Henderson Road Improvement Project

Business 288 to SH 35

Drainage Study

Angleton, TX

February 9, 2022

STATE OF TEXAS
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1 Executive Summary

The City of Angleton is currently evaluating improvements to safety and mobility (pedestrians and vehicles) based on expected growth along the Henderson Road corridor from State Highway 288B to State Highway 35. On June 22, 2021, HDR Engineering, Inc. (HDR) completed the Henderson Road Traffic Study for this area that identified future traffic loading and required improvements to mobility and safety in the area. In order to accomplish these identified improvements, the existing open, roadside ditch (Henderson Ditch) adjacent to the existing Henderson Road, which accepts runoff from a large portion of the roadway and external drainage areas, must be enclosed along the full project length to provide sufficient room for a boulevard section with sidewalks. The project extent is shown in Figure 1, and the existing system is shown in Figure 2.

Figure 1. Project Extent

Approximately 271 acres drains to Henderson Road and outfalls at Brushy Bayou. Existing and proposed conditions models were created to identify any potential impact to upstream or downstream areas. For existing conditions, peak runoff rates were determined using the Rational Method. Using HEC-HMS, hydrographs were generated at key locations. Through the Angleton ISD property, Henderson Ditch enters dual 60” RCPs. To account for storage within Henderson Ditch and the dual RCPs, the HEC-HMS hydrographs were input into an XP-SWMM model, which produced a hydrograph at the drainage system outfall that more accurately represents routing of the flow through the existing system.

Figure 2. Existing Drainage System

For the proposed conditions, the HEC-HMS model was updated with the proposed roadway improvements and modified times of concentration, and the entire system was modeled within XP-SWMM. Storm sewer segments were designed to fully contain the 100-year storm event while maintaining a velocity between 3 fps and 10 fps while flowing full. The proposed storm sewer sizing is shown in Figure 3.

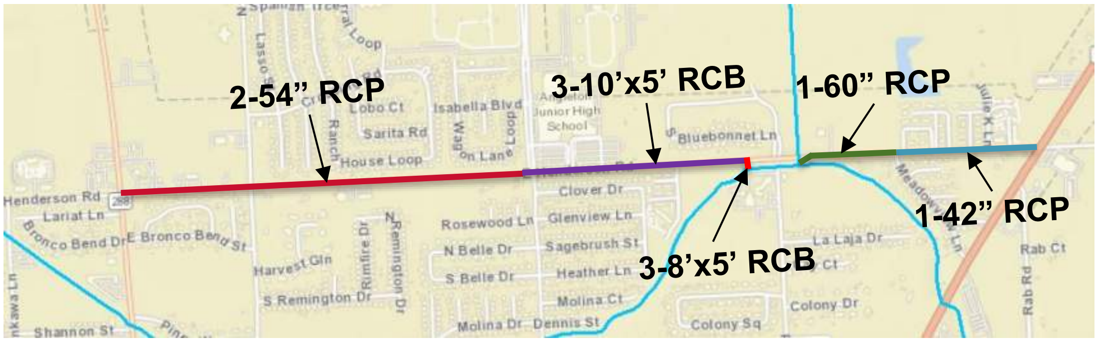


Figure 3. Proposed Storm Sewer System

The Angleton Drainage District (ADD) has been performing improvements along Brushy Bayou which have improved its capacity and conveyance which could potentially accommodate increases in peak discharge from Henderson Road. However, HDR was unable to verify the amount of storage or flow capacity available in Brushy Bayou using the available HEC-2 models of that stream. As a result, the hydrographs from each outfall were compared between existing and proposed conditions to determine the volume of storage required to accommodate project impacts. This analysis indicated a total of 45.3 acre-feet of detention would need to be provided either within the channel of Brushy Bayou, a new regional detention pond, or the detention pond near Rabb Road.

A planning level opinion of probable construction cost was developed for the proposed storm sewer system and a detention pond. The total project cost, including the detention pond, is $15.6 million.

2 Background Information

2.1 Project Site Information

The existing Henderson Road is a two-lane roadway with intermittent center turning lane. Council has provided direction to HDR that the proposed section will be a four-lane boulevard section with turn lanes as outlined in the Henderson Traffic Study. The proposed location of this section will be between Business 288 (North Velasco Street) and State Highway 35 (East Mulberry Street) (see Exhibit 1). Most of the runoff draining to Henderson Road is conveyed via a large drainage channel (Henderson Ditch) immediately north of and parallel to the roadway. Figure 4 shows a view of Henderson Ditch looking west. Currently, storm sewer exists along the Angleton ISD property. Survey indicates dual 60-inch RCP through the school property. Drainage into the Henderson Ditch ultimately is conveyed eastward, emptying into Brushy Bayou via existing dual 8'x5' box culverts (Figure 5, left) west of Buchta Road. The existing system is shown in Exhibit 3.

Figure 4. Henderson Ditch

Rancho Ditch is a tributary of Brushy Bayou. Rancho Ditch outfalls into Brushy Bayou via dual 12’x8’ RCBs at Henderson Road (Figure 5, center). This culvert crossing is located east of Buchta Road. East of Rancho Ditch, smaller (as compared to Henderson Ditch) roadside ditches convey runoff from Henderson Road to a 48-inch RCP which also outfalls to Brushy Bayou (Figure 5, right).

Figure 5. Henderson Road Outfalls into Brushy Bayou (west to east)

2.2 Available Data

The following information was readily available for use in this analysis:

- Survey data (Baker & Lawson, Inc., 2021)
- Windrose Green Drainage Impact Analysis HEC-HMS and HEC-RAS models for Rancho Ditch (Costello, 2020)
- Aerial imagery (H-GAC, 2020)
- LiDAR elevation data (TNRIS, 2018)
- Angleton Sub-Regional Detention H&H Analysis Report (HDR, 2013)

- Final Brazoria County Drainage Criteria Manual (Klotz, 2003)
- Final Brazoria County Master Drainage Plan Report (Klotz, 2002)
- HEC-1 and HEC-2 Models for Brushy Bayou (Klotz, 2002)

2.3 Drainage Design Criteria

In general, the roadway improvement impacts were analyzed in accordance with the Brazoria County Drainage Criteria Manual (BCDCM), dated November 2003, with several exceptions indicated in this report. Most notably, the rainfall depths used in this analysis were obtained from NOAA Atlas 14. In instances where the procedures within the BCDCM did not apply, Harris County Flood Control District criteria was followed. In general, application of the Harris County Flood Control District criteria results in a more conservative design.

3 Existing Conditions

3.1 Hydrologic Parameters

The BCDCM indicates the Rational Method is applicable for drainage areas less than 100 acres. The Rational Method utilizes the following equation to generate peak runoff rates:

$$Q = C * i * A * C_f$$

Where: Q = the peak runoff rate in cubic feet per second (cfs);

C = the runoff coefficient

i = the rainfall intensity in inches per hour (in/hr);

A = the drainage area in acres (ac)

C_f = the frequency factor adjustment (1.25 for 100-yr event)

Drainage areas were delineated using LiDAR elevation data. A total of 12 sub-watersheds were delineated along Henderson Road. A drainage area map is shown below in Figure 6 and Exhibit 2.

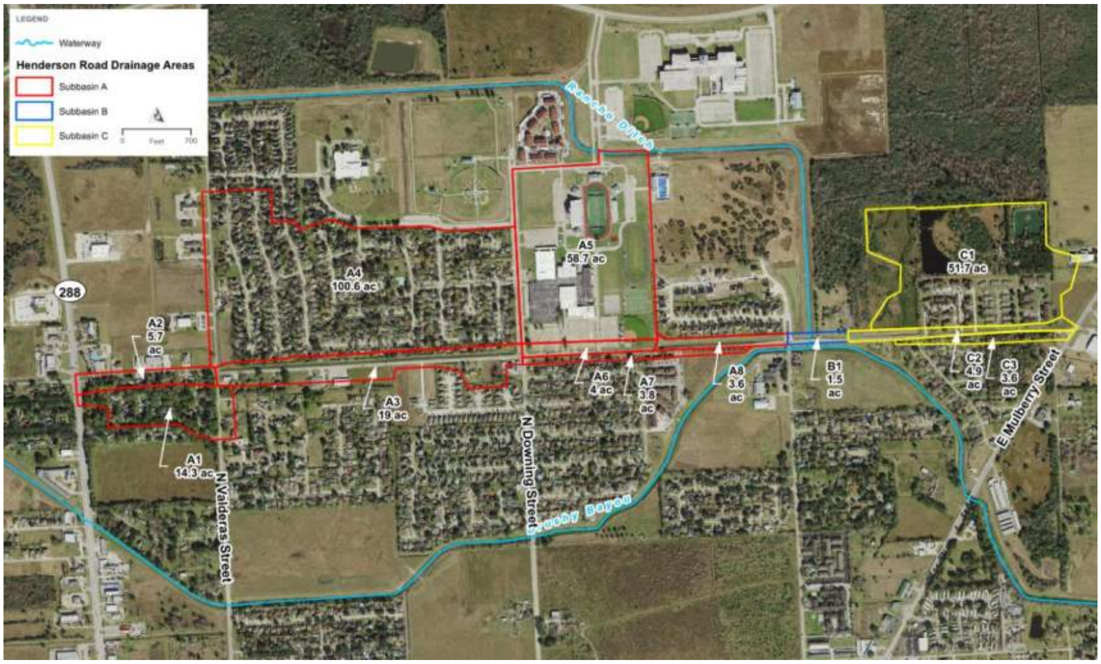


Figure 6. Project Drainage Areas

The BCDCM indicates Clark's unit hydrograph should be used in calculating peak discharge. The Clark's unit hydrograph is described by the Tc and R parameters. Due to the small size of the drainage areas, which was required to accurately determine roadway improvement impacts and analyze peak discharge values at key locations, calculation of Tc and R using watershed parameters described in the BCDCM was not appropriate. The BCDCM recommends using parameters such as longest flow path, channel slope and percent land urbanization. Because nearly all the project drainage areas are less than 100 acres and currently developed, and because the parameters do not include a velocity component, they are not well-suited in demonstrating impacts due to roadway improvements. Therefore, Tc was calculated using NRCS Upland Methodology which divides the longest flow path into segments of overland flow, shallow concentrated flow, roadside ditch flow, and storm sewer flow. The storage coefficient (R) was initially set at three times Tc. A tabulation of key parameters is shown in Appendix A.

Using the computed Tc values, rainfall intensities were determined based on NOAA Atlas 14 data, as specified in the scope of work for this project. The final parameter required to calculate peak discharge, C, was determined using aerial imagery, Table 2-3: Rational Method Runoff Coefficients from the BCDCM, and additional runoff coefficients for other land use descriptions consistent with the Windrose Green Drainage Impact Analysis. A frequency factor adjustment, C_f, of 1.25 was applied to the 100-year peak discharge, per BCDCM guidance.

3.2 HEC-HMS Model

A hydrologic model of the watershed drainage to Henderson Road was developed using HEC-HMS version 4.0 (consistent with the Windrose Green Drainage Impact Analysis). As with the Windrose Green and the Brushy Bayou LOMR hydrologic models, the Initial & Constant Loss Method was used to account for rainfall infiltration losses. The percent impervious value for each sub-watershed was determined using aerial imagery and Table 2-2: Typical Average Values for Impervious Cover from the BCDCM.

After an initial simulation, the storage coefficient (R) for each drainage sub-watershed was iterated such that the peak flow rate computed with the HEC-HMS model matched the peak flow rate computed using the Rational Method. The results are shown in Table 1.

Table 1. Existing Conditions HEC-HMS Model Results

Sub-Basin	Drainage Area (acres)	Peak Discharge (cfs)		
		2-Year	10-Year	100-Year
A1	14.3	21.6	30.3	57.2
A2	5.7	12.1	17.0	32.0
A3	19.0	27.7	38.7	72.4
A4	100.6	201.7	281.9	527.8
A5	58.7	92.1	129.9	247.4
A6	4.0	14.2	20.2	38.6
A7	3.8	3.7	5.2	9.9
A8	3.6	7.7	10.9	20.7
Combined Discharge at West Outfall to Brushy Bayou		300.1	443.0	829.3
B1 (Outfall to Rancho Ditch)	1.5	4.3	6.2	11.9
C1	51.7	40.8	57.6	109.3
C2	4.9	6.5	9.1	17.1
C3	3.6	5.3	7.4	14.0
Combined Discharge at East Outfall to Brushy Bayou		51.3	72.7	137.3
Combined Discharge at Brushy Bayou		**351.4**	**515.8**	**962.3**

3.3 XP-SWMM Model

In order to assess the adequacy of the existing Henderson Ditch and storm sewer system through the Angleton ISD property, a 1D hydraulic model was developed using 2019 XP-SWMM. This model was also created to appropriately compare impacts for the proposed enclosed system. The hydrographs generated from the HEC-HMS model were input into the XP-SWMM model which was used to evaluate the storage within the existing Henderson Ditch and within the storm sewer along the Angleton ISD property.

For the existing conditions, the XP-SWMM model only contained the segment of Henderson Ditch that discharges to the west outfall (sub-basins with A designations in the table above). The segments east of Buchta Road were not modeled in XP-SWMM for the existing conditions as they did not contain storm sewer. Additionally, the roadside ditches for those segments are shallower and narrower, and therefore significantly less storage is provided.

Survey data collected by Baker & Lawson, Inc. was utilized to determine the ditch invert elevations along Henderson Ditch between N Valderas Street and Buchta Road. Survey data was also used to determine the top of bank elevation and culvert geometry. HEC-HMS hydrographs were inserted into the XP-SWMM model at strategic locations. The downstream boundary condition conservatively set the water surface elevation at the top of the box culvert inverts which assumes water elevations in Brushy Bayou would submerge the outfall. The results are shown in Table 2.

Table 2. Existing Conditions XP-SWMM Model for Henderson Ditch

Storm Event	Peak Discharge (cfs) at West Outfall to Brushy Bayou
2-Year	282.0
10-Year	386.3
100-Year	567.5*
* Storage capacity within Henderson Ditch is exceeded. Some level of street flooding is anticipated.	

As compared to Table 1, the peak discharges in Table 2 account for the available storage within the Henderson Ditch and storm sewer system. As a result, peak discharges in Table 2 are lower than the corresponding values in Table 1. However, during the 100-year event, the XP-SWMM model indicates that the Angleton ISD storm sewer causes runoff to backup into Henderson Ditch between N Valderas Street and N Downing Street. This causes water to exceed the top of bank through this segment.

4 Proposed Conditions

4.1 HEC-HMS Model

The proposed condition assumes the existing Henderson roadway will be replaced with a four-lane divided boulevard. In order to accommodate the widened roadway, Henderson Ditch will become an enclosed storm sewer system along the full length of the project. The existing watershed parameters were modified to add additional impervious area for the expanded roadway. Times of concentration for impacted sub-watersheds were updated to account for the proposed storm sewer system.

A comparison of existing and proposed peak flow rates, determined using the Rational Method, is shown in Table 3.

Table 3. HEC-HMS Existing and Proposed Peak Discharges

Sub-Basin	Peak Discharge (cfs)					
	Existing Conditions			Proposed Conditions		
	2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
A1*	21.6	30.3	57.2	21.6	30.3	57.2
A2	12.1	17.0	32.0	18.2	25.5	48.5
A3	27.7	38.7	72.4	37.3	52.1	97.9
A4*	201.7	281.9	527.8	201.7	281.9	527.8
A5*	92.1	129.9	247.4	92.1	129.9	247.4
A6	14.2	20.2	38.6	17.9	25.3	44.9
A7*	3.7	5.2	9.9	3.7	5.2	9.9
A8	7.7	10.9	20.7	11.7	16.5	31.5
B1	4.3	6.2	11.9	6.2	9.8	15.1
C1*	40.8	57.6	109.3	40.8	57.5	109.4
C2	6.5	9.1	17.1	10.5	14.8	27.8
C3*	5.3	7.4	14.0	5.3	7.4	14.0

* Off-site drainage areas are not impacted by the proposed roadway improvement. Therefore, proposed peak discharges match existing conditions.

In order to account for the routing through the proposed storm sewer, the hydrographs from HEC-HMS were used as inputs into an XP-SWMM model. The subsequent sections of this report describe the design assumptions and methodology used in developing the proposed condition XP-SWMM model.

4.2 Design Parameters and Assumptions

A preliminary design of Henderson Road is not available. Therefore, several assumptions were made regarding the future roadway expansion.

- HDR assumed the expansion would add additional lanes and a median to convert the roadway into a boulevard. As a result, the roadway coverage along the project length would approximately be doubled.
- HDR assumed two segments of storm sewer would be constructed.
  - The first segment would be constructed between N Valderas Street and Buchta Road. This would fully replace the roadside ditches and involve upsizing the storm sewer within the Angleton ISD property, as necessary. This segment would outfall at the existing box culverts west of Buchta Road.
  - The second segment would be constructed between E Mulberry Street and Rancho Ditch. The segment would outfall into Brushy Bayou adjacent to the Rancho Ditch outfall.
- The storm sewer should be sized to contain the 100-year storm event for proposed conditions.
- HDR assumed the outfall elevation would be elevation 14.0 feet at the Rancho Ditch outfall into Brushy Bayou, consistent with the downstream invert elevation of the 12’x8’ box culverts.
- HDR assumed the outfall elevation would be elevation 14.5 feet at the outfall west of Buchta Road. This is lower than the existing 8’x5’ RCBs. The elevation was set 0.5’ higher than the outfall at Rancho Ditch to conservatively account for this outfall being further upstream along Brushy Bayou.
- Velocity is maintained between 3 fps and 10 fps in the storm sewer while flowing full, according to the City of Sugar Land drainage criteria.
- Cover above the pipes is a minimum of 2.5 feet, assuming the existing roadway elevations are maintained.

4.3 XP-SWMM Model

The XP-SWMM model was updated with a storm sewer system in lieu of Henderson Ditch. The storm sewer was designed using the parameters and assumptions described above. The proposed sewer system that meets the requirement of fully containing the 100-year storm event is shown in Exhibit 4. The proposed storm sewer ranges in size between 42” RCP and triple 10’ x 5’ reinforced concrete boxes that replace the west outfall at Brushy Bayou.

Table 4 summarizes the existing and proposed peak discharges from the proposed two outfalls.

Table 4. Summary of Peak Discharges

Outfall	Peak Discharge (cfs)								
	2-Year			10-Year			100-Year		
	Exist.	Prop.	Diff.	Exist.	Prop.	Diff.	Exist.	Prop.	Diff.
West Outfall	282.0	364.2	+82.2	386.3	515.8	+129.5	567.5	957.5	+390
East Outfall	52.3	53.5	+1.2	74.5	76.7	+2.2	140.0	142.9	+2.9

5 Mitigation Alternatives

HDR has compared the 100-year peak hydrographs between existing and proposed conditions to evaluate the required detention to accommodate increases in runoff. The existing and proposed hydrographs are provided in Appendix B. Table 5 summarizes the required detention determined by comparing the hydrographs.

Table 5. Required Detention Storage

Outfall	Required Storage (Acre-feet)
West Outfall (Near Buchta Road)	44.5
East Outfall (Rancho Bayou)	0.8
Total	**45.3**

As shown in Table 5, approximately 45.3 acre-feet of detention is required to accommodate project impacts. The ADD has been performing improvements along Brushy Bayou which have improved its capacity and conveyance which could potentially accommodate increases in peak discharge from Henderson Road. Additionally, the ADD has purchased land for a regional detention pond along Brushy Bayou near Rabb Road. If Brushy Bayou and/or the proposed detention pond near Rabb Road do not have sufficient available storage to accommodate this volume, this storage could be provided within on-site detention ponds for future development. Alternatively, a larger regional detention pond could be constructed to accommodate the balance between the available storage within Brushy Bayou and the full 45.3 acre-feet.

There is limited available space for a detention pond. However, as sub-watershed C1 is not fully developed, this area would present the best site for a regional detention pond. Sub-watershed C1 can be found in Figure 6 and in Exhibit 2.

6 Opinion of Probable Construction Cost

An opinion of probable construction cost (OPCC) for the proposed storm sewer system was developed. Although the Angleton Drainage District indicated detention storage was available within Brushy Bayou or potential at the detention pond near Rabb Road, HDR provided a high-level cost estimate for a regional detention facility. Unit prices were determined using TxDOT Statewide average prices. The cost estimate is summarized below in Table 6. This estimate does not include the cost of the roadway improvement. A detailed cost estimate is provided in Appendix C.

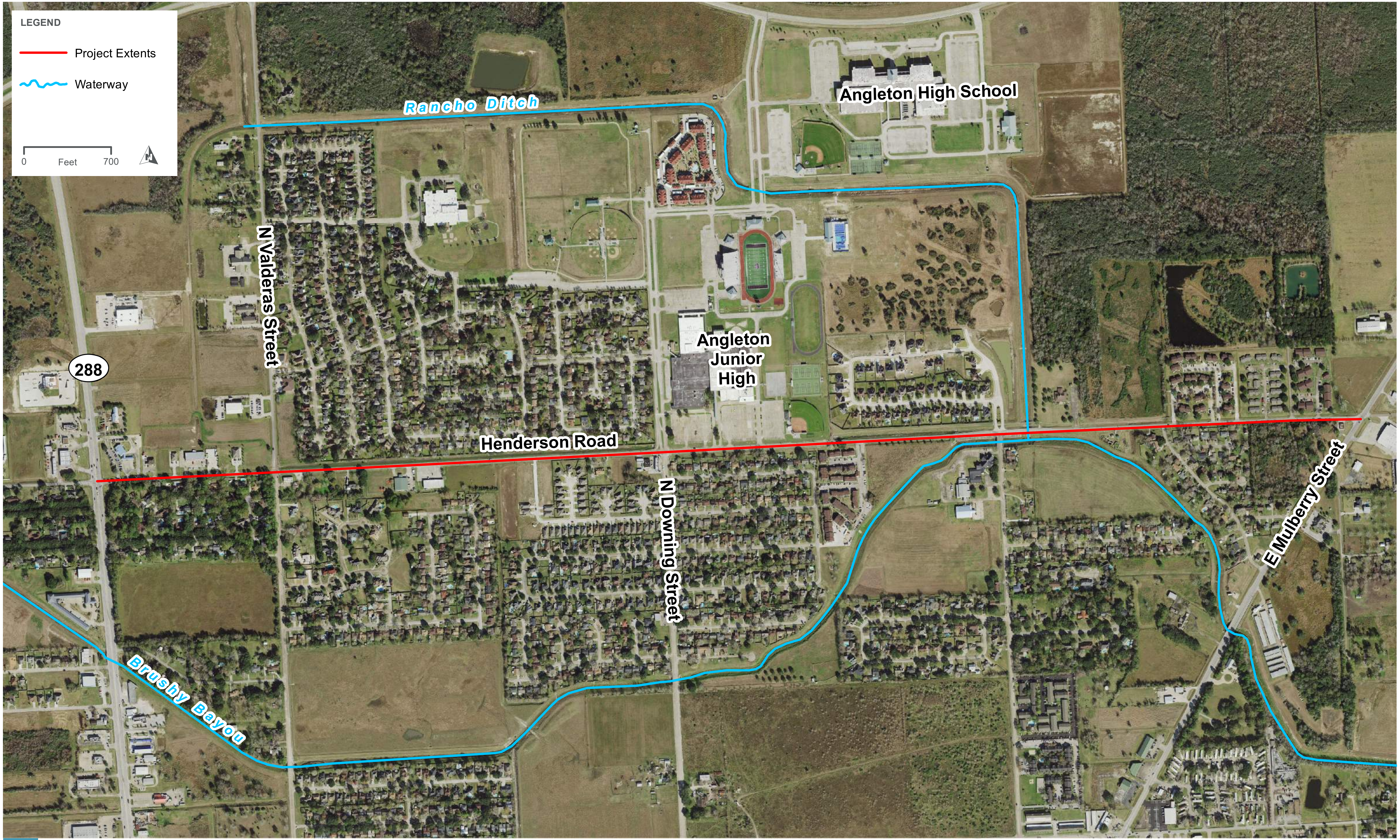
Table 6. Opinion of Probable Construction Cost

	Cost
Storm Sewer System	$13,298,904
Detention Pond (Optional)	$2,256,450
Total	**$15,555,354**

7 Conclusion

As part of the future roadway improvement project along Henderson Road, the large, existing roadside ditch (Henderson Ditch) will be converted from an open ditch to an enclosed storm sewer system, capable of fully containing the 100-year storm event for fully developed watershed conditions. The storm sewer system required to fully contain this storm event ranges between 42” RCP and 10’ x 5’ RCBs. The cost of the storm sewer system, not including the roadway cost, is approximately $13.3 million.

Detention is required to accommodate the roadway improvements (added impervious area and changes to the time of concentration), as well as potential future development within the watershed. Considering both items, 45.3 acre-feet of detention is required. The Angleton Drainage District has indicated storage within Brushy Bayou will be considered as the primary detention mitigation option. Additionally, there may be available storage within the detention pond near Rabb Road. However, HDR evaluated the cost of a regional detention pond within sub-watershed C1. The cost of the detention pond is approximately $2.3 million. This would result in a total project cost of approximately $15.6 million. This cost could be reduced if the City and Drainage District use storage or flow capacity within Brushy Bayou, or utilized storage within the Rabb Road detention pond.



HENDERSON ROAD IMPROVEMENT PROJECT DRAINAGE STUDY

VICINITY MAP

EXHIBIT 1

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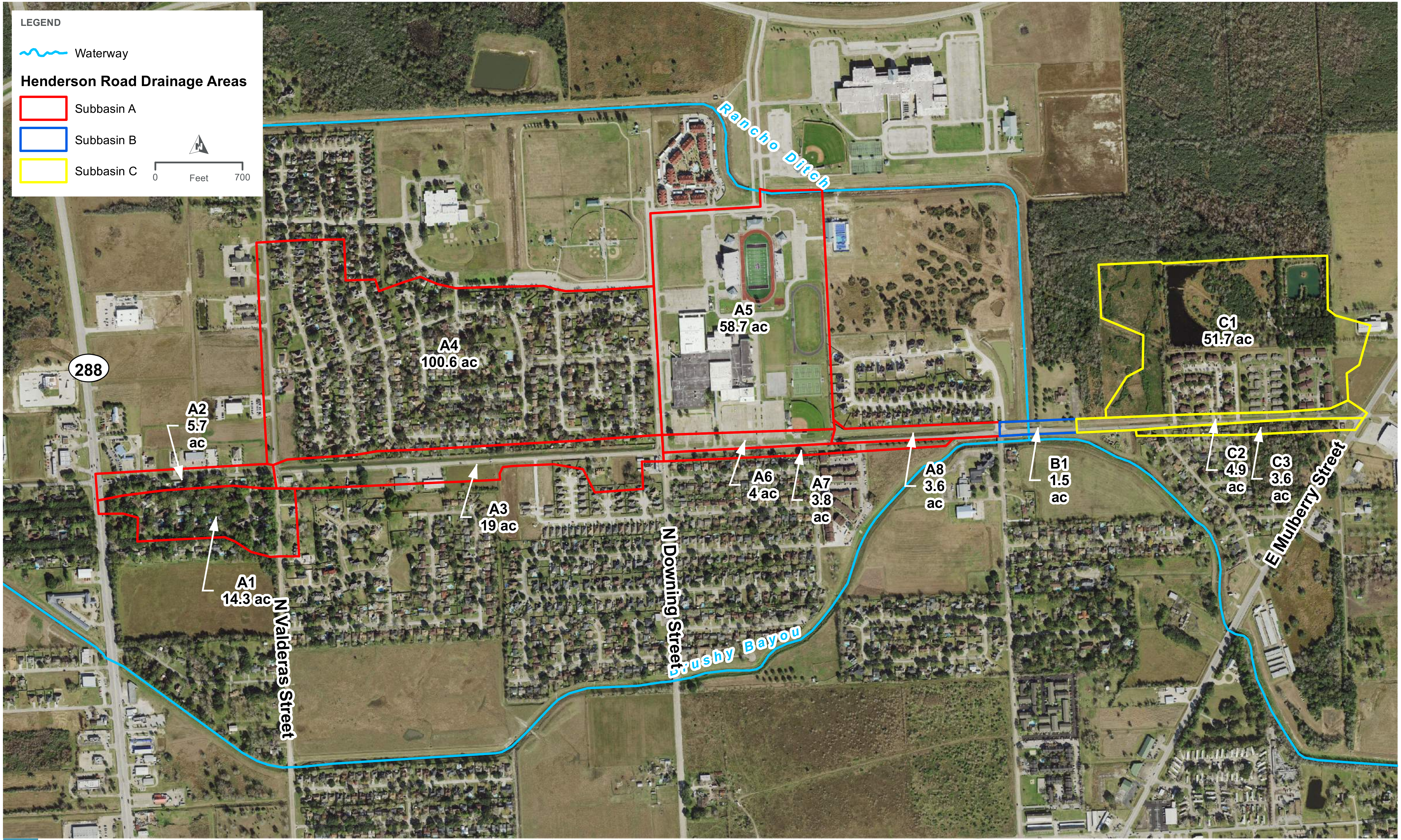

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HENDERSON ROAD IMPROVEMENT PROJECT DRAINAGE STUDY

DRAINAGE AREA MAP

EXHIBIT 2

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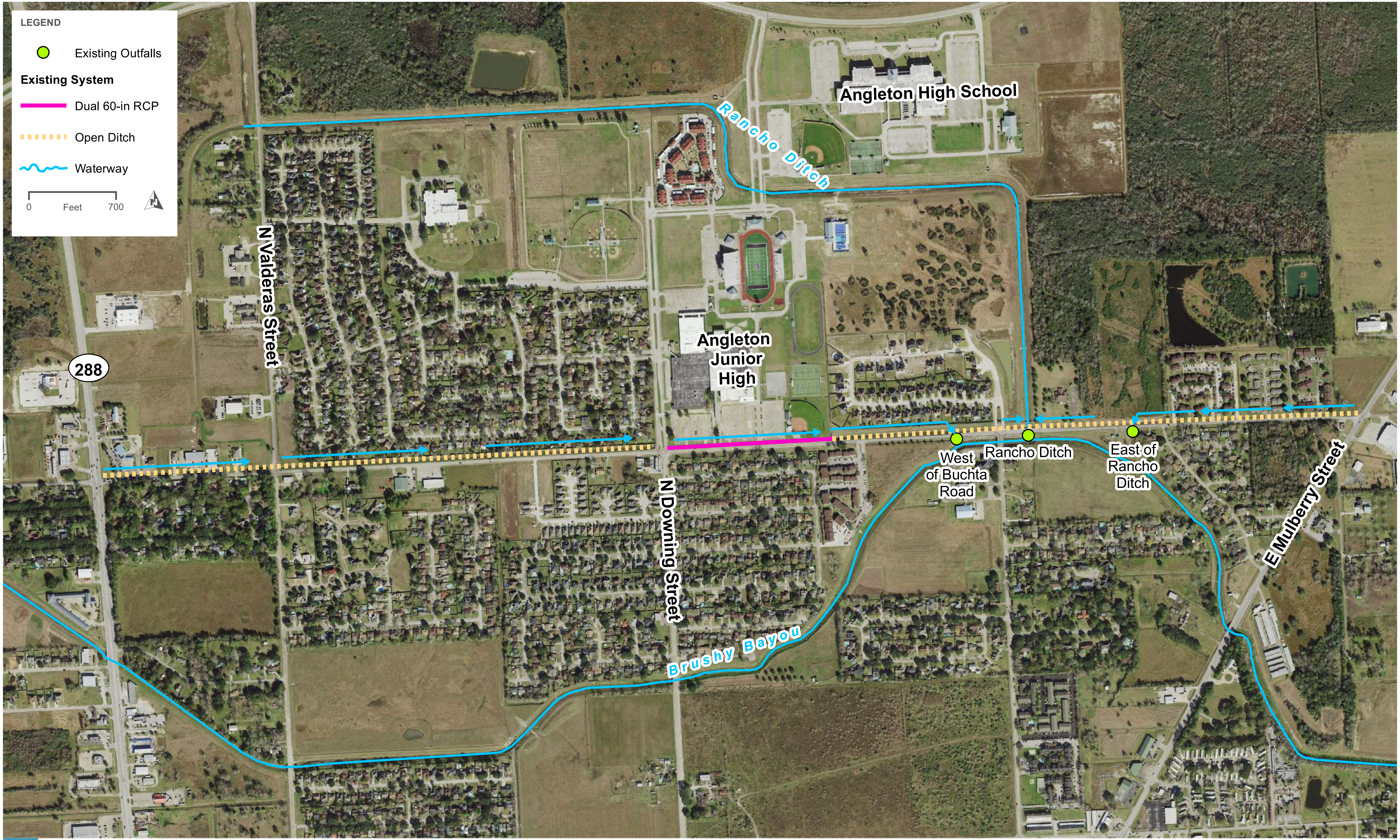

HENDERSON ROAD IMPROVEMENT PROJECT DRAINAGE STUDY

EXISTING DRAINAGE SYSTEM FEATURES

EXHIBIT 3

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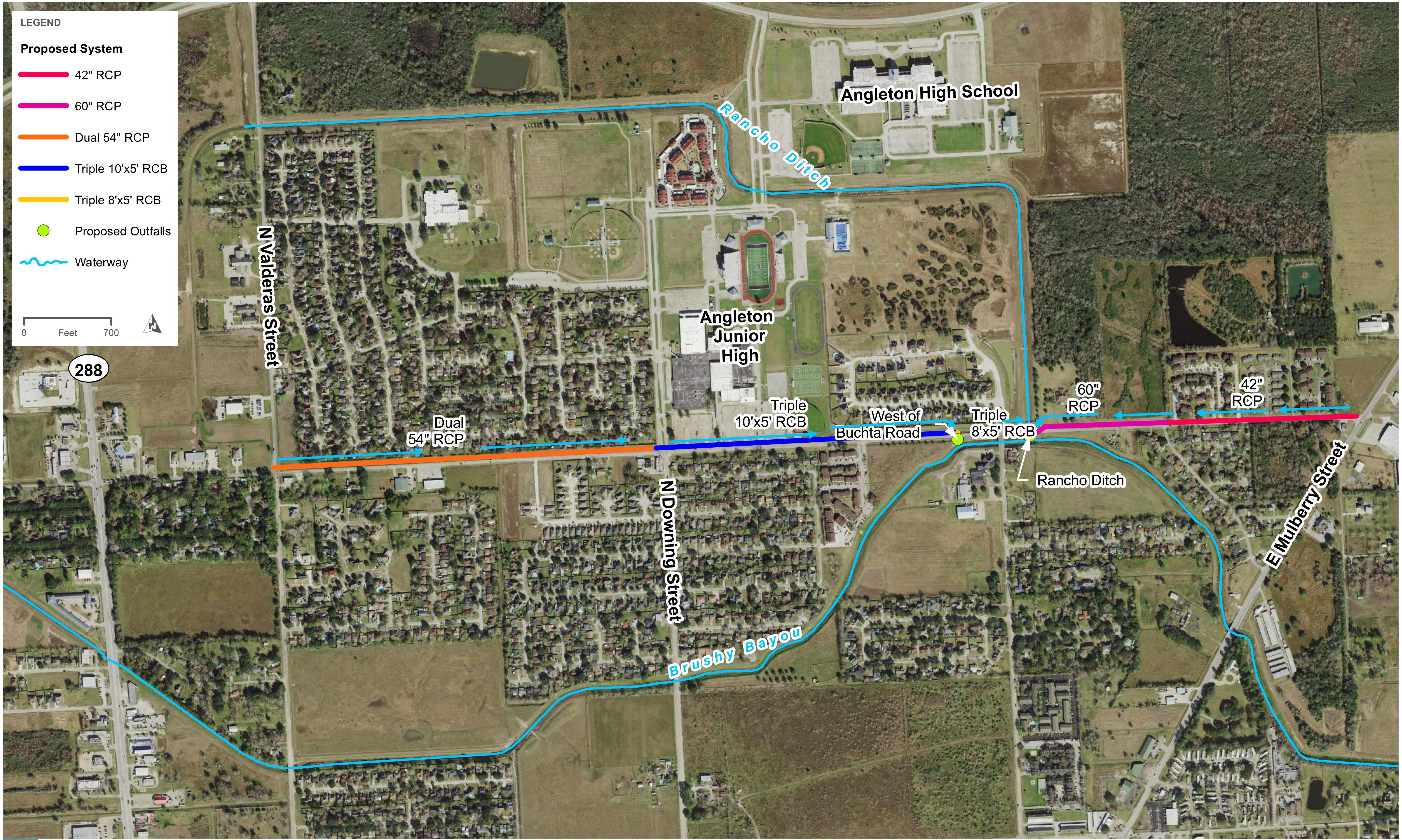

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HENDERSON ROAD IMPROVEMENT PROJECT DRAINAGE STUDY

PROPOSED DRAINAGE SYSTEM FEATURES

EXHIBIT 4

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Appendix A. Hydrologic Parameters

Drainage Study for Henderson Road Improvement Project
City of Angleton, TX

NRCS Upland Method Calculations
Existing Conditions

TIME OF CONCENTRATION CALCULATIONS USING THE NRCS UPLAND METHOD													
Sub-Area	**Units**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**B1**	**C1**	**C2**	**C3**
Basin Drainage Area													
Drainage Area	acres	14.3	5.8	19.0	100.6	58.7	4.0	3.8	3.6	1.5	51.7	4.9	3.6
Drainage Area	sq. mi.	0.022	0.009	0.030	0.157	0.092	0.006	0.006	0.006	0.002	0.081	0.008	0.006
Impervious Cover													
Description	**Imperv.**												
Undeveloped	0%	0.00	1.75	4.90	1.52	19.46	1.34	2.73	2.38	0.84	35.77	3.56	1.87
Commercial	85%					39.2	1.7						0.4
Multi-Family	85%												
Industrial	72%												
Single-Family (1/4 Ac)	38%		2.6	3.8	94.7			0.7			15.9		1.3
Single-Family (1/2 Ac)	25%	14.3		7.6									
Roadway	80%		1.4	2.7	4.4		1.0	0.4	1.2	0.7		1.3	
Impervious Area	acres	3.6	2.1	5.5	39.5	33.3	2.2	0.6	1.0	0.6	6.0	1.0	0.8
Impervious Cover	%	25.0%	36.7%	29.0%	39.3%	56.8%	55.6%	15.3%	26.8%	36.4%	11.7%	21.4%	23.4%
Runoff Coefficient C													
Description	**C**												
Undeveloped	0.20	0.00	1.75	4.90	1.52	19.46	1.34	2.73	2.38	0.84	35.77	3.56	1.87
Commercial	0.85					39.2	1.7						0.4
Multi-Family	0.65												
Industrial	0.65												
Single-Family (1/4 Ac)	0.55		2.6	3.8	94.7			0.7			15.9		1.3
Single-Family (1/2 Ac)	0.35	14.3		7.6									
Roadway	0.85		1.4	2.7	4.4		1.0	0.4	1.2	0.7		1.3	
Sum-Product		5.0	3.0	8.0	56.1	37.2	2.6	1.3	1.5	0.8	15.9	1.8	1.4
Weighted Average		0.35	0.52	0.42	0.56	0.63	0.63	0.33	0.42	0.50	0.31	0.37	0.40
Time of Concentration													
SCS Uplands Method Curve B - Overland Flow in Woodland Areas													
Distance	feet												
Slope	percent												
Velocity	ft/sec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Travel Time	minutes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCS Uplands Method Curve C - Overland Flow in Grassy Areas													
Distance	feet	100	100	100	50	100		50	100		100	100	100
Slope	percent	0.10	0.10	0.10	0.10	0.10		0.10	0.10		0.10	0.10	0.10
Velocity	ft/sec	0.22	0.22	0.22	0.22	0.22	0.00	0.22	0.22	0.00	0.22	0.22	0.22
Travel Time	minutes	7.55	7.55	7.55	3.78	7.55	0.00	3.78	7.55	0.00	7.55	7.55	7.55
SCS Uplands Method Curve F - Shallow Concentrated Flow in Grassed Waterway													
Distance	feet					1140					834		
Slope	percent					0.15					0.10		
Velocity	ft/sec	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.47	0.00	0.00
Travel Time	minutes	0.00	0.00	0.00	0.00	33.03	0.00	0.00	0.00	0.00	29.65	0.00	0.00
SCS Uplands Method Curve G - Paved Areas (Sheet Flow) and Upland Gullies													
Distance	feet				550	639	100			50	500		
Slope	percent				0.07	0.16	0.10			0.10	0.10		
Velocity	ft/sec	0.00	0.00	0.00	0.52	0.78	0.62	0.00	0.00	0.62	0.62	0.00	0.00
Travel Time	minutes	0.00	0.00	0.00	17.56	13.61	2.67	0.00	0.00	1.33	13.33	0.00	0.00
Roadside Ditch													
Distance	feet	1020	1033	1116				3272		355		1871	1674
Velocity	ft/sec	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Travel Time	minutes	11.33	11.48	12.40	0.00	0.00	0.00	36.36	0.00	3.94	0.00	20.79	18.60
Storm Sewer													
Distance	feet				1284		1433						

Notes:

TIME OF CONCENTRATION CALCULATIONS USING THE NRCS UPLAND METHOD													
Sub-Area	**Units**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**B1**	**C1**	**C2**	**C3**
Velocity	ft/sec	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Travel Time	minutes	0.00	0.00	0.00	7.13	0.00	7.96	0.00	0.00	0.00	0.00	0.00	0.00
Open Channel													
Distance	feet		400	1976					957				
Velocity	ft/sec	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Travel Time	minutes	0.00	2.22	10.98	0.00	0.00	0.00	0.00	5.32	0.00	0.00	0.00	0.00
TC	**minutes**	**18.88**	**21.25**	**30.93**	**28.47**	**54.19**	**10.63**	**40.13**	**12.87**	**10.00**	**50.54**	**28.34**	**26.15**
TC	**hours**	**0.31**	**0.35**	**0.52**	**0.47**	**0.90**	**0.18**	**0.67**	**0.21**	**0.17**	**0.84**	**0.47**	**0.44**

Notes:

If Tc<10, 10

Drainage Study for Henderson Road Improvement Project
City of Angleton, TX

NRCS Upland Method Calculations
Proposed Conditions with Existing Land Use

TIME OF CONCENTRATION CALCULATIONS USING THE NRCS UPLAND METHOD													
Sub-Area	**Units**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**B1**	**C1**	**C2**	**C3**
Basin Drainage Area													
Drainage Area	acres	14.3	5.8	19.0	100.6	58.7	4.0	3.8	3.6	1.5	51.7	4.9	3.6
Drainage Area	sq. mi.	0.022	0.009	0.030	0.157	0.092	0.006	0.006	0.006	0.002	0.081	0.008	0.006
Impervious Cover													
Description	**Imperv.**												
Undeveloped	0%	0.00	0.35	2.20	1.52	19.46	0.34	2.73	1.18	0.14	35.77	2.26	1.87
Commercial	85%					39.2	1.7						0.4
Multi-Family	85%												
Industrial	72%												
Single-Family (1/4 Ac)	38%		2.6	3.8	94.7			0.7			15.9		1.3
Single-Family (1/2 Ac)	25%	14.3		7.6									
Roadway	80%		2.8	5.4	4.4		2.0	0.4	2.4	1.4		2.6	
Impervious Area	acres	3.6	3.2	7.7	39.5	33.3	3.0	0.6	1.9	1.1	6.0	2.1	0.8
Impervious Cover	%	25.0%	56.1%	40.3%	39.3%	56.8%	75.4%	15.3%	53.6%	72.7%	11.7%	42.8%	23.4%
Runoff Coefficient C													
Description	**C**												
Undeveloped	0.20	0.00	0.35	2.20	1.52	19.46	0.34	2.73	1.18	0.14	35.77	2.26	1.87
Commercial	0.85					39.2	1.7						0.4
Multi-Family	0.65												
Industrial	0.65												
Single-Family (1/4 Ac)	0.55		2.6	3.8	94.7			0.7			15.9		1.3
Single-Family (1/2 Ac)	0.35	14.3		7.6									
Roadway	0.85		2.8	5.4	4.4		2.0	0.4	2.4	1.4		2.6	
Sum-Product		5.0	3.9	9.8	56.1	37.2	3.2	1.3	2.3	1.2	15.9	2.7	1.4
Weighted Average		0.35	0.67	0.51	0.56	0.63	0.80	0.33	0.64	0.79	0.31	0.55	0.40
Time of Concentration													
SCS Uplands Method Curve B - Overland Flow in Woodland Areas													
Distance	feet												
Slope	percent												
Velocity	ft/sec	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Travel Time	minutes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCS Uplands Method Curve C - Overland Flow in Grassy Areas													
Distance	feet	100	100	100	50	100		50	100		100	100	100
Slope	percent	0.10	0.10	0.10	0.10	0.10		0.10	0.10		0.10	0.10	0.10
Velocity	ft/sec	0.22	0.22	0.22	0.22	0.22	0.00	0.22	0.22	0.00	0.22	0.22	0.22
Travel Time	minutes	7.55	7.55	7.55	3.78	7.55	0.00	3.78	7.55	0.00	7.55	7.55	7.55
SCS Uplands Method Curve F - Shallow Concentrated Flow in Grassed Waterway													
Distance	feet					1140					834	35	
Slope	percent					0.15					0.10	0.01	
Velocity	ft/sec	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00	0.47	0.12	0.00
Travel Time	minutes	0.00	0.00	0.00	0.00	33.03	0.00	0.00	0.00	0.00	29.65	4.91	0.00
SCS Uplands Method Curve G - Paved Areas (Sheet Flow) and Upland Gullies													
Distance	feet				550	639	100			50	500		
Slope	percent				0.07	0.16	0.10			0.10	0.10		
Velocity	ft/sec	0.00	0.00	0.00	0.52	0.78	0.62	0.00	0.00	0.62	0.62	0.00	0.00
Travel Time	minutes	0.00	0.00	0.00	17.56	13.61	2.67	0.00	0.00	1.33	13.33	0.00	0.00
Roadside Ditch													
Distance	feet	1020	100					3272					1674
Velocity	ft/sec	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Travel Time	minutes	11.33	1.11	0.00	0.00	0.00	0.00	36.36	0.00	0.00	0.00	0.00	18.60
Storm Sewer													
Distance	feet		1333	3092	1284		1433		957	355		1836	

Notes:

TIME OF CONCENTRATION CALCULATIONS USING THE NRCS UPLAND METHOD													
Sub-Area	**Units**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**B1**	**C1**	**C2**	**C3**
Velocity	ft/sec	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Travel Time	minutes	0.00	7.41	17.18	7.13	0.00	7.96	0.00	5.32	1.97	0.00	10.20	0.00
Open Channel													
Distance	feet												
Velocity	ft/sec	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Travel Time	minutes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TC	**minutes**	**18.88**	**16.07**	**24.73**	**28.47**	**54.19**	**10.63**	**40.13**	**12.87**	**10.00**	**50.54**	**22.66**	**26.15**
TC	**hours**	**0.31**	**0.27**	**0.41**	**0.47**	**0.90**	**0.18**	**0.67**	**0.21**	**0.17**	**0.84**	**0.38**	**0.44**

If Tc<10, 10

Notes:

Figure 15–4 Velocity versus slope for shallow concentrated flow

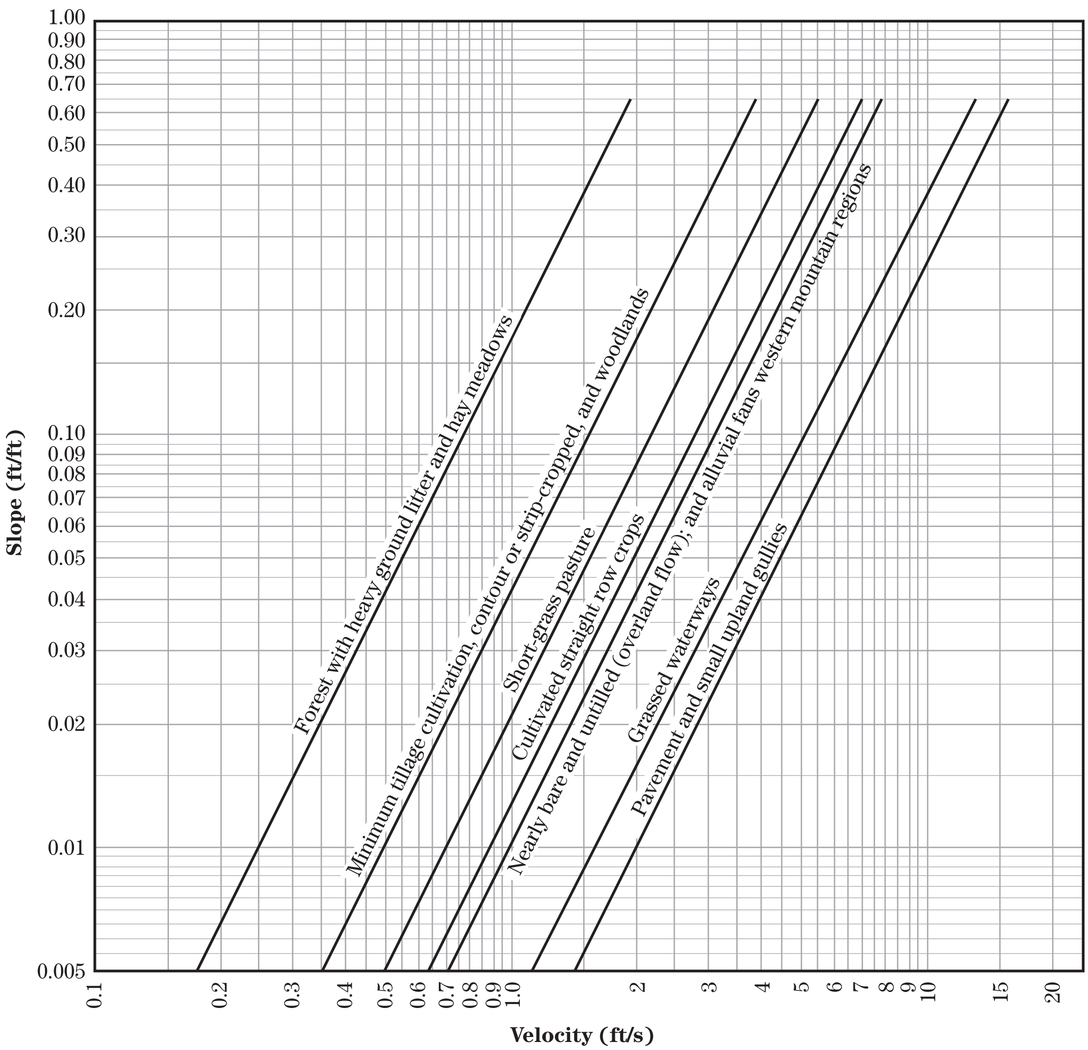
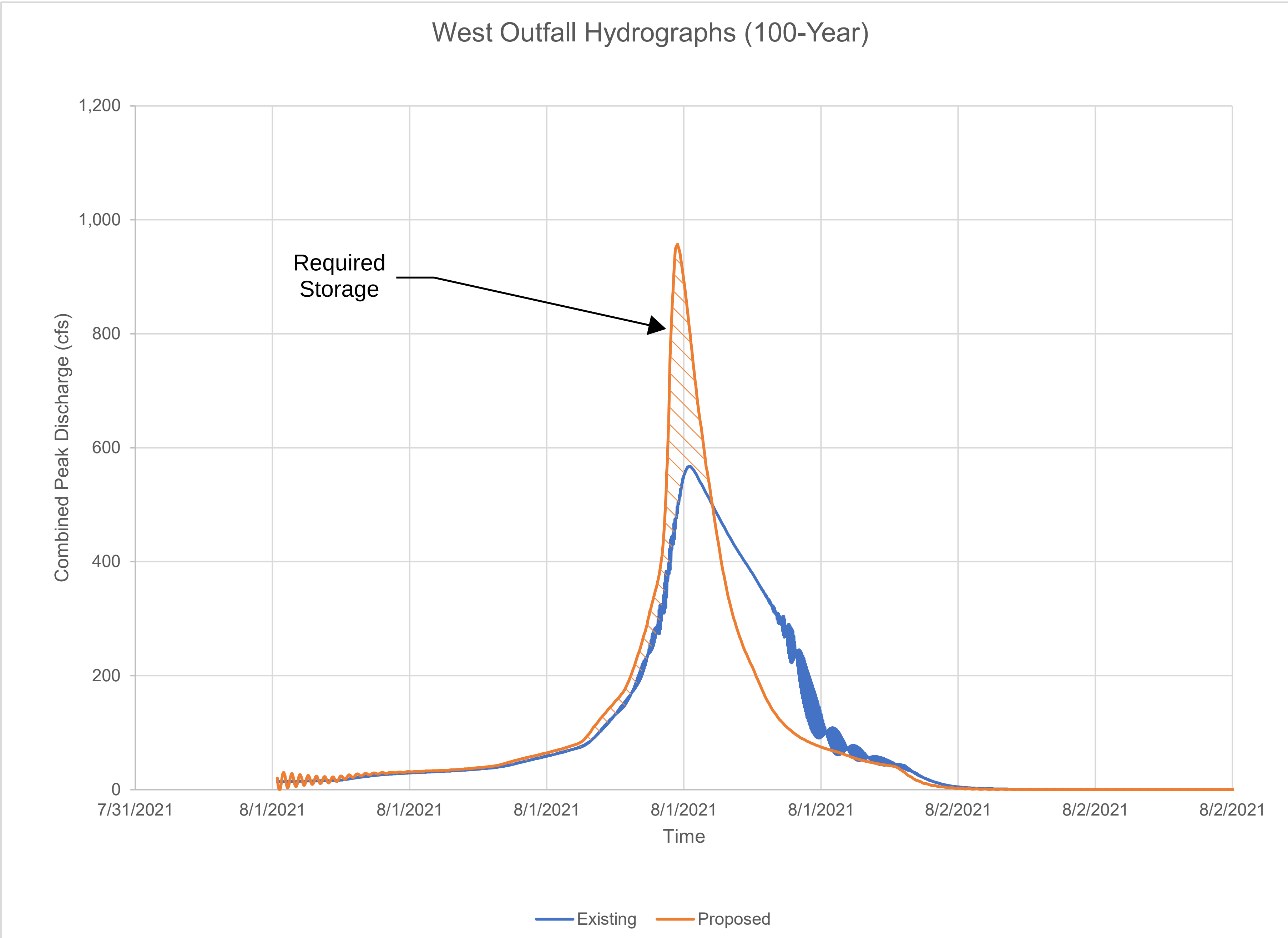


Table 15–3 Equations and assumptions developed from figure 15–4

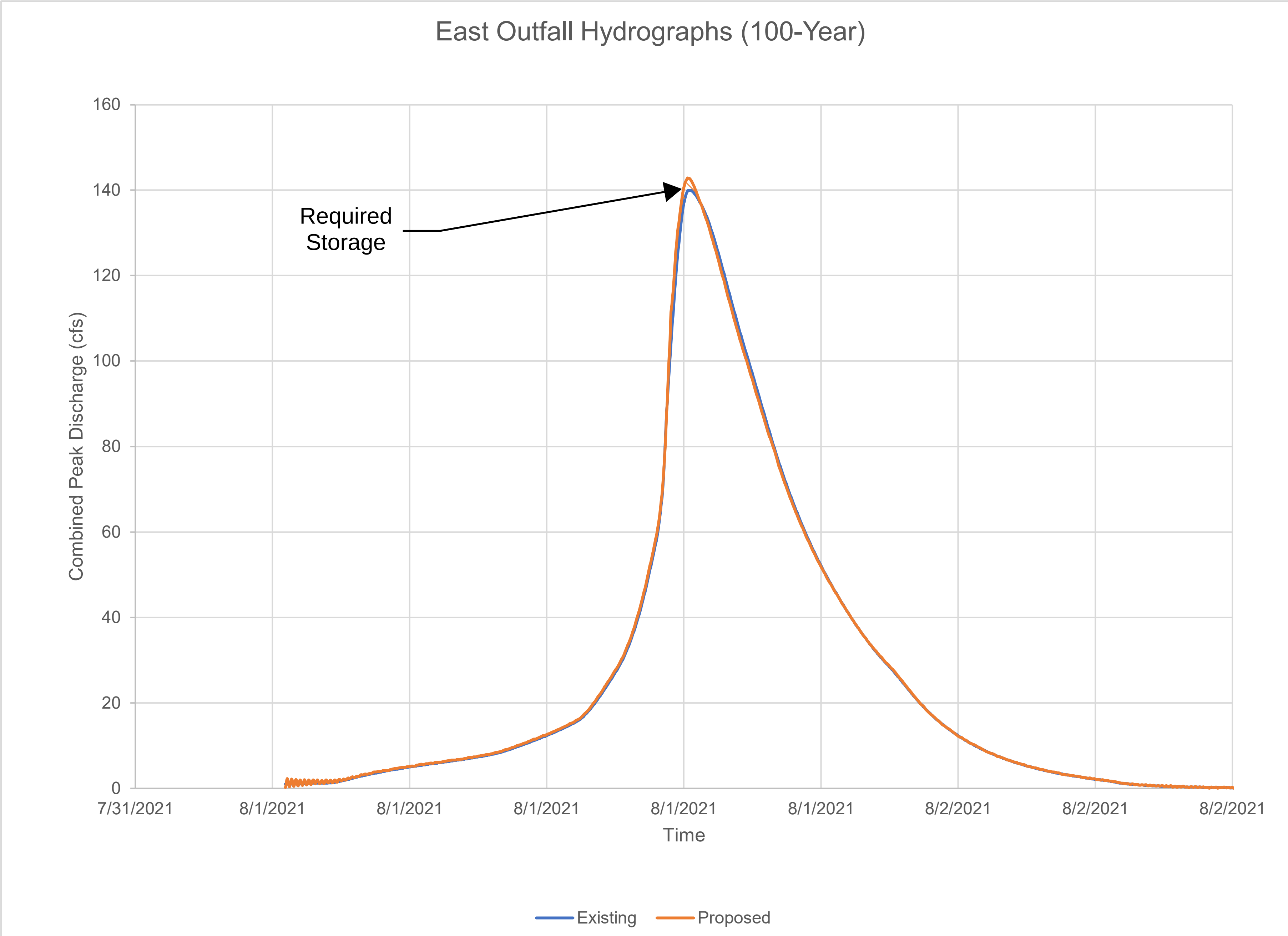
Flow type	Depth (ft)	Manning's *n*	Velocity equation (ft/s)
Pavement and small upland gullies	0.2	0.025	$V = 20.328(s)^{0.5}$
Grassed waterways	0.4	0.050	$V=16.135(s)^{0.5}$
Nearly bare and untilled (overland flow); and alluvial fans in western mountain regions	0.2	0.051	$V=9.965(s)^{0.5}$
Cultivated straight row crops	0.2	0.058	$V=8.762(s)^{0.5}$
Short-grass pasture	0.2	0.073	$V=6.962(s)^{0.5}$
Minimum tillage cultivation, contour or strip-cropped, and woodlands	0.2	0.101	$V=5.032(s)^{0.5}$
Forest with heavy ground litter and hay meadows	0.2	0.202	$V=2.516(s)^{0.5}$

Source: NRCS, Chapter 15

Appendix B. Hydrographs



West Outfall Hydrographs (100-Year)
Required Storage
Combined Peak Discharge (cfs)
1,200
1,000
800
600
400
200
0
7/31/2021
8/1/2021
8/1/2021
8/1/2021
8/1/2021
8/1/2021
8/2/2021
8/2/2021
8/2/2021
Time
Existing
Proposed


East Outfall Hydrographs (100-Year)
Required Storage
160
140
120
100
80
60
40
20
0
Combined Peak Discharge (cfs)
7/31/2021
8/1/2021
8/1/2021
8/1/2021
8/1/2021
8/1/2021
8/2/2021
8/2/2021
8/2/2021
Time
Existing
Proposed

Appendix C. Opinion of Probable Construction Cost

Storm Sewer System

Item	Item Description	Unit of Measure	Unit Price	Quantity	Item Cost
1	Remove 60" RCP	LF	$ 20.00	2,860	$ 57,200.00
2	Remove Inlets (All Types)	EA	$ 370.00	29	$ 10,800.00
3	Remove Manholes (All Types, All Depths)	EA	$ 1,150.00	2	$ 2,300.00
4	Manholes (for 42" to 60" Diam Pipe)	EA	$ 6,000.00	2	$ 12,000.00
5	Junction Box	EA	$ 10,000.00	8	$ 80,000.00
6	42" RCP	LF	$ 145.00	1,500	$ 217,500.00
7	54" RCP	LF	$ 255.00	6,030	$ 1,537,700.00
8	60" RCP	LF	$ 315.00	1,000	$ 315,000.00
9	8'x5' RCB	LF	$ 620.00	309	$ 191,600.00
10	10'x5' RCB	LF	$ 795.00	7,200	$ 5,724,000.00
11	Trench Safety System	LF	$ 2.00	8,018	$ 16,100.00
12	Curb Inlets (All Types)	EA	$ 5,000.00	9	$ 45,000.00
				Subtotal	*$ 8,209,200.00*
13	Ancillary Items			10%	$ 820,920.00
14	General Items			10%	$ 820,920.00
				Subtotal	*$ 9,851,040.00*
15	Contingency			20%	$ 1,970,208.00
16	Engineering Design			15%	$ 1,477,656.00
				Total	**$ 13,298,904.00**

Detention Pond

Item	Item Description	Unit of Measure	Unit Price	Quantity	Item Cost
17	Detention Pond (Dry)	AC-FT	$ 30,000.00	45.3	$ 1,359,000.00
18	Ancillary Items			10%	$ 135,900.00
19	General Items			10%	$ 135,900.00
20	Contingency			20%	$ 271,800.00
21	Engineering Design			15%	$ 203,850.00
22	Real Estate Acquisition	Acre	$ 15,000.00	10.0	$ 150,000.00
				Total	**$ 2,256,450.00**

Combined Cost $ 15,555,354.00