29.69525	-95.55696	HCFCD	80
470	D100 Brays Bayou @ Belle Park Drive	29.71106	-95.58717	HCFCD	83
475	D100 Brays Bayou @ Bellaire Boulevard	29.70394	-95.56574	HCFCD	85
480	D118 Keegans Bayou @ Roark Road	29.65643	-95.56228	HCFCD	87
485	D100 Brays Bayou @ SH 6	29.71563	-95.64421	HCFCD	89
490	D118 Keegans Bayou @ Keegan Road	29.66558	-95.59516	HCFCD	90
1020	Reliant Park	29.68781	-95.41279	HCFCD	176
2010	Barker Dam	29.76966	-95.64657	HCFCD	279
2210	W100 Buffalo Bayou @ Turning Basin	29.74939	-95.29105	HCFCD	300
2240	W100 Buffalo Bayou @ Shepherd Drive	29.76066	-95.40877	HCFCD	304
2260	W100 Buffalo Bayou @ San Felipe Drive	29.75083	-95.50523	HCFCD	308
2270	W100 Buffalo Bayou @ West Beltway 8	29.76226	-95.55776	HCFCD	310
2290	W100 Buffalo Bayou @ Dairy Ashford Road	29.76195	-95.60627	HCFCD	314
3020	I-45 HOV Downtown Terminal	29.74278	-95.35833	TXDOT	338
3040	US 59 @ Jefferson	29.74611	-95.36139	TXDOT	347
3050	US 59 @ McGowen	29.74056	-95.36583	TXDOT	355
3070	SH 288 @ Loop 610	29.67978	-95.38104	TXDOT	361
3240	Allen Parkway @ Waugh	29.76111	-95.39826	City of Houston	378
3380	Holcombe @ Buffalo Speedway	29.70610	-95.42760	Metro	392
3490	Telepsen North Bound Master	29.72310	-95.32840	TXDOT	420
3630	I-45 @ HOV Louisiana	29.75102	-95.37352	TXDOT	470
4450	East Sugar Creek Ditch @ Sugar Creek	29.62471	-95.59052	Sugar Land	634
4480	Oyster Creek @ SH 6	29.63470	-95.65127	Sugar Land	643
4490	Covington Ditch @ Jess Pirtle	29.63444	-95.62723	Sugar Land	646
4840	Spur 5 @ IH 45 Gulf	29.72721	-95.33684	TXDOT	786

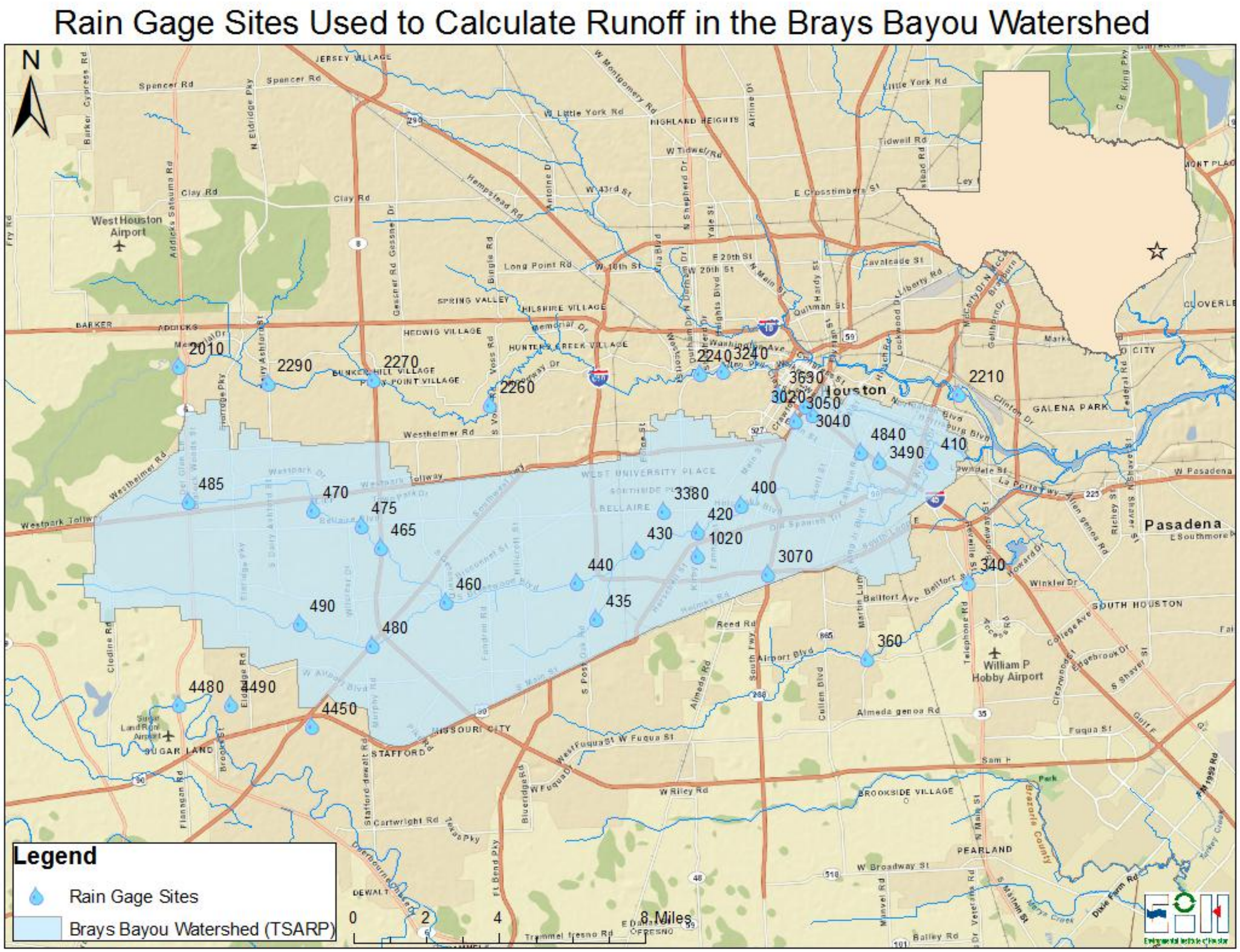

Figure 7. Rainfall gage sites used for rainfall-runoff analysis and modeling within the Brays Bayou watershed. Site numbers corresponds to data in Table 3. The Mason Park study site is located at the furthest most downstream point of the Brays Bayou watershed.

Mason Park Summary Analysis

The following discussions and conclusions are based on a simplified hydrological analysis conducted to understand the hydrological regime at the site. Multiple lines of investigation have been conducted in order to understand how the wetland site is functioning during rainfall events. These include 1) determining the capacity of pond 1 (WP) (Figure 8) and the rainfall event needed to produce sufficient runoff volume that would fill pond 1 (WP) up to the Agridrain 1 weir level so water starts flowing into pond 2 (TW), 2) analyzing the implications of the elevated mainstem Brays Bayou streamflow on the wetland site, in terms of overbank flooding and modification of drainage, using a simplified hydrological approach, 3) recent (June 2012) visual observations at the site and analysis of recent hydrology, and 4) correlation analysis of historical rain (2/1/2002 to 1/30/2012) gage network data.

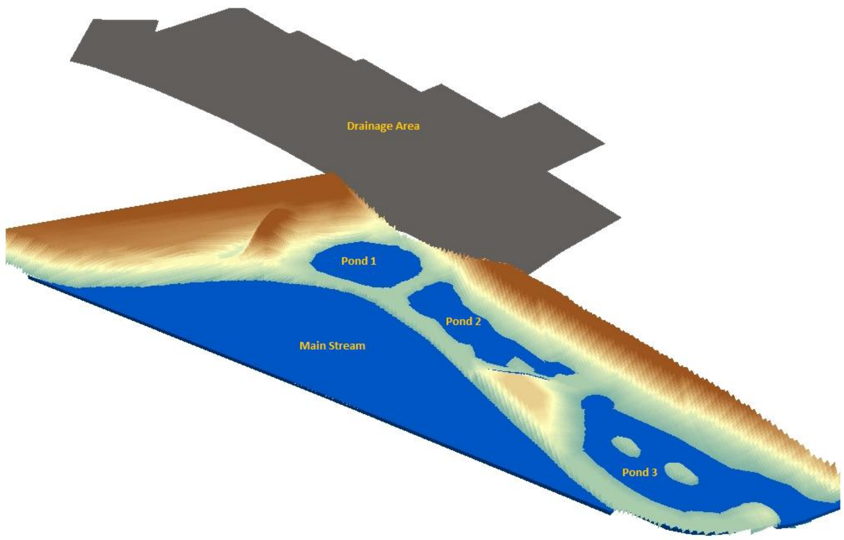

Figure 8. Illustration of the investigated site showing the main stream, three ponds (pond 1 = WP, pond 2 = TW, and pond 3 = TM), and the adjacent urban drainage area.

The hydrological analysis is based on the use of the NRCS Runoff Curve Number method to calculate the runoff volume produced by daily rainfall events (USDA-SCS 1985) . The method is also used in reverse to identify rainfall events that may produce predefined runoff volumes at the site. The method is widely used as it is a product of more than 20 years of studies involving rainfall-runoff relationships under varying land use and soil types. It was developed by the U.S. Department of Agriculture and Natural Resources Conservation Service (NRCS), which is formally known as the Soil Conservation Service (SCS). The primary inputs into the method include the runoff curve number, rainfall, and the drainage area size. It is based on the notion that for a single storm; the ratio of actual soil retention (after runoff begins) to potential retention is equal to the ratio of direct runoff to the storm rainfall (USDA-SCS 1985). This principle and after algebraic manipulation and simplifying assumptions results in equation (1) that is found in the National Engineering Handbook (USDA-SCS 1985):

(1) $$Q = \frac{(P-0.2S)^2}{P+0.8S}$$

Where:

Q is runoff (inch)

P is rainfall (inch)

S is the potential maximum soil moisture retention after runoff begins (inch). This parameter is calculated from next equation using the runoff Curve Number (CN):

(2) $$S = \frac{1000}{CN} - 10$$

The amount of water before runoff *Ia* (also named as initial abstraction), such as infiltration or rainfall interception by vegetation is directly related to *S* as in the equation (3).

(3) $$Ia = 0.2S$$

The CN values usually range from 30 to 100 with lower numbers indicating lower runoff while larger numbers are related to increasing runoff potential. The CN is an empirical parameter that is primarily related to soil characteristics and land use (surface cover). In general, the infiltration rate of the soil surface is affected by surface conditions and soil profiles. As soil profiles may be considerably altered due to urbanization, the hydrological soil groups (HSG) are established according to the texture of the surface soil (Table 4).

Table 4. Hydrological soil groups.

HSG	Soil Texture
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

In general, the “Group A” soils are associated with the lowest runoff potential and high infiltration rates even when thoroughly wetted, while the “Group D” soils are associated with the highest runoff potential as it has very low infiltration rates when thoroughly wetted.

Results

Calculation of precipitation and runoff volumes

The water capacity of pond 1 (WP) was calculated as a volume (cf) using the contours of the original plan used for developing the wetland site (Wetland Solutions, Inc. 2002). These contours were used in GIS to produce a continuous representation of the site and consequently the surface volume at the Agridrain 1 weir level (i.e. the first weir that is located between pond 1 and pond 2) was calculated as 116,825 cf. The nearest Harris County floodplain topographic reference mark at South 75th Street was used to determine the elevation at the weir using ground surveying. Then, the NRCS Runoff Curve Number method was used to back calculate a hypothetical rainfall event that is required to produce the runoff volume of water in pond 1 (WP) considering the urbanized drainage area associated with the site (Figure 9). Assuming pond 1 is empty; EIH found that a daily rainfall event of 2.01 inch would produce the runoff volume sufficient to fill up pond 1 to the weir level, beyond which water would start to flow to the next pond. However, considering that there is always water in pond 1, a smaller rainfall event would produce a sufficient runoff volume to bring the water level in Pond 1 to the weir level.

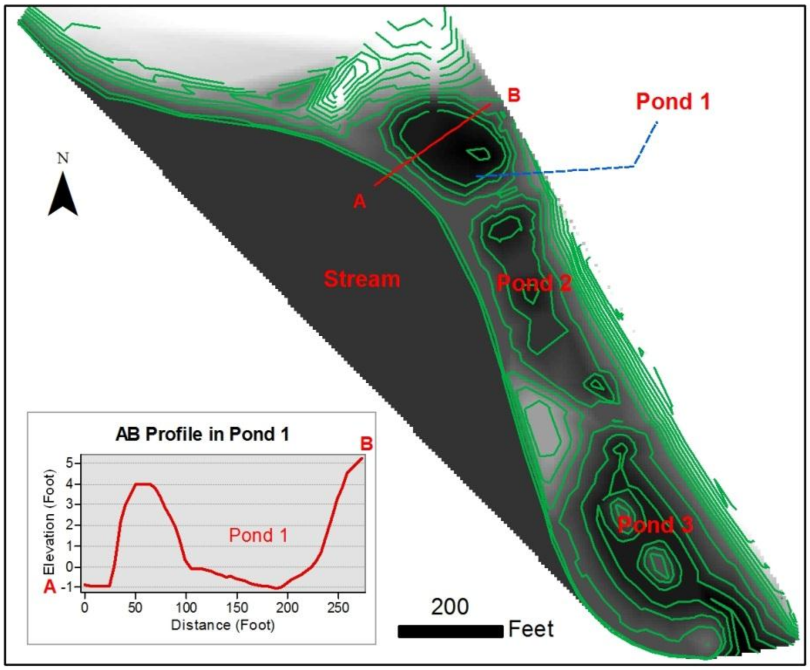

Figure 9. Topographic profile of pond 1 showing the elevation of the stream bank at 4 feet.

Influence of Brays Bayou streamflow on wetland site

Possible implications from elevated Brays Bayou streamflow on the wetland site were analyzed by estimating runoff volumes from the upstream area of the delineated watershed using the above described NRCS Runoff Curve Number method for daily rainfall over 10 years. The hydrological soil groups are extracted from the NRCS soil data and overlaid on the Brays watershed (source: TSARP delineated watersheds). EIH found that the watershed contains the hydrological soil group D only. This indicates a very high runoff potential due to the very low infiltration rate. It is also noted that the watershed includes a high percentage of impervious surfaces as shown in Figure 4.

For calculating the CN values, the land use/cover classes in the Brays watershed were narrowed down to two main groups: imperious surfaces and pervious surfaces. For this purpose, the 2006 national impervious data set (source: http://www.mrlc.gov/nlcd06_data.php) was used to calculate the percentage of imperviousness for upstream area of the wetland site (Fry et al. 2011). This was found to be 51.2% reflecting highly urbanized watershed (Figure 4). The CN for the D hydrological group was assigned a value of 95; reduced from 98 in order to account for evaporation effect due to high temperature. The pervious category for the D hydrological group was given average weighted numbers based on the land use/cover types and their percentages classes within the upstream areas. As a result, the CN value for previous surfaces was determined as 84. The two CN values are then combined based on the percentage of impervious and pervious surfaces of each upstream area.

The runoff volumes were calculated with the consideration of the upstream area that may influence the water level in the stream at the wetland site. This was achieved by identifying the rain gages that are surrounding and within the Brays watershed. A total number of 34 rain gages were selected after excluding a number of gages that were associated with suspicious readings. Afterwards, the area of influence from each rain gage was estimated and constructed in ArcGIS using the Thiessen polygon algorithm, which can proportionally divide and distribute the gage coverage into gage regions. These regions are generally known as Thiessen or Voronoi polygons. The gage regions are intersected with the watershed layer to exclude the parts that are located outside the watershed. In this manner, the weight for each gage station is calculated as a percentage of the individual gage region areas of the upstream area of the wetland site. Thus, the runoff volumes at wetland site were calculated for daily rainfalls using equations 1 and 2 once the rainfall exceeds the initial abstraction that is expressed in equation 3. The upstream area of delineated watershed and the weights of each rain gage were used to calculate the total estimated runoff volumes in cubic feet at the wetland site.

In order to analyze the possibility of the wetland site being inundated from overbank flooding of Brays Bayou, EIH extracted the most recent daily rainfall and stream level records at the nearest rain gage to the wetland site (i.e. 410: D100 Brays Bayou @ Lawndale Street); which is located almost 1 mile upstream of the wetland site. Figure 10 depicts a reasonably explained relationship between rainfall and stream level (R^2 is almost at 70%). This relationship was then used to determine the rainfall event that may bring the stream level to the stream bank at the wetland site so the water starts to flood the site as it will be described in the following sections.

The lowest elevation of stream bank at the wetland site was measured as 4.136 ft. using terrestrial surveying. This was achieved using a total station and the coordinates of the nearest benchmark, (Floodplain Reference Mark No. 040020) located on the bridge @ 75th Street. This elevation value is very close to the value obtained from the GIS analysis (i.e. 4 ft) as shown in the profile in Figure 9 indicating that this data set provides a sound representation of the site.

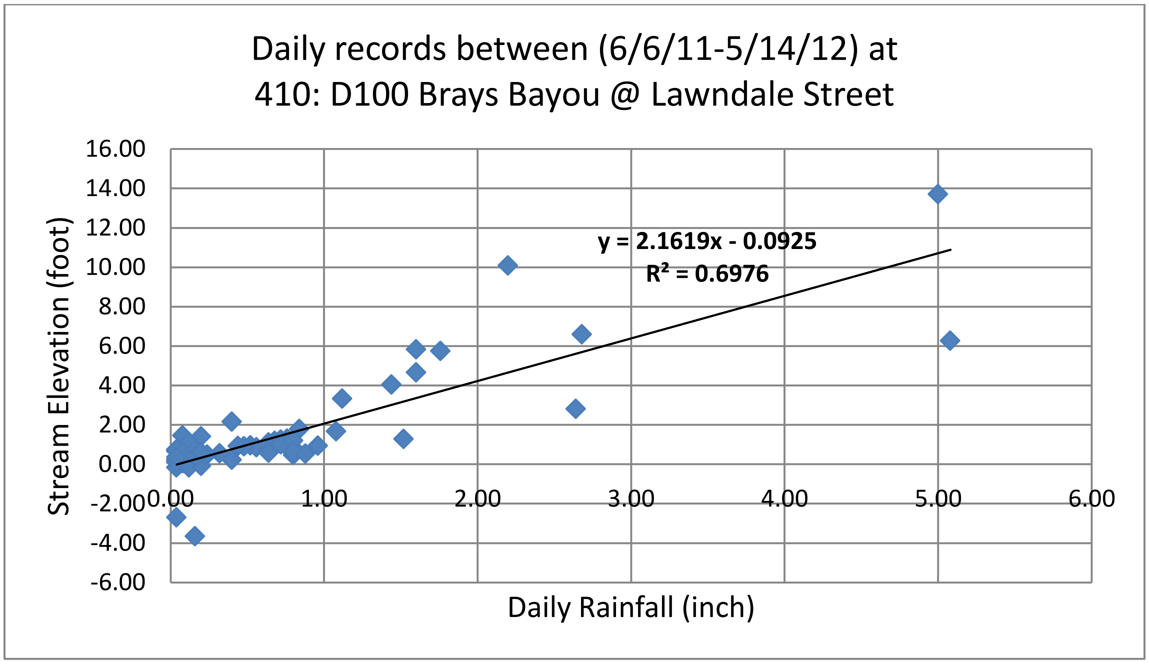

Figure 10. Relationship between daily rainfall and stream elevation at the 410:D100 gage over a 1 year period.

Based on the relationship between rainfall and stream elevation, a hypothetical uniform daily rainfall of 1.956 inch over the Brays watershed was identified as the smallest rain event that would bring the stream to bank full level and consequently the water in Brays Bayou would start to overbank flood the wetland site. It is worth recognizing here that this analysis is more relevant to the profile at the rain gage site and that one should expect a margin of uncertainty when applying this value at the wetland site as the stream profile there is different. Considering the Brays Bayou stream profile adjacent to the wetland site has a wider span than the rain gage site (approx. 1 mile upstream), it is expected that a larger rainfall event is required to bring the water level to the overflow point on the stream bank at the wetland site.

The hypothetical daily rainfall of 1.956 inch was then utilized to estimate the runoff volume using the NRCS Runoff Curve Number method. The estimated runoff volume was 315,228,330 cf. This water volume was compared with the runoff volume estimates over the last ten years and it was found that this runoff volume was produced 30 times excluding an event that happened on May 11, 2012 (see the next section for more details) as the data of that day was not included in the analysis. In total, our modeling and observations indicate that the site may have been flooded 31 times over the last 10 years on an average of 3 flood events/year.

A supporting comparative analysis was done using 10 years of stream gage height data (2001-2011) from the Lawndale 410 gage site and the published 10.40 ft. bench mark value for the top of bank (TOB) value published by HCFCD on their web site. This data suggests that daily stream gage heights at Lawndale exceeded the TOB value some 31.7% of the time (Figure 11). Since many of these days represent a continuation of individual flood events, the number of individual multi-day flood events will be a lower value. Both analyses suggest that the wetland site is frequently flooded by Brays Bayou during high rainfall events concurrently affecting the 22 acre watershed and the Brays Bayou watershed. During these periods, treatment of any water entering the site from the upper 22 acre watershed would be reduced by the direct linkage with Brays Bayou created by flood waters entering the wetland system.

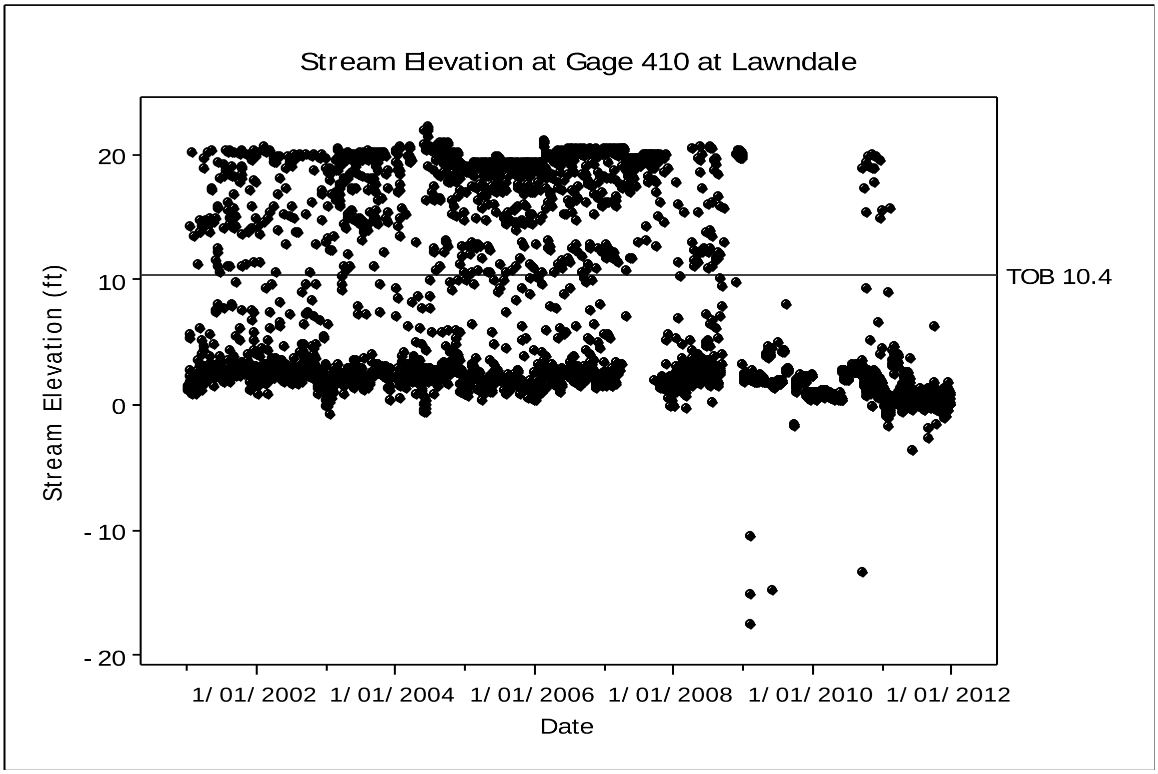

Figure 11. Daily stream elevation measurements at the Lawndale 410 gage site on Brays Bayou during a recent 10 year period (January 2001 to December 2011). TOB denotes top of bank elevation. Source: HCFCD web site.

Recent events and observations

Evidence of flooding at the wetland site was observed during a visit on June 31, 2012. The following pictures were taken during that visit. The high edge of the debris line was measured using terresterial survey instruments (i.e. total station). These measurements indicate that the water level may have reached 6.4 inches above the flood levee during this flood event (Figure 12-Figure 15).

Figure 12. Debris line observed on June 31, 2012, at the edge of pond 1 marking recent maximum water levels during last flood event.

Figure 13. Accumulated debris on vegetation observed on June 31, 2012 at the edge of pond 2 believed to be deposited by a recent flood event.

Figure 14. Accumulated debris at the edge of pond 3 observed on June 31, 2012 believed to have been deposited by recent flood events.

Figure 15. Debris at the high edge of weir 2 observed on June 31, 2012 between pond 2 and pond 3 believed to have been depositived by flood events.

The rainfall and stream elevation records at the rain gage, at Brays Bayou @ Lawndale Street, for the period between April 15 and May 15, 2012 were examined (Figure 16 and Figure 17). During this period the stream elevation peaked to 10.09ft on May 12, while two significant daily rainfall events were recorded on May 11 at 2.64 inch and on May 12 at 2.2 inch. This shows a time lag of one day that is needed for the rain to reach the stream and raise the stream elevation to the recorded level. This can be explained by the dry period documented between April 21 and May 9, as the ground needed time to become saturated and the runoff to start. Also due to the large size of watershed, post-rainfall event, it will take time for the runoff from the rain event to reach the stream and in turn our study site which is located at the bottom of the watershed.

Relationship between rain gage sites in Brays Bayou Watershed

Data from all precipitation gages from the contributing watershed as defined using GIS and the TSARP watershed were compared using Pearson correlation analysis to determine whether there is a strong relationship between the Lawndale 410 gage and other sites within the watershed. Based on our analysis the majority (>90%) of the sites within the watershed exhibited highly significant positive correlations ($r = 0.7$, $p < 0.001$) and all but one exhibited significant correlations ($r = 0.33$ to 0.69, $p < 0.001$) with the 410 Lawndale gage (Table 5). This suggests that when there is heavy precipitation occurring near the wetland and the associated 22 acre watershed it is highly probable that similar amounts of rainfall are occurring within other portions of the watershed. The significance of this pattern is that there will be few scenarios where surface runoff from the 22 acre contributing watershed to the treatment wetlands will be occurring in the absence of concurrent runoff and associated elevated stream levels within the Brays Bayou watershed. This would likely be most obvious during heavy rainfall when the likelihood of overbank flooding would occur.

Water Quality Monitoring

Results of automated datasonde monitoring at sites 2 and 3 are presented
Table 6. Most water quality variables exhibited fairly constant levels and/or expected fluctuations such as water temperature. However, data collected during April and May 2011 documents elevated (3-10X higher) specific conductance levels. Furthermore, starting April 24, 2011 and extending through April 26, 2011, the lower southern site 3 datasonde first detected higher specific conductance levels, which was subsequently detected in the northern site 2 datasonde starting April 27, 2011. From this date until the end of the logging period on May 19, 2011, the specific conductance levels remained elevated. However, the site 2 datasonde continued to exhibit lower specific conductance levels in contrast to site 3, suggesting a gradient of increasing specific conductance closer to the exit to Brays Bayou existed in the wetland complex. This is unusual and may indicate some sub-surface seepage, or more likely based on the pattern of datasonde detections during April 24-26, 2011, a reverse flow of higher conductivity water from Brays Bayou into the wetland complex. However, there is no evidence for overbank flood conditions observed at nearby gage sites during this period. Tidal gage readings downstream at the Manchester gage in the Houston Ship Channel, suggest higher than usual average tide levels during this period which may responsible for reverse flows or higher conductivity water into the wetland complex (Figure 19). Reverse flows of river water into the wetland complex from Brays Bayou would increase residence time or completely stop any downstream movement of water within the wetland system.

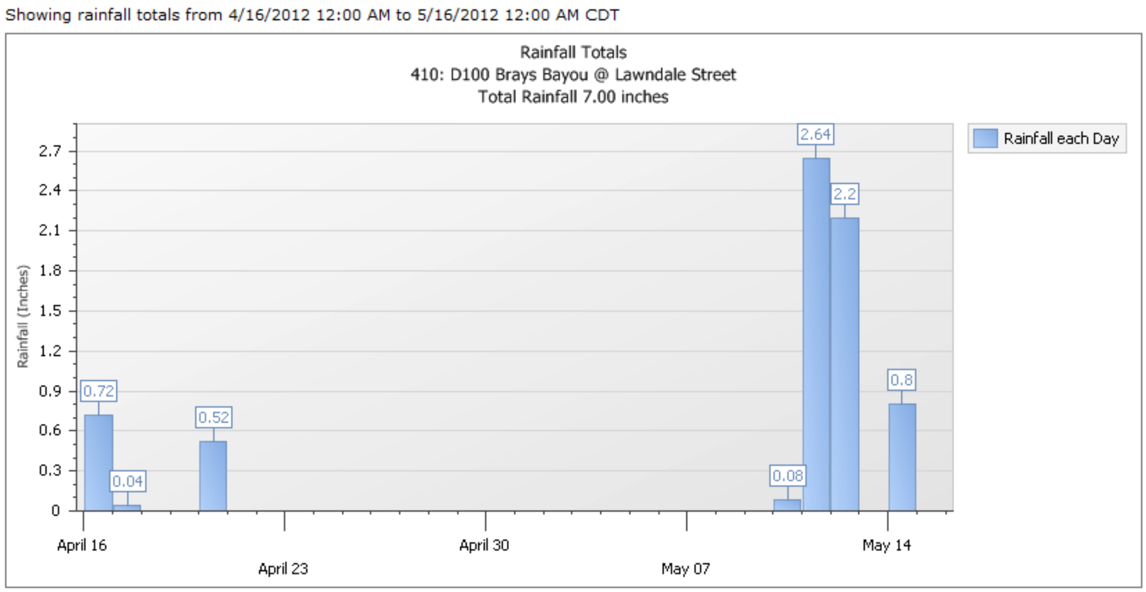

Figure 16. Rainfall records between April 15 to May 15 at the nearest rain gage (410: D100 Brays Bayou @ Lawndale Street), Source: HCFCD, Flood Warning System.

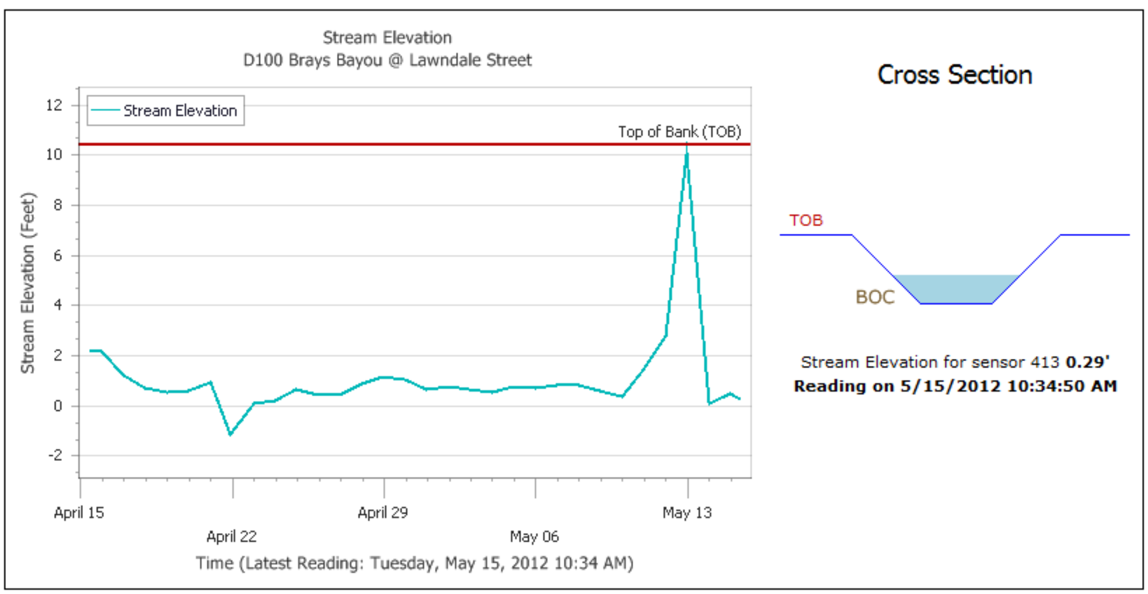

Figure 17 . Stream elevation records between April 15 to May 15 at the nearest rain gage (410: D100 Brays Bayou @ Lawndale Street), Source: HCFCD, Flood Warning System.

Table 5. Pearson correlation coefficient (r) between gage 410 (Brays Bayou at Lawndale), located closest to the Mason Park site, and other rain gages in the Brays Bayou watershed.

TSARP Watershed	HCFCD Gage	*r*	*p* value
Yes	340	0.87	<0.001
Yes	360	0.85	<0.001
Yes	400	0.79	<0.001
Yes	420	0.77	<0.001
Yes	430	0.79	<0.001
Yes	435	0.27	<0.001
Yes	440	0.75	<0.001
Yes	460	0.74	<0.001
Yes	465	0.71	<0.001
Yes	470	0.73	<0.001
Yes	475	0.71	<0.001
Yes	480	0.70	<0.001
Yes	485	0.70	<0.001
Yes	490	0.73	<0.001
Yes	1020	0.79	<0.001
No	2010	0.68	<0.001
No	2210	0.86	<0.001
No	2240	0.78	<0.001
No	2260	0.71	<0.001
No	2270	0.71	<0.001
No	2290	0.68	<0.001
Yes	3020	0.84	<0.001
Yes	3040	0.76	<0.001
Yes	3050	0.82	<0.001
No	3070	0.79	<0.001
No	3240	0.57	<0.001
No	3380	0.54	<0.001
Yes	3490	0.55	<0.001
No	3630	0.11	0.736
No	4450	0.55	<0.001
No	4480	0.57	<0.001
No	4490	0.53	<0.001
Yes	4840	0.33	<0.001

Table 6. Average, Minimum, and Maximum YSI datasonde readings from field survey site 2 and 3 from February 15, 2011 through May 19 2011.

			Temp (°C)	SpCond (uS/cm)	TDS (g/L)	Salinity (ppt)	pH	Count (n)
Field Survey Site 2	February, 2011	Min	14.93	396	0.26	0.19	7.55	1246
		Max	24.49	423	0.28	0.20	8.97	
		Average	**20.59**	**410**	**0.27**	**0.20**	**8.24**	
	March, 2011	Min	16.08	433	0.28	0.21	7.45	2839
		Max	27.71	565	0.37	0.27	8.04	
		Average	**21.82**	**502**	**0.33**	**0.24**	**7.65**	
	April, 2011	Min	18.74	555	0.36	0.27	7.46	2511
		Max	31.51	3495	2.27	1.82	8.72	
		Average	**25.83**	**736**	**0.48**	**0.36**	**7.88**	
	May, 2011	Min	20.75	1792	1.17	0.90	7.39	885
		Max	31.98	3642	2.37	1.90	8.64	
		Average	**25.82**	**2950**	**1.92**	**1.53**	**7.73**	
Field Survey Site 3	February, 2011	Min	10.53	455	0.30	0.22	7.03	1246
		Max	19.54	498	0.32	0.24	7.52	
		Average	**16.58**	**474**	**0.31**	**0.23**	**7.17**	
	March, 2011	Min	16.09	493	0.32	0.24	7.03	2839
		Max	23.17	595	0.39	0.29	7.38	
		Average	**19.19**	**540**	**0.35**	**0.26**	**7.16**	
	April, 2011	Min	18.53	593	0.39	0.29	7.08	2511
		Max	26.62	5092	3.31	2.74	7.63	
		Average	**22.94**	**1075**	**0.70**	**0.54**	**7.21**	
	May, 2011	Min	20.80	4659	3.03	2.49	7.11	885
		Max	26.49	5039	3.28	2.71	7.41	
		Average	**23.86**	**4851**	**3.15**	**2.60**	**7.18**	

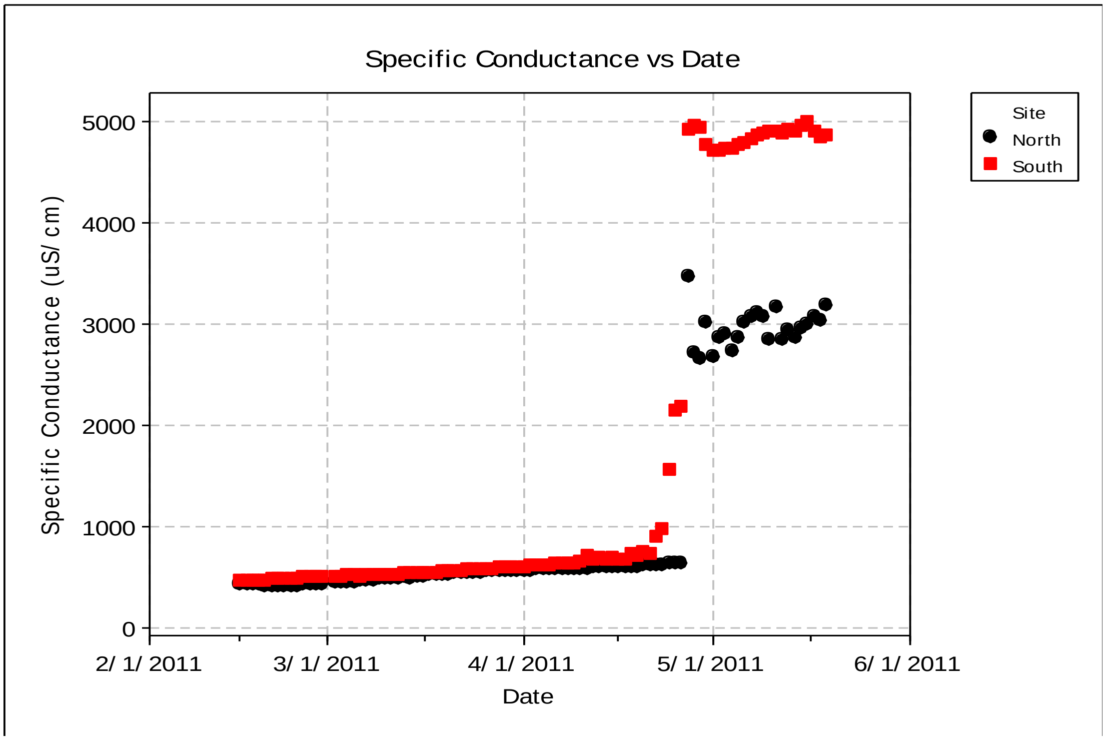

Figure 18. Trends in specific conductance at the automated monitoring sites at the Brays Bayou wetland site during February 15, 2011 to May 19, 2011.

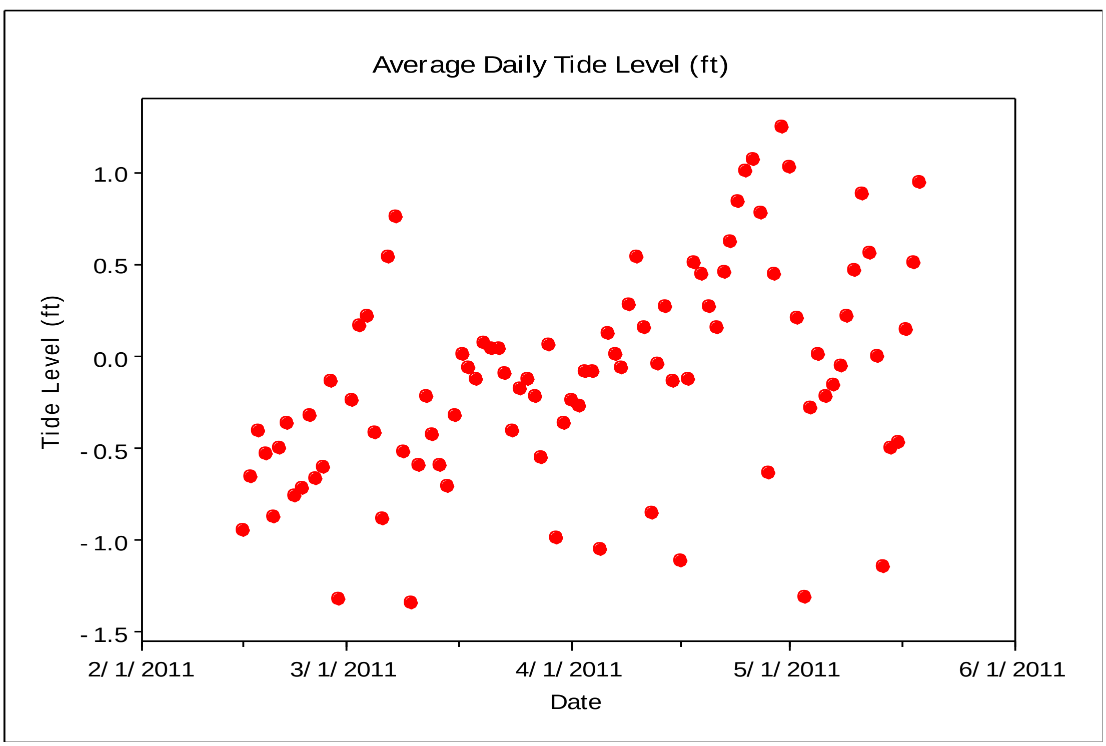

Figure 19. Tide level readings at the Manchester gage in the Houston Ship Channel.

Conclusions and Recommendations

Due to the drought conditions that occurred during 2011, EIH was not able to effectively conduct a dye tracer study to estimate time of travel and residence time within the Mason Park created wetland system. As a result, EIH investigated a tertiary objective to determine whether there is sufficient runoff from the contributing 22 acre watershed during storm events to transport water through the wetland complex per the original hydrological design. In addition, EIH investigated the likelihood of concurrent high precipitation in the much larger Brays Bayou watershed and possible overbank flooding of the created wetland from Brays Bayou. Concurrent flooding would effectively hinder the designed movement of water from the 22 acre watershed through the wetland system. Our main findings include the following:

1. A review of 10 years of rainfall data showed that the Mason Park wetland site may have been flooded by Brays Bayou on an average rate of 3 overbank flood events per year. Consequently, the wetland site is subject to complicated hydrology and during overbank fold events, the stormwater treatment capability of the wetland may not be functioning as it was designed in regards to water quality treatment. The evaluation of empirical stream elevations confirmed these observations.

2. The Mason Park Created wetland site may improve water quality in the case of localized rainfall events of 2 inches within 24 hours. However, it should be recognized that similar rainfall events at the larger Brays Bayou watershed scale may lead to the site to be overbank flooded by Brays Bayou. EIH found for example, that most of the precipitation data from rain gages in the watershed were highly correlated to the nearby Lawndale site. This suggests that most significant (significant is an event which causes a measurable rise and fall in the water level of the bayou) rain events affect a large portion of the Brays Bayou watershed, which would lead to high water levels and possible overbank flooding at the site, or backup of bayou water into the Tidal Marsh (pond 3) preventing downstream flow through the wetland system. In either case this would reduce downstream movement of water from the 22 acre drainage area through the wetland, effectively reducing measureable stormwater treatment efficiency.

EIH produced a simulation of pond 1 (wet pond) based on the assumption that the pond was empty. This simulation indicated that a rainfall event of 2 inches in 24 hours may bring the water level in the pond 1 up to the Agridrain Box 1 weir level. From this EIH concluded that the wetland site could be functioning reasonably well for a range of rainfall events that is linked to attaining this critical water volume in pond 1. To identify the range of these events, more monitoring of the water level in pond 1 is needed, along with concurrent measurements of water quality such as specific conductance to examine potential tidal influence at the site. Additional automated visual monitoring using game cameras might provide additional data on flood events at the site as well.

3. In the case of drought conditions, the water at the ponds is more likely to stay static and the site hydrology will not function as it was designed due to the lack of water flow through the system. Any water quality testing during such droughts should be avoided as these tests would likely yield inconclusive results.

4. The hydrological design of the wetland site should be examined closely especially in the case of extreme rainfall events and possible overbank flooding from Brays Bayou. Also, the observed increase in specific conductance suggests that alternate pathways such as groundwater seepage or backflow due to tidal influence may be occurring at the wetland site. Further investigations are needed to develop an accurate hydrological flow pattern at the site during both wet weather and dry weather events.

Due to the positive correlation between significant rainfall events and runoff both in the contributing watershed to the treatment wetlands and the larger Brays Bayou watershed, there are likely only a few scenarios where stormwater runoff entering the Mason Park wetlands will be treated according to the designed hydrological regime of the site. During many events high rainfall will lead to overbank flooding and diversion of runoff directly into Brays Bayou. During dry periods there will not be sufficient runoff to allow water to move through the wetland and ultimately discharge into Brays Bayou after being naturally treated by the created wetlands effectively. EIH recommends that additional monitoring be conducted during non-drought conditions that utilizes 1) automated water quality monitors, 2) photographic evidence, 3) additional gage and monitor sites and measurements and 4) analysis of regional rainfall and runoff patterns 5) investigate the effects of the adjustable Agridrain weir structures to better manage the hydrology regime of the wetland site, and 6) if feasible new renewed attempts to conduct flourometric dye tracer studies. This will lead to a better understanding of the hydrology within this system, allowing for proper water quality monitoring planning so that the optimal conditions under which maximum treatment efficiency for pollutants can be measured.

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Appendix 1. Field Data

Electronic Supplement

Appendix 2. Sonde Data

Electronic Supplement

Appendix 3. Sonde Calibration

Electronic Supplement

Appendix 4. Photographic Record

Electronic Supplement

Appendix 5. Rainfall Data

Electronic Supplement

Appendix 6. Tide Data

Electronic Supplement

Appendix 7. Runoff Calculations

Electronic Supplement

Appendix 8. Statistical Analyses

Electronic Supplement