Appendix

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Drainage Evaluation for Dead-End Streets

July 6, 2017

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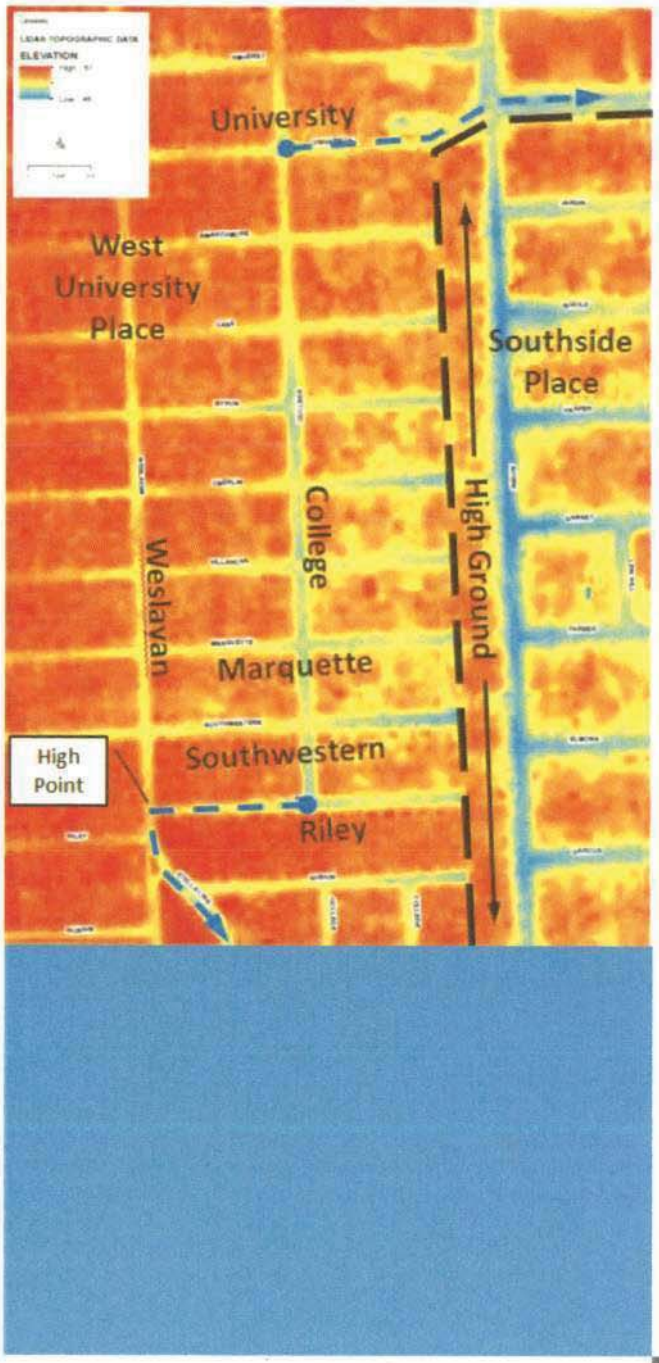

Drainage Evaluation for Dead-End Streets

City of West University Place

Poor Farm Ditch Watershed

HCFCD Unit No. D111-00-00

Harris County, TX

July 6, 2017

STATE OF TEXAS
DUANE BARRETT
63703
LICENSED
PROFESSIONAL ENGINEER

7/6/2017

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EXECUTIVE SUMMARY

This report is associated with drainage planning and feasibility investigations requested by the City of West University Place for nine (9) dead-end streets that drain to an existing storm sewer system located along the shared corporate boundary between West University Place and Southside Place. Flooding of those streets has occurred to varying extents in recent years, and the City is considering options for reducing the depth, duration, and frequency of street flooding. Alternatives evaluated include improvements to the existing storm sewer system along its current alignment, construction of a new system along Auden Street within the City of Southside Place to complement the capacity of the existing shared system, and construction of a relief sewer along University Boulevard.

The analysis described in this report indicates that the existing shared storm sewer system does not have sufficient capacity to convey peak runoff rates from a 2-year storm event as computed using current City of Houston storm sewer design methods. Improvements to the existing shared system along its existing alignment would provide 2-year flow capacity to areas in West University Place and Southside Place that drain to the shared system. Construction of a new storm sewer along Auden Street (within Southside Place) would provide 5-year capacity for the existing shared system and the new Auden Street system for localized rainfall events, but for more widespread events and for events more severe than the 2-year design storm, capacity would be limited to a 2-year design event for both systems. The construction of a relief storm sewer along University Boulevard may be considered as a stand-alone project or could be constructed in conjunction with a new storm sewer along Auden Street to provide 2-year capacity for the existing shared system and an improved Auden Street system. The following table summarizes estimated costs associated with a) improvements to the existing shared system to increase the level of service of that system to a 2-year storm event, b) construction of a new parallel system along Auden Street to provide a 5-year local level of service for the shared and parallel systems, and c) construction of a new system along Auden plus a small system along University Boulevard to provide a 2-year level of service for the shared and parallel systems.

Description of Alternative	Level of Service	Estimated Cost
Improve Existing Shared Storm Sewer Along Existing Alignment	2-Year	$3,565,201.25
Construct Parallel System Along Auden Street Draining 11.23 Acres in West U	5-Year	$2,787,128.50
Construct Parallel System Along Auden Plus Separate System Along University	2-Year	$2,681,805.75

The storm improvements described above will provide improved drainage during smaller events (generally less than or equal to 2-year), but will not operate as efficiently during greater events. Thus, the potential for impacts on downstream flow rates and flood levels will be limited during larger storm events by high-water conditions along Brays Bayou and Poor Farm Ditch. Since the 10-year event is generally considered to represent the “threshold” for flooding along Brays Bayou, increases in drainage efficiency for lesser storm events do not represent a significant risk in terms of increased flooding. For these reasons, detention is not recommended in connection with the improvements described in this report.

Improvements to the existing system will be expensive and disruptive to local residents of both cities. Construction of a new parallel system along Auden Street within Southside Place offers a very reasonable and mutually beneficial option for reducing flow to the shared system and providing capacity ranging from 2-year to 5-year depending on whether drainage from West University Place flows to the Auden Street system. An alternative that includes a new system along Auden plus a new storm sewer along University Boulevard would provide 2-year capacity at a total cost consistent with that of a single 5-year-capacity system along Auden that accepts storm runoff from an area of approximately 11.17 acres within West University Place. Both of the alternatives involving a new system along Auden provide greater benefit at lower cost than replacing the existing shared system with larger storm sewers along the existing alignment. HDR recommends that an alternative involving a new system along Auden be evaluated very seriously by the City of West University Place in cooperation with the City of Southside Place.

INTRODUCTION

This report is associated with drainage planning and feasibility investigations requested by the City of West University Place. The effort described in this report covers analyses of the following specific tasks and questions as communicated to us by Mr. Patrick Walters. The following preparatory tasks involving various field investigations were completed by the City during the week of May 8th, 2017 with the assistance of one engineering staff member from HDR.

- Jet the lines at the intersection of Amherst and University to verify that they are clear.
- Get elevation shots of storm sewer inverts in the intersection of Amherst and University.
- Obtain measurements of inverts and pipe sizes of existing inlet(s) that should connect to the 54" storm sewer behind the elementary school, which was not completed across the ball field.

The following tasks have been be completed by HDR Engineering, Inc.

1. Determine the capacity of the shared storm sewer line that runs along the boundary between West U and Southside Place (SSP), just east of the cul-de-sacs at the east ends of Swarthmore, Case, Byron, Oberlin, Villanova, Marquette, Southwestern, Riley, and Ruskin Streets. Check pipe sizes and drainage boundaries established in previous studies. Determine whether this line meets the 2-yr design criteria established by West U, and if not, identify the location at which it becomes inadequate to convey the 2-yr storm flow.
2. If any portion of the existing storm sewer system along the West U / Southside boundary does not satisfy current 2-year design storm criteria, determine the storm sewer pipe size(s) necessary to provide 2-year capacity. Prepare a preliminary estimate of the cost necessary to replace the undersized pipes in their existing location and a separate estimate for one alternative alignment (e.g., along Auden Street in Southside Place).
3. Determine the location of the elevation/drainage break-point on Marquette St. Determine how much runoff flows to the west towards College Street and how much flows east to the common system line between West U and Southside Place.
4. It appears that a storm sewer pipe extends eastward along Riley towards the dead end at the West U / Southside boundary. Determine whether there is an elevation break point on Riley and what the drainage pattern is in this area (i.e., how much area drains to the east to the West U / Southside boundary and how much drains westward to the College Avenue storm sewer system).
5. Update the city-wide drainage area map for West U, adding drainage breaks from the Marquette St. and Riley St. evaluations on the current drainage area map as well as any prior drainage system modifications identified in completing the preceding tasks. Include updated drainage boundaries and pipe sizes and alignments from the Ruskin / College project.

The following sections of this report present HDR's findings regarding the various tasks described in the scope of work. Figure 1 on the following page of this report provides a general overview of the project area.

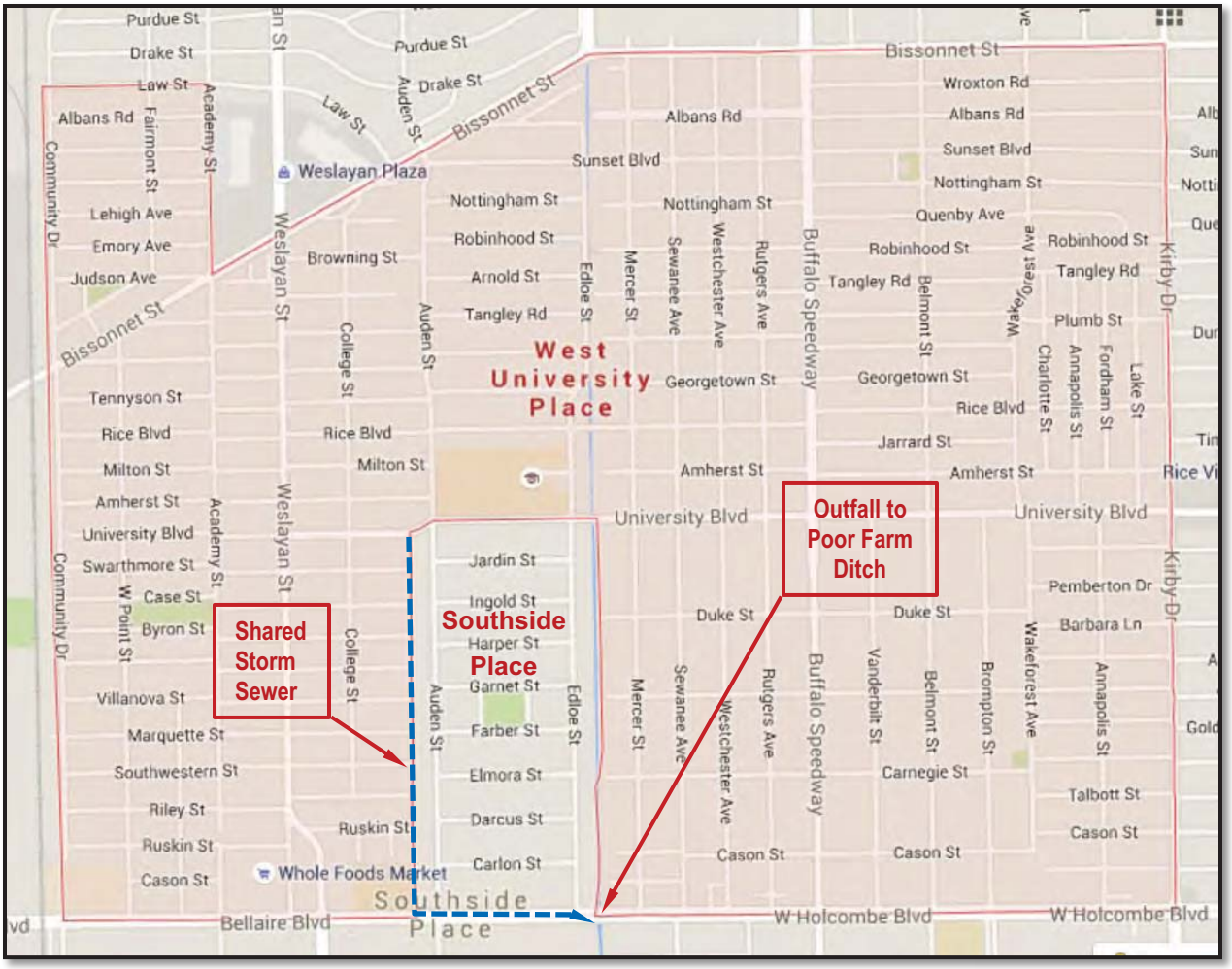


Figure 1: Map of West U and Southside Place

ENGINEERING BASIS FOR CALCULATIONS PRESENTED IN THIS REPORT

Capacities of storm sewer pipes are estimated using the Manning Equation, which utilizes the pipe cross-sectional area, rougness, and slope to produce a "full gravity flow" flow capacity in units of cubic feet per second. The standard Manning formula is as follows.

$$Q = (1.49/n)\ A\ R^{2/3}\ S^{1/2}$$

In the Manning formula, Q is the flow capacity in cubic feet per second (cfs), n is the roughness coefficient, A is the cross-sectional area of the pipe in square feet, R is the hydraulic radius of the pipe (computed as the area divided by the wetted perimeter, or the circumference, of the pipe) and S is the slope in units of feet of drop in elevation per foot of length of pipe. In the Houston area, standard engineering practice is to design storms sewers to flow at 3 feet per second under full flow conditions. Pipe slope is varied with size to provide the standard 3-foot-per-second velocity.

Runoff flow rates for given drainage areas are computed using the Rational Method, which associates peak runoff rates with a runoff coefficient that describes the relative level of development and impervious cover, the rainfall intensity in inches per hour, and the drainage area. The standard Rational Method formula is as follows.

$$Q = CIA$$

Where C is the runoff coefficient, I is the rainfall intensity, and A is the drainage area. Specific techniques and parameters developed by the City of Houston have been utilized in this analysis of storm sewers within the City of West University Place. The following excerpts from Chapter 9 of the City of Houston Design Manual define the approach utilized to apply the Rational Method to local watersheds.

Time of concentration can be calculated from the following formula:

$$TC = 10A^{0.1761} + 15$$

Where: TC = time of concentration (minutes)
A = subarea (acres)

Land Use Type	Runoff Coefficient (C)
Residential Districts	
Lots more than 1/2 acre	0.35
Lots 1/4 - 1/2 acre	0.45
Lots less than 1/4 acre	0.55

Calculate Intensity: The intensity calculation is based on duration equal to the time of concentration. The intensity is calculated as follows:

$$I = b/(d + T_C))^e$$

Where b, d, and e are coefficients dependent on the storm event, as provided in Table 9.1, below and are based on City of Houston depth-duration-frequency values.

Table 9.1
Rainfall Intensity Parameters

Rainfall Frequency	b	d	e
2-year	75.01	16.2	0.8315
3-year	77.27	17.1	0.8075
5-year	84.14	17.8	0.7881
10-year	93.53	18.9	0.7742
25-year	115.9	21.2	0.7808
100-year	125.4	21.8	0.7500

FIELD CHECKS AND ADJUSTMENTS TO CITY-WIDE DRAINAGE AREA MAP

Field measurements indicate that the drainage break on both Marquette and Riley Streets is approximately 290 feet east of the curb return on the east side of College Avenue. Those measurements, additional field observations, and other available information were used to update the City-wide drainage area map as requested. Attachment 1 to this report is a drainage area map for the shared system. The updated map shows a total area of 34.72 acres draining to the shared system from West University Place. Five (5) interconnections with the existing Southside Place drainage system along Auden Street are noted on available drainage areas maps dating back a number of years. The connector pipes range in size from 15 inches to 24 inches in diameter. In order to account for drainage to the shared storm sewer system at each connection, the capacity of each connector pipe was estimated using a standard design velocity of 3.0 feet per second. An equivalent drainage area was then determined using the Rational Method formula and solving for the drainage area as follows.

$$A = Q / CI$$

Table 1 provides equivalent drainage area values developed for the various connections. The computed total equivalent drainage area contributing flow to the shared storm sewer system via the SSP connectors is 18.83 acres.

Table 1: Equivalent Drainage Area Contributions from Southside Place Storm Sewer Connections

Connector Location	West U Street	Connector Pipe Diam. (inches)	Flow Area (sq. ft.)	Connector Capacity (cfs)	Equivalent DA (acres)	Tc (min.)	Intensity (in/hr)	2-Yr Flow (cfs)
Ingold	Case	24	3.14	9.4	5.37	28.44	3.19	9.4
Garnet	Villanova	15	1.23	3.7	2.02	26.32	3.32	3.7
Farber	Marquette	21	2.41	7.2	4.05	27.79	3.23	7.2
Elmora	Riley	24	3.14	9.4	5.37	28.44	3.19	9.4
Darcus	Ruskin	15	1.23	3.7	2.02	26.32	3.32	3.7

Figure 2 is a snapshot of a typical curb-and-gutter street in the project area. Significant ponding in local streets is not uncommon. Figure 3 represents a portion of the West University Place city-wide drainage area map, with focus on the areas draining to the shared storm sewer along the West University Place / Southside Place corporate boundary. Blue shading represents the area within the City of West University Place that drains to the shared West U / SSP storm sewer. Text in black denotes West U storm sewer sizes, drainage areas, times of concentration, and 2-year flow rates, while green lines and orange dots represent existing West U storm sewers and inlet locations. Red arrows and corresponding text (e.g., 24") represent locations where the existing Southside Place storm sewer along Auden Street connects to the shared storm sewer system along the corporate boundary. Red text denotes the equivalent drainage area corresponding to each connector pipe.

Figure 2: Typical Street in the Project Area

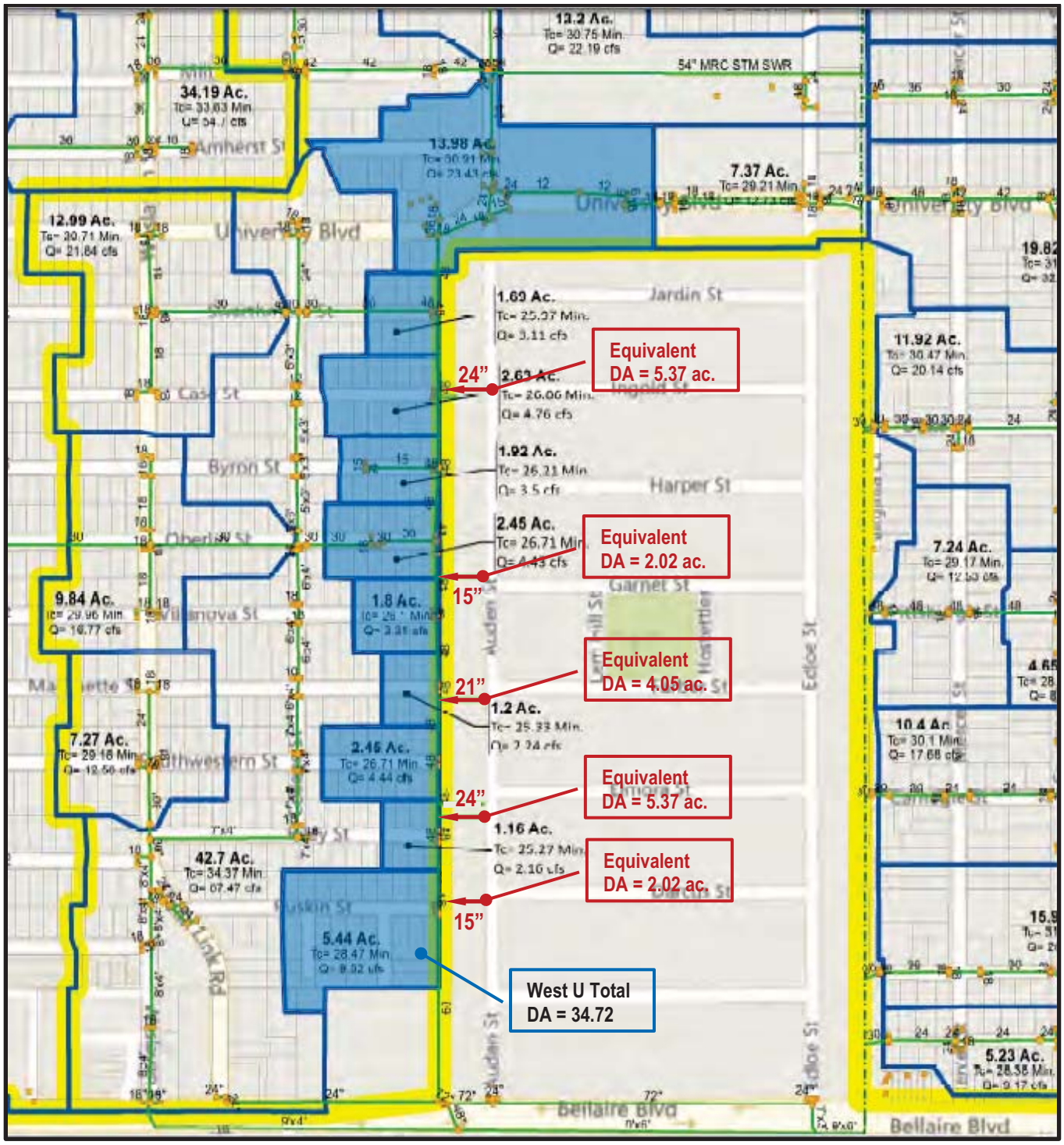


Figure 3: Drainage Area Map

EVALUATION OF EXISTING SHARED STORM SEWER SYSTEM

The existing shared storm sewer system along the corporate boundary between the Cities of West University Place and Southside Place consists of a single 48-inch reinforced concrete pipe (RCP) storm sewer from University Boulevard southward to Riley Street. From that point southward to Bellaire Boulevard, the shared sytem consists of a single 60-inch

RCP. The capacities of the 48-inch and 60-inch lines are estimated using the standard design velocity of 3 feet per second.. Table 2 presents pipe capacity estimates for 48-inch and 60-inch storm sewer pipes with slopes required to generate the typical design velocity of 3 feet per second using the Manning Equation.

Table 2: Pipe Capacity Estimates for Shared System along Corporate Boundary

Pipe Diameter (inches)	Roughness Coefficient	Section Area (sq. ft.)	Pipe Circumference (feet)	Hydraulic Radius (feet)	Pipe Slope (ft/ft)	Flow Velocity (ft/sec)	Pipe Capacity (cfs)
48	0.013	12.57	12.57	1.00	0.0007	3.00	37.7
60	0.013	19.63	15.71	1.25	0.0005	3.00	58.9

The peak runoff rate is computed at each of the streets that "dead end" at the corporate boundary between the Cities of West University Place and Southside Place. Table 3 summarizes the peak flow calculations completed in connection with the analysis. Flow contributions from West University Place and Southside Place are accounted for in the analysis. Computed 2-year flow rates are compared with the capacity of the shared storm sewer. Shaded cells indicate locations where the computed 2-year flow rate exceeds the estimated pipe capacity. As indicated, the estimated available pipe capacity is exceeded at Case Street and at all locations downstream of Case Street. Note that in the table, rainfall intensities decrease with increased drainage area and time of concentration, as in order for the probability of occurrence to remain constant (50% for a 2-year storm event) with increasing drainage areas and longer times of concentration, the rainfall and rainfall intensity are reduced. This is standard practice when using the Rational Method to complete peak runoff calculations.

Table 3: Calculations for 2-Year Event – Existing Shared Storm Sewer System

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	2-Year Intensity (in/hr)	2-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	13.98	0.00	13.98	30.91	0.55	3.05	23.4	48	37.7
Swarthmore	15.67	0.00	15.67	31.23	0.55	3.03	26.1	48	37.7
Case	18.30	5.37	23.67	32.46	0.55	2.97	**38.6**	48	**37.7**
Byron	20.22	5.37	25.59	32.70	0.55	2.95	**41.6**	48	**37.7**
Oberlin	22.67	5.37	28.04	32.99	0.55	2.94	**45.3**	48	**37.7**
Villanova	24.47	7.39	31.86	33.40	0.55	2.92	**51.2**	48	**37.7**
Marquette	25.67	11.44	37.11	33.90	0.55	2.90	**59.1**	48	**37.7**
Southwestern	28.12	11.44	39.56	34.11	0.55	2.89	**62.8**	48	**37.7**
Riley	29.28	16.81	46.09	34.63	0.55	2.86	**72.5**	60	**58.9**
Ruskin	34.72	18.83	53.55	35.16	0.55	2.84	**83.5**	60	**58.9**

EVALUATION OF POSSIBLE IMPROVEMENTS TO EXISTING SHARED SYSTEM

Adjustments were made to the existing storm sewer pipe sizes in order to determine what changes would be necessary to allow the shared system to convey the computed 2-year flow rates. Table 4 provides an updated analysis with existing pipe sizes replaced by pipes large enough to provide the required 2-year flow capacity at standard velocity of 3 feet per second. As shown, proposed pipe diameters range from 48 inches to 72 inches where existing values range from 48 inches to 60 inches. Proposed pipe capacities are adequate to convey computed 2-year flow rates under this improved scenario. Note

that one pipe capacity is slightly less than the computed peak flow rate, but the shortfall is small enough (0.3%) to be negligible. In design, a slight increase in pipe slope would suffice to increase the velocity and capacity to the required value.

Table 4: Calculations for 2-Year Event – Improved Shared System along Existing Alignment

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	2-Year Intensity (in/hr)	2-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	13.98	0.00	13.98	30.91	0.55	3.05	23.4	48	37.7
Swarthmore	15.67	0.00	15.67	31.23	0.55	3.03	26.1	48	37.7
Case	18.30	5.37	23.67	32.46	0.55	2.97	38.6	54	47.7
Byron	20.22	5.37	25.59	32.70	0.55	2.95	41.6	54	47.7
Oberlin	22.67	5.37	28.04	32.99	0.55	2.94	45.3	54	47.7
Villanova	24.47	7.39	31.86	33.40	0.55	2.92	51.2	60	58.9
Marquette	25.67	11.44	37.11	33.90	0.55	2.90	59.1	60	58.9
Southwestern	28.12	11.44	39.56	34.11	0.55	2.89	62.8	66	71.3
Riley	29.28	16.81	46.09	34.63	0.55	2.86	72.5	72	84.8
Ruskin	34.72	18.83	53.55	35.16	0.55	2.84	83.5	72	84.8

The estimated cost associated with upsizing existing storm sewer pipes from Case Street to Bellaire Boulevard is summarized in Table 5. It should be noted that replacement of pipe along the existing alignment will be very difficult due to the proximity of homes and appurtenant structures along both the West University Place and Southside Place sides of the corporate boundary. Figure 4 illustrates the heavily urbanized nature of the project area and the existing shared storm sewer alignment. The existing storm sewer lies within an existing easement, but that easement is heavily encumbered. Therefore, the pipe removal and installation prices used below reflect an assumed increase of 100% above typical values to cover anticipated difficulty accessing and working in the shared system easement. We have also included significant sums to cover site preparation and restoration in light of the limited available space and the need to remove and replace existing fencing.

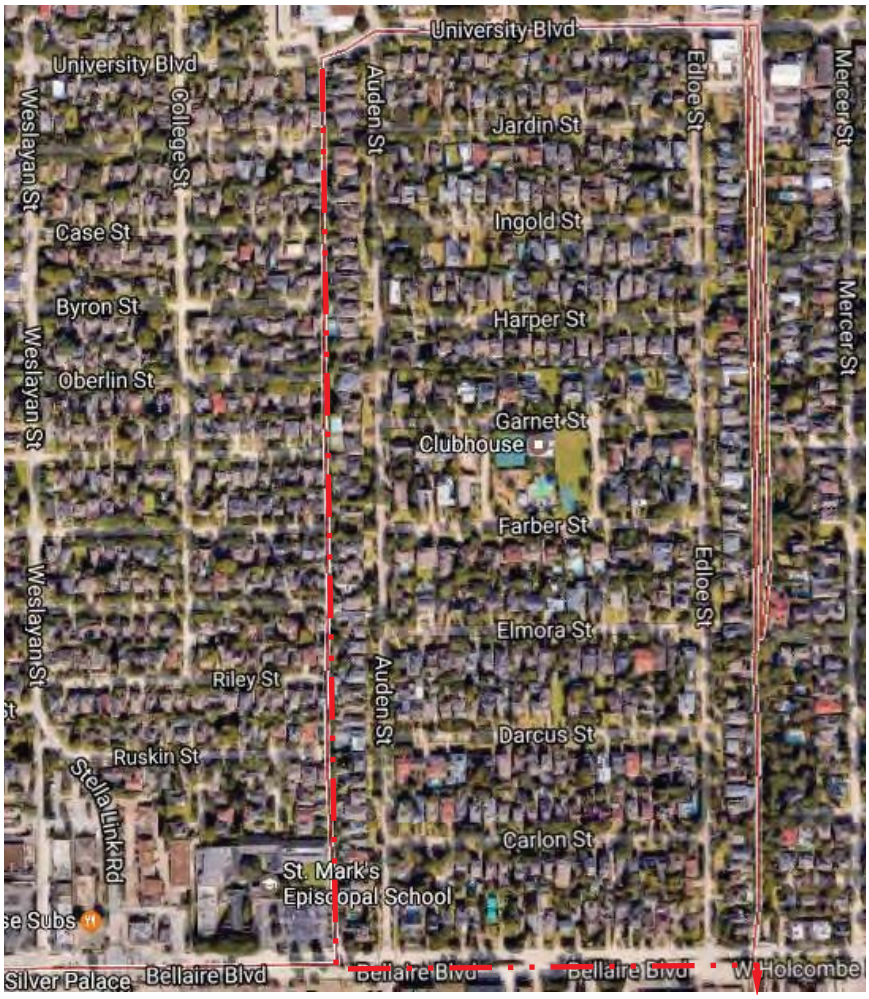


Figure 4: Urbanization in the Project Area

Table 5: Estimated Cost for Upgrading the Existing Shared System to 2-Year Capacity

Item Description	Quantity	Unit of Measurement	Unit Price	Cost
Mobilization	1	LS	$50,000.00	$50,000.00
Site Preparation	1	LS	$100,000.00	$100,000.00
Remove Pavement at Ends of All Streets (Curbs Incl.)	720	SY	$25.00	$18,000.00
Remove Existing Pipe, All Sizes	2480	LF	$25.00	$62,000.00
Install 54" Reinforced Concrete Pipe	760	LF	$540.00	$410,400.00
Install 60" Reinforced Concrete Pipe	520	LF	$590.00	$306,800.00
Install 66" Reinforced Concrete Pipe	240	LF	$720.00	$172,800.00
Install 72" Reinforced Concrete Pipe	960	LF	$810.00	$777,600.00
Remove & Replace Existing Curb Inlets	18	EA	$5,000.00	$90,000.00
Remove & Replace Existing Manholes	9	EA	$7,500.00	$67,500.00
Remove & Replace 24" Storm Sewer Laterals	270	LF	$95.00	$25,650.00
Replace Pavement at Ends of All Streets (Curbs Incl.)	720	SY	$75.00	$54,000.00
Site Restoration	1	LS	$200,000.00	$200,000.00
De-Mobilization	1	LS	$50,000.00	$50,000.00
Sub-Total	-----	-----	-----	$2,384,750.00
Contingency	30%	-----	-----	$715,425.00
Sub-Total	-----	-----	-----	$3,100,175.00
Engineering	15%	-----	-----	$465,026.25
Overall Total	**-----**	**-----**	**-----**	**$3,565,201.25**

CONSIDERATION OF OTHER ALTERNATIVES FOR IMPROVING STORM SEWER CAPACITY

Because the existing shared system is difficult to access and will be expensive to upgraded, a number of other alternatives to improving the existing storm sewer "in place" were evaluated by HDR, including the following.

1. Construct a new storm sewer along Auden Street in Southside Place to relieve the hydraulic loading on the existing shared system. This alternative has the advantage of using an existing public street right-of-way with adequate space to construct a new storm sewer system. The major disadvantage is the fact that the affected segment of Auden lies entirely within the City of Southside Place, and this will require development of an interlocal agreement.

2. Create additional storm sewer capacity and depth along College Avenue to allow the nine dead-end streets to drain to the west. This option would push the College Avenue system closer to the "extreme event" system previously considered but ultimately dismissed as too expensive. Another disadvantage is the possibility that water collected in the College Avenue system would back up into the nine streets during extreme events, inadvertently exacerbating flooding.

3. Use a pump(s) to evacuate storm water from the dead-end streets via a force main along the existing storm sewer alignment. The major advantage of this approach is that a force main would be significantly smaller than a gravity line, and a force main could potentially be installed adjacent to the existing shared system at a significantly lower cost than replacing the existing storm sewer with larger pipes. However, there is no room to locate a pump station(s) with the required back-up power.

ALTERNATIVE INVOLVING A PARALLEL STORM SEWER ALONG AUDEN STREET

Careful consideration of the available alternatives indicates that construction of a parallel system along Auden Street represents the most favorable option. Two approaches to the design and construction of that system are available. The first would involve construction of a parallel system with sufficient capacity to replace the existing shared system. The second is to construct a system along Auden Street with sufficient capacity that, when combined with the capacity of the existing system, provides enough capacity to convey the 2-year design flow. The first approach would involve abandonment of the existing system, which we understand to be in reasonable condition. The second offers the possibility of developing an effective solution at a lower cost. Therefore, we have investigated the option of creating a parallel system along Auden Street that, when combined with the existing shared storm sewer, provides adequate total capacity to accommodate at minimum a 2-year storm event. Table 6 reflects revised calculations for the existing system with all Southside Place drainage areas assumed to drain to a new storm sewer along Auden Street. In addition, approximately 11.23 acres of the 13.98-acre drainage area along and north of University Boulevard is assumed to drain to a new system along Auden, with the residual 2.75 acres (area that cannot be easily re-directed to a system along Auden) draining to the existing shared system. As indicated in Table 6, the proposed reduction in the area draining to the existing shared system brings 2-year design flows well below the estimated conveyance capacity of the existing 48-inch and 60-inch storm sewer pipes.

Table 6: Calculations for 2-Year Event – Existing Shared System with Reduced Drainage Area

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	2-Year Intensity (in/hr)	2-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	2.75	0.00	2.75	26.95	0.55	3.28	5.0	48	37.7
Swarthmore	4.44	0.00	4.44	28.00	0.55	3.21	7.8	48	37.7
Case	7.07	0.00	7.07	29.11	0.55	3.15	12.2	48	37.7
Byron	8.99	0.00	8.99	29.72	0.55	3.11	15.4	48	37.7
Oberlin	11.44	0.00	11.44	30.36	0.55	3.08	19.4	48	37.7
Villanova	13.24	0.00	13.24	30.76	0.55	3.06	22.2	48	37.7
Marquette	14.44	0.00	14.44	31.00	0.55	3.04	24.2	48	37.7
Southwestern	16.89	0.00	16.89	31.45	0.55	3.02	28.0	48	37.7
Riley	18.05	0.00	18.05	31.64	0.55	3.01	29.9	60	58.9
Ruskin	23.49	0.00	23.49	32.43	0.55	2.97	38.3	60	58.9

In order to determine the level of service that could be achieved along the existing shared system with the proposed drainage area reduction, flow rates for 3-year and 5-year storm events have been computed. Table 7 compares computed 5-year flow rates with estimated existing conditions pipe capacities. As indicated in the table, computed 5-year flow rates are less than existing pipe capacities at all points, indicating that the system would have sufficient capacity to accommodate runoff from a 5-year event. Please note, however, that downstream conditions, including high flood levels in Brays Bayou and limited capacity in the existing storm sewer systems along Bellaire Boulevard, may constrain the actual capacity of the shared system to something less than a 5-year event. Under those conditions, the unused storm sewer capacity would serve as in-line storage.

Table 7: Calculations for 5-Year Event – Existing Shared System with Reduced Drainage Area

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	5-Year Intensity (in/hr)	5-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	2.75	0.00	2.75	26.95	0.55	4.21	6.4	48	37.7
Swarthmore	4.44	0.00	4.44	28.00	0.55	4.13	10.1	48	37.7
Case	7.07	0.00	7.07	29.11	0.55	4.05	15.8	48	37.7
Byron	8.99	0.00	8.99	29.72	0.55	4.01	19.8	48	37.7
Oberlin	11.44	0.00	11.44	30.36	0.55	3.97	25.0	48	37.7
Villanova	13.24	0.00	13.24	30.76	0.55	3.94	28.7	48	37.7
Marquette	14.44	0.00	14.44	31.00	0.55	3.93	31.2	48	37.7
Southwestern	16.89	0.00	16.89	31.45	0.55	3.90	36.2	48	37.7
Riley	18.05	0.00	18.05	31.64	0.55	3.89	38.6	60	58.9
Ruskin	23.49	0.00	23.49	32.43	0.55	3.84	49.6	60	58.9

Table 8 provides preliminary storm sewer design capacity calculations for a parallel system along Auden Street. Figure 5 illustrates the drainage boundaries established for the purposes of analyzing a system along Auden. Red lines represent the area within Southside Place assumed to drain to the Auden Street system. The eastern boundary of that area coincides with the western edge of the Chilos Street right-of-way on the west side of Fire Truck Park. Dashed red lines represent approximate breaks between areas that flow to Auden along various east-west streets. Red boxes with leader lines and red text represent approximate areas that drain to the storm sewer interconnects along Auden Street. For the purposes of this conceptual design exercise, we have assumed that 11.23 acres of land within West University Place will drain to the system at University Boulevard, and that the eastern boundary of the area within the City of Southside Place draining to the system may be represented by a straight line approximately 1/3 of the way from Auden Street to Edloe Street. In order to provide the same level of service as the shared system, we have computed 5-year flow rates for the purposes of preparing a conceptual design for the Auden system. Pipe sizes required to convey 5-year flow rates along Auden range from 42 inches at University Boulevard to 78 inches at Bellaire Boulevard.

Table 8: Calculations for 5-Year Event - New Parallel Storm Sewer along Auden Street

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	5-Year Intensity (in/hr)	5-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	11.23	0.00	11.23	30.31	0.55	3.97	24.5	42	28.9
Jardin	11.23	3.82	15.05	31.12	0.55	3.92	32.5	48	37.7
Ingold	11.23	8.12	19.35	31.85	0.55	3.88	41.3	54	47.7
Harper	11.23	12.20	23.43	32.43	0.55	3.84	49.5	60	58.9
Garnet	11.23	16.86	28.09	32.99	0.55	3.81	58.8	60	58.9
Farber	11.23	21.27	32.50	33.46	0.55	3.78	67.6	66	71.3
Elmora	11.23	25.64	36.87	33.88	0.55	3.76	76.2	72	84.8
Darcus	11.23	30.23	41.46	34.27	0.55	3.73	85.1	72	84.8
Riley	11.23	33.46	44.69	34.53	0.55	3.72	91.4	78	99.5

Note that the construction of a new storm sewer along Auden will likely require the addition of a connector between the existing 72-inch storm sewer on the north side of Bellaire Boulevard and the existing box culvert storm sewer on the south side of Bellaire Boulevard, similar to the existing 48-inch connector between the two systems at the point where the existing shared storm sewer ties into the 72-inch system.

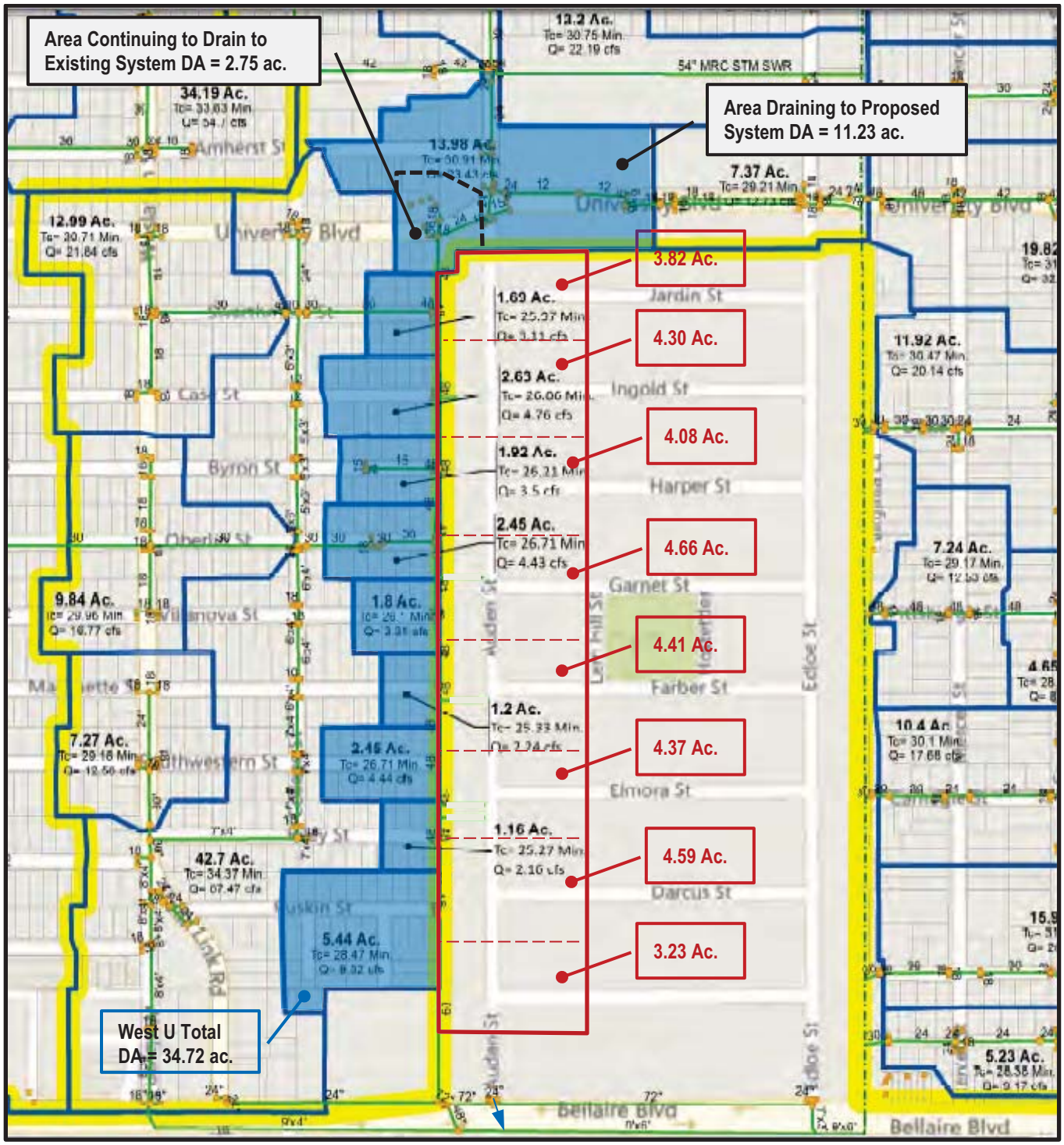


Figure 5: Drainage Area Map for Proposed Conditions

The cost associated with constructing a new storm sewer along Auden Street is estimated as shown in Table 9.

Table 9: Estimated Cost for New Storm Sewer along Auden Street (5-Year Capacity)

Item Description	Quantity	Unit of Measurement	Unit Price	Cost
Mobilization	1	LS	$25,000.00	$25,000.00
Site Preparation	1	LS	$25,000.00	$25,000.00
Remove Pavement (One 12' Lane x 3200')	4270	SY	$15.00	$64,050.00
Remove Existing Pipe, All Sizes	2600	LF	$10.00	$26,000.00
Install 42" Reinforced Concrete Pipe	350	LF	$180.00	$63,000.00
Install 48" Reinforced Concrete Pipe	350	LF	$210.00	$73,500.00
Install 54" Reinforced Concrete Pipe	350	LF	$270.00	$94,500.00
Install 60" Reinforced Concrete Pipe	350	LF	$295.00	$103,250.00
Install 66" Reinforced Concrete Pipe	350	LF	$360.00	$126,000.00
Install 72" Reinforced Concrete Pipe	700	LF	$405.00	$283,500.00
Install 78" Reinforced Concrete Pipe	750	LF	$550.00	$412,500.00
Remove & Replace Existing Curb Inlets	30	EA	$3,500.00	$105,000.00
Remove & Replace Existing Manholes	10	EA	$5,000.00	$50,000.00
Remove & Replace 24" Storm Sewer Laterals	450	LF	$95.00	$42,750.00
Replace Pavement (One 12' Lane x 3200')	4270	SY	$75.00	$320,250.00
Site Restoration	1	LS	$25,000.00	$25,000.00
De-Mobilization	1	LS	$25,000.00	$25,000.00
Sub-Total	-----	-----	-----	$1,864,300.00
Contingency	30%	-----	-----	$559,290.00
Sub-Total	-----	-----	-----	$2,423,590.00
Engineering	15%	-----	-----	$363,538.50
Overall Total	**-----**	**-----**	**-----**	**$2,787,128.50**

The cost of constructing a new storm sewer system along Auden Street, while costly, is significantly lower in cost than the alternative that calls for replacement of existing pipes along the existing shared system alignment. Based on the very preliminary cost numbers developed for this report, the cost of the Auden Street storm sewer is only about 3/4 of the cost associated with storm sewer replacement along the existing alignment. This fact, coupled with the difficulty of accessing the existing storm sewer and potential impacts to local residents in both West University Place and Southside Place, indicates that the Auden Street alternative warrants serious consideration.

ALTERNATIVE INVOLVING A NEW STORM SEWER ALONG UNIVERSITY BOULEVARD

We have also evaluated a possible project in which storm water from the 13.98-acre drainage area along University Boulevard is conveyed eastward along that roadway to Poor Farm Ditch. This improvement may be evaluated as a stand-alone project that could be implemented relatively quickly because it would involve work only in West University Place. It also represents an alternative to draining water from the 13.98-acre drainage area southward along Auden. Table 10 provides a summary of peak flow calculations and storm sewer pipe sizing for a storm sewer along University Boulevard. Note that the “DA Bndy.”

location refers to a point at the eastern boundary of the 13.98-acre drainage area. That point is approximately halfway between Auden Street and Edloe Street.

Table 10: Calculations for 2-Year Event – New Storm Sewer along University Boulevard

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	2-Year Intensity (in/hr)	2-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
Auden	11.23	0.00	11.23	30.31	0.55	3.08	19.0	36	21.2
DA Bndy.	18.60	0.00	18.60	31.73	0.55	3.00	30.7	48	37.7

Table 11 provides a summary of residual 2-year flow rates along the existing shared system with 11.17 acres of drainage area diverted to a proposed system along University Boulevard. As indicated, 2-year flow rates still exceed pipe capacities at several locations, but flow rates are significantly reduced as compared with the existing conditions values presented in Table3, which range from 23.4 cfs at University to 83.5 cfs at Ruskin.

Table 11: Calculations for 2-Year Event - Existing Shared System with New Storm Sewer along University Blvd.

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	2-Year Intensity (in/hr)	2-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	2.75	0.00	2.75	26.95	0.55	3.28	5.0	48	37.7
Swarthmore	4.44	0.00	4.44	28.00	0.55	3.21	7.8	48	37.7
Case	7.07	5.37	12.44	30.59	0.55	3.06	21.0	48	37.7
Byron	8.99	5.37	14.36	30.99	0.55	3.04	24.0	48	37.7
Oberlin	11.44	5.37	16.81	31.44	0.55	3.02	27.9	48	37.7
Villanova	13.24	7.39	20.63	32.04	0.55	2.99	33.9	48	37.7
Marquette	14.44	11.44	25.88	32.73	0.55	2.95	42.0	48	37.7
Southwestern	16.89	11.44	28.33	33.02	0.55	2.94	45.8	48	37.7
Riley	18.05	16.81	34.86	33.69	0.55	2.91	55.7	60	58.9
Ruskin	23.49	18.83	42.32	34.34	0.55	2.87	66.9	60	58.9

Table 12 summarizes 2-year flow rates and pipe sizes for a system along Auden that does not receive drainage from West University Place. With no inflow from West University Place, the required storm sewer sizes range from 24 inches at Jardin Street to 60 inches at Bellaire Boulevard. Figure 6 illustrates the existing condition of Auden Street, which as indicated is a curb-and-gutter street in a residential area.

Figure 6: View Looking Southward along Auden Street

Table 12: Calculations for 2-Year Event - New Storm Sewer along Auden (Assumes New System along University)

Location	West U DA (acres)	SSP DA (acres)	Total Area (acres)	Tc (minutes)	Runoff Coefficient	2-Year Intensity (in/hr)	2-Year Flow (cfs)	Pipe Size (inches)	Pipe Capacity (cfs)
University	0.00	0.00	0.00	15.00	0.55	4.29	0.0	---	---
Jardin	0.00	3.82	3.82	27.66	0.55	3.23	6.8	24	9.4
Ingold	0.00	8.12	8.12	29.46	0.55	3.13	14.0	30	14.7
Harper	0.00	12.20	12.20	30.53	0.55	3.07	20.6	36	21.2
Garnet	0.00	16.86	16.86	31.45	0.55	3.02	28.0	42	28.9
Farber	0.00	21.27	21.27	32.13	0.55	2.98	34.9	48	37.7
Elmora	0.00	25.64	25.64	32.71	0.55	2.95	41.7	54	47.7
Darcus	0.00	30.23	30.23	33.23	0.55	2.93	48.7	60	58.9
Riley	0.00	33.46	33.46	33.56	0.55	2.91	53.6	60	58.9

Table 13 provides an estimate of the total cost of a system along University Boulevard, while Table 14 provides an estimate of the cost of a system along Auden that does not receive runoff from West University Place. The total cost for the two projects is estimated to be $2,681,805.75. This total is consistent with the estimated cost of $2,787,128.50 for 5-year storm sewer along Auden as presented in Table 8.

Table 13: Estimated Cost for New Storm Sewer System along University Boulevard

Item Description	Quantity	Unit of Measurement	Unit Price	Cost
Mobilization	1	LS	$10,000.00	$10,000.00
Site Preparation	1	LS	$10,000.00	$10,000.00
Remove Pavement (One 12' Lane x 1300')	1740	SY	$15.00	$26,100.00
Remove Existing Pipe, All Sizes	2100	LF	$10.00	$21,000.00
Install 36" Reinforced Concrete Pipe	550	LF	$160.00	$88,000.00
Install 48" Reinforced Concrete Pipe	750	LF	$210.00	$157,500.00
Remove & Replace Existing Curb Inlets	12	EA	$3,500.00	$42,000.00
Remove & Replace Existing Manholes	6	EA	$5,000.00	$30,000.00
Remove & Replace 24" Storm Sewer Laterals	360	LF	$95.00	$34,200.00
Replace Pavement (One 12' Lane x 1300')	1740	SY	$75.00	$130,500.00
Site Restoration	1	LS	$10,000.00	$10,000.00
De-Mobilization	1	LS	$10,000.00	$10,000.00
Sub-Total	-----	-----	-----	$569,300.00
Contingency	30%	-----	-----	$170,790.00
Sub-Total	-----	-----	-----	$740,090.00
Engineering	15%	-----	-----	$111,013.50
Overall Total	**-----**	**-----**	**-----**	**$851,103.50**

Table 14: Estimated Cost for New Storm Sewer System along Auden (Assumes New System along University)

Item Description	Quantity	Unit of Measurement	Unit Price	Cost
Mobilization	1	LS	$25,000.00	$25,000.00
Site Preparation	1	LS	$25,000.00	$25,000.00
Remove Pavement (One 12' Lane x 2850')	3800	SY	$15.00	$57,000.00
Remove Existing Pipe, All Sizes	2600	LF	$10.00	$26,000.00
Install 24" Reinforced Concrete Pipe	350	LF	$95.00	$33,250.00
Install 30" Reinforced Concrete Pipe	350	LF	$120.00	$42,000.00
Install 36" Reinforced Concrete Pipe	350	LF	$160.00	$56,000.00
Install 42" Reinforced Concrete Pipe	350	LF	$180.00	$63,000.00
Install 48" Reinforced Concrete Pipe	350	LF	$210.00	$73,500.00
Install 54" Reinforced Concrete Pipe	350	LF	$270.00	$94,500.00
Install 60" Reinforced Concrete Pipe	750	LF	$295.00	$221,250.00
Remove & Replace Existing Curb Inlets	26	EA	$3,500.00	$91,000.00
Remove & Replace Existing Manholes	9	EA	$5,000.00	$45,000.00
Remove & Replace 24" Storm Sewer Laterals	390	LF	$95.00	$37,050.00
Replace Pavement (One 12' Lane x 3200')	3800	SY	$75.00	$285,000.00
Site Restoration	1	LS	$25,000.00	$25,000.00
De-Mobilization	1	LS	$25,000.00	$25,000.00
Sub-Total	-----	-----	-----	$1,224,550.00
Contingency	30%	-----	-----	$367,365.00
Sub-Total	-----	-----	-----	$1,591,915.00
Engineering	15%	-----	-----	$238,787.25
Overall Total	**-----**	**-----**	**-----**	**$1,830,702.25**

COMPARISON OF ALTERNATIVES

Table 15 provides a brief comparison of the alternatives evaluated in connection with the analysis described in this letter report, which include the following.

1. Improve the existing shared storm sewer system along the West U / Southside Place corporate boundary in place to provide 2-year capacity. This alternative assumes that a contractor will remove the existing storm sewer pipe and replace it along the existing pipe alignment.
2. Construct a new storm sewer along Auden Street with approximately 11.23 acres in West University Place included in the system drainage area. Design for 5-year capacity to match the level of service provided by the existing shared system with reduced drainage area.
3. Construct a new storm sewer along University Boulevard to convey flow from the 11.23-acre mentioned above plus an additional 7.37 acres along University to an outfall at Poor Farm Ditch. Construct a separate system along Auden Street to convey flow from Southside Place only.

The results briefly summarized in Table 15 indicate that the second alternative, involving a parallel system along Auden Street with inflow from 11.23 acres from West University Place, has the second-lowest cost but represents the most cost-effective option because it provides a greater level of service for the areas it would serve.

Table 15: Comparison of Estimates Costs for the Various Alternatives

Description of Alternative	Level of Service	Estimated Cost
Improve Existing Shared Storm Sewer Along Existing Alignment	2-Year	$3,565,201.25
Construct Parallel System Along Auden Street Draining 11.23 Acres in West U	5-Year	$2,787,128.50
Construct Parallel System Along Auden Plus Separate System Along University	2-Year	$2,681,805.75

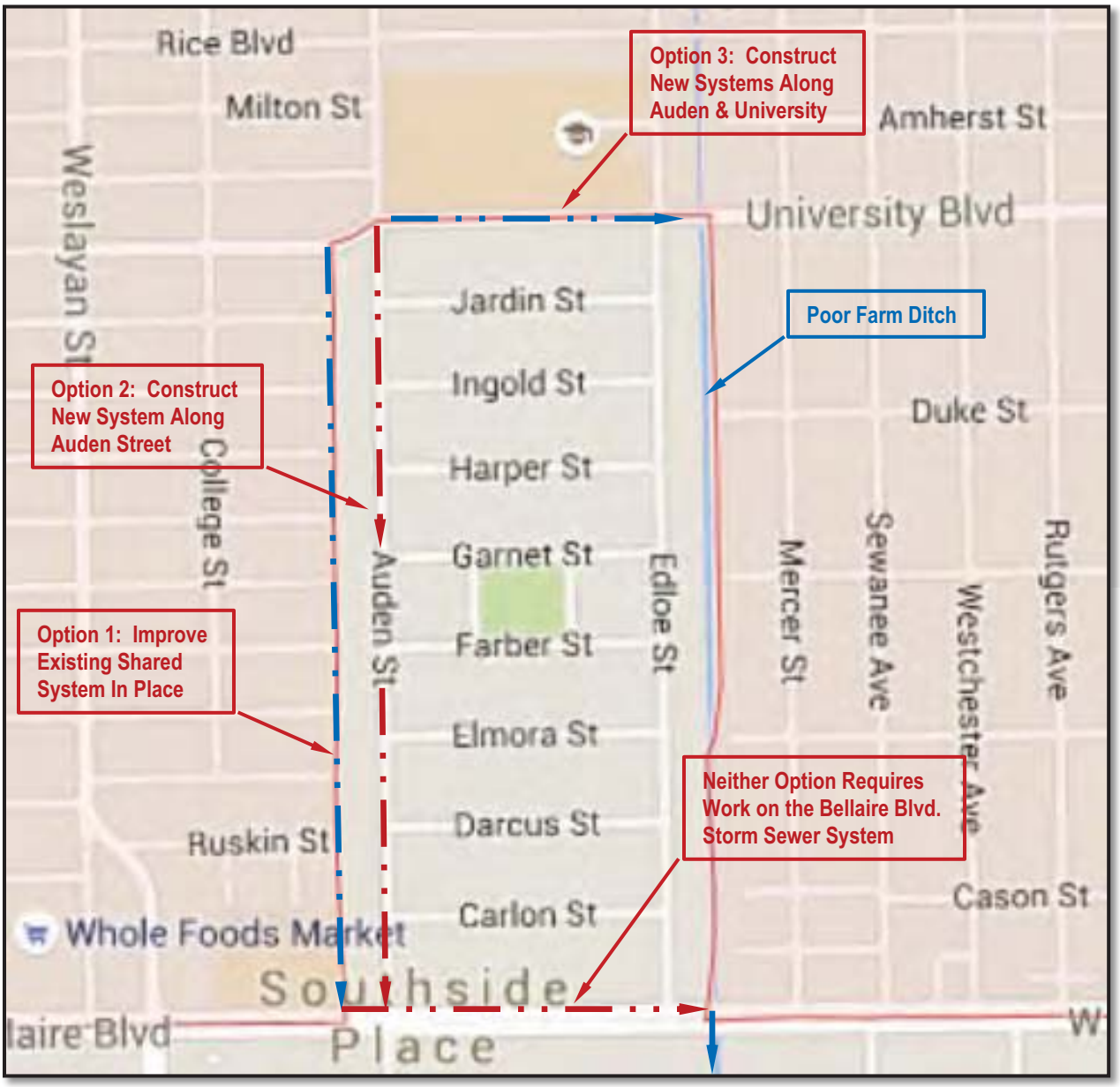


Figure 7: Improvement Alternatives

IMPACT & DETENTION CONSIDERATIONS

When planning development and drainage improvements in Harris County and the Greater Houston area, care must be taken to evaluate the potential for impacts on flood flow rates and flood elevations in downstream areas. The major reasons for requiring detention in connection with development, storm sewer improvements, and related roadway improvements is that impervious cover and runoff volume are increased, storm water is evacuated more efficiently via improved drainage systems, and streets are typically graded to provide more efficient surface flow to outfall channels. In the case of the improvements considered in this report, the following observations may be made.

1. The project area is already developed, and no increase in impervious cover is proposed. Therefore, runoff volumes will not be increased. Storm sewer systems are already in place, and thus the timing of flows to Poor Farm Ditch and Brays Bayou will not be significantly altered.

2. With the exception of the relatively small storm sewer that would be constructed along University Drive under Option 3, the storm sewer systems identified for possible improvement tie into existing storm sewers along Bellaire Boulevard with capacity to accommodate runoff from only a 2-year storm event. Those downstream systems will tend to regulate discharges from the improved systems and limit the potential for downstream impacts under more severe events. Out of bank flooding along Brays Bayou generally does not occur or is very limited within the project area during storms less severe than the 10-year event.

3. Re-grading of streets will be limited only to Auden (no re-grading of existing dead-end streets in West University Place is proposed), and top of pavement elevations along Auden are low enough that high water elevations in Brays Bayou and Poor Farm Ditch will limit the flow-carrying capacity of the street. In addition, opportunities for significant re-grading will be limited by existing development along the road. Therefore, no significant increase in flow-carrying capacity is anticipated.

4. Brays Bayou top of bank elevations at Buffalo Speedway and Stella Link Road (which bracket the project area to the east and west) range from about 48 feet to 49 feet. Top of bank elevations between those roadways range from about 45 feet to 48 feet. Information from the Flood Insurance Study for Harris County, Texas indicates that Brays Bayou flood elevations reach the following levels at various key points near the project area.

   - **Poor Farm Ditch**: 43.7', 46.0', and 48.3' for 10-year, 50-year, and 100-year events, respectively;
   - **Buffalo Speedway**: 44.3', 46.7', 49.0' for 10-year, 50-year, and 100-year events, respectively;
   - **Stella Link Road**: 45.5', 47.5', and 49.6' for 10-year, 50-year, and 100-year events, respectively.

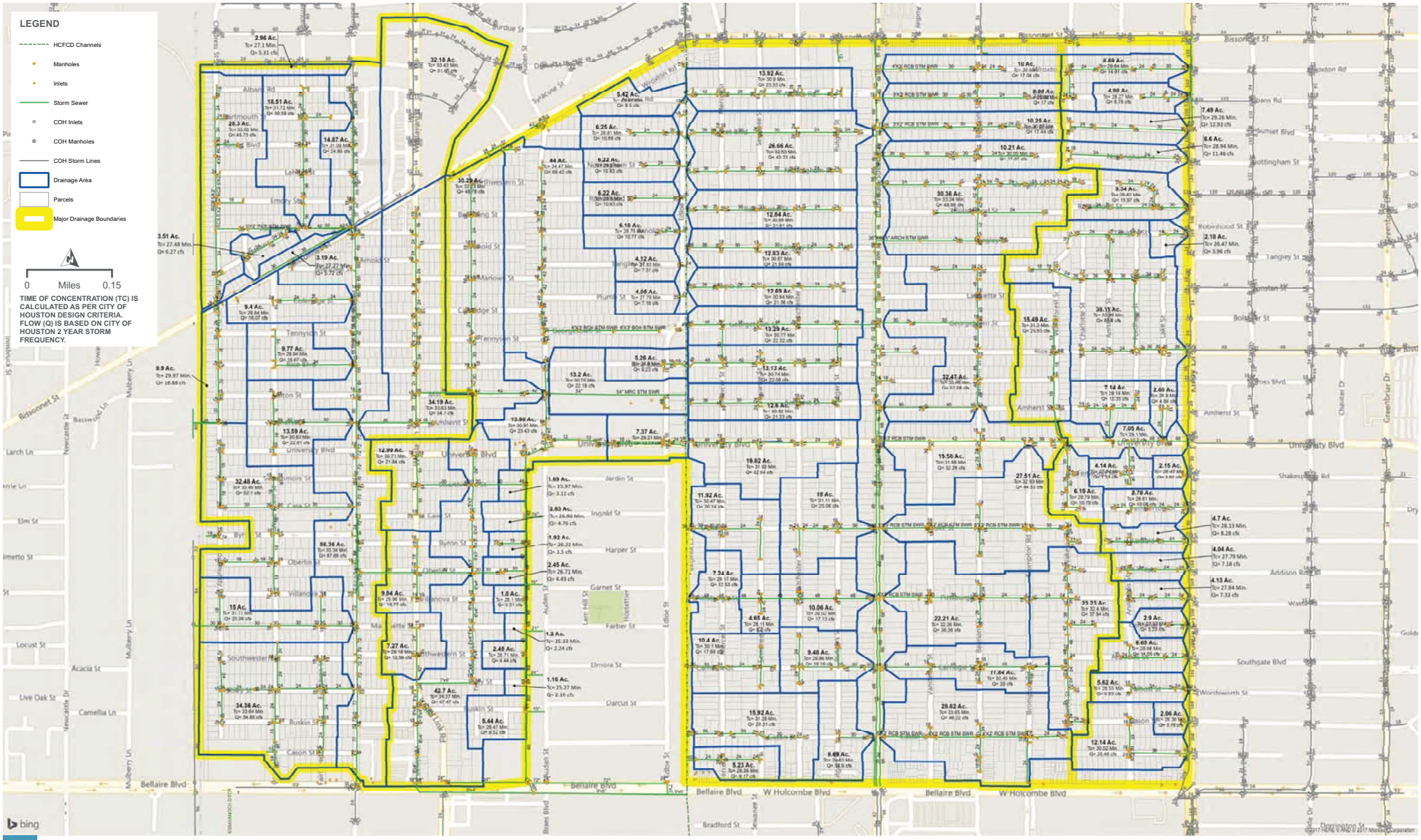
   The dead-end streets within West University Place experience substantial ponding at elevations of 48 feet and higher, and Auden Street experiences substantial ponding at elevations of 47 feet and higher. Even if the ongoing Project Brays improvements reduce flood elevations in the area, flooding will not be eliminated, and flood elevations will likely still be high during severe events. Under those conditions, tailwater in Brays Bayou and Poor Farm Ditch will still be high enough to affect drainage from the project area during events more severe than the 10-year. With backwater from Brays Bayou and Poor Farm Ditch, discharges from the storm sewer systems analyzed in connection with this report will be restricted.

Given these observations and considerations, it appears that the storm improvements described above will provide improved drainage during smaller events (generally less than the 10-year), but will not operate as efficiently during 10-year and greater events. Thus, the potential for impacts on downstream flow rates and flood levels will be limited during 10-year and greater events by conditions along Brays Bayou and Poor Farm Ditch. Since the 10-year event is generally considered to represent the "threshold" for flooding along Brays Bayou, increases in drainage efficiency for lesser storm events do not represent a significant risk in terms of increased flooding. For these reasons, detention is not recommended in connection with the

improvements described in this report. Note, however, that if any of the mitigating circumstances described above should change, the detention issue should be revisited.

CONCLUSION

The existing shared storm sewer system along the corporate boundary between the Cities of West University Place and Southside Place lacks capacity to accommodate a standard 2-year design storm event. Improvements to the existing system will be expensive and disruptive to local residents of both cities. Construction of a new parallel system along Auden Street within Southside Place offers a very reasonable alternative for reducing the flow to the existing shared system and providing capacity ranging from 2-year to 5-year depending on whether drainage from West University Place flows to the Auden Street system. An alternative that includes a new system along Auden plus a new storm sewer along University Boulevard would provide 2-year capacity at a total cost consistent with that of a single 5-year-capacity system along Auden that accepts storm runoff from an area of approximately 11.17 acres within West University Place. Both of the alternatives involving a new system along Auden provide greater benefit at lower cost than replacing the existing shared system with larger storm sewer along the existing alignment. HDR recommends that an alternative involving a new system along Auden be evaluated very seriously by the City of West University Place in cooperation with the City of Southside Place.



CITY OF WEST UNIVERSITY PLACE, TEXAS

DRAINAGE AREA MAP

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