Appendix

B

Preliminary Storm Sewer Drainage Analysis for Six Ponding Locations in the Academy Street Drainage System in West University Place

April 21, 2016

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West University Place, Texas

April 2016

HDR

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CONTENTS

List of Tables

List of Figures

List of Exhibits

List of Acronyms

AEP	Annual Exceedance Probability
CFS	Cubic Feet Per Second
COH	City of Houston
CN	Curve Number
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FPS	Feet Per Second
FT	Feet
GIS	Geographic Information System
H-GAC	Houston-Galveston Area Council
IN/HR	Inches Per Hour
LiDAR	Light Detection and Ranging
NAIP	National Aerial Imagery Program
NAVD	North American Vertical Datum
NRCS	Natural Resources Conservation Service
ROW	Right-Of-Way
TxDOT	Texas Department of Transportation
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WSE	Water Surface Elevation

1.0 Executive Summary

A preliminary storm sewer drainage analysis was performed for six (6) ponding locations in the City of West University Place. A significant portion of the city is within the 100-year floodplain of Brays Bayou. However, none of the six locations of interest are within the 100-year floodplain. The existing layouts and sizes of storm sewer lines were obtained from the report titled "Comprehensive Plan for Infrastructure Improvements" dated April 1993 and prepared for the City of West University Place by Langford Engineering, Inc., with supplemental information from construction documents prepared for paving and drainage projects completed in the City since 1993. Note that the report does not provide invert elevation information for storm sewer lines.

Elevation profiles were plotted for the streets where these intersections are located. It is found that most of the intersections are located at low points along street profiles. Any excess of runoff above the conveyance capacity of the storm sewer lines serving these locations will accumulate and pond in the intersections instead of sheet-flowing away along the streets.

The 2-year peak flow rate was computed at locations of interest using the Rational Method to estimate the required inlet and storm sewer capacities serving the areas of interest. The required capacities were then compared to the existing capacities to determine the deficiencies. A constant 3 fps storm sewer flow velocity was used in estimating the existing and required storm sewer capacities. This assumption reflects standard design procedure in the Greater Houston area and is considered adequate for this preliminary study. A detailed study involving hydrologic and hydraulic modeling tools is recommended to size the storm sewer lines in order to account for the slope of the storm sewer system. In order to complete that study, field survey data will be required to define the storm sewer elevation data.

The results of this preliminary study show that inlet capacity is insufficient at the intersections of Academy Street and Albans Road, and Academy Street and Bissonnet Street. In addition, inlet density is found to be inadequate along the street gutters around the commercial area located within the City of Houston and bounded by Law Street, Academy Street, and Bissonnet Street. It is likely that the insufficient inlet density on the bounding gutters of this commercial section will fail to capture all the runoff flow generated from the commercial section, which lies within the City of Houston. The excess of flow will travel to surrounding intersections and may contribute to ponding within West University Place.

The existing conveyance capacities of most storm sewer lines serving the locations of interest do not satisfy current 2-year storm capacity requirements. The existing storm sewer lines will have to be upsized in order to provide the 2-year storm capacity. The required storm sewer sizes are provided in ***Table 3-6*** in this report.

2.0 INTRODUCTION

2.1 Project Name and Purpose

This study includes a preliminary drainage analysis of the storm sewer systems of interest in the City of West University Place, Texas. The purpose of this study is to assess ponding issues that occur at six (6) street intersections during storm events. This report is prepared for the Public Works Department of the City of West University Place.

2.2 Project Location

The project area is within the city limits of West University Place in Harris County. The six ponding locations of interest are listed below. ***Exhibit 1*** shows the six ponding locations of interest and the city limits.

1. Academy Street at Albans Road
2. Fairmont Street at Judson Avenue
3. Academy Street at Bissonnet Street
4. West Point Street at Amherst Street
5. West Point Street at Oberlin Street
6. West Point Street at Villanova Street

2.3 Project Objectives

This drainage study includes drainage area delineation, peak flow estimation, and storm sewer evaluation. The storm frequency used in this analysis is the 2-year storm event. The objective of the analysis is to assess the capacities of the existing storm sewer systems at the locations of interest.

2.4 FEMA Flood Zones

The project area is located in the western portion of the City of West University Place. The area is located on Harris County FIRM Panel 48201C0855L. A significant portion of the City of West University Place is within the regulatory floodplain of Brays Bayou (HCFCD Channel D100-00-00) designated as Zone AE with defined flood elevations, as shown on ***Exhibit 2***. The City of West University Place is located approximately between FIRM panel Cross Section BF and Cross Section AX (see ***Exhibit 3***). Zone AE indicates that base flood elevation has been determined for this stream. The BFE value of Brays Bayou in the West University Place city limits ranges from 47 ft at Kirby Drive to 49 ft at College Avenue (NAVD 88 2001 adjustment). The portion of the city west of College Avenue lies mostly outside of the regulatory floodplain.

Although a significant portion of the city is within the regulatory floodplain, this report does not address the flooding issues caused by Brays Bayou. Instead, this report focuses on the capacity of the existing storm sewer system at each of the locations of interest and the storm sewer's ability to convey standard 2-year design runoff rates.

2.5 Data Sources

A list of data that were used for this project is provided below.

- The 2008 H-GAC LIDAR (NAVD 1988 2001 adjustment) was used for drainage area delineation and was also used to evaluate street elevation profiles to determine low points along streets where ponding may occur.

- The report titled "Comprehensive Plan for Infrastructure Improvements" dated April 1993 and prepared for the City of West University Place by Langford Engineering, Inc. (referred to as the Report in this document) was provided by the Public Works Department of the City of West University Place. This report presents the layouts and sizes of the existing storm sewer lines within the City of West University Place, but does not provide information on invert elevations of storm sewer lines.

- The GIS layer of storm sewer lines within the West University Place city limits was downloaded from the City of Houston (COH) GIMS database. It is noted that the storm sewer data within the project area in this database is limited. It is likely that COH does not collect and maintain the infrastructure data for the area within the city limits of West University Place. The data downloaded from GIMS was used as a supplement to the storm sewer information obtained from the Report.

- Construction documents for paving and drainage projects completed within the City of West University Place since 1993 were used to supplement and update information obtained from the Report and from the City of Houston GIMS database.

- Harris County FIRM maps were obtained from the FEMA web site.

- H-GAC aerial images dated 2014 were used in the study.

- Field visits were conducted by HDR staff in November 2015 to visually evaluate the general condition of the roadway and storm sewer systems, especially inlet density and size, within the project area. Photos were taken during field visits.

3.0 Drainage Analysis

A hydrologic analysis was performed to delineate drainage areas and to determine the 2-year peak flow rates for the storm sewer systems where the ponding occurs. This section describes the methodologies used in the peak flow calculations and presents the results.

3.1 Existing Condition

The six ponding locations of interest are shown on ***Exhibit 1***. The City of West University Place is primarily developed in single family residential areas with some light commercial areas scattered within the city limits. The ground elevation slopes south-eastward ranging from approximately 54.0 ft (NAVD 88 2001 Adjustment) at the northwest corner of the city to approximately 47.5 ft at the southeast corner. A topographic map is provided as ***Exhibit 3***. The ponding locations on Fairmont Street, West Point Street and Academy Street (a total of 6 locations) are served by storm sewers that drain to the main storm sewer line along Academy Street, which drains southward to Bellaire Blvd, then westward along Bellaire Blvd, and eventually outfalls to Kilmarnock Ditch (HCFCD Channel D113-00-00). ***Exhibit 4*** presents the storm sewer systems in the project area, including the storm sewer lines serving the six locations of interest, as well as storm sewers along Academy Street.

In some areas, storm sewer systems have been improved over a number of years. For example, a new storm sewer trunk line was installed on College Avenue (See ***Exhibit 4***) to improve drainage for that area. Other improvements have been completed in various portions of the City. However, available information indicates that no significant upgrades to the main trunk storm sewer along Academy Street have been completed since that system was originally constructed.

3.2 Brays Bayou Water Surface Elevation

The City of West University Place is located approximately between FIRM panel Cross Section BF and Cross Section AX (see ***Exhibit 3***). A significant portion of West University Place is within the 100-year floodplain of Brays Bayou. ***Exhibit 5*** illustrates the FEMA water surface elevation (WSE) profile for this portion of Brays Bayou. This profile is taken directly from the FEMA FIS study report for Harris County. ***Exhibit 3*** plots the FEMA cross sections of Brays Bayou with 10- and 100-year WSE indicated on a contour and color-shaded topographic map of West University Place. ***Table 3-1*** summarizes the 10-, 50, 100- and 500-year water surface elevations along Brays Bayou at FEMA Cross Sections BF, BE, BD, BC, BB, BA, AZ, AY and AX. The 10-year WSE from west to east within the city limits ranges from 46.4 ft at Cross Section BF to 41.9 ft at Cross Section AX; the 100-year WSE ranges from 50.8 ft to 46.9 ft.

Table 3-1. Brays Bayou Water Surface Elevation (feet) within City Limits

FEMA Cross Section	BF	BE	BD	BC	BB	BA	AZ	AY	AX
500-Year WSE	52.2	52.0	51.7	51.7	51.6	51.4	51.1	50.9	50.5
100-Year WSE	50.8	50.7	49.5	49.4	49.3	49.0	48.3	48.1	46.9
50-Year WSE	48.8	48.7	47.3	47.2	47.0	46.6	45.9	45.7	44.1
10-Year WSE	46.4	46.1	45.1	44.9	44.7	44.3	43.3	43.1	41.9

3.3 Street Profiles

Most of the locations of interest are on West Point Street and Academy Street. Street profiles were plotted along these streets and the streets that intersect with them. ***Exhibit 1*** shows the extents of these street profile plots. ***Figure 1*** to ***Figure 8*** illustrate the actual street profiles.

It is noted that the intersections where ponding occurs are usually located at low points along the street profile. In some cases, the centerline of the road (e.g., Bissonnet Street on Academy Street profile in ***Figure 1***) is elevated, but both edges of the roadway are depressed, and water ponds along the curb. If the runoff during a storm event exceeds the conveyance capacity of the storm sewer inlets and pipes serving these areas, water will accumulate and pond instead of sheet-flowing away along the streets.

Figure 1. Academy Street Profile

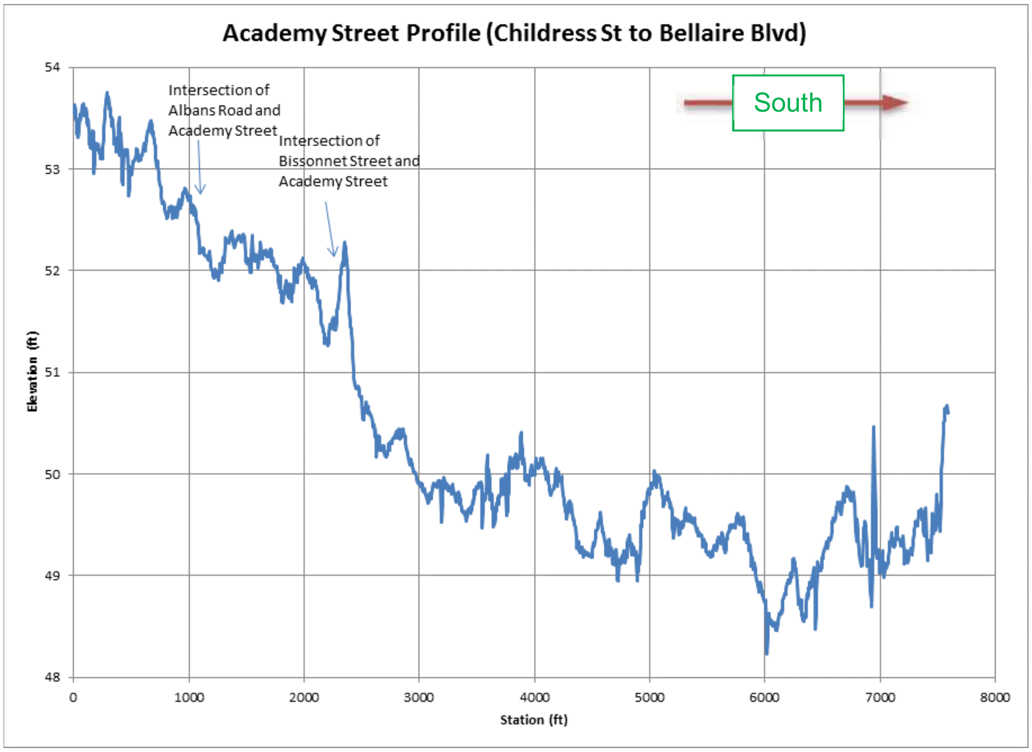


Figure 2. Fairmont Street Profile

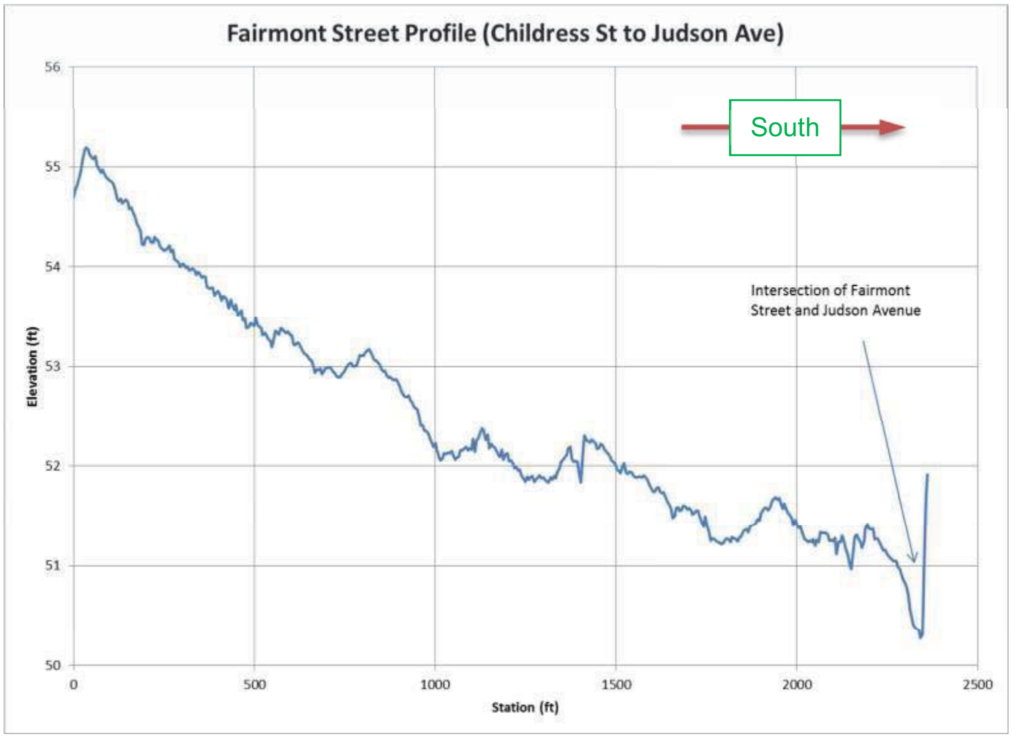


Figure 3. Albans Road Profile

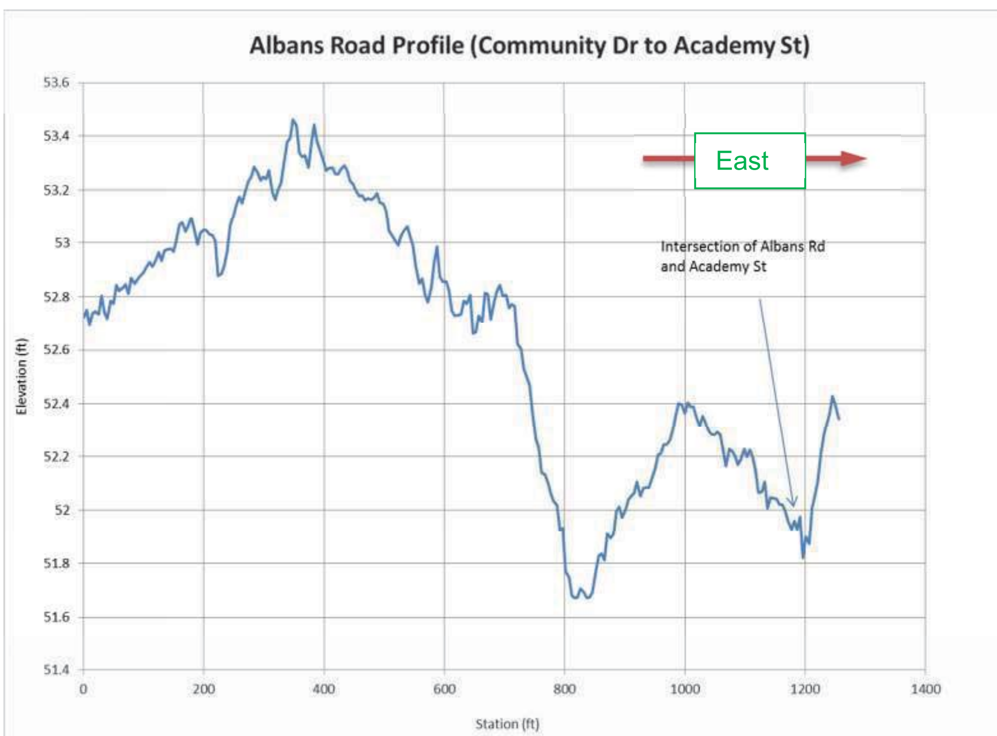


Figure 4. Judson Avenue Profile

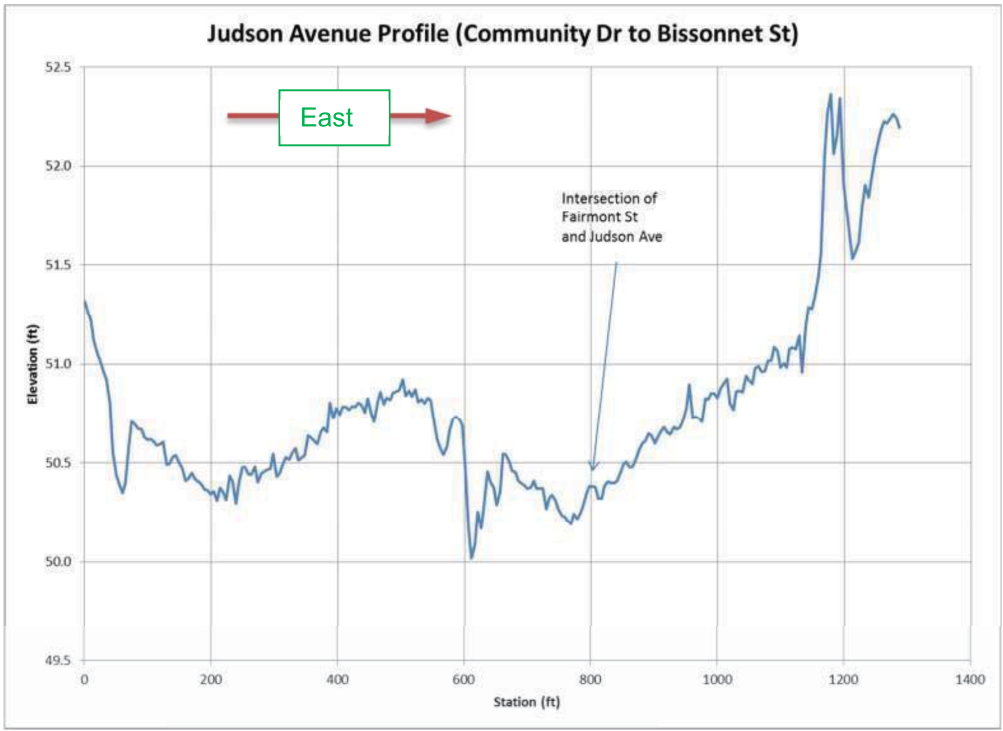


Figure 5. West Point Street Profile

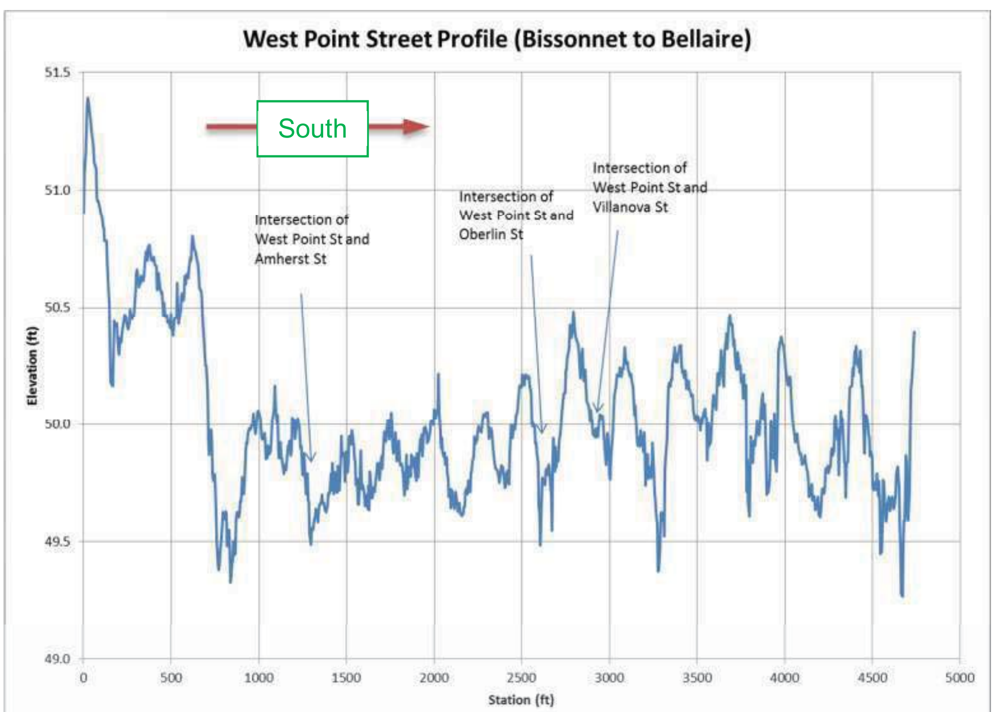


Figure 6. Amherst Street Profile

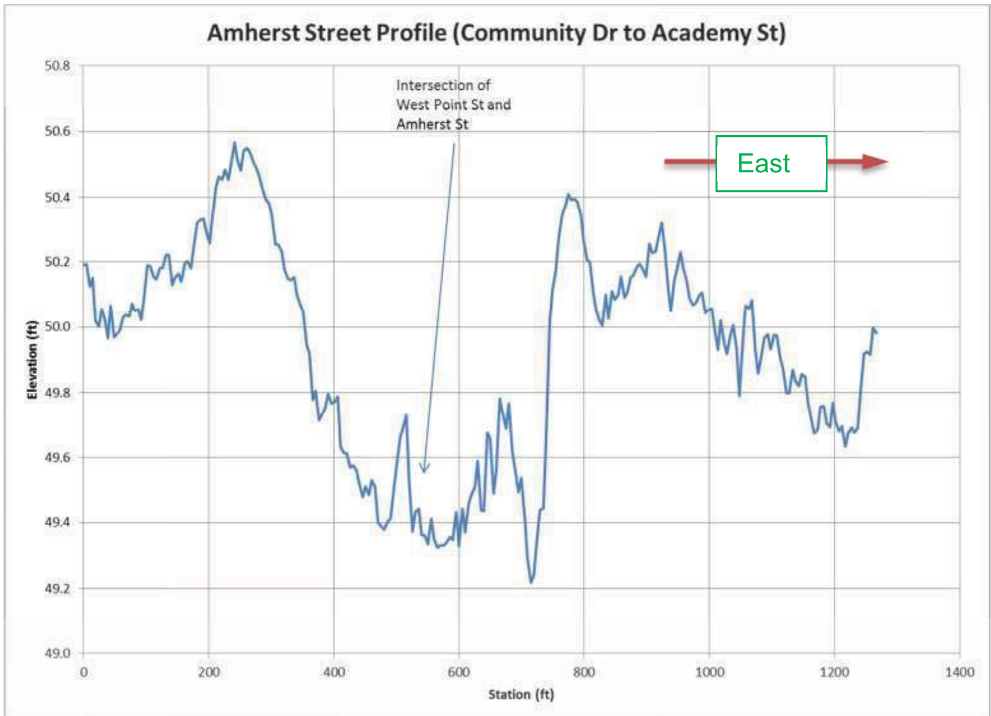


Figure 7. Oberlin Street Profile

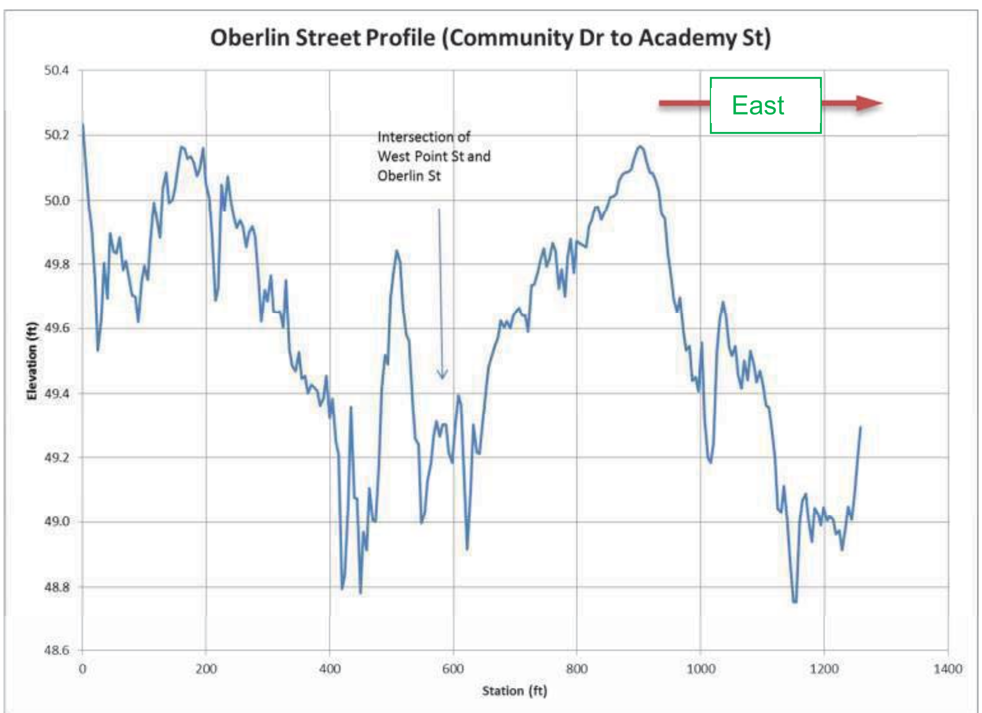
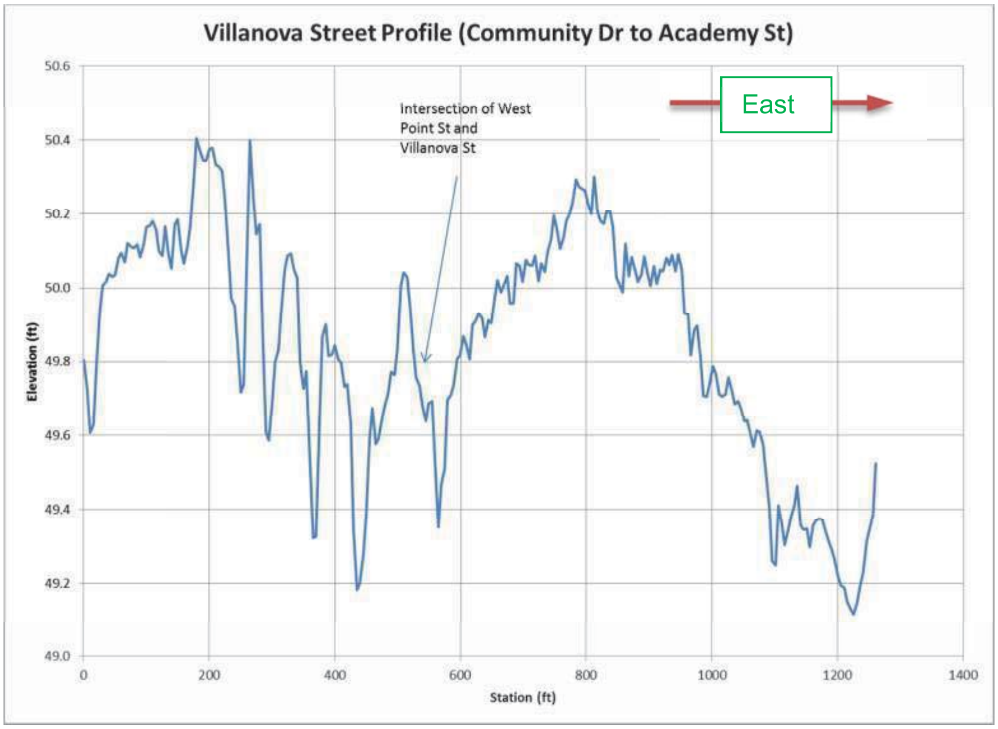


Figure 8. Villanova Street Profile



3.4 Inlets at Ponding Locations

Inlet type and density at the ponding locations were checked to see if sufficient inlet capacity is provided to satisfy the standard 2-year design storm requirement. ***Table 3-2*** summarizes the inlet type and number at these intersections. ***Figure 9*** to

Figure ***12*** are aerial photos showing inlet locations at these intersections and in the surrounding areas. Most of the inlets at these intersections are double B inlets. Occasionally singe B inlets are observed at some locations. Single B inlets are an old type of inlet, while double B inlets are popularly used currently; as the name implies, they double the inlet opening and capacity of single B inlets. Inlet capacity is a function of inlet type, size, location (on grade or in sag), ponding depth, gutter depression, longitudinal gutter slope, transverse gutter slope, transverse gutter width, etc. Typically, a single B inlet or grate inlet provides approximately 2 cfs capacity, whereas a double B inlet provides 2 x 2 = 4 cfs capacity.

Table 3-2. Inlets at Locations of Interest

Intersection	Number of Existing Inlets	Type of Inlet
Academy Street at Albans Road	2	Double B
Fairmont Street at Judson Avenue	3	Double B
Academy Street at Bissonnet Street	2	One single B; One double B
West Point Street at Amherst Street	4	Double B
West Point Street at Oberlin Street	4	Double B
West Point Street at Villanova Street	4	Double B

Two double B inlets are provided at the intersection of Academy Street and Albans Road. Also, two single B inlets are provided approximately 120 ft south of the intersection on Academy Street. The area between Albans Road and Bissonnet Street along Academy Street east of the road is a commercial area in the City of Houston with extensive parking areas and lots of impervious cover.

Only a single B inlet (on Bissonnet Street) and a double B inlet (on Academy Street) was observed at the intersection of Bissonnet Street and Academy Street. Two single inlets were observed approximately 110 ft north of the intersection on Academy Street. There are three double B inlets at the intersection of Fairmont Street and Judson Avenue.

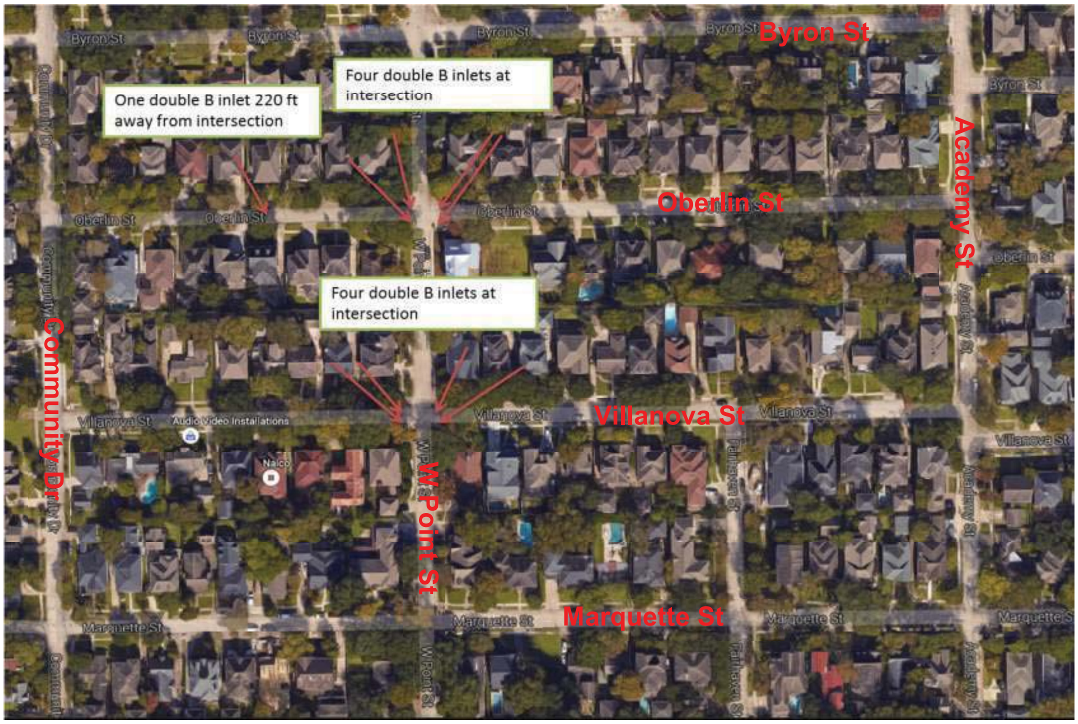
The intersection of West Point Street and Amherst Street also has four double B inlets. Additionally, there are two double B inlets approximately 300 ft east of this intersection on Amherst Street. Both the intersection of West Point Street and Oberlin Street and the intersection of West Point Street and Villanova Street have four double B inlets. There is a double B inlet on Oberlin Street located approximately 220 ft west of the intersection of West Point Street and Oberlin Street.

Figure 9. Inlets on Academy Street in Project Area (1)

Figure 10. Inlets on Academy Street and Fairmont Street in Project Area (2)

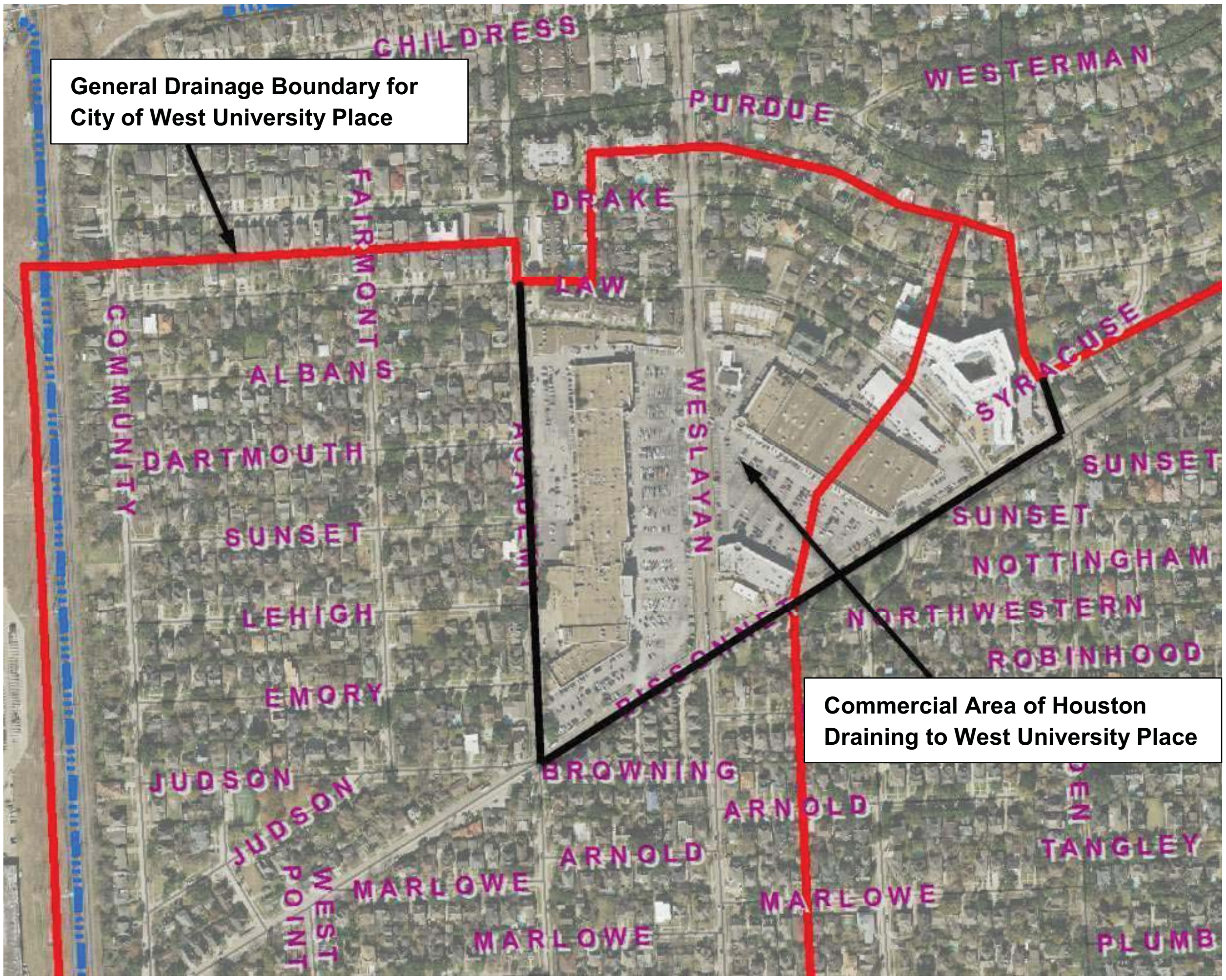
Figure 11. Inlets on West Point Street in Project Area (1)

Figure 12. Inlets on West Point Street in Project Area (2)



The commercial area (shown in ***Figure 13***) bounded by Academy Street, Law Street and Bissonnet Street consists of a Randall's supermarket, along with a number of restaurants and retail stores with large, impervious parking lots. This commercial area lies within the City of Houston. Weslayan Street passes through the commercial area from north to south and divides it into two parts. Four grate inlets were observed during field visits around the parking lot of the Wells Fargo Bank located at the northwest corner of the eastern portion of the commercial area. No other onsite inlets were found on the parking lots of the commercial area. Therefore, runoff generated from the commercial area, except for that on the Wells Fargo Parking lot, has to be captured by the street inlets along Weslayan Street. Some street inlets were observed at or near the driveway to the commercial area that appear to be intended to capture runoff leaving the commercial section. However, the street inlets do not appear to be adequate for this extensive impervious area. The 1,550 ft long east street gutter bounding the commercial area along Academy Street between Law Street and Bissonnet Street has three single B inlets and one grate inlet. The gutter bounding the commercial area along the south side of the 1,750 ft long segment of Law Street between Academy Street and Bissonnet Street has two double B inlets and one single B inlet. The street gutter along the west side of the 1,700 ft long segment of Bissonnet Street between Law Street and Academy Street has three single B inlets and one grate inlet. The 1,200 ft long segment of Weslayan Street that passes through the commercial area between Law Street and Bissonnet Street has only one double B inlet and 1 single B inlet on its west gutter and one double B inlet on its east gutter. It appears that the inlet capacity is not adequate on these street gutters bounding the commercial section to capture the runoff from the commercial section, especially for Weslayan Street. The excess of water above and beyond the inlet and storm sewer capacity may flow to surrounding intersections within the City of West University Place, potentially including the intersections of Academy Street and Bissonnet Street, Academy Street and Albans Road, and Fairmont Street and Judson Avenue, and may cause ponding problems at those locations. It is understood that the commercial section is outside of the West University Place City corporate boundary, and those bounding streets (except for Academy Street) that lack inlet capacity are also outside the city limits. The City of West University Place would have to discuss this issue with the City of Houston in order to formulate a plan for addressing the problem.

Figure 13. Commercial Area of Houston Draining to West University Place



3.5 Drainage Area

The City of Houston GIMS database and the storm sewer information obtained from the Report and construction plans were used to delineate the approximate drainage areas used for this study. ***Exhibit 6*** presents an overall drainage map for the City of West University Place. This overall drainage map includes the City of Houston areas that drain to the City of West University Place drainage systems. The western portion of the city, including the six locations of interest, discharges to Kilmarnock Ditch. The middle portion drains to Poor Farm Ditch. The eastern portion drains to storm sewer lines on Kirby Drive, which in turn drain to City of Houston storm sewer systems. The major areas that belong to the City of Houston but drain to the City of West University Place are indicated on the map. These areas include the triangular commercial area east of Academy Street and north of Bissonnet Street, and the areas north of the City of West University Place boundary along Bissonnet Street that drain southward into the City's storm sewer systems.

The project drainage areas for the storm sewer systems that serve the ponding locations of interest were further delineated using available maps and storm sewer data. The delineated drainage areas were used to calculate 2-year peak flow rates for the storm sewer lines under consideration in this study. ***Exhibit 7*** displays the project drainage areas delineated for analysis.

3.6 Hydrologic Methods

The Rational Method was utilized to compute 2-year peak flow rates in this study. The Rational Method requires the composite C value and time of concentration (t_c) for each drainage area. The e, d and b values developed by TxDOT for Harris County were used to compute rainfall intensities.

3.6.1 Land Use

Land-use data are required to estimate the composite C value for each drainage area. The land use classification was determined based on the aerial photography of the project area. The land-use types within the project drainage areas were defined into two classifications: single-family residential and commercial/multi-family. ***Exhibit 8*** depicts the land use types defined for the project area. Typical Rational Method runoff coefficients were assigned to each of the two land use classifications. ***Table 3-3*** presents the land-use types and the associated runoff coefficients used in the study.

Table 3-3. Land-Use Categories

General Land-Use Categories	C Value
Single Family Residential	0.40
Commercial or Multi-Family	0.65

The land-use data were combined with drainage areas to allow computation of the composite C value for each drainage area. The combined land-uses and associated areas for each drainage area were identified. Using the following equation, the composite land-use C value was calculated for each drainage area:

$$\bar{C} = \frac{\sum_{\mathrm{i}=0}^{\mathrm{n}} A_i RC_i}{\sum_{\mathrm{i}=0}^{\mathrm{n}} A_i}$$

where:

C_i = C value of each land-use type for a drainage area;

A_i = area associated with land-use type for a drainage area; and

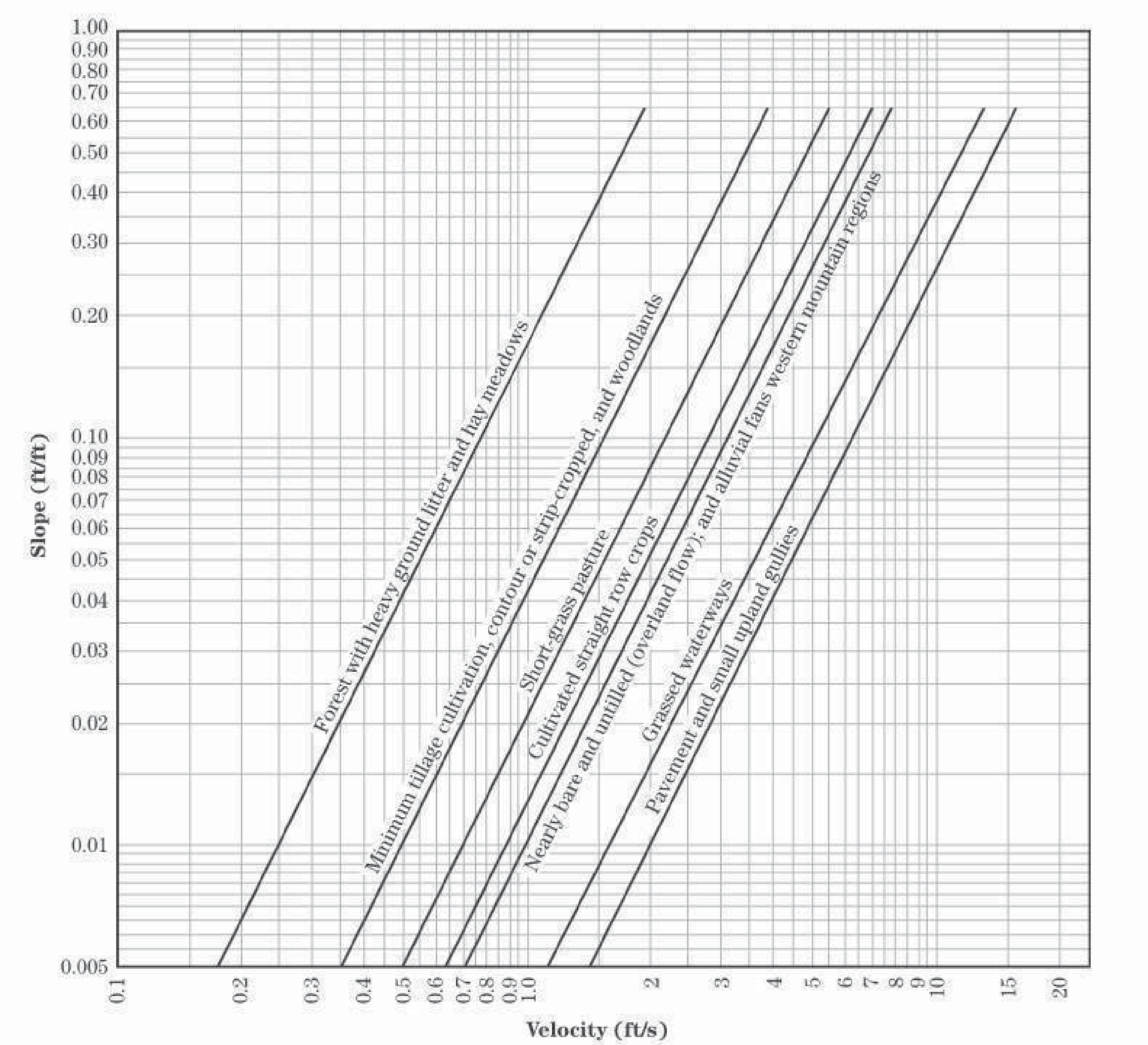
$\bar{C}$= composite *C* value for a drainage area.

The area-weighted C value for each drainage area was then used in the Rational Method to compute the 2-year peak flow rate.

3.6.2 Time of Concentration

The NRCS Upland Method was used to estimate the time of concentration (t_c) for each of the drainage areas. Flow paths were divided into flow segments that were defined by various flow classifications, including short grass overland flow, paved area/shallow gutter flow, and storm sewer flow. Flow velocity for each flow segment was determined based on the flow classification and slope of flow path (except for storm sewer flow, which used a constant design flow velocity of 3 fps per standard design practice in the Greater Houston area). The travel time through each flow segment was summed for each drainage area to obtain the time of concentration. ***Figure 14*** presents the NRCS Upland Method correlation between flow velocity, surface flow type and flow path slope.

Figure 14. Upland Method Correlation between Flow Velocity, Surface Type, and Slope



A ten-minute minimum time of concentration was utilized for all inlet drainage areas.

3.6.3 Rational Method

The Rational Method equation is expressed as:

$Q = CIA$

where:

Q = computed peak runoff discharge (cfs);
C = weighted runoff coefficient;
I = average rainfall intensity (in/hr); and
A = drainage area (ac).

The rainfall intensity was determined using the equation

$$I = \frac{b}{(t_c + d)^e}$$

where:

I = rainfall intensity (in/hr);
t_c = time of concentration (min); and
b, *d*, *e* = coefficients for each storm frequency.

The *b*, *d,* and *e* values for Harris County are presented in ***Table 3-4***.

Table 3-4. Harris County 2-Year Intensity-Duration-Frequency Coefficients

Coefficient	2-year
e	0.800
b	68
d	7.9

Once the runoff coefficient (*C*), average rainfall intensity (*I*), and drainage area acreage (*A*), were determined for each drainage area, these values were substituted into the Rational Method equation to calculate the 2-year peak flow rates. The Rational Method is usually used for drainage area less than 200 acres. The accumulative drainage area in this study draining to the Academy Street storm sewer and eventually to Kilmarnock Ditch (HCFCD Channel D113-00-00) is greater than 200 acres. This drainage area is divided into several sub-drainage areas that are less than 200 acres. The flow contributions to each node from these sub-drainage areas were calculated separately but summed at the nodes to comply with the criterion of a maximum drainage area of 200 acres for the Rational Method.

3.7 Calculated 2-Year Peak Flow Rates

The 2-year flow rates calculated using the Rational Method for the study storm sewer segments serving the areas of interest (see ***Exhibit 4***) are summarized in ***Table 3-5***. These 2-year flow rates were compared with the estimated capacities of existing storm sewer pipes to identify any capacity deficiencies in the existing systems. Note that the start node and end node of each storm sewer segment are shown on ***Exhibit 4***.

Table 3-5. Accumulative Drainage Area and 2-Year Flow Rate for Storm Sewer Segments

Storm Sewer Segment		Drainage Area (acres)	2-Year Flow Rate (cfs)	Existing Storm Sewer Capacity (cfs)	Deficiency (cfs)
From Node	To Node				
11-a	11	3.6	8.5	5.3	3.2
13	14	48	82.3	66.5	15.7
14-a	14	3.4	6.8	9.4	No Deficiency
11	15	17	32.7	21.2	11.5
14	15	52	89.1	28.8	60.2
12	15	32	50.4	47.7	2.7
15	16	121	211.3	58.9	152.5
16	17	136	225.1	71.2	153.9
18	20	3.3	8.7	5.3	3.4
19	20	3.5	9.6	5.3	4.3
20	21	11	27.8	14.7	13.1
17	21	179	258.7	71.2	187.5
21	28	200	279.2	84.8	194.4
23	25	3.0	8.1	5.3	2.8
24	25	4.8	8.6	5.3	3.3
25	26	12	21.0	5.3	15.7
26	27	17	27.2	5.3	21.9
27	28	33	48.5	14.7	33.8
28	29	240	303.5	84.8	218.7
29	30	284	351.0	84.8	266.2
30	31	298	353.1	84.8	268.3
31	32	308	360.4	84.8	275.6
32	33	318	360.4	84.8	275.6

3.8 Storm Sewer Conveyance Capacity Required

The street profiles show that each of the locations of interest where the ponding occurs are usually located at a low point along the street. In a storm event the runoff exceeds the storm sewer conveyance capacity serving these locations, and the excess of water cannot flow away via sheet (surface) flow, but accumulates and ponds at these locations.

The 2-year flow rates calculated by the Rational Method were used to evaluate the storm sewer systems serving these areas to check if the existing storm sewer has sufficient capacity to convey the 2-year flow, and if not, the required size of each storm sewer segment was estimated.

It is typically recommended that hydrologic and hydraulic modeling tools (e.g., SWMM or WinStorm) be used to evaluate storm sewer systems. However, modeling of storm sewer systems requires details of the systems, including the invert elevations of the storm sewer lines. This information was not available for this study. Because this study is a preliminary drainage analysis, instead of completing detailed storm sewer modeling, a rough storm sewer evaluation was performed using the required conveyance flow rates (i.e. the 2-year flow calculated above) and storm capacities based on an assumed constant average storm sewer flow velocity of 3 fps for all storm sewer lines to estimate the storm sewer size required. The flow rate ($ft^{3/}sec$) in a storm sewer was divided by the flow velocity of 3 fps to determine the cross-sectional area required, and then to obtain the storm sewer dimensions that provide the required cross-sectional area. As stated above, this method only provides a rough estimate of the storm sewer size required, but it is adequate for this preliminary study. A detailed study involving storm sewer modeling is recommended for a more accurate evaluation.

Table 3-6 shows the approximate storm sewer sizes required to convey the 2-year flow in comparison with the existing storm sewer sizes. It can been seen that most of the existing storm sewer lines that serve the locations of interest do not have sufficient conveyance capacity, which explains at least in part why these locations frequently suffer ponding problems.

Table 3-6. Existing and Required Storm Sewer Size to Convey 2-Year Flow Rates

Storm Sewer Segment		Existing Circular Pipe Diameter (ft)	Storm Sewer Size Required			
From Node	To Node		Storm Sewer Shape	Diameter for Circular; or Width for Box (ft)	Height for Box (ft)	Barrel Quantity
11-a	11	1.5	Circular	2.0	-----	1
13	14	2.5 and 3.5	Circular	4.5	-----	2
14-a	14	2	Circular	2.0	-----	1
11	15	3	Circular	4.0	-----	1
14	15	3.5	Circular	6.5	-----	1
12	15	4.5	Circular	5.0	-----	1
15	16	5	Box	9	8	1
16	17	5.5	Box	9	9	1
18	20	1.5	Circular	2.0	-----	1
19	20	1.5	Circular	2.5	-----	1
20	21	2.5	Circular	3.5	-----	1
17	21	5.5	Box	10	9	1
21	28	6	Box	10	10	1
23	25	1.5	Circular	2.0	-----	1
24	25	1.5	Circular	2.0	-----	1
25	26	1.5	Circular	3.0	-----	1
26	27	1.5	Circular	3.5	-----	1
27	28	2.5	Circular	5.0	-----	1
28	29	6	Box	11	10	1
29	30	6	Box	11	11	1
30	31	6	Box	11	11	1
31	32	6	Box	11	11	1
32	33	6	Box	11	11	1

Table 3-7 summarizes the existing inlet capacity at each of the intersections of interest and the required capacity, which is the 2-year flow rate generated in the direct drainage area contributing to each intersection. The actual inlet capacity is affected by many factors. For this study, the evaluation of inlet capacity at each intersection is simplified by assuming an inlet capacity of 2 cfs for single B inlets or grate inlets and 4 cfs for double B inlets, which is typical capacity for these inlets. This assumption is considered adequate for the preliminary level study. Insufficient inlet capacity was found at the intersections of Academy Street and Albans Road and Academy Street and Bissonnet Street. In addition, inlet density is found to be inadequate on the bounding street gutters around the City of Houston commercial section bounded by Law Street, Academy Street and Bissonnet Street. The area is indicated

on both ***Exhibit 6*** and ***Exhibit 7***. The inlet density on Weslayan Street between Law Street and Bissonnet Street within the commercial section also appears to be insufficient. The excess of flow from the commercial section is likely to make its way to surrounding intersections and may cause ponding within the City of West University Place.

Note that the required capacity presented in ***Table 3-7*** is only the runoff generated within the direct drainage area contributing to the intersections of interest and does not account for any additional flows that exceed the capacity of nearby street inlets and travel along the street gutters to the intersections of interest. It is likely that some intersections will receive the excess of flow from surrounding areas, especially the intersections of Academy Street and Bissonnet Street, Academy Street and Albans Road, and Fairmont Street and Judson Avenue, because they are close to the commercial section bounded by Academy Street, Law Street and Bissonnet Street where the bounding street gutters appear to lack adequate inlet density. The quantification of the excess of runoff from other inlets requires a more detailed storm sewer modeling tool (e.g. WinStorm or SWMM) and is not reflected in this preliminary study.

Table 3-7. Summary of Inlet Capacity

Intersection	Number of Inlet	Type of Inlet	Available Capacity (cfs)	Required Capacity (cfs)	Additional Double B Inlets
Academy Street at Albans Road	2	Double B	8	8.5	1
Fairmont Street at Judson Avenue	3	Double B	12	7.3	0
Academy Street at Bissonnet Street	2	One single B; One double B	6	14.7	2
West Point Street at Amherst Street	4	Double B	16	12.2	0
West Point Street at Oberlin Street	4	Double B	16	8.6	0
West Point Street at Villanova Street	4	Double B	16	10.4	0

It should be noted that inlet capacity has been supplemented over the years as streets have been repaired or upgraded. Thus, inlet capacity appears to be adequate at many of the intersections evaluated in connection with this study and report. However, storm sewer systems have not been upgraded for the most part in the identified areas of interest, and they show deficiencies when compared with standard 2-year design flow rates.

A rough cost estimate for upgrading the existing storm sewer systems analyzed in this study to standard 2-year design storm sewer and inlet capacity was prepared for this report. The cost estimate includes the removal of existing undersized storm sewer systems (inlets, manholes and storm sewer lines), the removal of pavement, the replacement of inlets, manholes, storm sewer lines, and pavement, and provisions for a potential detention requirement. The estimate includes 15% for ancillary items and another 15% for contingencies. Since the detailed inlet and manhole database is not available, it was assumed for cost estimating that there are four inlets at each four-way intersection and three at each "T" intersection. It is also assumed that there is a manhole at each storm sewer junction to estimate the number of manholes.

The detention requirement was estimated using a Basin Development Factor (BDF) approach developed by HDR for the Harris County Flood Control District to estimate detention requirements in urban areas. The worksheet facilitates determination of the total BDF value, which is a function of channel, storm sewer, and street conditions, for both existing conditions and improved conditions with 2-year capacity. The difference between the existing and improved BDF values was then used to estimate the detention storage rate (ac-ft of required detention storage per acre of drainage area) based on a Detention Storage Rate versus Change in BDF Value chart. The detention storage rate to improve the project area was determined to be 0.12 ac-ft of detention per acre of drainage area. For a total drainage area of 270 acres for the area within West University Place analyzed in connection with this study and report, the total required detention volume was then determined to be 0.12 ac-ft/acre x 270 acres = 32.4 ac-ft. Note that the COH area that drains to West University Place was excluded in determining the storage requirement as it is assumed that West University Place does not need to improve the City of Houston storm sewer system and does not need to provide storage for the COH drainage area. A detention basin depth of 6.5 ft (including 1 ft unusable freeboard) was used to estimate the total acreage of the detention basin, which includes 30-ft maintenance berms around the basin. The total area of the detention basin site was determined to be approximately 8.2 acres.

The cost estimate is presented in ***Table 3-8***. The unit prices were taken from the City of Houston's *FY15 Pre-Engineering Bid Unit Prices*. The cost for land acquisition was estimated based on an approximate average HCAD value of $15 per square ft in the general project area. A multiplier of 3 was then applied to the average HCAD value to estimate the land acquisition cost.

Table 3-8. Cost Estimate of Storm Sewer System Improvement for Project Area

ITEM	DESCRIPTION	UNIT	UNIT PRICE	QUANTITY	COST
1	Remove Storm Sewer Pipe (All Types)	LF	$15	14,175	$212,625
2	Remove Storm Sewer Box (All Types)	LF	$15	0	$0
3	Remove Inlets (All Types)	EA	$340	132	$44,880
4	Remove Manholes (All Types, All Depths)	EA	$350	24	$8,400
5	Inlets (All Types)	EA	$2,150	132	$283,800
6	Manholes (42" Dia Pipe and Smaller) (All Types)	EA	$2,800	10	$28,000
7	Manholes (48" to 72" Dia Pipe) (All Types)	EA	$6,000	4	$24,000
8	Manholes (78" Dia Pipe and Larger) (All Types)	EA	$10,000	9	$90,000
9	24" RCP	LF	$75	2,469	$185,175
10	30" RCP	LF	$105	521	$54,705
11	36" RCP	LF	$126	259	$32,634
12	42" RCP	LF	$142	1,011	$143,562
13	48" RCP	LF	$173	1,270	$219,710
14	54" RCP	LF	$221	840	$185,640
15	60" RCP	LF	$277	1,379	$381,983
16	66" RCP	LF	$311	0	$0
17	72" RCP	LF	$355	0	$0
18	78" RCP	LF	$425	83	$35,275
19	9'X8' RCB	LF	$600	702	$421,200
20	9'X9' RCB	LF	$600	584	$350,400
21	10'X9' RCB	LF	$600	570	$342,000
22	10'X10' RCB	LF	$600	768	$460,800
23	11'X10' RCB	LF	$600	991	$594,600
24	11'X11' RCB	LF	$600	1,657	$994,200
25	12'X11' RCB	LF	$1,200	0	$0
26	Trench Safety System	LF	$2	27,590	$55,180
27	Remove Pavement	SY	$6	36,680	$220,080
28	8" Reinforced Concrete Pavement	SY	$43	36,680	$1,577,240
29	Detention Pond (DRY)	AC-FT	$20,000	32.4	$648,000
30	Detention Pond Land Acquisition	AC	$1,960,200	8.2	$16,073,640
				COST	**$23,667,729**
				20% ANCILLARY ITEMS	**$4,733,546**
				20% GENERAL ITEMS	**$4,733,546**
				TOTAL COST	**$33,134,821**

4.0 **Conclusion**

Based on the results of the analysis described in this report, the following conclusions are reached.

1. A significant portion of the City of West University Place is within the regulatory floodplain of Brays Bayou (HCFCD Channel ID D100-00-00) designated as Zone AE with defined flood elevations. In an extreme storm event, the floodplain is affected by the water from Brays Bayou (via overtopping of the channel banks and backwater through channels and storm sewer lines). Improving storm sewer systems alone in areas located within the regulatory floodplain would not solve the flooding issue caused by Brays Bayou.

2. The ponding intersections studied are located at low points along the roadway profile. Runoff water that exceeds the conveyance capacity of the storm sewer lines serving these areas cannot sheet-flow away, but accumulates and ponds at these intersections.

3. Most of these ponding intersections have sufficient inlet capacity. However, the following intersections were found to have insufficient inlet capacity:
   - Academy Street at Albans Road;
   - Academy Street at Bissonnet Street.

4. The commercial area bounded by Law Street, Academy Street and Bissonnet Street does not have adequate onsite inlets. The inlet density does not appear to be adequate on the gutters of Law Street, Academy Street, Bissonnet Street and Weslayan Street, all of which bound or pass through the commercial area, which is located within the City of Houston.

5. The existing conveyance capacities of most storm sewer lines serving these locations of interest are not sufficient for the current standard 2-year design storm. These existing storm sewer lines will have to be upsized in order to satisfy the 2-year flow rate capacity requirement. The approximate storm sewer sizes required to convey the 2-year flow rates are presented in ***Table 3-6***.

6. A further study using more detailed storm sewer system modeling tools is recommended to size the storm sewer lines in order to account for the slope of the storm sewer system with accurate storm sewer invert elevations, roadway and top of curb elevations, inlet throat elevations and measurements, and other important details. Such a detailed modeling study requires survey to obtain the existing storm sewer elevation data.

EXHIBIT 1. AREAS OF INTEREST AND VICINITY MAP

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE

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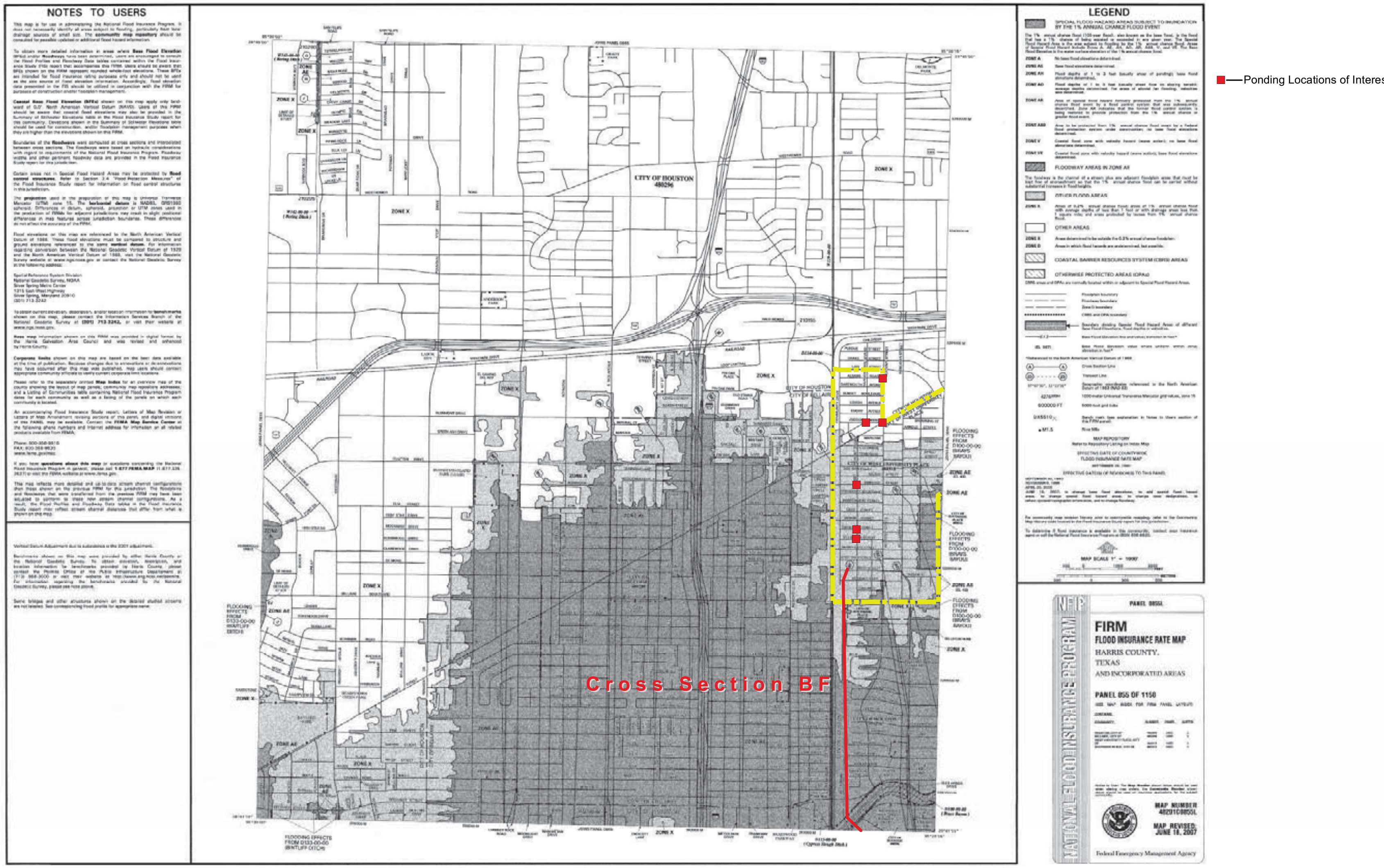

EXHIBIT 2. FLOODPLAIN MAP OF WEST UNIVERSITY PLACE (MAP NUMBER 48201C0855L)

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE

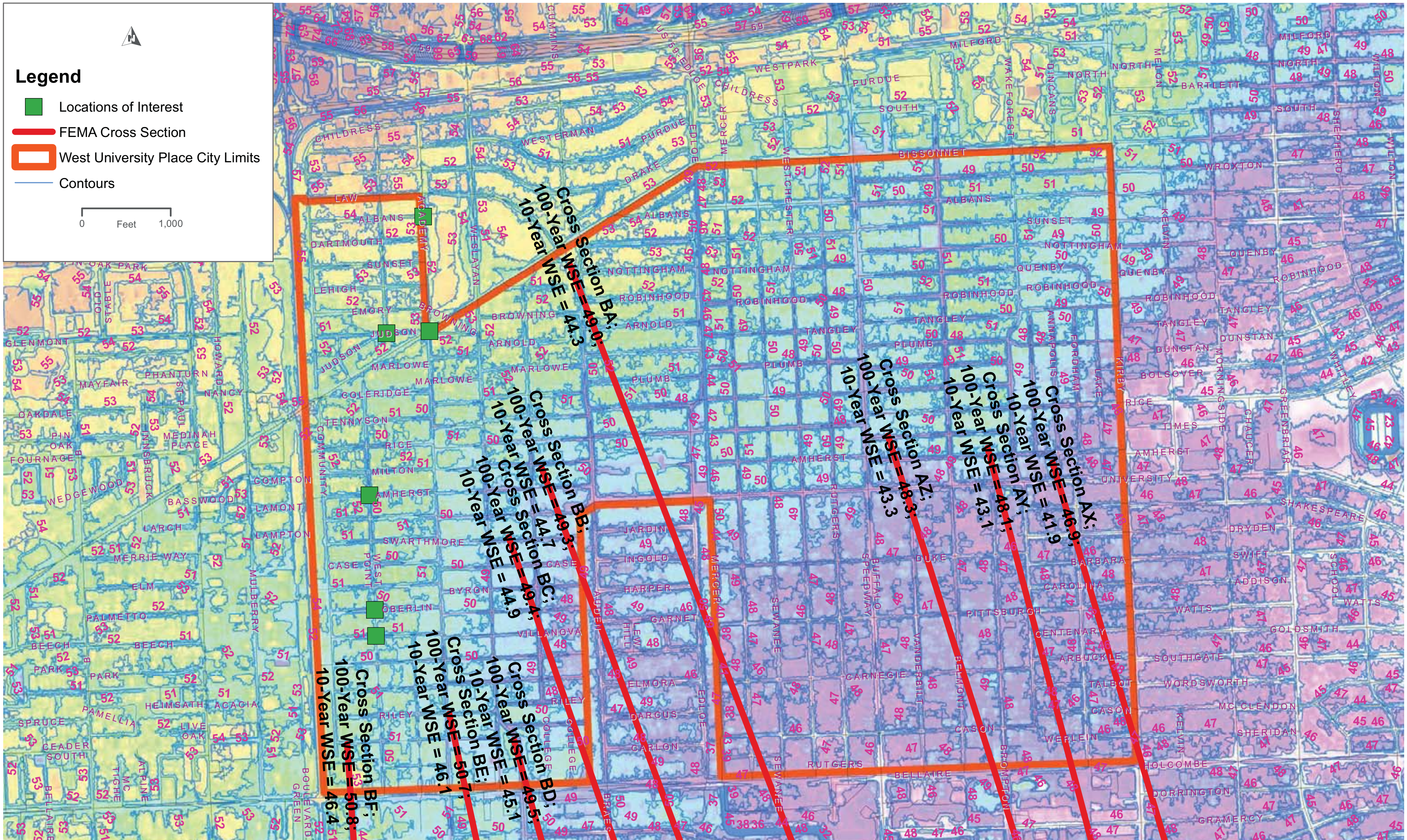

EXHIBIT 3. TOPOGRAPHIC MAP OF PROJECT AREA

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE

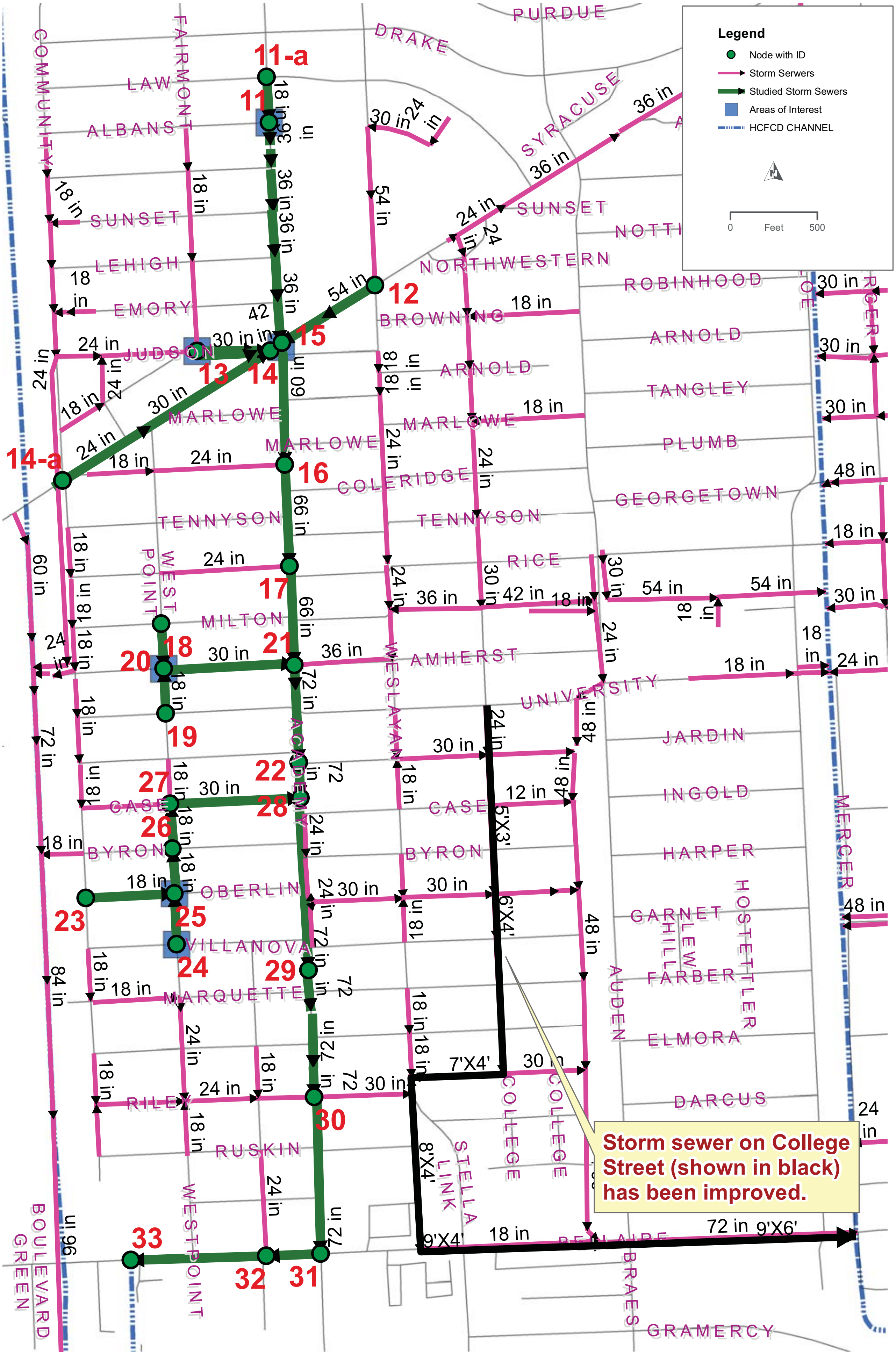

EXHIBIT 4. STORM SEWER LAYOUT IN PROJECT AREA

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATION IN WEST UNIVERSITY PLACE

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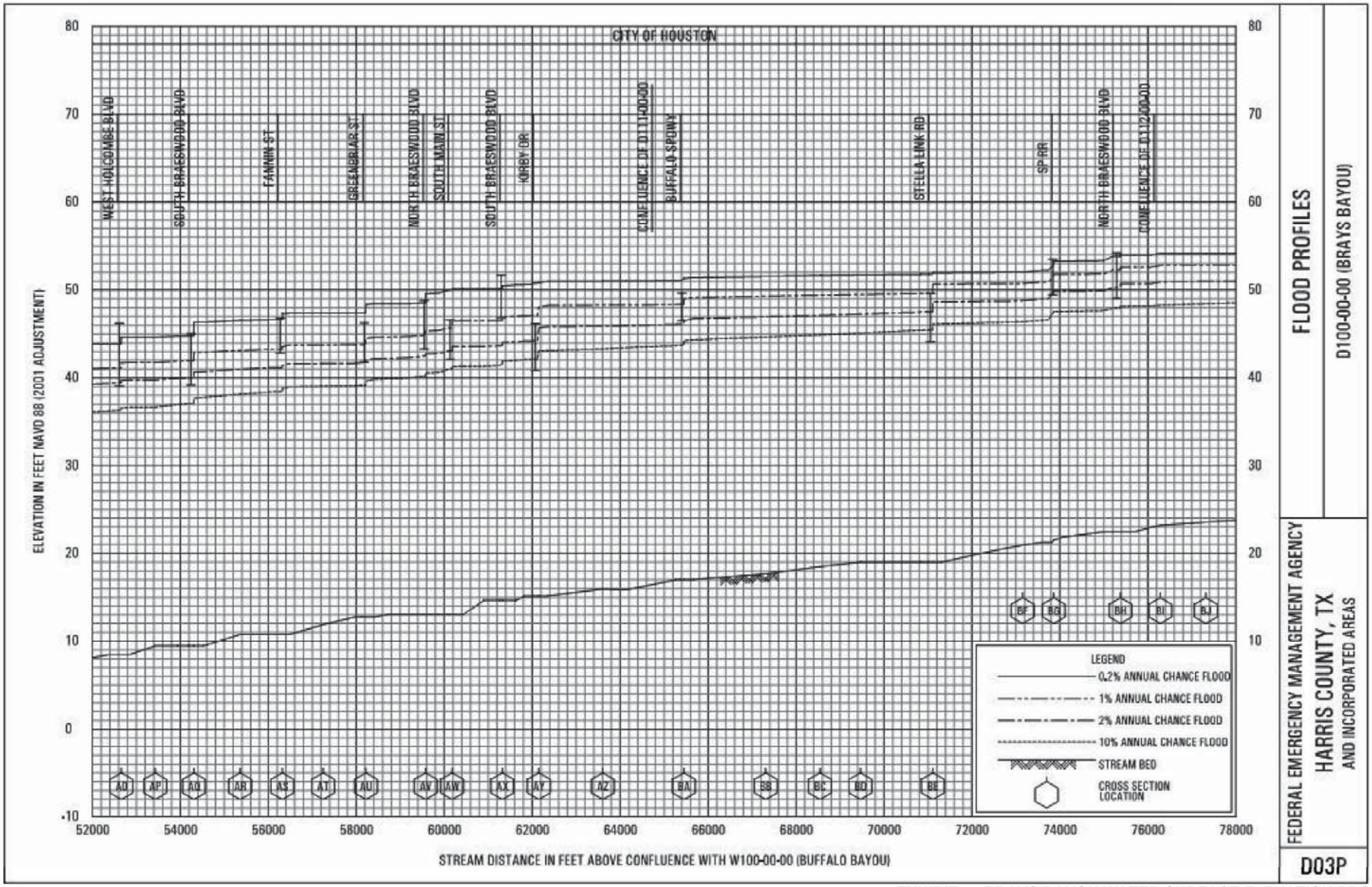
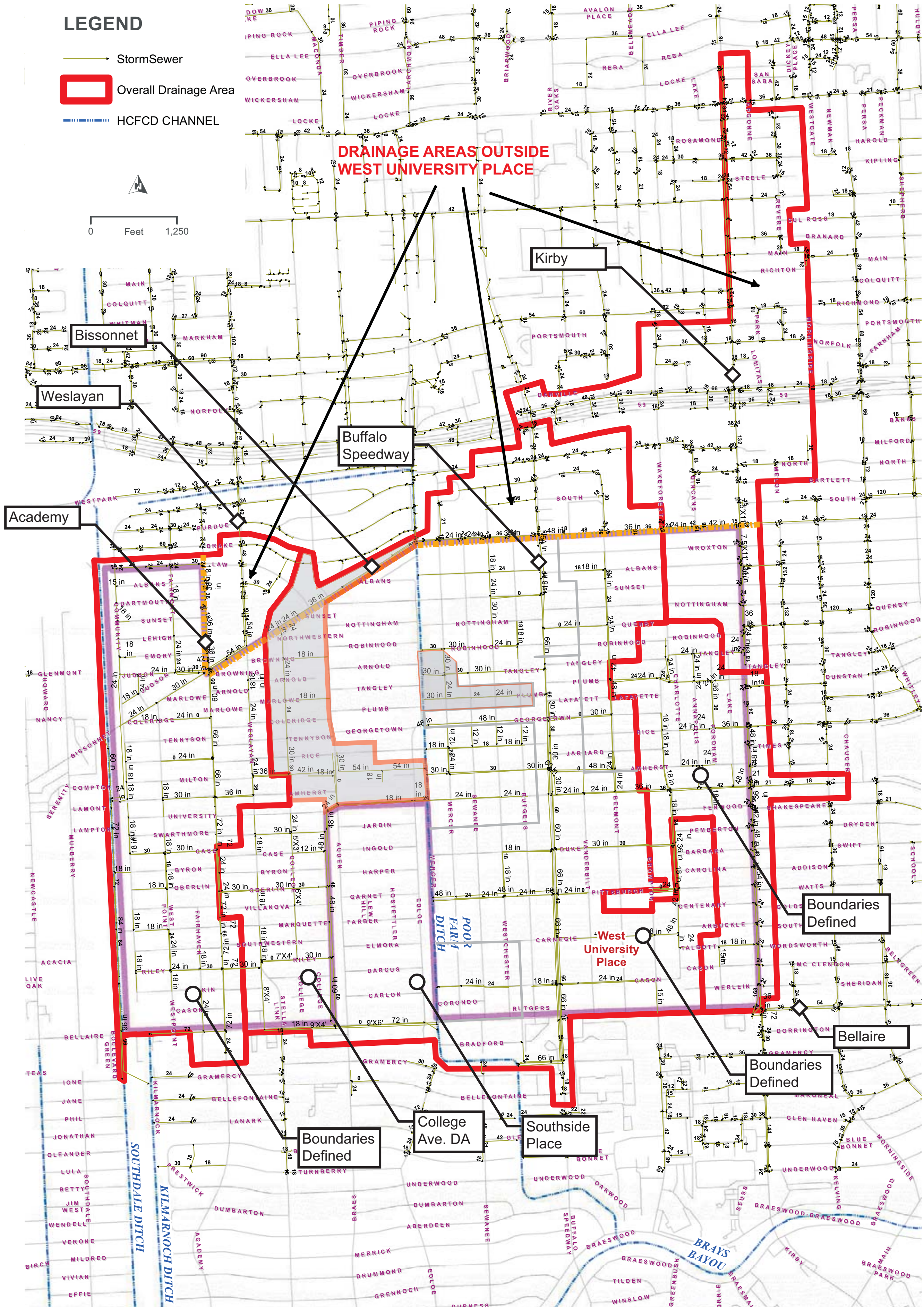


EXHIBIT 5. BRAYS BAYOU WATER SURFACE ELEVATION PROFILES

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE



HDR

EXHIBIT 6. OVERALL DRAINAGE AREA MAP

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE

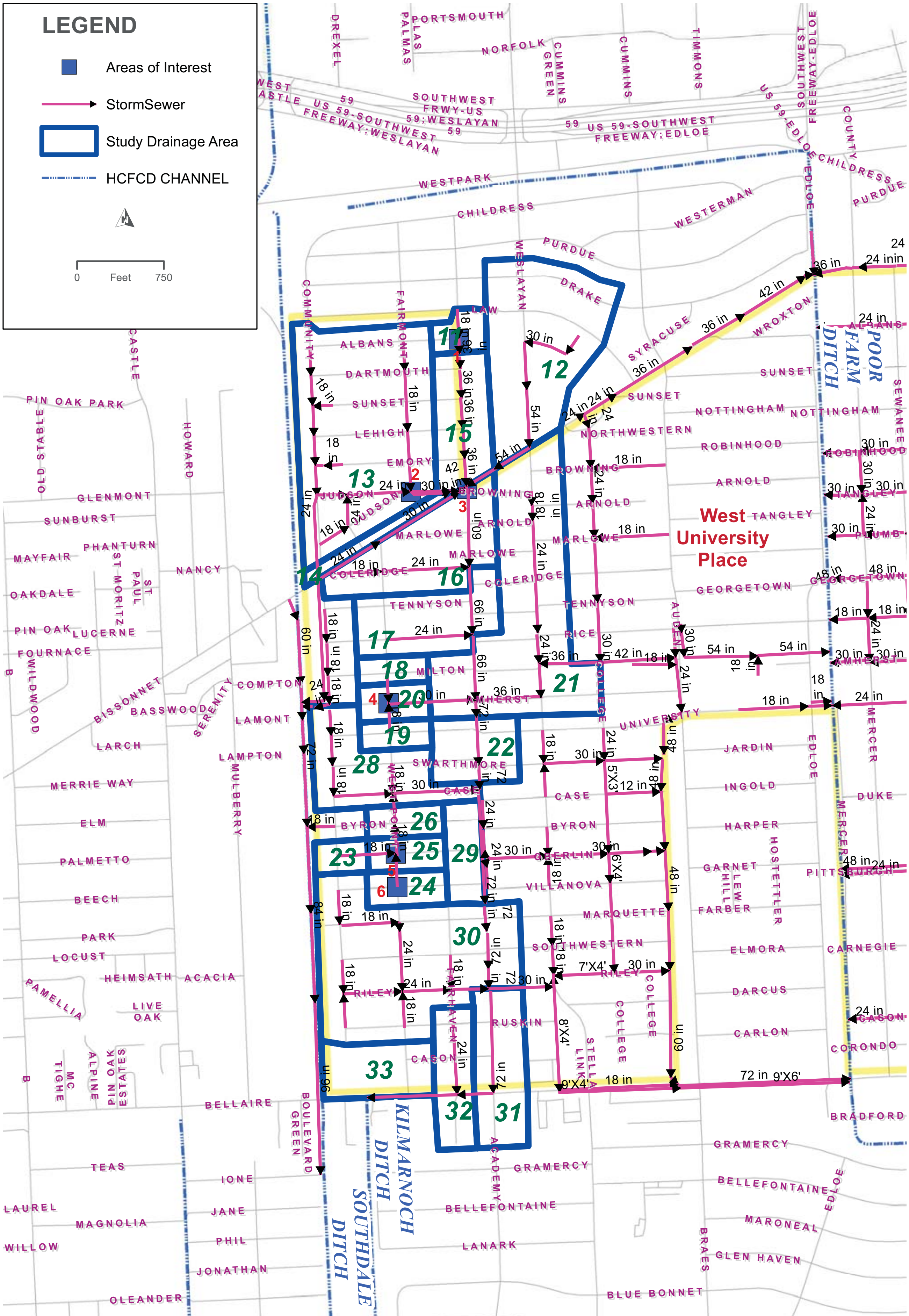


EXHIBIT 7. STUDY DRAINAGE AREA MAP

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE

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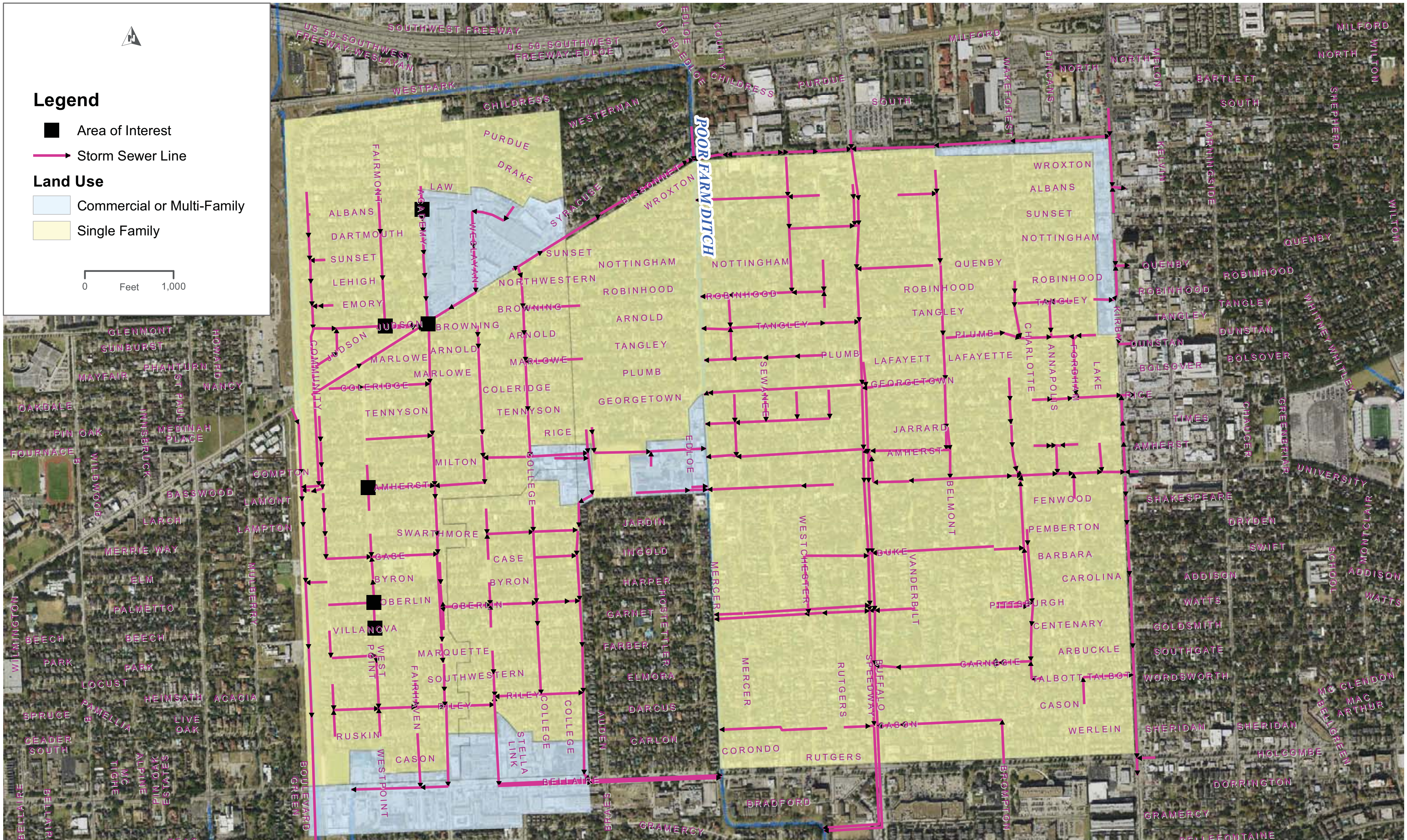

EXHIBIT 8. LAND USE TYPE MAP

PRELIMINARY STORM SEWER DRAINAGE ANALYSIS FOR SIX PONDING LOCATIONS IN WEST UNIVERSITY PLACE