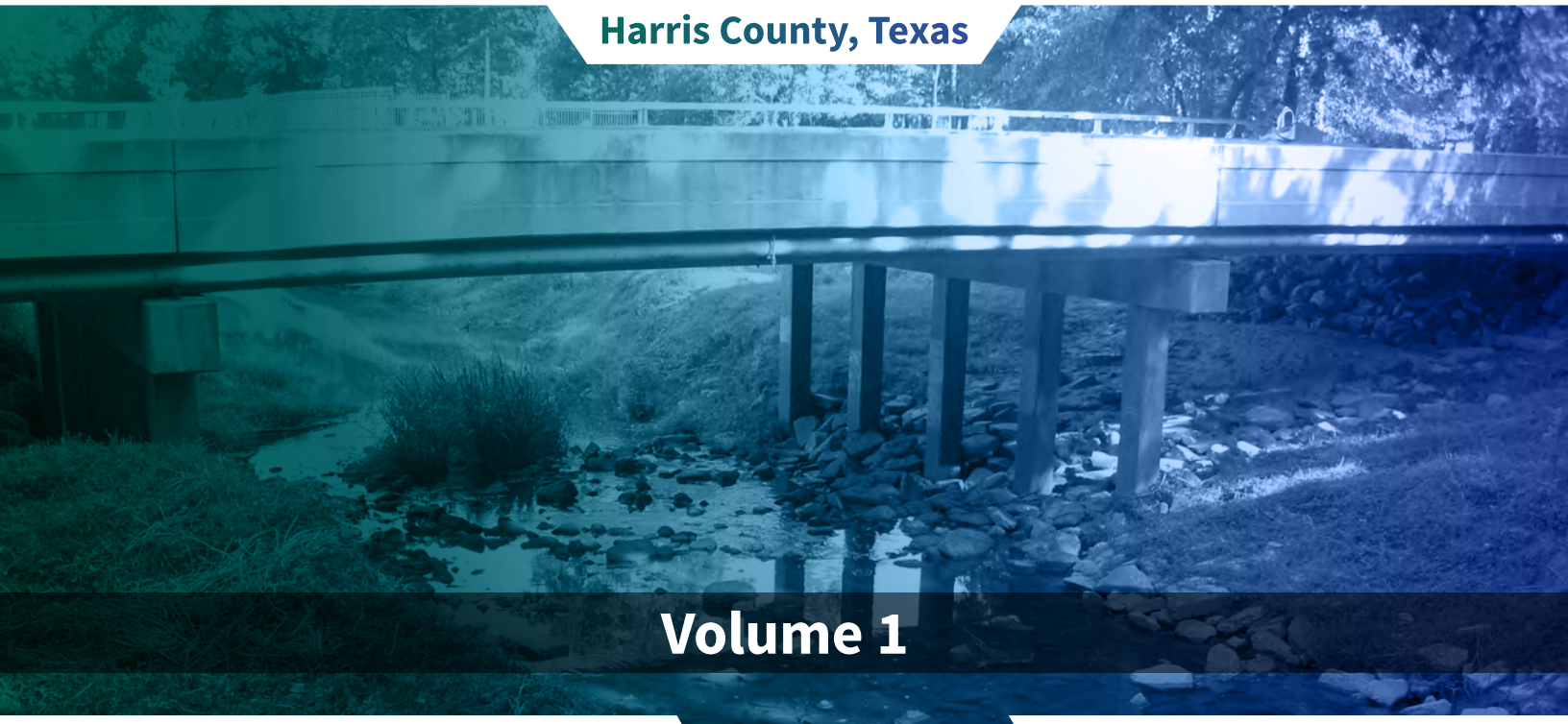
Kingwood Drainage Study

Conceptual Watershed Plan for Flood Damage Reduction in Kingwood

HCFCD Project ID#: Z100-00-00-P027
Bond Program Map ID F-14

Harris County, Texas



Volume 1

Project No. 15327.000

July **2020**

Prepared for

HARRIS COUNTY FLOOD CONTROL DISTRICT

CITY OF HOUSTON TEXAS

Lake Houston Redevelopment Authority TIRZ #10

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FIRM Registration No. **2697**

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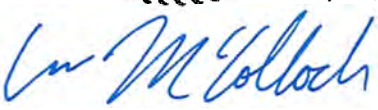
July 15, 2020



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Sections above relating to Mills Branch (G103-80-031A), Taylor Gully (G103-80-031B), G103-41-00 (Sand Branch) , and G103-80-01 (Green Tree Ditch)

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Executive Summary

This report presents the Conceptual Watershed Plan for flood damage reduction in the Kingwood Area. Neel-Schaffer, Inc. (NSI) was contracted by Harris County Flood Control District (HCFCD) and Lake Houston Redevelopment Authority TIRZ Number 10, City of Houston (COH), to perform a watershed study for the streams within the Kingwood Area to identify the existing level-of-service (LOS) and develop improvement options to obtain a 100-year LOS. An Interlocal Agreement between HCFCD and Lake Houston Redevelopment Authority (Agreement No. 2019-153) was completed to perform the drainage study.

The purpose of this study was to create a Conceptual Watershed Plan to evaluate and quantify the existing flooding problems along the streams within the Kingwood Project Area and develop strategies to eliminate existing flood problems while accounting for improved drainage infrastructure required to achieve a 100-year open channel level-of-service within the Kingwood Project Area. The study was performed utilizing the Atlas 14 rainfall data and MAAPNext hydrologic methodology. The drainage study included:

- Evaluation of the Historical Flooding
- Overland Flow Analysis
- Existing Open Channel Level of Service Analysis
- Channel Improvement Analysis
- Detention Estimate

The existing streams within the Kingwood Area are located within right-of-way (ROW) owned by either HCFCD, City of Houston, Public, and others (e.g. Harris County, utility districts, neighborhood associations and communities). Some of these channels are entirely owned by entities other than HCFCD, however analysis of these streams was included to provide information to the respective owners.

Historical Flooding

The Kingwood area has experienced significant structural flooding several times in the last few years as a result of heavy rainfalls. HCFCD provided five sources documenting historical flooded structures in the area were examined to help confirm the flooding: (1) Hurricane Ike September 2008, (2) Memorial Day 2015, (3) Tax Day 2016, (4) Memorial Day 2016, and (5) Hurricane Harvey August 2017. As part of this drainage study, a carpet count was performed immediately following Tropical Storm Imelda. The flooded structure data was contextualized by using nearby rain gage data to perform a rainfall annual exceedance probability (AEP) analysis for the recent historical storm events.

The results of this analysis show that the rainfall experienced during several events, such as Hurricane Ike in 2008, Memorial Day 2015, Tax Day 2016 and Memorial Day 2016 were relatively frequent rainfall AEP events. However, Tropical Storm Imelda was approximately a 100-year event during the 60-minute to 3-hour duration rainfall, and Hurricane Harvey was approximately a 24-hour 500-year event. The results also show that during Hurricane Harvey, the area experienced 100-year and 500-year rainfall totals for 24-hour to 4-day durations resulting in riverine flooding. Tropical Storm Imelda resulted in 100-year rainfall totals during the shorter 60-minute to 3-hour duration rainfall resulting in flooding associated with overwhelmed local drainage systems. The analysis also showed that during Tropical Storm Imelda, the East Fork San Jacinto River also experienced longer duration 100-year rainfall resulting in additional

riverine flooding along the eastern border of Kingwood. This generally matches the flooded structure data available for the project area.

While the Kingwood area has been mostly spared from recent historical flooding events, Hurricane Harvey and Tropical Storm Imelda have highlighted certain deficiencies in existing streams and internal drainage systems related to longer and shorter duration 100-year rainfall events.

Overland Flow Analysis

In an effort to understand the overland flow paths in the Kingwood Area, a 2D hydraulic model was developed for Kingwood and the surrounding area. Innovyze ICM 2D modeling software was chosen which allows the study of both the overland flow and storm sewer systems. The overland flow analysis is intended to be a high-level analysis of the drainage trends in the area, and a basis to confirm results from the steady and unsteady analysis of the drainage channels within the Kingwood Study Area. Limited analysis of the storm sewer infrastructure was conducted to assist in understanding runoff patterns. A thorough evaluation of the storm sewer network was not conducted. The study identified potential areas that are at risk to riverine flooding and areas at risk of overland sheet flow based on the performance of the existing storm sewer during extreme events. Storm sewers are typically designed to a 2-year storm frequency with an evaluation of performance during an extreme event when storm sewers are surcharged. This results in street ponding that may result in overland sheet flows to the drainage outfalls during extreme storm events. Areas where street ponding and overland flows appear to put existing properties at risk of flooding during extreme events represent areas that have been identified for additional investigations to confirm the results from this limited 2D high-level study. Study recommendations are for these existing drainage systems to be checked against current City of Houston Infrastructure Design Manual Criteria post Atlas 14.

Existing Level of Service Analysis

In order to effectively quantify the extent and frequency of flooding within the Kingwood Area, the existing conditions modeling needed to be performed. The base models for the hydrologic and hydraulic analyses are identified as the FEMA Effective HEC-HMS and HEC-RAS models for San Jacinto River watershed. Hydrologic analysis for this project was performed using the HEC-HMS Version 4.2.1. The MAAPNext hydrologic methodology for developing runoff hydrographs was utilized for this study with the Atlas 14 rainfall amounts. The USACE HEC-RAS computer model version 5.0.7 was used to perform the hydraulic analysis along the streams in the project area. The FEMA Effective HEC-RAS models for HCFCD Unit G103-33-00 (Bens Branch), HCFCD Unit G103-80-03.1A (Mills Branch), and HCFCD Unit G103-80-03.1B (Taylor Gully) were simulated in unsteady state. Additionally, the HCFCD Unit G103-33-00 model was extended into Montgomery County to just upstream of the confluence with HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was added to the unsteady model. For all other streams, a steady state HEC-RAS model was developed.

The data from the hydraulic models was used to develop the frequency event floodplains for the Kingwood Area utilizing RAS Mapper within the HEC-RAS program. The level of service was determined for each stream's reach based on whether the frequency event inundation limits were contained to the streams ROW or the wooded trails and areas next to the stream. Additionally, the streams were evaluated to determine whether the roadway crossings were overtopped during a specific frequency event. A structure inventory analysis was performed for the 100-year storm event to identify structures located

within the 100-year stream inundation. A structure inventory file supplied by HCFCD was used and an average structure ground elevation was estimated from 2018 LiDAR data. For every instance where the average elevation of a structure fell below the computed water surface elevation of the 100-year storm event, that structure was considered "flooded" and tallied into a count of "structures at risk."

Improvement Analysis

Improvements to provide structural flooding protection for the 100-year frequency event within the Kingwood Area were analyzed. As per direction from HCFCD, the improvement analysis was performed assuming improvements to the local drainage system (generally City of Houston maintained storm sewer and roadside ditch systems) to the current standards within the Kingwood Area and a portion of Northpark Drive within Montgomery County. The scope for this project only includes a structure inventory analysis to determine the potential "at risk structures" located within the 100-year stream inundation. The scope for this project does not include an evaluation of other potential impacts associated with increases in water levels from increased peak flows due to assumed local drainage improvements within existing channels found to have a 100-year level-of-service with no "at risk structures". *It is recommended after this study is completed that a more detailed study be performed by the City of Houston to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.*

Channels and streams that were found to have an existing 100-year level-of-service were reevaluated utilizing the proposed peak flows based on assumed future storm sewer and overland flow improvements. If the stream was still determined to have a 100-year level-of-service with no structural flooding within the 100-year stream inundation limits, no improvements are proposed.

Drainage improvements considered for the open channel system include:

- Improved drainage channels including widening, deepening, and/or lining for increased conveyance capacity.
- Improved conveyance capacity of existing roadway crossings through lengthening or raising existing bridge structures or additional culverts.
- Watershed diversions using enclosed conduits (following existing roadway alignments or other public ROW) or along existing streams.
- Property buy-outs

A structural benefit analysis was performed as a result of any expected lowering of water surface elevations from recommended improvements. "Structures at risk" identified as flooding from a 100-year event were deemed to "benefit" if a drop in the water surface elevations allowed the "structures at risk" to no longer be located in the 100-year inundation as a result of recommended improvements. These structures are noted on accompanying maps as "removed," meaning their footprints are no longer within the 100-year stream inundation.

Preliminary cost estimates were developed for each of all improvement options. The construction costs were subdivided based on the channel reaches. The results of the proposed improvements and preliminary cost estimates are summarized in the table at the end of this section.

Due to Harris County's current policy requirement (also adopted by HCFCD) that detention volume must be included for any projects that outfall into Lake Houston, a mitigation analysis was performed to

determine potential detention needs due to increased runoff associated with the proposed channel improvements and the assumed local drainage improvements. Due to the scale of improvements analyzed throughout the Kingwood Area, detention would need to be provided regionally in large detention ponds; therefore, peak flow impacts and mitigation volume needs were measured at the outfall locations out of the Kingwood Area.

A detailed analysis of detention volume requirements for each alternative drainage improvement was not performed, but rather, the potential detention volume was calculated by comparing the difference between the existing and proposed outflow hydrograph at the identified outfall locations. A 20% contingency was applied to the resulting calculated volume. A summary of the potential detention needs are provided in the summary table at the end of this section.

It is recommended that the improvement options be constructed from downstream to upstream to ensure that the receiving systems have the necessary capacity without some form of flow restriction which limits the benefit of the constructed improvements and to ensure that no downstream impacts occur. Additionally, the improvement options for HCFCD Unit G103-38-01, HCFCD Unit G103-38-01.1 and HCFCD Unit G103-33-04, tributaries to HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), cannot be constructed until the receiving channels have the necessary capacity. Therefore, the improvement option for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) must be constructed first. Likewise, local drainage improvements cannot be constructed until after the detention mitigation plan and improvement options have been implemented for the receiving channel.

Stream	Reach*	Existing Channel Description					Recommended Improvement							
		Channel Type (Natural/Improved/ Concrete)	Maint. Berm	ROW	Owner	Level of Service	Improvement Description	ROW Required	Add. ROW Required	Construction Cost Estimate (Including ROW)	Total Benefited Structures	Detention Estimate Channel Improvement		
												Channel	Local	Constr. Cost (W/O ROW)
		(--)	(--)	(ft)	(--)	(--)	(--)	(ft)	(ac)	($)	(--)	(ac-ft)	(ac-ft)	(ac-ft)
HARRIS COUNTY FLOOD CONTROL MAINTAINED STREAMS														
G103-33-00 (Ben's Branch)	R1	Improved	No	100-120	HCFCD Public	<2-Yr	Flow Diversion, Culvert Replacement			$179,000	8	540.9		$14,699,000
	R2	Natural	No	100	Other	2-Yr	Channel modifications, bridge replacement, low water crossing removal	180	19.2	$8,651,000	2			
	R3	Improved	No	160-260	HCFCD	<2-Yr	Channel modifications, bridge replacement	200-260	2.4	$6,355,000	29			
	R4	Improved	No	--	COH Private	2-Yr	Channel modifications	270-300	20.8	$9,045,000	18			
G103-33-01	R1	Improved	Yes	140-150	HCFCD	100-Yr	NO IMPROVEMENT							
G103-33-02	R1	Improved	Yes	100-150	HCFCD	100-Yr	NO IMPROVEMENT							
G103-33-03	R1	Improved	Yes	80	HCFCD	100-Yr	NO IMPROVEMENT							
G103-33-04	R1	Improved	No	110-130	HCFCD	<2-Yr	Channel modifications, culvert replacement	110-140	0.5	$2,168,000	18			
G103-38-00 (Ben's Branch Diversion)	R1	Improved	Yes	195-300	HCFCD	100-Yr	Channel Control Structure, Flow Diversion, Channel modifications, bridge replacement	210-340	12.8	$25,428,000	282	834.3	414.2	$33,928,000
	R1-R4	G103-33-00 (Ben's Branch)					NO IMPROVEMENTS CONSTRUCTED				356			
	R2	Improved	No	140-300	COH	<2-Yr	NO IMPROVEMENT							
G103-38-01	R1	Improved	Yes	50	Public	100-Yr	NO IMPROVEMENT							
	R2	Concrete	Yes	90	HCFCD Other	100-Yr	Revise existing concrete channel section			$2,157,000	130			
G103-38-01.1	R1	Improved	Yes	80	HCFCD Public	25-Yr	Channel modifications			$578,000	26			
G103-38-02	R1	Improved/Concrete	No	130-160	HCFCD	100-Yr	NO IMPROVEMENT							
G103-41-00	R1	Improved	Yes	130	HCFCD Public	100yr	NO IMPROVEMENT							
	R2	Improved	Yes	130	Private	>100yr	NO IMPROVEMENT							
G103-41-01	R1	Improved	Yes	110 - 130	HCFCD Public	50yr	NO IMPROVEMENT							
G103-45-00	R1	Improved	No	60-85	HCFCD	<2-yr	TARGETED BUYOUT AREA							
G103-80-01	R1	Natural Channel	Yes	130-145	HCFCD Public	100yr	NO IMPROVEMENT							
G103-80-03.1B (Taylor Gully)	R1	Improved	Yes	140	HCFCD	10yr	Channel Improvements			$2,600,000	132	115.6		$3,122,000
	R2	Improved	Yes	140-150	HCFCD	10yr	Channel Improvements			$14,938,000	317			
	R3	Natural Channel	No	150	HCFCD	100yr	Channel Improvement, New Outlet			$480,000	0			

Stream	Reach*	Existing Channel Description					Recommended Improvement							
		Channel Type (Natural/Improved/ Concrete)	Maint. Berm	ROW	Owner	Level of Service	Improvement Description	ROW Required	Add. ROW Required	Construction Cost Estimate (Including ROW)	Total Benefited Structures	Detention Estimate Channel Improvement		
												Channel	Local	Construction Cost (Without ROW)
		(--)	(--)	(ft)	(--)	(--)	(--)	(ft)	(ac)	($)	(--)	(ac-ft)	(ac-ft)	(ac-ft)
STREAMS MAINTAINED BY OTHERS														
G103-36-00	R1	Natural	No	90-180	Public	<2-Yr	Channel improvements			$1,749,000	66	18.0	105.5	$3,357,000
	R2	Improved	No	130-210	Other	100-Yr	NO IMPROVEMENT							
	R3	Improved	No	135	Other	100-Yr	NO IMPROVEMENT							
	R4	Improved	No	135	Other	100-Yr	NO IMPROVEMENT							
G103-36-01	R1	Natural	No	20-70	Other	100-Yr	NO IMPROVEMENT							
	R2	Natural	No	--	Other	100-Yr	NO IMPROVEMENT							
G103-36-02	R1	Improved/Natural	No	50	Other	100-Yr	NO IMPROVEMENT							
G103-36-02.1	R1	Improved	No	100	Public	100-Yr	NO IMPROVEMENT							
G103-36-03	R1	Improved	No	100	Public	<2-Yr	Upsize Culverts			$660,000				
G103-39-00	R1	Natural	No	100	Other	100-Yr	NO IMPROVEMENT							
	R2	Natural	No	--	--	<2-Yr	Targeted Buyout Area							
	R3	Natural	No	--	--	<2-Yr	Targeted Buyout Area							
G103-46-00	R1	Improved	No	35-85	HCFCD Other	<2-Yr	Targeted Buyout Area							
G103-46-01	R1	Improved	No	--	--	<2-Yr	Upsize Culverts			$889,000	52		19.3	$524,000
	R2	Concrete	--	50	Public Other	<2-Yr	Upsize Culverts			$1,420,000	3			
G103-80-03.1A (Mills Branch)	R1	Natural	No	--	--	100yr	NO IMPROVEMENT							
G103-80-04	R1	Improved	Yes	150	Public	100-Yr	NO IMPROVEMENT							
	R2	Natural	No	150-260	Public	100-Yr	NO IMPROVEMENT							

*See Exhibit 4 for Reach extents.

1. INTRODUCTION

This report presents the Conceptual Watershed Plan for flood damage reduction in the Kingwood Area. Neel-Schaffer, Inc. (NSI) was contracted by Harris County Flood Control District (HCFCD) and Lake Houston Redevelopment Authority TIRZ Number 10, City of Houston (COH), to perform a watershed study for all the streams within the Kingwood Area to identify the existing level-of-service (LOS) and develop improvement options to obtain a 100-year LOS. An interlocal agreement between HCFCD and Lake Houston Redevelopment Authority (Agreement No. 2019-153) was completed to perform a drainage study of 5 streams within the Kingwood Area to their confluence with the adjoining river. The five streams that are studied as part of the interlocal agreement are:

1. HCFCD Unit G103-33-00 (Bens Branch) from 3500 feet upstream of Kingwood Blvd. to 2000 feet downstream of Lake Houston Blvd.
2. HCFCD Unit G103-33-01
3. HCFCD Unit G103-38-00 (Kingwood Diversion Ditch)
4. HCFCD Unit G103-80-01 (Green Tree Ditch)
5. HCFCD Unity G103-80-03.1B (Taylor Gully)

In addition to these five channels studied as part of the interlocal agreement, HCFCD opted to study all of the remaining open channels within the Kingwood Area. Sub-consultants include Gauge Engineering (Gauge) and Hollaway Environmental & Communication Services.

1.1. STUDY AREA AND PROBLEM

The Kingwood Project Area is part of the San Jacinto River watershed. It is bounded by the West Fork San Jacinto River to the south, the East Fork San Jacinto River and White Oak Creek to the east and the county divide between Harris County and Montgomery County. The Project Area encompasses 25.2 square miles as shown on **Exhibit 1**.

The central and western portions of the Kingwood area were mostly developed in the 1970s and 1980s following design criteria at the time that did not include extreme event sheetflow and detention requirements for increased runoff. The eastern portion of the Kingwood area was developed more recently and designed following more recent criteria which includes extreme event sheetflow and detention for increased runoff. The Kingwood Area streams also drain portions of Montgomery County which has also experienced significant development over time some being constructed with detention mitigation ponds. Additionally, limited areas of the Kingwood area also lack channel capacity. This has resulted in the project area experiencing structural flooding during recent extreme storm events.

1.2. STUDY PURPOSE AND SCOPE

The purpose of this study is to create a Conceptual Watershed Plan to evaluate and quantify the existing flooding problems along the streams within the Kingwood Project Area and develop strategies to eliminate existing flood problems while accounting for improved drainage infrastructure required to achieve a 100-year open channel level-of-service within the Kingwood Project Area. The study was

performed utilizing the Atlas 14 rainfall data and MAAPNext hydrologic methodology. The following primary task activities were included in the scope of work:

- Project Management
- Project Meetings
- Data Collection and Review
- Evaluation of Historical Flooding
- Overland Flow Analysis
- Existing Open Channel Level of Service Analysis
- Improvement Analysis
- Detention Estimate
- Preliminary Construction Cost Estimate
- Study Report

1.3. RIGHT-OF-WAY

The existing streams within the Kingwood Area are located within right-of-way (ROW) owned by either HCFCD, City of Houston, Public, and others (e.g. Harris County, utility districts, neighborhood associations and communities) as shown on **Exhibit 2**. Some of these channels are entirely owned by entities other than HCFCD or the COH, however analysis of these streams was included to provide information to the respective owners. The following streams and their limits do not contain HCFCD or COH ROW:

- HCFCD Unit G103-36-00 and its tributaries
- HCFCD Unit G103-39-00
- HCFCD Unit G103-46-00 and its tributary
- HCFCD Unit G103-38-01 upstream of the confluence with HCFCD Unit G103-38-01.1
- HCFCD Unit G103-33-00 (Bens Branch) from Rocky Woods Drive to Woodland Hills Drive
- HCFCD Unit G103-80-04
- HCFCD Unit G103-80-03.1A (Mills Branch)

Additionally, portions of the Kingwood Area streams are located within multiple easements owned by HCFCD, COH and other entities. The following streams and their limits contain multiple ROW with multiple owners:

- HCFCD Unit G103-33-00 (Bens Branch) downstream of North Park Drive from Glade Valley Drive to Plum Valley Drive contains 60'HCFCD ROW and 60' Public ROW.
- HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) from the confluence with HCFCD Unit G103-38-01 to Palmetto Lane contains 220' HCFCD ROW and 50' Harris County ROW.
- HCFCD Unit G103-38-01 from confluence with HCFCD Unit G103-38-01.1 to confluence with HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) contains 40' HCFCD ROW and 50' Harris County ROW.
- HCFCD Unit G103-38-01.1 contains 30' HCFCD ROW and 50' Public ROW.

During the course of this project, HCFCD obtained a limited 100' easement from Bear Branch Trails Association and Friendswood Development Company along HCFCD Unit G103-33-00 (Bens Branch) from Woodland Hills Drive to Rocky Woods Drive to perform maintenance activities such as desnagging. The easement prohibits any form of channel modification. The importance of ROW along the Kingwood area channels is that HCFCD and COH cannot legally construct drainage improvements along channels that they do not have property rights.

When HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was originally constructed, sufficient ROW was purchased to allow for the construction of channel improvements in the future. The ROW ranges from 195 feet at the county boundary to 310 feet at Woodland Hills Drive near the confluence with the West Fork San Jacinto River. Additionally, Kingwood Drive and North Park Drive bridges were originally constructed to span the entire ROW which allows for channel improvements without the need to replace the existing bridge structures.

1.4. DATA COLLECTION

Data collected and relied upon for this study included the following:

1. FEMA Effective Hydrology Computer Models,
2. FEMA Effective Hydraulic Computer Models,
3. HCFCD Historical Flood Data,
4. HCFCD 2018 Building Footprints,
5. HCFCD Impervious Raster,
6. HCFCD Watershed Master Plan Drainage Areas,
7. HCFCD Targeted Buyout Area,
8. H-GAC's 2018 LiDAR DEM,
9. Field Reconnaissance, and
10. Aerials

No topographic surveys were performed for this study. During the field reconnaissance, measurements were taken for the existing bridge structures such as deck thickness, distance from low chord to channel flowline, culvert size, rail height, and pier sizes. Photographs were also taken at each bridge crossing and included in **Appendix A**.

1.5. PROJECT DATUM

The project datum is the North American Vertical Datum (NAVD) 1988, 2001 adjustment. No topographic survey data was collected for this project. For this project, 1-meter LiDAR, 2018 Texas Strategic Mapping (StratMap), topographic data was utilized. All elevations referenced in this report are referenced to the project datum unless otherwise noted.

1.6. TOPOGRAPHY AND LAND USE

The Kingwood Area extends from the county boundary with Montgomery County to the West Fork San Jacinto River, White Oak Creek, East Fork San Jacinto River and encompasses 21.7 square miles. The

topography is generally characterized by steep and mild terrain with the upper portion of the project area sloping to the east and the lower portion sloping east and southeast. The project area exhibits overland slopes ranging from a mild slope of 4.1 feet/mile to steep slopes of 70.4 feet/mile with an average slope of 21.7 feet/mile. The stream gradients range from a mild slope of 0.3 feet/mile to a steep slope of 48.5 feet/mile with an average slope of 9.0 feet/mile. Several of the streams within the Study Area were constructed counter to the existing topography. HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) runs north to south and parallels the contours. Additionally, HCFCD Unit G103-80-03.1B (Taylor Gully) was constructed through an existing high area. This results in inefficient channel sections.

The Kingwood Area is mostly developed with residential lots with western areas constructed prior to 1984 and eastern areas post 1984 with some industrial, commercial, schools, and developed green areas such as golf courses and parks. The upper and eastern portion of the project area is made up of mostly residential neighborhoods constructed within the past 30 years with the neighborhoods closer to the channel constructed more recently.

1.7. FEMA FLOOD HAZARD AREAS

HCFCD Unit G103-33-00 (Bens Branch), HCFCD Unit G103-80-03.1B (Taylor Gully) and HCFCD Unit G103-80-03.1A (Mills Branch) are FEMA studied streams with the 100-year regulatory floodplain in the project area located in the FEMA Flood Insurance Rate Map (FIRM) for Harris County, Texas and Incorporated Areas, Map Number 48201C0305L, 48201C0310L, 48201C0315L, and 48201C0320L, with the Effective Date of June 18, 2007. For HCFCD Unit G103-33-00 (Bens Branch), the mapped floodplains south of Kingwood Drive are associated with the water surface elevations along the West Fork San Jacinto River which are much higher than those along Bens Branch. The FEMA effective floodplains are shown on **Exhibit 3.**

1.8. REFERENCES

The following references and criteria manuals were utilized in performing the drainage study:

- *Hydrology and Hydraulics Guidance Manual*, Harris County Flood Control District, December 2009.
- *Policy Criteria and Procedure Manual for Approval and Acceptance of Infrastructure*, Harris County Flood Control District, Updated October 2018.
- *Harris County Flood Control District Interim Guidelines and Criteria for Atlas 14 Implementation*, Harris County Flood Control District, July 2019.
- *TSARP White Papers*, TSARP Technical Committee, Houston, Tx, 2002.
- *MAAPnext Program Hydrologic Methodology*, Harris County Flood Control District, Revised March 10, 2019.

2. Methodology

For this study, the hydrologic modeling was performed using United States Army Corps of Engineers (USACE) Hydrologic Engineering Center "Hydrologic Modeling System" (HEC-HMS) Version 4.2.1 and water surface profiles were computed using USACE Hydrologic Engineering Center "River Analysis System" (HEC-RAS) Version 5.0.7 and Federal Highway Association HY-8 Version 7.5. FEMA Effective hydrologic and hydraulic models were acquired for the studied streams HCFCD Unit G103-33-00 (Bens Branch), HCFCD Unit G103-80-03.1B (Taylor Gully), and HCFCD Unit G103-80-03.1A (Mills Branch) from the HCFCD Model and Map Management (M3) System.

2.1. MODEL DESCRIPTION

The base models for the hydrologic and hydraulic analyses are identified as the FEMA Effective HEC-HMS and HEC-RAS models for San Jacinto River watershed. The following basin models and plans were used in the HEC-HMS and HEC-RAS models for this study:

- Duplicate Effective (Original FEMA Effective HEC-HMS Model)
- Existing
    - HEC-HMS – Models were developed/revised utilizing Atlas 14 rainfall values, subcatchments delineated for this study, and hydrologic parameters calculated utilizing the MAAPNext Hydrologic Methodology.
    - HEC-RAS – Steady state models were developed for unstudied streams.
    - FEMA Effective HEC-RAS – Models were revised utilizing 2018 LiDAR data, adding missing or new roadway crossings utilizing measurements from the field reconnaissance, and converting the steady state HEC-RAS models to an unsteady HEC-RAS model.
- Proposed (Watershed characteristics accounting for local drainage infrastructure improvements and cross sections revised for proposed improvements)

The HCFCD Unit G103-33-00 (Bens Branch) HEC-RAS Effective model was updated in the overbanks utilizing the 2018 LiDAR data, and the model was extended to include HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) to develop an integrated model accounting for the diversion of flow within Montgomery County.

2.2. STREAM SEGMENTATION

For the purposes of presenting the data and proposed improvements, the streams were segmented into reaches defined by the limits in the HCFCD Kingwood Area Drainage Assessment Reports. Each stream or tributary was divided into a maximum of 4 reaches. The limits for the stream segmentation are shown on **Exhibit 4.**

2.3. HYDROLOGIC METHODOLOGY

Hydrologic analysis for this project was performed using the HEC-HMS Version 4.2.1. The MAAPNext hydrologic methodology for developing runoff hydrographs was utilized for this study. The MAAPNext

hydrologic methodology utilizes the Basin Development Factor (BDF) and equations to calculate the Clark Unit Hydrograph parameters, time of concentration (Tc) and storage coefficient (R). The Basin Development Factor (BDF) is as a measure of urbanization and the efficiency of the subcatchment drainage system. The urbanization is represented by five (5) land classification categories: (1) Undeveloped, (2) Open Space, (3) Developed Roadside Ditch, (4) Developed Storm Sewer Pre 1984, and (5) Developed Storm Sewer Post 1984. The efficiency of the subcatchment is measured utilizing three (3) classifications for the majority major conveyance system: (1) No channel/Natural, (2) Improved, and (3) Concrete. In addition to the base "Tc" and "R" methodology, the BDF methodology includes steps to make adjustments for slope, detention, and ponding areas. The watershed characteristics were measured and computed using topographic data, aerials, parcel data, and information from the field reconnaissance.

Subcatchments were identified to allow for a more granular level of assessment detail. Subcatchments were generally divided at confluences, channel slope changes, major thoroughfares, notable changes in floodplain width or profile (studied channels), and land use changes. Each subcatchment was anticipated to serve approximately a 200-acre to 400-acre drainage area, with the exception for areas within Montgomery County. For streams which were analyzed utilizing an unsteady HEC-RAS model, subcatchments were delineated to serve up to a 200-acre drainage area. For streams modeled in a steady state HEC-RAS model, subcatchments were delineated to serve up to a 400-acre drainage area. Subcatchments were delineated based on a combination of 2018 Lidar elevations, FEMA Effective study, and GIS datasets depicting storm sewer drainage systems, and HCFCD Watershed Master Plan drainage areas.

HCFCD hydrologic methodology uses the Green and Ampt infiltration method for estimating rainfall losses. The Green and Ampt method utilizes percent impervious cover and four parameters of physical soil properties, namely, initial loss, volume moisture deficit, wetting front suction, and hydraulic conductivity. These four parameters have been established by HCFCD on a watershed wide basis. **Table 1** shows the Green and Ampt parameters used in the analysis. The impervious cover for each subcatchment was calculated by utilizing the provided HCFCD impervious raster.

Table 1. Green and Ampt Method Parameters

Watershed	Initial Loss (in)	Volume Moisture Deficit	Wetting Front Suction (in)	Hydraulic Conductivity (in/hr)
San Jacinto River	0.024	0.46	3.5	0.024

Five statistical rainfall events, 50% (2-year), 10% (10-year), 4% (25-year), 2% (50-year) and 1% (100-year), were simulated using the USACE HEC-HMS model. Rainfall data was based on Atlas 14 Harris County Hydrologic Region 2 and a 24-hour storm duration was used. Precipitation amounts for the various storm events are provided in **Table 2**.

Table 2. Atlas 14 Rainfall Depths for Harris County Region 2

Storm Event	Duration							
	5-min	15-min	60-min	2-hr	3-hr	6-hr	12-hr	24-hr
2-Year	0.58	1.17	2.22	2.79	3.13	3.75	4.4	5.11
10-Year	0.85	1.69	3.22	4.25	4.94	6.15	7.39	8.71
25-Year	1.01	2.01	3.84	5.24	6.21	7.94	9.66	11.5
50-Year	1.13	2.25	4.29	6.02	7.27	9.48	11.7	14
100-Year	1.26	2.49	4.78	6.89	8.48	11.3	14	16.9

HCFCD methodology recommends Modified Puls flood routing method for simulating runoff hydrograph movement through a channel, floodplain, or detention system. This routing method uses a predefined storage versus discharge relationship as well as a number of routing subreaches calculated using HEC-RAS as per the HCFCD Hydrology and Hydraulics Guidance Manual. Based on this methodology, the peak flows used in HEC-RAS for determining the storage-outflow curves were updated iteratively, from the results of HEC-HMS models. Therefore, after the initial peak flows were prescribed with an arbitrary storage-outflow curve, the iteration continued in both the HEC-HMS and HEC-RAS models until the 1% exceedance probability (100-year) flows used in both models for each converge to within 5% of their respective values.

2.4. HYDRAULIC METHODOLOGY

The USACE HEC-RAS model, Version 5.0.7, was used to perform the hydraulic analysis along the streams in the project area. The FEMA Effective HEC-RAS models for HCFCD Unit G103-33-00 (Bens Branch), HCFCD Unit G103-80-03.1A (Mills Branch), and HCFCD Unit G103-80-03.1B (Taylor Gully) were simulated in unsteady state. Additionally, the HCFCD Unit G103-33-00 model was extended into Montgomery County to just upstream of the confluence with HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was added to the unsteady model. For all other streams, a steady state HEC-RAS model was developed.

Normal depth downstream boundary condition was used for all the streams except for HCFCD Unit G103-38-01 and HCFCD Unit G103-46-01 due to existence of a culvert at the downstream end. For these two streams, the performance of the outlet culverts was simulated using a rating curve computed utilizing the Federal Highway Administration HY-8 Culvert Hydraulic Analysis Program, Version 7.6.

The manning's roughness coefficients were assigned using a combination of values extracted from the Effective FEMA model, HCFCD Hydrology and Hydraulics Guidance Manual, HCFCD photos on the Kingwood Area Drainage Assessment website, and site visit photographs.

For the FEMA studied streams, the FEMA Effective HEC-RAS model was used as the base model and revised by:

- Adding existing bridge structures not currently included in the Effective model,
- Revising the existing bridge data such as culvert sizes utilizing the field reconnaissance data,
- Adding additional cross sections where necessary,
- Updating overbank elevations with 2018 LiDAR data, and

- Creating unsteady flow files from the HEC-HMS modeled inflow hydrographs inserted at the corresponding cross sections.

For subbasins located along the channel with multiple outfall locations, the runoff hydrograph was entered as uniform lateral inflow hydrographs. Flow from contributing tributaries or subbasins with a single outfall, the hydrograph was entered as a lateral inflow hydrograph at the outfall location.

For the unstudied streams, a steady-state HEC-RAS model was developed using RAS Mapper. The 2018 Lidar data was used to create station-elevation points for the cross sections. Bridges were added to the model utilizing the information gathered from the field reconnaissance. *The bridge information should be considered approximate and should be revised based on survey data during the design phase.* Survey was not obtained for this project. HEC-HMS node peak flows were used to establish the flows for HEC-RAS steady state models. The HEC-HMS peak flows are applied to appropriate cross sections in HEC-RAS model. Flows at other cross sections not directly associated with a point inflow were interpolated based on the cross section stationing and a semi-log relationship based on the guidance provided in the HCFCD Hydrology and Hydraulics Guidance Manual. The upstream peak flow rates were determined as a percentage of total peak flow for the sub-basin. This percentage was determined based on the ratio of the drainage areas that was located upstream from the first cross section.

2.5. STRUCTURE INVENTORY METHODOLOGY

In order to determine the number of flooded structures within the computed stream inundation, a structure inventory analysis was performed. The structure inventory analysis was performed utilizing the HCFCD building footprint file and calculating the average elevation from the 2018 LiDAR data. This average elevation was compared against an elevation raster created from the HEC-RAS water surface elevation results. For every instance where the average LiDAR elevation of a structure was below the computed water surface elevation of the 100-year event, that structure was considered “flooded”.

3. Historical Flooding Analysis

The Kingwood area has experienced structural flooding several times in the last few years as a result of heavy rainfalls. HCFCD provided five sources documenting historical flooded structures in the area were examined to help confirm the flooding: (1) Hurricane Ike September 2008, (2) Memorial Day 2015, (3) Tax Day 2016, (4) Memorial Day 2016, and (5) Hurricane Harvey August 2017. Immediately after Tropical Storm Imelda impacted the Kingwood Area in September 2019, a carpet count was performed as part of the scope of this project to approximate the number and location of flooded structures within the Kingwood Area. This data supplemented the flooded structure data provided by HCFCD. These flooded structure data was contextualized by using nearby rain gage data to perform a rainfall annual exceedance probability (AEP) analysis for the recent historical storm events. HCFCD rain gages 755 (San Jacinto River @ Lake Houston Pkwy), 760 (San Jacinto River @ US 59), and 790 (East Fork San Jacinto River @ FM 1485) as shown on **Exhibit 5** were used in conjunction with the HCFCD rainfall frequency and duration table. This information is summarized in **Table 3**.

Table 3. Annual Exceedance Probability for Recent Storms

Storm Event	Site ID	15-min	30-min	60-min	2-hr	3-hr	6-hr	12-hr	24-hr	2-day	4-day
Ike	755	0.8	1.2	2.3	3.6	3.7	4.2	7.0	7.4	11.5	11.5
	760	0.9	1.1	1.6	2.6	3.3	5.2	7.5	8.0	11.4	11.4
	790	0.8	1.0	1.3	2.2	2.9	4.8	7.8	9.4	12.0	12.0
Memorial Day 2015	755	0.7	1.2	1.8	3.1	3.4	3.6	3.6	3.6	4.8	5.1
	760	0.7	1.2	2.1	3.5	3.8	4.0	4.0	4.2	5.3	5.7
	790	1.2	1.6	1.9	3.0	3.0	3.2	3.2	3.2	4.3	4.8
Tax Day 2016	755	1.4	2.6	3.5	3.6	3.7	4.3	5.2	7.3	7.5	7.5
	760	1.4	2.4	3.2	3.4	3.4	5.8	6.6	6.7	6.8	6.8
	790	1.6	2.3	2.6	2.7	2.8	5.4	6.4	6.5	6.5	6.5
Memorial Day 2016	755	0.8	1.2	1.4	2.6	3.6	4.6	7.8	8.6	11.4	11.4
	760	0.6	0.9	1.6	2.6	3.0	3.8	3.9	4.0	4.0	4.0
	790	0.9	1.4	2.0	2.7	3.1	4.2	4.8	8.1	8.1	8.2
Harvey	755	*	*	*	*	*	*	*	*	*	*
	760	0.8	1.4	2.4	3.9	4.4	5.9	11.2	17.8	24.3	32.7
	790	0.8	1.4	1.7	2.2	3.0	5.0	8.0	15.5	20.4	27.2
Imelda	755	1.1	2.1	3.8	6.1	8.0	9.8	10.8	11.8	17.2	17.7
	760	1.5	2.9	5.4	7.3	9.0	10.8	11.4	11.7	15.8	16.2
	790	1.4	2.8	4.4	7.0	9.8	13.1	17.6	21.0	29.0	29.6

Color Coding of Atlas 14 Exceedance Probability							
<2-Year	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year

The results of this analysis show that the rainfall experienced during Hurricane Ike in 2008, Memorial Day 2015, Tax Day 2016 and Memorial Day 2016 were more frequent rainfall events. Imelda was approximately a 100-year event, and Harvey was approximately a 500-year event. The results also show

that during Hurricane Harvey, the area experienced 100-year and 500-year rainfall totals for 24-hour to 4-day durations resulting in riverine flooding. Tropical Storm Imelda also resulted in 100-year 24-hour to 4-day durations, however unlike Hurricane Harvey, Tropical Storm Imelda also resulted in 100-year rainfall totals during the shorter duration (60-min to 3-hour) rainfall that typically causes the local storm sewer systems to be overwhelmed thus resulting in extensive flooding within the subdivisions. HCFCD rain gage 790 shows that the East Fork San Jacinto River also experienced longer duration 100-year rainfall resulting in additional riverine flooding along the eastern border of Kingwood. This generally matches the flooded structure data available for the project area.

A summary of the historical flooding is provided in **Table 4**. In analyzing the data, the historical flooded structures were identified as either stream or localized flooding. Stream flooded structures are those structures located near or within influence of the streams and experienced flooding most likely as a result of water surface elevations along the stream. Localized flooded structures are those structures that are located outside of the influence of the streams and most likely experienced flooding from either overland flow conveyance limitations in the area or limitations of the existing internal drainage systems. Engineer's judgement was utilized in identifying the data as either stream or localized flooding. Memorial Day 2015 only had three recorded flooded structures caused by localized flooding and was excluded from the table.

Based on the data, the Kingwood area did not experience significant flooding of homes outside of Hurricane Harvey and Tropical Storm Imelda. While the other historical storm events such as Memorial Day 2015 resulted in flooding throughout Harris County, the Kingwood area experienced rainfall totals associated with more frequent storm events with frequencies less than the 10-year. Many of the structures that flooded during Hurricane Harvey were located within the 500-year FEMA floodplain associated with the West Fork San Jacinto River and East Fork San Jacinto, whose riverine floodplains are more influenced by the longer duration (24-hour to 4-day) rainfall totals. During Harvey, the shorter duration rainfall totals (60-min to 3-hour) were those of more frequent events and therefore did not overwhelm the internal drainage systems and smaller streams and tributaries. Tropical Storm Imelda also resulted in multiple flooded structures, most of which were identified as localized flooding outside the influence of their respective channels. This is most likely associated with the extremely heavy rainfall intensities experienced during Tropical Storm Imelda which quickly overwhelmed the existing internal drainage systems. The northeastern part of Kingwood experienced 100-year rainfall totals for shorter and longer duration (2-hr – 4-day) events and the data confirms both localized flooding and riverine flooding from the East Fork San Jacinto River and along Taylor Gully.

While the Kingwood area has been mostly spared from recent historical flooding events, Hurricane Harvey and Tropical Storm Imelda have highlighted certain deficiencies in existing streams and internal drainage systems related to longer and shorter duration 100-year rainfall events.

Table 4. Kingwood Historical Flooded Home Counts

Stream and Reach		Hurricane Ike 2008		Tax Day 2016		Memorial Day 2016		Hurricane Harvey		Tropical Storm Imelda	
		Stream	Local	Stream	Local	Stream	Local	Stream	Local	Stream	Local
HCFCD MAINTAINED STREAMS											
G103-33-00 (Bens Branch)	R1							5	2	9	4
	R2		1		1			4	16	1	12
	R3							450		2	
	R4							149			
G103-33-01	R1								33		133
G103-33-02	R1				1				7		9
G103-33-03	R1				1				11	2	33
G103-33-04	R1		1					273	8		12
G103-38-00 (Kingwood Diversion Ditch)	R1				2			49	62		63
	R2							228			
G103-38-01	R1		2						67		56
	R2		1						8		1
G103-38-01.1	R1								24		3
G103-38-02	R1		1								
G103-41-00	R1							48			10
	R2							151			
G103-41.01	R1							179			1
G103-45-00	R1							32	17	1	1
G103-80-01	R1							3	50		3
G103-80-03.1B	R1							2		135	15
	R2							22	200	237	60
	R3							2	20	1	2
STREAMS MAINTAINED BY OTHERS											
G103-36-00 (Bear Branch)	R1		1					64	16	4	46
	R2							54			
	R3							273			
	R4							0	0		
G103-36-01	R1							53			
	R2							0	0		
G103-36-02	R1							45	7		1
G103-36-02.1	R1							27	3		2
G103-36-03	R1							99			
G103-39-00	R1		1							3	10
	R2					1		1		64	
	R3		1			3		3		36	
G103-46-00	R1					9		76	4		
G103-46-01	R1								50		
	R2								1		
G103-80-03.1A	R1							1	2		
G103-80-04	R1								2		1
	R2							32			3

4. Overland Flow Analysis

In an effort to better understand the overland flow paths in the Kingwood Area a 2D hydraulic model was developed for Kingwood and the surrounding area. The original scope of services for this project identified the use of HEC-RAS 2D for this analysis, but due to the extent of existing storm sewer within the Kingwood Area an analysis of the hydraulic capacity of these existing storm sewers in addition to the riverine flooding was desired. With HEC-RAS unable to fully evaluate existing storm sewers, Innovyze ICM 2D modeling software was chosen which allows the study of both of these elements.

As with any other area in Harris County, there are several different ways that homes can flood. Bayou flooding for areas within a floodplain can directly result in flooding of structures, but additionally, water trying to make its way to the bayous can also result in flooding. Thus, analyzing overland flow in the Kingwood area is an attempt to identify how water moves from high points in Kingwood to the major drainage channels. This overland flow will be impacted by storm sewer systems, as storm sewer systems (and roadside ditches where they exist) provide a direct path for rainfall runoff to drain into the major drainage channels. Storm sewer systems are typically designed to handle a 2/3 year rainfall event; thus, the addition of extreme event sheet flow paths is the measure by which excess runoff can flow overland to the major drainage channel. Extreme event sheet flow design standards were not developed as a requirement for new development until around the year 2000, thus many portions of Kingwood were constructed without a path for overland flow to follow. Thus, when rainfall rates exceed approximately 1 inch per hour, we would expect to start seeing street flooding and if the short duration rainfall intensity continues that flooding can result in sheet flow flooding as water builds up in area roads.

The main goals of this high-level overland flow analysis are as follows.

Primary Goals of Overland Flow Analysis

- Evaluate the potential for riverine flooding
- Evaluate the patterns of overland sheet flow from Montgomery County
- Evaluate the risk of upland areas where the performance of the existing collection system (storm sewers and overland flow) may put existing developments at risk
- Compare results to effective existing flood plain boundaries
- Compare results to previous historical flooding reports from previous storm events (Harvey, Imelda, Tax Day, etc.)

The overland flow analysis is intended to be a high-level analysis of the drainage trends in the area, and a basis to confirm results from the steady and unsteady analysis of the drainage channels within the Kingwood Study Area. Limited analysis of the storm sewer infrastructure was conducted to assist in understanding runoff patterns. Therefore, this analysis is based on information that is readily available from City of Houston GIMS and other local agencies and not based on any detailed survey information. A more detailed and thorough analysis of the drainage system is recommended before comprehensive improvement options for the collection system can be provided. The following is a breakdown of the assumptions and data that was used to develop the 2D hydraulic model for the project area existing conditions.

2D Modeling Parameters and Assumptions

- 2018 LiDAR from HGAC was used to develop as the surface mesh for the 2D Model
    - Streams were hydraulically enhanced to remove bridge and culvert structures in the major channels.
    - Woodridge Subdivision improvements are not reflected in the 2018 LiDAR data.
- Software = Innovyze ICM 2D (Version 9.0.4.18017)
- Rainfall = Atlas 14 Rainfall Depths – Full rainfall depths for the 2, 5, 10, 25, 50, 100-yr rainfall frequencies were simulated. Only the 100-year rainfall frequency analysis was used to evaluate the overland flow conditions in the study area.
- Storm Sewer – Used City of Houston GIMS data for main storm sewer trunk lines, manholes and inlets. The inlets were set to accept flow from the mesh with no limitations, so flow restrictions were based on storm sewer trunk line capacity as modeled by the 2D analysis flows to the underground storm sewer systems were not limited by inlet capacity.
    - Storm sewer pipe sizes and flowlines were only included where the City of Houston had information available for download from GIMS online.
    - Areas outside the City of Houston and areas of Montgomery County did not include underground storm sewer as that information was not readily available.

Key findings from the 2D Overland Flow Analysis are listed below by region below and shown on **Exhibit 6**. Areas that are at risk to riverine flooding are shown per the 100-year storm frequency inundation zones, and areas at risk of overland sheet flow due to storm sewer surcharged conditions during extreme events are shown in the highlighted magenta storm sewers that are noted as Recommended Storm Sewer Investigation Area (SSIA). The numbers correspond to the locations described below. These highlighted existing storm sewers are in areas that warrant additional investigation to verify performance during extreme event conditions. The storm sewers may be in areas that have had historical flooding, and/or have ponding greater than 2-feet with the 2D overland flow analysis. Recommendations are for these storm sewers to be checked against current City of Houston criteria post Atlas 14. ArcHydro overland flow lines are also shown on the exhibit that represent data available from HCFCD. The 2D overland flow analysis is divided in the watershed regions below, and Montgomery County which is treated separately as it covers multiple watersheds.

Montgomery County

The 2D modeling within Montgomery county was limited to the existing 2018 LiDAR as storm sewer, detention, and culvert information was not readily available. The scope of work did not include a thorough evaluation of the region to confirm the LiDAR topographic representation against the actual conditions. Changes to the region that occurred following the collection of the 2018 LiDAR were not incorporated. The goal was to confirm overland flow zones and how these flows may impact Harris County drainage facilities.

- Overflow from Bens Branch to Taylor Gully Watershed occur during extreme events north of Woodridge Forest Middle School and south of Meadow Lane as shown on Exhibit 1 of 6.

- Flows to Taylor Gully tend to occur from the region bounded by Ford Road to the north, Meadow Lane to the west, and Ford Road to the east within Montgomery County.
- Sheet flow from west to east to Taylor Gully follows an existing channel that runs south of Woody Lane, and Needham Road to the existing L-Shaped basin that was constructed prior to Woodridge Improvements.
- Flows to Bens Branch flow south from this area via existing drainage channels within the North Park Recreation Area around the Kingwood Park High School, and drainage channels to the west of Woodridge Forest Middle School (Bens Branch Tributary No. 1)
- A review of the Bentwood Diversion Channel west of IH 69 shows that there may be overflows occurring during extreme events into the upper portions of Bens Branch, as the Bens Branch channel extends west to this channel but is not directly connected.

Mills Branch – (G103-80-03.1A)

- The North Kingwood Forest Subdivision is located in the historic Mills Branch channel watershed west of Mills Branch Road. Overland flow from the north of this subdivision now drains west towards Taylor Gully and it is collected in a large backslope swale and interceptor within Harris County just west of the subdivision. This appears to be a large drainage area for the existing interceptor channel and additional interceptors may be warranted in this area for extreme events to allow water to drain into Taylor Gully.
- Areas east / downstream of Mills Branch Road appear to sheet flow according to more recent HCFCD guidelines as ponding areas are not significant.
- The southern portions of the Country Colony Subdivision have storm sewers that drain north, but extreme event overflows will follow the natural contours south to Mills Branch.
- Overland sheet flow investigation areas –
    - Private culvert for sand pit appears to be undersized compared to adjacent structures, but overflows in this area of the watershed do not impact properties.

Taylor Gully – (G103-80-03.1B)

- Confirmed sheet flow from Montgomery County at the upstream end of Taylor Gully that appears consistent with residential reports, and ponded areas on the 2D inundation map tend to reflect the current effective 0.2% flood zones in the area of Elm Grove.
- The low area where ponding shown on the map west of W. Lake Houston Blvd. in the Elm Grove neighborhood is due mainly to riverine conditions as street ponding starts to occur in the Elm Grove area near the 10-year storm frequency.
- A separate low area shown on the inundation maps extends from areas east of W. Lake Houston Blvd. south of Taylor Gully, then continues to the northeast towards Mills Branch Road, then follows Mills Branch Road to the southeast back towards Taylor Gully. This area is also evident on the current FEMA effective 0.2% flood hazard zone maps.
- Overland sheet flow investigation areas –
    - SSIA #1 - Review of storm sewer capacity extreme event flow paths along Pikwick Park Dr. and Manor Forest Dr. is warranted as there are ponding areas evident in this area that may be due to backwater from Taylor Gully.

- SSIA #2 - Brook Shore Ct. and Laurel Mist Ct. – Cul-de-sac streets channel overland flows towards Taylor Gully, a review of extreme event storm sewer and overland flow performance is warranted, and a review of the existing culvert crossing at Scenic Woods Trail to the south that drains a small tributary of White Oak Creek as residents in the area note ponding in this channel. Residents in the area identify backwater from White Oak Creek as an issue in this area that impacts low areas near the Berry Knoll cul-de-sac, and other lower properties in this area. Evaluation of White Oak Creek was not part of this analysis and it is likely that backwater from White Oak Creek and the adjacent East Fork San Jacinto River may be the dominant factor in the street ponding in this area vs. Taylor Gully that would require additional investigation as this area is considered in the 500-year effective floodplain of the East Fork San Jacinto River.
- SSIA #3 - Pine Prairie Ln and Dobbin Springs Ln. – Cul-de-sac streets channel overland flows to Taylor Gully and a review of extreme event storm sewer and overland flow performance is warranted as there is no clear path for overflows to Taylor Gully. Existing 100-year inundation in this area shows that channel improvements may improve storm sewer performance by lowering WSEL's in Taylor Gully.
- SSIA#4 - Pine Breeze Drive to Tree Manor Ln – This is a regional low area where overflow from the roadside ditch areas on Long Leaf Lane tend to drain towards Mills Branch Drive. GIMS records show 12-inch pipes were installed along the back lots on Pine Breeze. A review of possible overflows from Acorn and Long Leaf Roads following the overland sheet flow lines towards Pine Breeze is warranted.
- SSIA#5 - Rock Springs Drive and Natural Bridge Drive – both of these north/south corridors near Northpark Drive have existing storm sewer trunk lines that drain either side of Hidden Hollow Elementary. Deep street ponding is evident in these corridors around Hilden Hollow Elementary and homes in the general area appear to be at risk based on the 2D results. Extreme event analysis is warranted in this area due to the proximity to the school. Existing 100-year inundation in this area shows that channel improvements may improve storm sewer performance by lowering WSEL's in Taylor Gully.
- SSIA#6 - Echo Mountain Drive near Mills Branch Drive – This is in the 0.2% overflow zone from Mills Branch Drive from the northwest and has a 72-inch outfall to Taylor Gully. Excessive ponding is evident in this area, and additional study of extreme event storm sewer and overland flow performance is warranted in this area up to Spruce Bay Dr. Existing 100-year inundation in this area shows that channel improvements may improve storm sewer performance by lowering WSEL's in Taylor Gully.

<u>Green Tee Ditch (G103-80-01)</u>

- Riverine modeling suggest that the existing channel has conveyance capacity for the 100-year storm event.
- Overland sheet flow investigation areas –

- SSIA#7 - Areas around Shadow Forest Elementary – The area from Autumn Sage Ln. near the school south to Riverchase Village Dr. north of Mills Branch Dr. show street ponding. Additional extreme event review of the storm sewer design for this area is warranted due to the proximity to the school.
- SSIA#23 - Woodland View Dr. near Green Tree Ditch – a number of storm sewers converge in this area, but overland sheet flow to the ditch does not appear to have a clear path to G103-80-01. Ponding in the neighborhood in this area is approaching structures in areas near Haven Pines, Hill Springs and Brook Shadow Dr. where ponding is most evident. A review of extreme event storm sewer capacity to G103-80-01 in this area is warranted as overflows tend to drain south to the adjacent watershed G103-33-01.

Backland Gully (G103-80-04)

- Riverine modeling suggest that the existing channel has conveyance capacity for the 100-year storm event.
- Overland sheet flow investigation areas –
  - SSIA#8 - Areas around Riverwood Middle School – The ponding in this area appears to be localized around the Middle School as it is the high area between a number of watersheds. A review of the storm sewer extreme event design on Kingwood Drive to the west and Whispering Fern and Hazy Hillside to the east are warranted due to the proximity to the school.

Sand Branch – G103-41-00 and G103-41-01

- Riverine modeling suggest that the existing channel has conveyance capacity for the 100-year storm event.
- There is some riverine ponding risk near Kingwood Drive and the parking lot areas for Strawbridge United Methodist, and First Presbyterian Church but levels appear to be below structures in this area.
- Overland sheet flow investigation areas –
  - SSIA#9 - Cul-de-Sac Streets – the ends of Lone Cedar, Woodland Creek and Spring Lodge tend to block overland sheet flows to Sand Branch and must drain through existing properties. An investigation of extreme event relief is warranted to provide conveyance directly to Sand Branch.
  - SSIA#10 - Low area from Wooded Villas Dr. and Garden Point Dr. – A low area runs along Wooded Villas Dr. south to Hemlock Lakes Drive, Mt. Forest Dr. then south to an existing lake. Homes along this low area appear to be at risk due to the collection of overland flows from areas to the north up to Willow Terrace Drive. Imelda rainfall significantly impacted this area, and investigation of extreme events is warranted for the storm sewers draining this area.
  - Areas around Shadow Forest Elementary – The area from Autumn Sage Ln. near the school south to Riverchase Village Dr. north of Mills Branch Dr. show extensive street ponding. These areas appear to be impacted more by backwater from the Sand Branch vs. storm sewer conditions.

Bens Branch (G103-33-00)

- Riverine modeling suggest that the existing channel only has a conveyance capacity of a 2-yr event, however with most of the riverine flood risk areas within close proximity to the main channel as slopes are generally steep to the main channel. The St. Martha Catholic School has been one of the main properties impacted in the vicinity of Bens Branch, along with Northpark Dr. and Aspen Glade Dr. that runs parallel and south of Northpark.
- Overland sheet flow investigation areas –
    - SSIA#11 - Storm sewer along Hidden Pines – Main ponding areas are at a localized low area between the intersection of Little Cedar Dr. and Middle Creek Dr. Improvements to the Kingwood Diversion Ditch may improve storm sewer performance as this area may be impacted more by backwater from Bens Branch.
    - SSIA#12 - Area near Woodland Hills Elementary – storm sewer along Little Cedar Dr. west of the school appears to have significant ponding and overflows south west towards Woodland Hills and Lake Hills Drive via. the open trail areas. A review of the storm sewer performance under extreme event conditions is warranted to determine if overflows from this area can be reduced.

Kingwood Diversion Ditch (G103-38-00)

- This channel runs through areas that are relatively high upland areas compared to Bens Branch so 100-year flows are contained within the channel.
- Overland Sheet Flow Zones –
    - SSIA#13 - Storm sewer along Lake Hills that drains outfalls near Shadow Rock Dr. - Large collection of homes at risk in the area of Lake Hills Dr. and Round Springs Drive to Three Pines Dr. where an extreme event storm sewer investigation is warranted to determine if more flow can be directed to G103-38-00 and reduce overland flows to the east.
    - SSIA#14 - Main ponding areas appear to be localized low area between the intersection of Little Cedar Dr. and Middle Creek Dr. This storm sewer is connecting a low area that is in close proximity to the storm sewers along Hidden Pines to Bens Branch that that need to be reviewed for extreme event conditions as well.

G103-33-01

- Riverine HEC-RAS modeling suggest that the existing channel has conveyance capacity, however flows are overtopping banks upstream of Sandy Forks Drive in proximity to Creekwood Middle School.
- Apparent overland sheet flow investigation areas –
    - Many localized sheet flow zones within the area with many homes impacted during Imelda, all of storm sewers at these locations need to be reviewed to evaluate performance during extreme event conditions.

- SSIA#15 - Storm sewer trunk line at upstream end near Northpark Drive that extends north along Flint Creek Dr.
- SSIA#16- Storm sewer along Silver Falls
- SSIA#17 - Storm sewer along Village Park
- SSIA#18 - Storm sewer along Park Garden

G103-33-04

- Riverine HEC-RAS modeling suggest that the existing channel has riverine flooding in close in areas near Kingwood Dr. and the existing shopping center parking lots.
- Apparent overland sheet flow investigation areas are localized in a few areas that relate to some of the major storm sewers that outfall to G103-33-04.
    - SSIA#19- Storm sewer that drains from Grove Terrace Dr. to Oakwood Forest to Highland Laurels to Grand Falls Dr. south to the main channel. Apparent potential structural flooding areas appear to be on the upper end of the system along Grove Terrace and street ponding along Oakwood Forest. Extreme event analysis is warranted on the storm sewers in this area.
    - SSIA#20 - Areas around Aspen Mountain Trail, Pecan Park Lane and Deer Hollow Drive north of Kingwood Drive have a number of homes impacted by Imelda, with areas near Deer Hollow related to overland sheet flow paths in this area. Areas on Pecan Park Ln. appear to be lower and subject to riverine flooding.

G103-36-00

- Riverine HEC-RAS modeling suggest that the existing channel has riverine flooding in close in areas north of Kingwood Dr. on Royal Circle Dr.
- Overland sheet flow investigation areas – These are localized in a few areas that relate to some of the major storm sewers that outfall to this channel.
    - Extensive ponding areas around Kingwood Middle School, Lake Hills Dr. and Woodland Hills Dr. appear to get overflows from storm sewers draining to Bens Branch to the north. An investigation into possible backwater conditions on G103-36-00 may contribute to the risk to this area and require additional investigation as this may be more due to the adjacent 100-year areas vs. storm sewer capacity.
    - SSIA#21 - Low concentrated sheet flow zone – There is a low area that runs from approximately Trailwood Village Dr. and Laurel Hill Dr. and traverse's northeast towards Kingwood Dr. and Big Springs Dr. then to the outfall near Woodland Hills Dr. and Rolling Meadows Dr. The west portions of this area drain to the Bens Branch Bypass channel. Potential limitations of that system may contribute to sheet flows that drain to G103-36-00 and cause excessive ponding on Kingwood Blvd. west of Woodland Hills. A review of the area shows that there are not many locations for overflows to be collected along this low area and all of the pipes leading collecting this area are only 24-inch in diameter. A review of storm sewers draining to the Kingwood Diversion Ditch, G103-36-00, and G103-36-02.1 are warranted as improvements to all of these systems may be necessary as the overflow zone crosses all of these storm sewer systems.

G103-36-02/G103-36-01 and G103-36-03

- Riverine HEC-RAS modeling suggest that the existing channel has 100-year capacity and includes a large wooded / wetland area that drains into the West Fork San Jacinto River and flooding in this area more dependent on flows to the San Jacinto River than local flows.
- Overland sheet flow investigation areas –
    - SSIA#22 - Storm sewer along 7 Oaks Drive appears to be the main issue in this area as there is a channel and storm sewer that drains towards the back lots of homes on 7 Oaks Drive that appears to put homes on the north side of 7 Oaks Drive at risk, an extreme event analysis is warranted on this storm sewer system to check performance.

5. Existing Conditions & Level of Service Analysis

Existing hydrologic (HEC-HMS Version 4.2.1) and hydraulic (HEC-RAS Version 5.0.7) models were developed following the methodology outlined in Section 2.4. The data from the hydraulic models was used to develop the frequency event floodplains for the Kingwood Area utilizing RAS Mapper within the HEC-RAS program. The level of service was determined for each stream's reach based on whether the frequency event inundation limits were contained to the streams ROW or the wooded trails and areas next to the stream. Additionally, the streams were evaluated to determine whether the roadway crossings were overtopped during a specific frequency event. The limits for the stream segmentation are shown on **Exhibit 4.**

5.1. HCFCD MAINTAINED STREAMS

5.1.1. HCFCD UNIT G103-33-00 (BENS BRANCH)

Bens Branch (HCFCD Unit G103-33-00) is a tributary to West Fork San Jacinto River, HCFCD Unit G103-00-00. Inside Harris County, the channel has a length of approximately 4.7 miles from the Montgomery County boundary draining southeast towards the outfall into West Fork San Jacinto River, HCFCD Unit G103-00-00. An additional 1.3 miles extends into Montgomery County. Historical aerials show that much of the development within the Bens Branch watershed within Harris County had occurred prior to 1980. Most of the development within Bens Branch watershed was constructed without detention mitigation or in consideration of extreme event flowpaths. Based on available aerials, Bens Branch was originally a natural channel with some improvements such as the clearing of trees and channel improvements constructed along with the development within the watershed. A portion of the channel from downstream of Woodland Hills Drive to Rocky Woods Drive was left in its natural condition.

The Kingwood area has recently experienced significant widespread flooding with Hurricane Harvey and Tropical Storm Imelda. Within Bens Branch watershed Hurricane Harvey in 2017 was responsible for 626 flooded structures while 28 structures flooded during Tropical Storm Imelda in 2019. Only a single structure reported flooding in the 2016 Tax Day floods and there was no recorded flooding during the 2015 and 2016 Memorial Day Storm Events.

For purposes of presenting the data, the stream was segmented into 4 reaches defined as:

- Reach 1 – From the border with Montgomery County to the confluence with HCFCD Unit G103-33-02.
- Reach 2 – From the confluence with HCFCD Unit G103-33-02 to Rocky Woods Drive.
- Reach 3 – From Rocky Woods Drive to downstream of West Lake Houston Parkway at the confluence with HCFCD Unit G103-33-04.
- Reach 4 – From the confluence with HCFCD Unit G103-33-04 to the confluence with West Fork San Jacinto River, HCFCD Unit G103-00-00.

A summary of physical characteristics is shown below in **Table 5**.

Table 5. Summary of HCFCD Unit G103-33-00 (Bens Branch) Physical Characteristics

HCFCD Unit G103-33-00	Reach 1	Reach 2	Reach 3	Reach 4
Condition	Improved	Natural	Improved	Improved
Depth (ft)	5.5-8.0	5.5-11.0	6.5-9.5	7.0-14.0
Top width (ft)	25-65	20-135	85-240	270-295
Longitudinal slope (ft/ft)	.0012	.0017	.0007	.0005
Side slope (H:V)	3.1:1 – 4.0:1	--	2.0:1 – 4.0:1	4.0:1
Maintenance berm	No	No	No	No
ROW	HCFCD/Public	Friendswood and Bear Branch Trail Association	HCFCD	Other
ROW Width (ft)	100 – 120	100	160 – 260	--

5.1.1.1 Hydrologic Analysis

The topology along Bens Branch drains southeasterly towards the West Fork San Jacinto River. Bens Branch drains a total of 9.8 square miles through the Kingwood area and ultimately outfalls into the West Fork San Jacinto River. Approximately half of the drainage area, 4.67 square miles, is located outside of Harris County within Montgomery County. Historically, there was an additional 4.8 square miles located west of US 59 that drained to Bens Branch; however a channel was constructed in the early 1990's that rerouted this area to drain to the West Fork San Jacinto River. During high rainfall events, some of the water still drains towards Bens Branch due to out of bank flooding following the existing topography. This rerouted drainage area is identified in the FEMA effective HEC-HMS model as G10333A. For the purposes of this project, the flow diversion relationship from the FEMA effective model was maintained. *In order to determine a new diversion relationship, a more detailed drainage analysis would need to be performed.* The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**. A comparison of the FEMA drainage areas and the revised drainage areas is shown on **Exhibit 7**.

The land use along Bens Branch is a mix of single-family residential, commercial, and undeveloped land. The land use Basin Development Factor (BDF) within Harris County is primarily Pre-1984 Storm Sewer with a mix of undeveloped natural areas along the channel and some open space. Some post-1984 storm sewers exist downstream of Kingwood Drive within newer developments. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

The storage routing reaches within the FEMA effective HEC-HMS model upstream of the county boundary were maintained. Development for the storage routing reaches along the tributaries were done following the methodology of **Section 2.0**. Routing along Bens Branch and Kingwood Diversion Ditch was performed within an unsteady HEC-RAS model and are not included within the HEC-HMS model.

A hydrologic analysis was performed to determine the runoff hydrographs along Bens Branch for five (5) Atlas 14 frequencies which include the 2-, 10-, 25-, 50- and 100-year storm events. A comparison of the FEMA effective and the existing condition 100-year peak flows is shown in **Table 6**. The results show an

increase in 100-year peak flows ranging from approximately 40% downstream of the confluence with the Kingwood Diversion Ditch and 18% at the confluence with the West Fork San Jacinto River. The large difference in peak flows is a result of utilizing the Atlas 14 rainfall data and the amount of flow that is diverted to the Kingwood Diversion Ditch. The FEMA effective model inflow-diversion relationship at the Kingwood Diversion Ditch diverts a maximum flow of 999 cfs during the 100-year storm event The unsteady HEC-RAS model with increased peak flows as a result of Atlas 14 rainfall only diverts 720 cfs. The results show that the diversion relationship within the FEMA effective HEC-HMS model may not be accurate with the majority of flow continuing along Bens Branch.

Table 6. Peak Flow Comparison for HCFCD Unit G103-33-00 (Bens Branch)

Item		Reach 1	Reach 2	Reach 3	Reach 4
100-Yr Flow (cfs)	FEMA	2282 – 2651	2651 – 2983	2983 – 5454	5454
	Revised (Atlas 14)	3198 – 3799	3799 – 4477	4477 – 6235	6235 - 6434

5.1.1.2 Hydraulic Analysis

The FEMA effective model for Bens Branch was used as the base model for the analysis. The model was converted to an unsteady model and the existing cross sections revised following the methodology discussed in **Section 2.0**. Runoff hydrographs from the HEC-HMS model were input into the HEC-RAS model at their respective flow locations. A summary of the hydrograph distribution is provided in **Table 7**. The FEMA effective downstream boundary condition was maintained as normal depth.

Table 7. HCFCD G103-33-00 (Ben's Branch) Existing Hydrologic Input Summary

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
29615	Flow Hydrograph	G1033300_0009_J	854	1469	1933	2338	3287
29024.31 - 27513.68	Uniform Lateral Inflow	G1033300A	237	376	473	552	641
27441.69	Lateral Inflow	G1033303A	89	136	168	192	220
26458.74 - 24159.50	Uniform Lateral Inflow	G1033300B	132	211	265	309	360
24209.16	Lateral Inflow	G1033302A	209	330	413	480	557
23234.05 - 21847.04	Uniform Lateral Inflow	G1033300C	130	209	265	311	364
21221.31 - 19400.18	Uniform Lateral Inflow	G1033300D	137	221	280	330	386
18617.86 - 16519.62	Uniform Lateral Inflow	G1033300E	94	152	192	226	264
15455.73 - 13023.86	Uniform Lateral Inflow	G1033300F	152	238	297	345	398
14299.67	Lateral Inflow	G1033301_0000_J	708	1137	1425	1662	1928
12941.61 - 11521.57	Uniform Lateral Inflow	G1033300G	117	180	222	256	293
9501.098 - 7739.881	Uniform Lateral Inflow	G1033300H	178	278	347	403	466
7739.88	Lateral Inflow	G1033304_0000_J	444	698	877	1023	1186
6455.492 - 4371.619	Uniform Lateral Inflow	G1033300I	166	264	331	387	449

The model cross sections were revised following the methodology discussed in **Section 2.0**. Near the outfall into the West Fork San Jacinto River along Reach 4, the standing water surface elevation from Lake Houston prevents the LiDAR data to capture elevations below the water surface. The cross section data from the FEMA effective model was used to supplement the 2018 LiDAR data within the bank stations since this data was based on detailed survey. The FEMA effective HEC-RAS model begins at river station 29329.48 just downstream of the confluence with Kingwood Diversion Ditch. The model was extended to river station 29615 in order to model Kingwood Diversion Ditch and the confluence within this unsteady HEC-RAS model. Some of the cross sections were trimmed to prevent overlapping with new cross sections added for the Kingwood Diversion Ditch. Discussion for the hydrologic and hydraulic analysis of the Kingwood Diversion Ditch is presented in **Section 5.1.6**.

The Manning's coefficient n-values from the FEMA effective model were maintained. For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.07 was used, depending on the location along the reach. Overbank n-values ranging from 0.06 to 0.125 (0.99 for ineffective areas) were used. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

Bens Branch within the project area includes the following stream crossings:

- Roadway Culvert Crossing – Two (2) [North Park Drive Westbound, North Park Drive Eastbound]
- Roadway Bridge Crossing – Four (4) [Woodland Hills Drive, Tree Lane, Kingwood Drive, West Lake Houston Parkway]
- Pedestrian Culvert Crossing – One (1) [Bear Branch Trail at Park Point Drive]
- Low Water Crossing – One (1) [Between Westbound and Eastbound North Park Drive]

The FEMA effective HEC-RAS model did not include the pedestrian culvert crossing or the low water crossing. These crossings were added to the HEC-RAS model utilizing information collected from the field reconnaissance and 2018 LiDAR data. The following is a summary of the added stream crossings:

- Low Water Crossing (River Station 27730) – Culvert crossing located between the eastbound and westbound lanes of North Park Drive within Reach 1.
    - Bridge Width – 22 feet.
    - Four (4) 24-inch concrete culverts 25 feet in length.
- Pedestrian Culvert Crossing (River Station 21058.2) – Bear Branch Trail crossing located in Reach 2 that allows pedestrians to cross Bens Branch from Spring Gardens Drive to Sycamore Shadows Drive.
    - Bridge Width – 25 feet.
    - Three (3) 36-inch plastic pipes 25 feet in length.

Based on information gathered from the field reconnaissance, four (4) of the modeled bridges required revisions to match existing conditions. The following is a summary of the revisions to the stream crossings:

- Westbound North Park Drive (River Station 27951.87) – Construction of Woodridge Pkwy in Montgomery County occurred in 2008-2010 and resulted in lengthening of the culvert crossing.
    - The culvert length increased from 164 feet to 221 feet.
    - The deck width increased 70 feet.
    - Due to the increased bridge width, cross section 28041.94 was removed, and cross section 28114.66 became the upstream bounding cross section. The ineffective flow areas and reach lengths were revised accordingly.
- Eastbound North Park Drive (River Station 27561.33) – The FEMA effective model analyzed this crossing as 2–9'x7.5' concrete box culverts. Based on the field reconnaissance and HCFCD pictures of the stream crossing, the culvert crossing is 2 – 84" circular concrete pipes.
- Tree Lane (River Station 19468.8) – The downstream bounding cross section 19432.78 was located along the roadway embankment. This cross section was moved downstream to river station 19400.18 beyond the limits of the roadway embankment. Reach lengths were adjusted accordingly.
- Kingwood Drive (River Station 13136.92) – The cross section layout for Kingwood Drive in the FEMA effective model crossed Kingwood Drive within the right overbank and did not capture the lowest roadway elevation. The surrounding cross sections were revised to align parallel to Kingwood Drive and the high chord elevations were taken from 2018 LiDAR data. The resulting change to the bridge crossing allows water to overtop Kingwood Drive beginning at elevation 52.61 feet compared to the FEMA effective model which did not allow overtopping of the roadway until elevation 54.56 feet. The ineffective flow area elevations were adjusted accordingly.

5.1.1.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 45.3 feet near the confluence with West Fork San Jacinto River to 74 feet immediately downstream of the Kingwood Diversion Ditch to 75.7 feet at the upper limits of the model in Montgomery County. The FEMA effective model has water surface elevations ranging from 44.8 feet at the confluence with West Fork San Jacinto to 73.5 feet downstream of the Kingwood Diversion Ditch. The largest difference in water surface elevation occurs in Reach 3 with the unsteady HEC-RAS model producing water surface elevations that are up to 2.3 feet higher than the FEMA effective model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 8**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel does not have a 100-year level of service with a potential of 101 flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. Of the 101 structures, 7 were identified as critical structures, e.g., Kids in Action daycare, St. Martha Catholic School and buildings for Kingwood High School. The results show that the majority of Bens Branch has a less than 2-year level of service with inundation outside of the existing ROW. The results also show that while the channel does not have enough capacity, the ponding inundation limits is generally not widespread as highlighted by the relatively few potential flooded structures given the size of the Bens Branch watershed within the project area.

Table 8. HCFCD Unit G103-33-00 (Bens Branch) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	36	< 2-Year
2	13	2-Year
3	52	< 2-Year
4	0	< 2-Year

5.1.2. HCFCD UNIT G103-33-01

HCFCD Unit G103-33-01 is a 1.3 mile long tributary to HCFCD Unit G103-33-00 (Bens Branch) and runs parallel to West Lake Houston Parkway. The channel begins south of Northpark Drive and drains south to Bens Branch near Kingwood Drive. Historical aerials in the area show the channel undergoing construction to its current condition around 1978 with most of the watershed undeveloped with subdivisions adjacent to the west of the channel also under construction at that time. Most of the development in the watershed had been constructed by 1995 without any surface detention mitigation.

Based on available aerials, the channel geometry and alignment has not changed since construction in 1978. Recent storms have shown an increase in the number of flooded structures. While no structures were recorded to have suffered flood damage during the 2015 Memorial Day, 2016 Memorial Day or Tax

Day floods, 33 structures flooded during Hurricane Harvey in 2017. Tropical Storm Imelda in 2019 resulted in 133 structures flooding.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 9**.

Table 9. Summary of HCFCD Unit G103-33-01 Characteristics

HCFCD Unit G103-33-01	Reach 1
Condition	Improved natural
Longitudinal slope (ft/ft)	0.0024
Depth (ft)	8.5 – 14.5
Top width (ft)	70 – 100
Bottom width (ft)	7 – 23
Side slope (H:V)	2.5:1 – 3.5:1
Maintenance berm	Yes
ROW (ft)	140 – 150
Owner	HCFCD
Construction Date	Before 1978

5.1.2.1 Hydrologic Analysis

The topology along HCFCD Unit G103-33-01 drains south towards the HCFCD Unit G103-33-00 (Bens Branch). HCFCD Unit G103-33-01 drains a total of 1.2 square miles through the Kingwood area and ultimately outfalls into the Bens Branch. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-33-01 is a mostly single-family residential with some commercial areas and undeveloped land. The land use Basin Development Factor (BDF) within Harris County is primarily Pre-1984 Storm Sewer with some Post-1984 Storm Sewer and Roadside Ditch drainage and some undeveloped natural areas near the outfall. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.2.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 10**. The downstream boundary condition was established as normal depth.

Table 10. HCFCD Unit G103-33-01 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
6755.0	G1033301A	219	338	418	481	552
6539.0	Interpolated Flow	233	360	446	514	590
6283.0	Interpolated Flow	252	389	482	556	639
6010.0	Interpolated Flow	273	423	524	605	696
5741.0	Interpolated Flow	295	458	569	657	756
5507.0	Interpolated Flow	316	492	611	707	813
5200.0	Interpolated Flow	346	539	671	777	895
4943.0	G1033301_0002_J	373	583	726	841	969
4754.0	Interpolated Flow	392	613	765	886	1021
4594.0	Interpolated Flow	409	640	799	925	1068
4461.0	Interpolated Flow	424	664	828	960	1108
4145.0	Interpolated Flow	460	723	903	1047	1209
4020.0	Interpolated Flow	476	748	934	1084	1252
3754.0	Interpolated Flow	510	803	1004	1166	1348
3449.0	Interpolated Flow	553	872	1091	1268	1467
3291.0	G1033301_0001_J	577	910	1139	1324	1533
2789.0	Interpolated Flow	599	949	1187	1381	1599
2284.0	Interpolated Flow	622	989	1238	1441	1669
1976.0	Interpolated Flow	637	1014	1270	1479	1713
1165.0	Interpolated Flow	677	1084	1358	1583	1835
580.0	G1033301_0000_J	708	1137	1425	1662	1928

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.085. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-33-01 includes the following stream crossings:

- Roadway Bridge Crossing – One (1) [Sandy Forks Drive]
- Pedestrian Bridge Crossing – One (1) [Park Garden Drive]
- Drop Structure – Two (2) [Downstream of Sandy Forks Drive and the other is near Rocky Woods Drive]

5.1.2.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 54 feet near the confluence with Bens Branch to 66.5 feet at the upper limits of the model near Silver Falls Drive.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 11**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are

shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. At Creekwood Middle School, the 100-year stream inundation goes out of bank where there is an existing low-lying area, however, the inundation is contained in the low-lying grass areas near the school track and do not present any flood risk. There are structures within the subwatershed of G103-33-01 that flooded during the Atlas 14 100-year storm event, but the structural flooding is associated with the water surface elevations along HCFCD Unit G103-33-00 (Bens Branch) which are over 1 foot higher.

Table 11. HCFCD Unit G103-33-01 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.1.3. HCFCD UNIT G103-33-02

HCFCD Unit G103-33-02 is a 0.2 mile long tributary to HCFCD Unit G103-33-00 (Bens Branch) located near the county boundary. The channel starts at Northpark Drive and flows south. Historical aerials in the area show the channel undergoing construction around 1978. Residential development was also occurring north of Northpark Drive. Most of the development in the watershed had been constructed by 2002 without any surface detention mitigation.

Based on available aerials, the channel geometry and alignment has not changed since construction in 1978. Recent storms have only shown a few structures flooding in the watershed. Neither the 2015 nor 2016 Memorial Day floods caused reported structural flooding. Only 1 recorded structure flooded during the 2016 Tax Day Floods, 7 structures flooded during Hurricane Harvey in 2017 and 9 structures flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 12**.

Table 12. Summary of HCFCD Unit G103-33-02 Characteristics

HCFCD Unit G103-33-02	Reach 1
Condition	Man-made
Longitudinal slope (ft/ft)	0.002
Depth (ft)	50 – 12.0
Top width (ft)	50 - 100
Side slope (H:V)	3.2:1 – 3.7:1
Maintenance berm	Yes
ROW (ft)	100 - 150
Owner	HCFCD
Construction Date	Before 1978

5.1.3.1 Hydrologic Analysis

The topology along HCFCD Unit G103-33-02 drains south and southwest towards HCFCD Unit G103-33-00 (Bens Branch). HCFCD Unit G103-33-02 drains a total of 242 acres through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-33-02 is comprised of single-family residential areas. The land use Basin Development Factor (BDF) is mostly Pre-1984 storm sewers with minor undeveloped and open space graded areas. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.3.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. A constant peak flow was assigned to this channel**.** A summary of the hydrograph distribution is provided in **Table 13**. The downstream boundary condition was established as normal depth.

Table 13. HCFCD G103-33-02 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
1020	G1033302A	209	330	413	480	557

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.1. The HEC-RAS cross section layout is shown on **Exhibit 9**.

5.1.3.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 64.8 feet near the confluence with HCFCD Unit G103-33-00 (Bens Branch) to 65.8 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 14**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. There are structures within the subwatershed of G103-33-01 that flood during the Atlas 14 100-year storm event, but the structural flooding is associated with the flooding extents of HCFCD Unit G103-33-00 (Bens Branch) which has a 100-year water surface elevation more than 5.5 feet higher.

Table 14. HCFCD Unit G103-33-02 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.1.4. HCFCD UNIT G103-33-03

HCFCD Unit G103-33-03 is a 0.1 mile long tributary to HCFCD Unit G103-33-00 (Bens Branch) located near the county boundary. The channel starts at the intersection of Hidden Pines Drive and Aspen Glade Drive and flows east to Bens Branch. Historical aerials in the area show the channel constructed by 1978. The watershed was developed to its current condition by 1978 without any surface detention mitigation constructed.

Based on available aerials, the channel geometry and alignment has not changed since construction in 1978. Recent storms have only shown a few structures flooding in the watershed. Neither the 2015 nor 2016 Memorial Day floods caused reported structural flooding. Only 1 recorded structure flooded during the 2016 Tax Day Floods, 11 structures flooded during Hurricane Harvey in 2017 and 35 structures flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 15**.

Table 15. Summary of HCFCD Unit G103-33-03 Characteristics

HCFCD Unit G103-33-03	Reach 1
Condition	Improved natural
Longitudinal slope (ft/ft)	0.004
Depth (ft)	5.0 – 6.0
Top width (ft)	45 – 50
Side slope (H:V)	3.2:1 – 4.2:1
Maintenance berm	Yes
ROW (ft)	80
Owner	HCFCD
Construction Date	Before 1978

5.1.4.1 Hydrologic Analysis

The topology along G103-33-03 drains north along Hidden Pines Drive then east towards Bens Branch. HCFCD Unit G103-33-03 drains a total of 68 acres through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-33-03 is almost entirely single-family residential with some minor undeveloped areas. The land use Basin Development Factor (BDF) is mostly Pre-1984 Storm Sewer with some undeveloped areas. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was

used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.4.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. A constant peak flow was assigned to this channel**.** A summary of the hydrograph distribution is provided in **Table 16**. The downstream boundary condition was established as normal depth.

Table 16. HCFCD G103-33-03 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
477	G1033303A	89	136	168	192	220

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.1. The HEC-RAS cross section layout is shown on **Exhibit 9**.

5.1.4.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 65.1 feet near the confluence with Bens Branch to 66.7 feet at the upper limits of the model near Hidden Pines Drive.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 17**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. There are structures within the subwatershed of G103-33-03 that flood during the Atlas 14 100-year storm event, but the structural flooding is associated with the flooding extents of HCFCD Unit G103-33-00 (Bens Branch) which has a 100-year water surface elevation more than 7.5 feet higher.

Table 17. HCFCD Unit G103-33-03 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.1.5. HCFCD UNIT G103-33-04

HCFCD Unit G103-33-04 is a 1.2 mile long tributary to HCFCD Unit G103-33-00 (Bens Branch) located near the confluence with the West Fork San Jacinto River. The channel begins alongside the commercial development at the intersection of Kingwood Drive and West Lake Houston Parkway and drains south. Historical aerials in the area show the channel under construction in 1978 with some of the adjacent

subdivisions east of the channel beginning construction at the same time. Most of the development in the watershed had been constructed by 1995 without some surface detention mitigation constructed south of Kingwood Drive. The commercial development was constructed in 2016 with detention mitigation provided in a detention pond located at the HCFCD Unit G103-33-04 Kingwood Drive crossing. Prior to the construction of the commercial development, the development consisted of an apartment complex.

Based on available aerials, the channel geometry and alignment has not changed since construction in 1978. Recent storms have flooded structures in the watershed. No structures were recorded to have suffered flood damage during the 2015 or 2016 Memorial Day or 2016 Tax Day floods. A total of 281 structures flooded during Hurricane Harvey in 2017 and 12 structures flooded during Tropical Storm Imelda in 2019. The high number of flooded structures during Hurricane Harvey can be attributed to the water surface elevation along the West Fork San Jacinto River and Lake Houston.

For purposes of presenting the data, the stream the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 18**.

Table 18. Summary of HCFCD Unit G103-33-04 Characteristics

HCFCD Unit G103-33-04	Reach 1
Condition	Improved natural
Longitudinal slope (ft/ft)	0.0004
Depth (ft)	5.0 – 6.0
Top width (ft)	25 – 50
Side slope (H:V)	2.2:1 – 5.0:1
Maintenance berm	No
ROW (ft)	110-130
Owner	HCFCD
Construction Date	Before 1978

5.1.5.1 Hydrologic Analysis

The topology along HCFCD Unit G103-33-04 drains south. HCFCD Unit G103-33-04 drains a total of 0.9 square miles through the Kingwood. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along the stream is a mix of single-family residential, commercial, and undeveloped land and golf courses. The land use Basin Development Factor (BDF) is a mix of Pre-1984 Storm Sewer, Post-1984 Storm Sewer and undeveloped natural areas with some open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.5.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the

hydrograph distribution is provided in **Table 19**. The downstream boundary condition was established as normal depth.

Table 19. HCFCD G103-33-04 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
5176.0	G1033304A	168	253	309	353	401
4874.0	Interpolated	174	262	320	366	416
4671.0	Interpolated	178	269	328	375	427
4223.0	Interpolated	188	284	347	396	451
3705.0	Interpolated	200	302	370	423	481
3353.0	Interpolated	209	315	386	441	503
3086.0	G1033304_0002_J	216	326	399	456	520
2748.0	G1033304_0001_J	450	677	826	936	1066
1229.0	Interpolated	445	692	863	999	1153
677.0	G1033304_0000_J	444	698	877	1023	1186

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.02 to .085. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-33-04 includes the following stream crossings:

- Roadway Culvert Crossing – One (1) [Kingwood Drive – 2 – 8'x5' RBC]

5.1.5.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 48.2 feet near the confluence with Bens Branch to 50.5 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 20**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a less than 2-year level of service with inundation outside of the existing ROW and significant ponding within the parking lot of the commercial development. While no structures are flooded during the Atlas 14 100-year storm event, the results show inundation of over 2 feet.

Table 20. HCFCD Unit G103-33-04 (King's Crossing Ditch) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	< 2-Year

5.1.6. HCFCD UNIT G103-38-00 (KINGWOOD DIVERSION DITCH)

The Kingwood Diversion Ditch (HCFCD Unit G103-38-00) is a man-made channel that was constructed prior to 1978 designed to alleviate HCFCD Unit G103-33-00 (Bens Branch) by draining excess water around Kingwood to the West Fork San Jacinto River. Inside Harris County the channel has a length of approximately 3.86 miles from the Montgomery County boundary south towards the outfall into West Fork San Jacinto River. An additional 0.32 miles extends into Montgomery County to the connection with HCFCD Unit G103-33-00 (Bens Branch). Historical aerials show that the portion of the Kingwood Diversion Ditch watershed within Harris County east of the channel was developed prior to 1978 while the western portion of the watershed was developed after construction of the diversion ditch. Some of the newest development in the watershed occurs along the Harris County border with Montgomery County with construction completed approximately 10 years ago. Additional development in the watershed has occurred since then in Montgomery County. Most of the development within the Kingwood Diversion Ditch watershed was constructed without any detention mitigation with the exception of the more recent developments.

Based on available aerials, the alignment and dimensions of the channel have been consistent since it was constructed. The pedestrian bridge near Lake Village Drive and the Deer Ridge Estates Crossing were both constructed after the channel was built. The Woodland Hills Drive bridge crossing into River Grove Park was replaced in 2009 after the previous crossing collapsed. Downstream of Woodland Hills Drive the channel is in a natural condition. Recent storm events have resulted in flood damage to multiple structures. No structures in the subwatershed were recorded to have suffered flood damage during the 2015 or 2016 Memorial Day floods. Two structures flooded during the 2016 Tax Day floods. Hurricane Harvey in 2017 was responsible for 339 flooded structures while 63 structures flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was segmented into 2 reaches defined as:

- Reach 1 – Runs from the border with Montgomery County to Woodland Hills Drive
- Reach 2 – From Woodland Hills Drive to the confluence with West Fork San Jacinto River, HCFCD Unit G103-00-00.

A summary of physical characteristics is shown below in **Table 21.**

Table 21. Summary of HCFCD Unit G103-38-00 Characteristics

HCFCD Unit G103-38-00	Reach 1	Reach 2
Condition	Improved	Improved
Longitudinal slope (ft/ft)	.0013	0
Depth (ft)	> 7.8	2.0 – 5.0
Top width (ft)	45 – 160	40 – 80
Side slope (H:V)	1.8:1 – 3.3:1	1.7:1 – 4.7:1
Maintenance berm	Yes	No
ROW (ft)	195 – 300	140 – 300
Owner	HCFCD	COH
FEMA Studied	No	No
Construction Date	Before 1978	

5.1.6.1 Hydrologic Analysis

The topology along the Kingwood Diversion Ditch drains south and southeast towards the West Fork San Jacinto River. HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) drains a total of 4.1 square miles through the Kingwood area and a portion of the HCFCD Unit G103-33-00 (Bens Branch) flows and ultimately outfalls into the West Fork San Jacinto River. The FEMA effective HEC-HMS model for HCFCD Unit G103-33-00 (Bens Branch) includes a portion of HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) upstream of Deer Ridge Estates Blvd. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**. A comparison of the FEMA drainage areas and the revised drainage areas is shown on **Exhibit 7**.

The land use along HCFCD Unit G103-38-00 is a mix of single-family residential, commercial, and undeveloped land with some open space such as golf courses and River Grove Park. The land use Basin Development Factor (BDF) within Harris County is a mix of Pre-1984 Storm Sewer, Post-1984 Storm Sewer and Roadside Ditch drainage with some undeveloped natural areas and some open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

The storage routing reaches within the FEMA effective HEC-HMS model upstream of the county boundary were maintained. Development for the storage routing reaches along the tributaries were done following the methodology of **Section 2.0**. Routing along Bens Branch and Kingwood Diversion Ditch was performed within an unsteady HEC-RAS model and are not included within the HEC-HMS model.

A hydrologic analysis was performed to determine the runoff hydrographs along HCFCD Unit G103-33-00 (Kingwood Diversion Ditch) for five (5) Atlas 14 frequencies which include the 2-, 10-, 25-, 50- and 100-year storm events. A comparison of the FEMA effective and the existing condition 100-year peak flows is shown in **Table 22**. The results show an increase in 100-year peak flows ranging from approximately -28% downstream of the confluence with Bens Branch and 10% at the confluence with the West Fork San Jacinto River. The difference in peak flows is a result of utilizing the Atlas 14 rainfall data and the lower amount of flow that is diverted to the Kingwood Diversion Ditch. The FEMA effective model inflow-diversion relationship at the Kingwood Diversion Ditch diverts a maximum flow of 999 cfs during the 100-year storm event The unsteady HEC-RAS model with increased peak flows as a result of Atlas 14 rainfall only diverts 720 cfs. The results show that the diversion relationship within the FEMA effective HEC-HMS model may not be accurate with the majority of flow continuing along Bens Branch.

Table 22. Peak Flow Comparison for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch)

Item		Reach 1
100-Yr Flow (cfs)	FEMA	999 – 3697
	Revised (Atlas 14)	720 – 4050

5.1.6.2 Hydraulic Analysis

While a portion of HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was included within the FEMA effective HEC-HMS model, the stream is unstudied, and no HEC-RAS model was available. A new HEC-RAS model was created for this analysis. The Kingwood Diversion Ditch was modeled with Bens Branch to more

accurately model the interconnectivity of the two streams. The existing cross sections were created following the methodology discussed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 23**. The downstream boundary condition was established as normal depth.

Table 23. HCFCD G103-38-00 (Kingwood Diversion Ditch) Existing Hydrologic Input Summary

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
20789	Lateral Inflow	G1033800A	98	153	190	220	254
20553 - 17548	Uniform Lateral Inflow	G1033800B	88	138	172	200	231
17382 - 14289	Uniform Lateral Inflow	G1033800D	199	318	401	469	546
17382	Lateral Inflow	G1033800C	274	440	558	656	768
13880 - 11022	Uniform Lateral Inflow	G1033800E	232	368	461	537	624
13880	Lateral Inflow	G1033802_0000_J	359	564	703	815	940
10572	Lateral Inflow	G1033801_0000_J	343	542	680	792	919
10572 - 3313	Uniform Lateral Inflow	G1033800F	327	519	650	757	878
3245 - 1451	Uniform Lateral Inflow	G1033800G	158	265	343	411	488

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.06. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

The Kingwood Diversion Ditch within the project area includes the following stream crossings:

- Roadway Culvert Crossing – One (1) [Woodland Hills Drive – 4 – 8'x6' RBC]
- Roadway Bridge Crossing – Four (4) [Northpark Drive, Kingwood Drive, Walnut Lane, Deer Springs Drive]
- Pedestrian Bridge Crossing – One (1) [Lake Village Drive]

When the Kingwood Drive and Northpark Drive bridge crossings were constructed, they were constructed to span the ultimate channel section; therefore, the existing bridges span into the overbank areas on the east side of the channel.

5.1.6.3 Result

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 45.8 feet near the confluence with West Fork San Jacinto River to 74 feet immediately downstream of the confluence with HCFCD Unit G103-33-00 (Bens Branch).

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 24**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that most of the existing channel has 100-year level of service with a single structure flooding south of Hundred Oak Circle during the Atlas 14 100-year 24-hour rainfall storm event. The flooded structure appears to be a storage shed for the Deer Ridge Park. Downstream of Deer Ridge Estates Blvd. the 100-year flow is no longer contained within the southern portion of the ROW with

2142 cfs flowing away from the channel south into the West Fork San Jacinto River. This portion of the channel is located within the floodplain of the West Fork San Jacinto River and is a low-lying area with portions of the land at an elevation of 45 feet a little over 3 feet above the standing water surface elevation within West Fork San Jacinto River. There are no existing structures located within this portion of the channel. Downstream of Woodland Hills Drive, the channel has a less than 2-year level of service with significant inundation of the River Grove Park, however no structures are located within the park.

Table 24. HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	1	100-Year
2	0	<2-Year

5.1.7. HCFCD UNIT G103-38-01

5.1.7.1 Stream Description

HCFCD Unit G103-38-01 is a 1.3 mile long man-made tributary to HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). The channel begins at Laurel Springs Lane and drains east as a grass lined trapezoidal ditch to Chestnut Ridge Road. After Chestnut Ridge Road the channel is a concrete-lined channel with a rectangular concrete low flow structure that continues to flow east into HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). Historical aerials in the area show the channel constructed by 1989 with most of the current development constructed by that time. The 1989 aerials appear to show the concrete portion of the channel was originally a grass-lined channel and became a concrete section by 1995.

Based on available aerials, the channel geometry and alignment has had a minor change in geometry and alignment sometime between 1989 and 1995. In that time frame the channel downstream of Chestnut Ridge Road was changed to a concrete channel and the outfall was relocated to its current location and outfalls via culvert pipes. After Hurricane Harvey in 2017 the outfall for the concrete channel into HCFCD G103-38-00 had collapsed. HCFCD replaced the entire outfall in 2018 with 2 – 8'x8' RBC. Recent storms have flooded structures in the watershed. No structures were recorded to have suffered flood damage during the 2016 Memorial Day or 2016 Tax Day floods. A single structure flooded during the 2015 Memorial Day floods and a total of 79 structures flooded during Hurricane Harvey in 2017 and 57 structures flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was segmented into 2 reaches defined as:

- Reach 1 – Runs from Laurel Springs Lane to the confluence with HCFCD Unit G103-38-01.1 near Chimney Vine Lane.
- Reach 2 – Runs from the confluence with HCFCD Unit G103-38-01.1 near Chimney Vine Lane to the confluence with the Kingwood Diversion Ditch HCFCD Unit G103-38-00.

General characteristics of this stream can be seen in **Table 25**.

Table 25. Summary of HCFCD Unit G103-38-01 Characteristics

HCFCD Unit G103-38-01	Reach 1	Reach 2
Condition	Man-made	Man-made
Longitudinal slope (ft/ft)	0.002	0.0007
Depth (ft)	6.5 – 11.0	13.0 – 14.0
Top width (ft)	20 – 40	25 – 50
Side slope (H:V)	1.4:1 – 2.9:1	1.3:1 – 2.0:1
Maintenance berm	Yes	Yes
ROW (ft)	50	90
Owner	Public	HCFCD/Other
Construction Date	Before 1989	Before 1989

5.1.7.2 Hydrologic Analysis

The topology along the G103-38-01 drains towards HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). G103-38-01 drains a total of 0.6 square miles through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along the G103-38-01 is mostly of single-family residential areas with portion of the Kingwood Cove Golf Club. The land use Basin Development Factor (BDF) within Harris County is a mix of Roadside Ditch drainage with some graded open space at the Kingwood Cove Golf Club. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.7.3 Hydraulic Analysis

A HEC-RAS and FHWA HY-8 model was created for this analysis. The HY-8 model analyzed the culvert outfall into HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) and was used to develop the rating curve for the downstream boundary condition of the HEC-RAS model. The stream was analyzed by developing a HEC-RAS model. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 26**. The downstream boundary condition was maintained as a rating curve obtained from the analysis of the outfall pipe in HY-8.

Table 26. HCFCD G103-38-01 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
6994	G1033801A (10%)	22	35	44	51	59
6767	Interpolated	25	39	50	58	67
6539	Interpolated	28	45	56	66	76
6220	Interpolated	33	53	67	78	91
5765	Interpolated	43	68	86	101	117
5431	Interpolated	52	82	103	121	141
5125	Interpolated	61	97	122	143	166
4409	Interpolated	91	144	182	212	247
4010	Interpolated	113	180	226	264	307
3601	Interpolated	141	225	283	331	385
3246	Interpolated	172	274	345	403	468
3043	Interpolated	192	306	385	450	524
2814	G1033801A	218	348	437	511	594
2665	G1033801_0001_J	269	428	538	628	729
2167	Interpolated	283	449	564	658	763
1281	Interpolated	308	488	613	714	829
512	Interpolated	332	525	658	767	890
164	G1033801_0000_J	343	542	680	792	919

For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.015 was used and overbank n-values were set at 0.06. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-38-01 within the project area includes the following stream crossings:

- Roadway Culvert Crossing – Two (2) [Players Path – 2 – 54" RCP, Chestnut Ridge Rd – 10'x8' RBC]

5.1.7.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 69.2 feet near the confluence with HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) to 77.3 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 27**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures within the 100-year stream inundation during the Atlas 14 100-year 24-hour rainfall storm event.

Table 27. HCFCD Unit G103-80-01 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year
2	0	100-Year

5.1.8. HCFCD UNIT G103-38-01.1

5.1.8.1 Stream Description

HCFCD Unit G103-38-01.1 is a 0.4 mile long man-made tributary to HCFCD Unit G103-38-01. The channel begins south of Kingwood Drive and drains south into HCFCD Unit G103-38-01 as a grass-lined trapezoidal ditch. Historical aerials in the area show the channel constructed by 1989 with most of the current development also constructed by that time.

Based on available aerials, the channel geometry and alignment have not changed since 1989. Recent storms have flooded structures in the watershed. No structures were recorded to have suffered flood damage during the 2015 or 2016 Memorial Day or 2016 Tax Day floods. A total of 24 structures flooded during Hurricane Harvey in 2017 and 3 structures flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 28**.

Table 28. Summary of HCFCD Unit G103-38-01.1 Characteristics

HCFCD Unit G103-38-01.1	Reach 1
Condition	Man-made
Longitudinal slope (ft/ft)	0.0008
Depth (ft)	3.5 – 5.0
Top width (ft)	25 – 35
Side slope (H:V)	2.0:1 – 3.3:1
Maintenance berm	Yes
ROW (ft)	80
Owner	HCFCD/Public
Construction Date	Before 1989

5.1.8.2 Hydrologic Analysis

The topology along G103-38-01.1 drains south towards HCFCD Unit G103-38-01. The channel drains a total of 52 acres through the Kingwood area and ultimately outfalls into the HCFCD Unit G103-38-01. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along G103-38-01.1 is a single-family residential. The land use Basin Development Factor (BDF) within Harris County is a primarily Roadside Ditch Drainage. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified

subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.8.3 Hydraulic Analysis

A new HEC-RAS model was created for this analysis analyzed with HCFCD G103-38-01. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 29**.

Table 29. HCFCD G103-38-01.1 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
1580.0	G10338011A (51%)	28	44	54	63	72
1417.0	Interpolated	30	47	59	68	78
1236.0	Interpolated	33	52	64	74	85
1078.0	Interpolated	36	56	69	80	92
830.0	Interpolated	40	63	78	90	104
592.0	Interpolated	45	71	88	101	116
410.0	Interpolated	50	77	96	111	127
200.0	G10338011A	55	86	106	123	141

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.06. The HEC-RAS cross section layout is shown on **Exhibit 9**.

5.1.8.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 75.3 feet near the confluence with HCFCD Unit G103-80-01 to 76.4 feet at the upper limits of the model.

The Existing Conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 30**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the channel has a 25-year level of service with inundation outside of the ROW. While there is inundation outside of the ROW, the results show that no structures flood during the Atlas 14 100-year storm event.

Table 30. HCFCD Unit G103-80-01.1 (Bens Branch) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	25-Year

5.1.9. HCFCD UNIT G103-38-02

5.1.9.1 Stream Description

HCFCD Unit G103-38-02 is a 0.7 mile long man-made tributary to HCFCD Unit G103-38-00. The channel begins west of Greenberry Drive and drains east towards HCFCD Unit G103-38-00 as a grass-lined trapezoidal ditch that becomes a concrete lined trapezoidal channel approximately 1,000 feet before the confluence with HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). Historical aerials in the area show the channel under construction in 1978. At that time the only development within the watershed was located between the channel and Kingwood Drive. Development in the watershed would continue with most of the development in the watershed constructed by 2009. Most of the construction after 1995 has occurred in Montgomery County with some minor development occurring in Harris County.

Based on available aerials, the channel geometry and alignment have not changed since 1989. No structures were recorded to have suffered flood damage during any of the recent major storm events that caused flooding damage in Kingwood.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 31**.

Table 31. Summary of HCFCD Unit G103-38-02 Characteristics

HCFCD Unit G103-38-02	Reach 1
Condition	Man-made
Longitudinal slope (ft/ft)	0.0017
Depth (ft)	10 – 12.5
Top width (ft)	70 – 115
Side slope (H:V)	2.6:1 – 4.2:1
Maintenance berm	Yes
ROW (ft)	130 – 160
Owner	HCFCD
Construction Date	Before 1978

5.1.9.2 Hydrologic Analysis

The topology along HCFCD Unit G103-38-02 drains east towards the HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). HCFCD Unit G103-38-02 drains a total of 0.5 square miles through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along G103-38-02 is a primarily commercial development along Kingwood Drive and single family residential along the channel. The land use Basin Development Factor (BDF) within Harris County is mostly Pre-1984 Storm Sewer, with some Roadside Ditch and Post-1984 Storm Sewer north of the channel. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**. HEC-HMS was used to develop runoff hydrographs for the identified subbasin. Routing of the

hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The HEC-HMS output is included in **Appendix B.**

5.1.9.3 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 32**. The downstream boundary condition was established as normal depth.

Table 32. HCFCD G103-38-02 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
3838.0	G1033802A	250	387	480	554	638
3398.0	Interpolated	261	405	502	580	668
2974.0	Interpolated	272	423	525	607	699
2500.0	Interpolated	285	444	551	637	734
2000.0	Interpolated	300	467	581	672	774
1500.0	Interpolated	315	492	611	708	816
1000.0	Interpolated	331	518	644	746	860
501.0	Interpolated	347	545	678	786	906
156.0	G1033800_0003_J	359	564	703	815	940

For the channel portion of the cross sections, a Manning's n-value of 0.015 to 0.04 was used and overbank n-values were set at 0.06 to 0.075. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-38-02 includes the following stream crossings:

- Roadway Culvert Crossing – One (1) [Greenberry Drive – 10'x8' RBC]

5.1.9.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 69.2 feet near the confluence with the Kingwood Diversion Ditch to 75.3 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 33**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event.

Table 33. HCFCD Unit G103-38-02 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.1.10. HCFCD UNIT G103-41-00 (SAND BRANCH)

5.1.10.1 Stream Description

Sand Branch (HCFCD Unit G103-41-00) and the tributary G013-41-01 are tributaries to West Fork San Jacinto River, HCFCD Unit G103-00-00. Inside Harris County, the main channel has a length of approximately 1.6 miles and the tributary 0.8 miles draining southeast towards the outfall into West Fork San Jacinto River, HCFCD Unit G103-00-00. Historical aerials show that much of the development within the Sand Branch watershed within Harris County started to develop after channel construction was completed in the late 1970's, with most development occurring post 1980. Generally, the development within Sand Branch watershed was constructed without detention mitigation. Based on available aerials, Sand Branch was originally a natural channel with some improvements such as the clearing of trees and channel improvements constructed along with the development within the watershed. The portions of the channel that go through the Deerwood Golf Club maintain some of the original channel characteristics, but much of the channel was improved and straightened for development of the watershed.

The Kingwood area has recently experienced significant widespread flooding with Hurricane Harvey and Tropical Storm Imelda. Within the Sand Branch watershed Hurricane Harvey in 2017 was responsible for 378 flooded structures while 11 structures flooded during Tropical Storm Imelda in 2019. Sand Branch is not a FEMA studied stream.

For purposes of presenting the data, the stream was segmented into 4 reaches defined as:

- Reach 1 – Upstream end near Sycamore Creek Drive downstream to the confluence with the old channel within the Deerwood Golf Club.
- Reach 2 – The old main channel of Sand Branch to the confluence with the W. Branch of the San Jacinto River
- G103-41-01 – Reach 1 – From the confluence with HCFCD G103-41-00 upstream to Elk Creek Drive.

A summary of physical characteristics is shown below in **Table 34**.

Table 34. Summary of HCFCD Unit G103-41-00 (Sand Branch) Characteristics

HCFCD Unit G103-41-00	Reach 1	Reach 2	G103-41-01 - Reach 1
Condition	Improved	Natural	Improved
Depth (ft)	8-12	6-8	7-12
Top width (ft)	55 to 75	40 to 120	50-60
Bottom width (ft)	6 - 20	20-30	6 – 10
Longitudinal slope (ft/ft)	.0014	.0010	.0010
Side slope (H:V)	3.0:1 – 4.0:1	1.5:1 to 6.0:1	2.0:1 – 3.0:1
Maintenance berm	Yes	No	Yes
ROW	HCFCD/Public	Golf Course / Private	HCFCD/Public
ROW Width (ft)	130	130	110 – 130

5.1.10.2 Hydrologic Analysis

The topology along Sand Branch drains southeasterly towards the West Fork San Jacinto River. Sand Branch drains a total of 1.57 square miles through the Kingwood area and ultimately outfalls into the West Fork San Jacinto River. All the drainage area is located inside of Harris County, with 0.31 square miles contributing to the tributary G103-41-01. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**.

The land use along Sand Branch and its tributary is a mix of single-family residential, natural and golf course areas. The land use Basin Development Factor (BDF) within Harris County is primarily Post-1984 Storm Sewer with a mix of undeveloped natural areas along the channel and some open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.10.3 Hydraulic Analysis

A HEC-RAS model for Sand Branch was developed from 2018 LiDAR and used as the base model for the analysis. The model was developed as a steady state model and the existing cross sections developed following the methodology discussed in **Section 2.0**. Steady state flows from the HEC-HMS model were input into the HEC-RAS model based on HCFCD methods. A summary of the steady state flow distribution is provided in **Table 35**.

Table 35. HCFCD G103-41-00 (Sand Branch) Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Q500 (cfs)
6200	J_G103-41-01_3	72	108	150	170	223
4700	J_G103-41-01_2	83	125	176	200	267
2325	R_G103-41-01_2	125	192	271	310	418
8650	J_G103-41-00_7	83	126	176	201	267
7125	J_G103-41-00_6	209	318	445	505	671
6875	J_G103-41-00_5	286	436	608	690	917
5425	J_G103-41-00_4	499	756	1054	1199	1586
4950	J_G103-41-00_3	560	851	1186	1347	1783
2050	J_G103-41-00_2	859	1348	1941	2225	3050
1000	J_G103-41-00_1	1042	1636	2373	2730	3772

The model cross sections were revised following the methodology discussed in **Section 2.0**. Near the outfall into the West Fork San Jacinto River along Reach 4, the standing water surface elevation from Lake Houston prevents the LiDAR data to capture elevations below the water surface. Normal depth was used as a downstream boundary condition.

The Manning's coefficient n-values ranged from 0.014 to 0.04, depending on the location along the reach. Overbank n-values were also 0.04 as most overbank areas are relatively open and it was found that there was limited overbank flow in this watershed. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

Sand Branch within the project area includes the following stream crossings and drop structures:

- Drop Structures – Two (2) [Upstream of Kingwood Drive, Near Pedestrian Bridge Turtle Bridge II]
- Roadway Bridge Crossing – One (1) [Kingwood Drive]
- Pedestrian Culvert Crossing – One (1) [Turtle Bridge II]

Sand Branch tributary G103-41-01 within the project area includes the following stream crossings and drop structures:

- Culvert – One(1) [Deerwood Golf Club]
- Golf Cart Bridge – One (1) [Near confluence with Sand Branch]
- Pedestrian Culvert Crossing – One (1) [Near confluence with Sand Branch]

5.1.10.4 Results

The Existing Conditions 100-year floodplain was developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 36**. The existing level of service was also identified for each reach along the stream. The 100-year floodplain, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel generally has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. The tributary G102-41-01 is noted as a 50-year level of

service due to some ponding on private property, but no structures showed flooding for a 100-year 24-hour rainfall storm event. The results show that the majority of the Sand Branch channels have adequate capacity, and the areas that go out of banks are within golf course areas that do not threaten homes.

Table 36. HCFCD Unit G103-41-00 (Sand Branch) Structure Inventory Summary

Reach	100-Year Floodplain		Level of Service
	Total	Critical	
1	0	0	100-Year
2	0	0	500-Year
1 (01)	0	0	50-Year

5.1.11. HCFCD UNIT G103-45-00

5.1.11.1 Stream Description

HCFCD Unit G103-45-00 is a 0.4 mile long man-made channel. The channel begins near Trail Tree Lane and travels southeast then turns south crossing Hamblen Road and discharging into the West Fork San Jacinto River. Historical aerials in the area show the channel constructed in 1978 with some development adjacent to the channel. Some of the development next to the channel has since been removed and the land reverted to open grassland.

Based on available aerials, the channel geometry and alignment has not changed since 1978. No recorded structural flooding occurred during the 2015 or 2016 Memorial Day Storm or during the 2016 Tax Day Floods. A total of 49 structures flooded during Hurricane Harvey in 2017 and 2 structures flooded during Tropical Storm Imelda in 2019. The flooding during Hurricane Harvey is likely attributed to the channel's proximity to the West Fork San Jacinto River.

For purposes of presenting the data, the stream was the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 37**.

Table 37. Summary of HCFCD Unit G103-45-00 Characteristics

HCFCD Unit G103-45-00	Reach 1
Condition	Man-made
Longitudinal slope (ft/ft)	0.002
Depth (ft)	3.5 – 8.5
Top width (ft)	25 – 60
Side slope (H:V)	2.4:1 – 5.2:1
Maintenance berm	No
ROW (ft)	60 – 85
Owner	HCFCD
Construction Date	Before 1978

5.1.11.2 Hydrologic Analysis

The topology along HCFCD Unit G103-45-00 drains southeast towards the West Fork San Jacinto River. HCFCD Unit G103-45-00 drains a total of 0.4 square miles through the Kingwood area and ultimately outfalls into the West Fork San Jacinto River. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-45-00 is a mix of single-family residential, and undeveloped land. The land use Basin Development Factor (BDF) is a mix of Post-1984 Storm Sewer and Roadside Ditch drainage with some undeveloped natural areas and some open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.11.3 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. A constant peak flow was assigned to this channel. A summary of the hydrograph distribution is provided in **Table 38**. The downstream boundary condition was established as normal depth.

Table 38. HCFCD G103-45-00 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
1747	G1034500A	229	360	450	523	605

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.08 to 0.1. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-45-00 includes the following stream crossings:

- Roadway Culvert Crossing – One (1) [Hamblen Road – 2 – 72" RCP]
- Culvert Crossing – One (1) [Between Burning Tree Ct and Aqua Vista Dr – 2 – 72" RCP]

5.1.11.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 48.6 feet near the confluence with West Fork San Jacinto River to 52.7 feet at the upper limits of the model.

The Existing Conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 39**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel does not have a 100-year level of service with a potential of 5 flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. The results show that G103-45-00 has a less than 2-year level of service with inundation outside of the existing ROW.

Table 39. HCFCD Unit G103-45-00 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	5	< 2-Year

5.1.12. HCFCD UNIT G103-80-01 (GREEN TREE DITCH)

5.1.12.1 Stream Description

Green Tree Ditch (HCFCD Unit G103-80-01) is a tributary to East Fork San Jacinto River, HCFCD Unit G103-80-01. Inside Harris County, the channel has a length of approximately 1.4 miles. Historical aerials show that much of the development within the Green Tree Ditch watershed within Harris County had occurred after 1980. The development within Green Tree Ditch watershed was constructed without detention mitigation. Based on available aerials, Green Tree Ditch was originally a natural channel with some improvements such as the clearing of trees and channel improvements constructed along with the development within the watershed. A portion of the channel from downstream of Misty River Trail was left in its natural condition.

The Kingwood area has recently experienced significant widespread flooding with Hurricane Harvey and Tropical Storm Imelda. Within Green Tree Ditch watershed Hurricane Harvey in 2017 was responsible for 53 flooded structures while 3 structures flooded during Tropical Storm Imelda in 2019. Green Tree Ditch is not a FEMA studied stream.

For purposes of presenting the data, the stream was not split into several reaches maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. A summary of physical characteristics is shown below in **Table 40**.

Table 40. Summary of HCFCD Unit G103-80-01 Characteristics

HCFCD Unit G103-80-01	Reach 1
Condition	Improved
Longitudinal slope (ft/ft)	.0012
Depth (ft)	13.0-16.0
Top width (ft)	75-120
Bottom width (ft)	6-20
Side slope (H:V)	3.0:1
Maintenance berm	Yes
ROW (ft)	130-145
Owner	HCFCD/Public
Construction Date	Before 1989

5.1.12.2 Hydrologic Analysis

The topology along Green Tree Ditch drains southeasterly towards the East Fork San Jacinto River. Green Tree Ditch drains a total of 1.1 square miles through the Kingwood area and ultimately outfalls into the East Fork San Jacinto River. All the drainage area is within Harris County, and this channel does not receive

overflows from adjacent channels. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**.

The land use along Green Tree Ditch is a mainly single-family residential. The land use Basin Development Factor (BDF) within Harris County is primarily Post-1984 Storm Sewer. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.1.12.3 Hydraulic Analysis

A HEC-RAS model for Green Tree Ditch was developed from 2018 LiDAR and used as the base model for the analysis. The model was developed as a steady state model and the existing cross sections developed following the methodology discussed in **Section 2.0**. Steady state flows from the HEC-HMS model were input into the HEC-RAS model based on HCFCD methods. A summary of the steady state flow distribution is provided in **Table 41**.

Table 41. HCFCD G103-80-01 (Green Tree Ditch) Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Q500 (cfs)
8800	J_G103-80-01_4	233	351	488	554	729
6600	J_G103-80-01_3	427	625	860	990	1346
3850	J_G103-80-01_2	721	1089	1505	1727	2367
1300	J_G103-80-01_1	963	1455	2041	2344	3230

The Manning's coefficient n-values ranged from 0.014 to 0.04, depending on the location along the reach. Overbank n-values were also 0.04 as most overbank areas are relatively open and it was found that there was limited overbank flow in this watershed. The HEC-RAS cross section layout is shown on **Exhibit 9.**

Stream Crossings

Green Tree Ditch within the project area includes the following stream crossings and drop structures:

- Drop Structures – One (1) [Near Misty River Trail]
- Roadway Bridge Crossing – Two (2) [Clover Valley, Mills Branch Drive]
- Pedestrian Culvert Crossing – Three (3) [Green Belt Trail at Terrace Pines Drive, Big Fir Drive, and Greentree Village Park]

5.1.12.4 Results

The Existing Conditions 100-year floodplain was developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 42**. The existing level of service was also identified for each reach along the stream. The 100-year floodplain, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel generally has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. The tributary G103-80-01 is noted as a 100-year level of service due to some ponding on private property, but no structures showed flooding for a 100-year 24-

hour rainfall storm event. The results show that the majority of the Green Tree Ditch channel has adequate capacity, and the areas that go out of banks are within the lower unimproved areas that are lower than existing homes.

Table 42. HCFCD Unit G103-80-01 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.1.13. HCFCD UNIT G103-80-03.1B (TAYLOR GULLY)

5.1.13.1 Stream Description

Taylor Gully (HCFCD Unit G103-80-03.1B) is a tributary to East Fork San Jacinto River, HCFCD Unit G103-80-00. Inside Harris County, the channel has a length of approximately 2.5 miles from the Montgomery County boundary draining southeast towards the outfall into White Oak Creek (HCFCD Unit G103-80-03.2), Caney Creek (HCFCD Unit G103-80-03) and ultimately the East Fork San Jacinto River, HCFCD Unit G103-80-00. An additional 1.3 miles extends into Montgomery County via the recently constructed improvements for the proposed Woodridge Village development. Historical aerials show that much of the development within the Taylor Gully watershed within Harris County had occurred after 1984. Most of the development within Taylor Gully watershed was constructed without detention mitigation. Based on available historical aerial photos, Taylor Gully was originally a natural channel up to approximately Mills Branch Road, with the upper portions noted as Odom Pond that formed the headwaters of the Mills Branch Channel to the north east. The Taylor Gully channel was improved during the development of the Kingwood Development in the late 1970's. Aerial photos from 1988 show that most of the Elm Grove neighborhood and portions of the Mills Branch Residential Sections were under construction near Mills Branch Road intersection at that time. Only a small portion of the channel has been left in natural conditions downstream of Willow Wood Trail and Brood Shore Court where Taylor Gully combines with White Oak Creek.

The Kingwood area has recently experienced significant widespread flooding with Hurricane Harvey and Tropical Storm Imelda. Within Taylor Gully watershed Hurricane Harvey in 2017 was responsible for approximately 246 flooded structures while approximately 450 structures flooded during Tropical Storm Imelda storm event in 2019. Taylor Gully is a FEMA studied stream with the 100-year regulatory floodplain in the project area located in the FEMA Flood Insurance Rate Map (FIRM) for Harris County, Texas and Incorporated Areas, Map Number 48201C0305L, and 48201C0310L, with the Effective Date of June 18, 2007. The mapped floodplains upstream of W. Lake Houston Parkway are wider due to the relatively lower out of bank elevations in these areas than a relatively high ridge between W. Lake Houston Parkway and Mills Branch Road. The FEMA effective floodplains are shown on **Exhibit 3**.

For purposes of presenting the data, the stream was segmented into 3 reaches defined as:

- Reach 1 – From the border with Montgomery County to a point midway upstream of Rustling Elms Drive and Montgomery County.

- Reach 2 – From the point upstream of Rustling Elms Drive and the downstream end of the improved channel near the outfall to White Oak Creek
- Reach 3 – The last remaining natural channel from the end of the improved channel to White Oak Creek.

A summary of physical characteristics is shown below in **Table 43**.

Table 43. Summary of HCFCD Unit G103-80-03.1B Characteristics

HCFCD Unit G103-45-00	Reach 1	Reach 2	Reach 3
Condition	Improved	Improved	Natural
Depth (ft)	5.5-8.0	8-17	6-8
Top width (ft)	90	90-113	50-80
Bottom width (ft)	10 - 30	10 – 30	40 - 60
Longitudinal slope (ft/ft)	.0008	.0011	.0007
Side slope (H:V)	3.0:1 – 4.0:1	3.0:1 – 4.0:1	2.0:1 – 4.0:1
Maintenance berm	Yes	Yes	No
ROW	HCFCD/Public	HCFCD/Public	HCFCD
ROW Width (ft)	140-150	150	150

5.1.13.2 Hydrologic Analysis

The topology along Taylor Gully drains southeasterly towards the East Fork San Jacinto River. Taylor Gully drains a total of 3.6 square miles through the Kingwood area and ultimately outfalls into the East Fork San Jacinto River. Approximately 55% of the drainage area, 1.9 square miles, is located outside of Harris County within Montgomery County. Additionally, Taylor Gully may receive overflow from the Bens Branch watershed within Montgomery County based on ArcHydro overland storm water sheet flow analysis of 2018 LiDAR ground elevations. A general rainfall on mesh 2D overland flow evaluation was also done to confirm the ArcHydro data and will be as discussed later in the report. For this hydrologic evaluation for Taylor Gully the traditional watershed methods were used as there is no evidence of riverine overflows occurring. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**. A comparison of the FEMA drainage areas and the revised drainage areas is shown on **Exhibit 7**.

The land use along Taylor Gully is generally all single-family residential in Harris County, and a mix of undeveloped and more recent land improvements in Montgomery County. The land use Basin Development Factor (BDF) within Harris County is all Post-1984 Storm Sewer. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

A hydrologic analysis was performed to determine the runoff hydrographs and peak flows along Taylor Gully for five (5) Atlas 14 frequencies which include the 2-, 10-, 25-, 50- and 100-year storm events. A comparison of the FEMA effective and the existing condition 100-year peak flows is shown in **Table 44**. The results show a general slight decrease in 100-year peak flows. The largest difference in peak flows is a result of utilizing the new BDF factors for the relatively undeveloped areas upstream in Montgomery County that offset this increase in Atlas 14 rainfall data.

Table 44. Peak Flow Comparison for HCFCD Unit G103-80-03.1B (Taylor Gully)

Item		Reach 1	Reach 2	Reach 3
100-Yr Flow (cfs)	FEMA	1497 – 1791	1791 – 3078	3078
	Revised (Atlas 14)	1217 –1539	1539 – 2954	2954

5.1.13.3 Hydraulic Analysis

The FEMA effective model for Taylor Gully was used as the base model for the analysis. The model was converted to an unsteady model and the existing cross sections revised following the methodology discussed in **Section 2.0**. For this channel the 2018 LiDAR data appeared to match the current cross sections well, so only limited changes to the effective model cross-sections were made. Runoff hydrographs from the HEC-HMS model were input into the HEC-RAS model at their respective flow locations. For subbasins located along the channel with multiple outfall locations, the runoff hydrograph was entered as uniform lateral inflow hydrographs. Flow from contributing tributaries or subbasins with a single outfall, the hydrograph was entered as a lateral inflow hydrograph at the outfall location. A summary of the hydrograph distribution is provided in **Table 45**. The FEMA effective downstream boundary condition was maintained as normal depth.

Table 45. HCFCD G103-80-03.1B (Taylor Gully) Hydrologic Input Summary

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Q500 (cfs)
13362.86	Flow Hydrograph	G103-80-03.1B_7	367	636	1013	1218	1816
11888.72	Uniform Lateral Inflow	G103-80-03.1B_6	307	475	680	782	1080
9411.30	Uniform Lateral Inflow	G103-80-03.1B_5	92	140	196	223	296
8129.90	Uniform Lateral Inflow	G103-80-03.1B_4	156	239	339	388	528
6101.61	Uniform Lateral Inflow	G103-80-03.1B_3	314	489	703	810	1124
4211.27	Uniform Lateral Inflow	G103-80-03.1B_2	312	468	649	736	958
2155.75	Uniform Lateral Inflow	G103-80-03.1B_1	103	155	214	242	311

The model cross sections were revised as necessary following the methodology discussed in **Section 2.0**. Near the outfall into the White Oak Creek tributary to the East Fork San Jacinto River at Reach 3, the standing water surface elevation from White Oak Creek prevents the LiDAR data to capture elevations below the water surface. The cross-section data from the FEMA effective model was used to supplement the 2018 LiDAR data. The FEMA effective HEC-RAS model begins at river station 13362.86 at the Montgomery County Line and extends downstream to river station 83.251 at the confluence with White Oak Creek. The Manning's coefficient n-values from the FEMA effective model were maintained. For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.015was used, depending on the location along the reach, as some areas near bridges and the existing drop structure are concrete lined. Overbank n-values of 0.11 (0.99 for ineffective areas) were used. The HEC-RAS cross section layout is shown on **Exhibit 9**.

<u>Stream Crossings</u>

Taylor Gully within the project area includes the following stream crossings:

- Roadway Culvert Crossing – One (1) [Rustling Elms Drive]
- Roadway Bridge Crossing – Four (4) [W Lake Houston Pkwy, Mill Bridge Way, Mills Branch, and Maple Bend Drive]
- Pedestrian Culvert Crossing – Two (2) [Downstream of W Lake Houston Pkwy, and near Seasons Trail, and part of the Greenbelt Trail System]
- Drop Structure – One (1) [near Sycamore Tree Court]

The FEMA effective HEC-RAS model was field checked, and all of the bridge crossings appeared to match in the model for Taylor Gully and were left unchanged.

5.1.13.4 Results

A comparison of the FEMA effective and existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 51.82 feet at the confluence with White Oak Creek to 72.25 feet at the Montgomery County Line. The FEMA effective model has water surface elevations ranging from 52.0 feet at the confluence with White Oak Creek to 72.8 feet at the Montgomery County Line. The largest difference in water surface elevation occurs in Reach 3 with the unsteady HEC-RAS model producing water surface elevations that are up to 2.3 feet higher than the FEMA effective model, and areas of Reach 1 near Montgomery County are actually lower than the effective model due to the reduced flows computed using the MAAPNext methodologies. Results of the high level 2D analysis showed much more flow from Montgomery County vs. these HEC-HMS watershed techniques which would benefit from additional investigation in this area as flows were evaluated using 2018 conditions and developments occurred upstream within Montgomery County after the 2018 data was acquired.

The Existing Conditions 100-year floodplain was developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 46**. The existing level of service was also identified for each reach along the stream. The 100-year floodplain, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel does not have a 100-year level of service with a potential of 387 flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. None of the structures are identified as critical structures. The results show that the majority of Taylor Gully has a 10-year level of service with much of inundation outside of the existing ROW west of W. Lake Houston Parkway. The results show that wide floodplain areas are associated with relative low areas where the homes and roadways are lower than the channel top of banks. In addition, the mid-section of the channel passes a relative high zone that tends to funnel flows into the main channel causing a flow restriction near the road crossing of Mill Bridge Way. The downstream areas near the confluence with White Oak Creek do not show inundation primarily due to the tailwater conditions evaluated in this study. Due to the proximity of the confluence of the East Fork San Jacinto River, Caney Creek and White Oak Creek at the outfall of Taylor Gully, these channels may impact flooding in this area and would need to be evaluated as 100-year water elevations of the FEMA effective maps for the East Fork San Jacinto River are at elevation 59-feet with backwater extending upstream of the drop structure.

Table 46. HCFCD Unit G103-80-03.1B Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	132	10-Year
2	255	10-Year
3	0	100-Year

5.2. STREAMS MAINTAINED BY OTHERS

5.2.1. HCFCD UNIT G103-36-00 (BEAR BRANCH)

HCFCD Unit G103-36-00 is a 3.5 mile long tributary to West Fork San Jacinto located at the southern boundary of Kingwood. The channel begins alongside Woodland Hills Drive and drains east then south through the Kingwood County Club before discharging into the West Fork San Jacinto River. Bear Branch acts as a golf course water hazard through the Kingwood County Club south of Kingwood Drive and is more like a series of ponds/lakes than a channel. Historical aerials in the area show the channel constructed by 1978 with most of the current development constructed at the same time. The only major development since then is the construction of the Barrington Kingwood subdivision south of the Kingwood County Club.

Based on available aerials, the channel geometry and alignment has not changed since construction in 1978. Recent storms have flooded structures in the watershed. No structures were recorded to have suffered flood damage during the 2015 or 2016 Memorial Day or 2016 Tax Day floods. A total of 407 structures flooded during Hurricane Harvey in 2017 and 50 structures flooded during Tropical Storm Imelda in 2019. The high number of flooded structures during Hurricane Harvey can be attributed to the water surface elevation along the West Fork San Jacinto River and Lake Houston.

For purposes of presenting the data, the stream was segmented into 4 reaches defined as:

- Reach 1 – The portion of the channel from Woodland Hills Drive to Kingwood Drive.
- Reach 2 – Kingwood Drive to the confluence with HCFCD Unit G103-36-01.
- Reach 3 – The confluence of HCFCD Unit G103-36-01 to South Cotswold Manor Drive.
- Reach 4 – From South Cotswold Manor Drive to the confluence with West Fork San Jacinto River.

General characteristics of this stream can be seen in **Table 47**.

Table 47. Summary of HCFCD Unit G103-36-00 Characteristics

HCFCD Unit G103-36-00	Reach 1	Reach 2	Reach 3	Reach 4
Condition	Improved natural	Manmade	Manmade	Manmade
Longitudinal slope (ft/ft)	.00164	Water Surface	Water Surface	Water Surface
Depth (ft)	8.5 – 10.5	1.0 – 2.0	1.0 – 4.0	1.0 – 1.5
Top width (ft)	25 – 50	42 – 215	30 – 810	120 – 155
Side slope (H:V)	--	2.6:1 – 4.8:1	5.0:1 – 6.2:1	3.2:1 – 5.0:1
Maintenance berm	No	No	No	No
ROW (ft)	90 – 180	13 – 210	135	135
Owner	Public	Other	Other	Other
Construction Date	Before 1978	Before 1978	Before 1978	Before 1978

5.2.1.1 Hydrologic Analysis

The topology along HCFCD Unit G103-36-00 (Bear Branch) drains south towards the West Fork San Jacinto River. HCFCD Unit G103-36-00 (Bear Branch) drains a total of 2.3 square miles through the Kingwood area and ultimately outfalls into the West Fork San Jacinto River. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along Bear Branch is a mix of single-family residential along with the Clubs of Kingwood Golf Course. The land use Basin Development Factor (BDF) is a mix of Pre-1984 Storm Sewer, Roadside Ditch Drainage, Post-1984 Storm Sewer and Undeveloped and Graded Open Space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.1.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 48**. The downstream boundary condition was established as normal depth.

Table 48. HCFCD G103-36-00 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
13795.0	G1033600A	236	369	459	532	614
13266.0	Interpolated	244	382	477	553	638
12902.0	Interpolated	250	392	489	567	656
12373.0	Interpolated	259	406	507	590	683
11848.0	Interpolated	267	421	526	612	710
11215.0	Interpolated	279	439	550	641	744
10713.0	Interpolated	288	455	570	665	773
10133.0	Interpolated	299	473	594	694	807
9511.0	Interpolated	311	493	620	725	845
8868.0	Interpolated	324	515	649	760	887
8217.0	Interpolated	338	538	679	797	931
7595.0	Interpolated	351	562	709	833	975
7020.0	Interpolated	365	584	738	869	1018
6495.0	Interpolated	377	605	766	903	1059
6054.0	G1033600_0004_J	388	624	790	932	1094
5640.0	G1033600_0003_J	506	821	1102	1317	1563
5123.0	Interpolated	516	852	1136	1365	1630
4942.0	G1033600_0002A_J	520	864	1149	1382	1655
4832.0	Interpolated	531	892	1184	1426	1707
4713.0	Interpolated	543	924	1224	1474	1766
4420.0	G1033600_0002_J	573	1007	1327	1600	1919
3087.0	Interpolated	589	1055	1387	1672	2007
2252.0	Interpolated	599	1086	1425	1719	2064
1506.0	G1033600_0001_J	608	1114	1460	1761	2116
1050.0	Interpolated	624	1148	1518	1830	2198
113.0	G1033600_0000_J	633	1180	1554	1874	2252

For the channel portion of the cross sections, a Manning's n-value of 0.02 to 0.07 was used and overbank n-values were set at 0.05 to 0.11. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

Bear Branch includes the following stream crossings:

- Roadway Culvert Crossing – One (1) [Kingwood Drive – 3 – 84" RCP]
- Pedestrian Bridge Crossing – Four (4) [Clubs of Kingwood Golf Course]

5.2.1.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 46.4 feet near the confluence with West Fork San Jacinto River 67.8 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was

performed and is summarized in **Table 49**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel upstream of Kingwood Drive has a less than 2-year level of service with a potential of 6 flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. The potential flooded structures are located within a natural low-lying area next to the channel. The rest of the topography along the channel upstream of Kingwood Drive is at a higher elevation and outside the 100-year stream inundation. Downstream of Kingwood Drive, the results show inundation within the golf course, however as the golf course is at an elevation only slightly above the standing water elevation and poses no structural flooding risk the channel was determined to have a 100-year level of service. The results also show that the ponding inundation limits are mostly located within the West Fork San Jacinto 100-year floodplain with a Base Flood Elevation of 55-57 feet.

Table 49. HCFCD Unit G103-36-00 (Bear Branch) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	6	< 2-Year
2	0	100-Year
3	0	100-Year
4	0	100-Year

5.2.2. HCFCD UNIT G103-36-01

HCFCD Unit G103-36-01 is a 0.7 mile long tributary to HCFCD G103-36-00. The channel begins at Woods Estates Drive and drains south across Kingwood Drive and through the Kingwood County Club before connecting with HCFCD Unit G103-36-00. Historical aerials in the area show the channel constructed by 1978 with most of the current development constructed by that time.

Based on available aerials, the channel geometry and alignment has not changed since 1978. The only storm event that resulted in recorded flooded structures was Hurricane Harvey in 2017 which flooded 53 structures. No flooded structures were recorded in the 2015 or 2016 Memorial Day Floods, the 2016 Tax Day Floods, or Tropical Storm Imelda in 2019. The high number of flooded structures during Hurricane Harvey can be attributed to the water surface elevation along the West Fork San Jacinto River and Lake Houston.

For purposes of presenting the data, the stream was segmented into 2 reaches defined as:

- Reach 1 – Woods Estates Drive to Kingwood Drive.
- Reach 2 – Kingwood Drive to the confluence with HCFCD Unit G103-36-00.

General characteristics of this stream can be seen in **Table 50.**

Table 50. Summary of HCFCD Unit G103-36-01 Characteristics

HCFCD Unit G103-36-01	Reach 1	Reach 2
Condition	Natural	Natural
Longitudinal slope (ft/ft)	.0024	.0008
Depth (ft)	1.0 – 1.5	1.0
Top width (ft)	15 - 25	15 – 95
Side slope (H:V)	--	--
Maintenance berm	No	No
ROW (ft)	20 - 70	--
Owner	Other	Other
Construction Date	Before 1978	Before 1978

5.2.2.1 Hydrologic Analysis

The topology along G103-36-01 drains south towards HCFCD Unit G103-36-00 (Bear Branch). HCFCD Unit G103-36-01 drains a total of 78 acres through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-36-01 is a primarily single-family residential with some open areas along the channel south of Kingwood Drive. The land use Basin Development Factor (BDF) is a mix of Pre-1984 Storm Sewer and Roadside Ditch drainage with some undeveloped natural areas and open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.2.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. HCFCD Unit G103-36-01 was included in the HCFCD Unit G103-36-00 (Bear Branch) HEC-RAS model. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 51**.

Table 51. HCFCD G103-36-01 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
4075.0	G1033601A (3%)	2	4	5	5	6
3591.0	Interpolated	6	9	12	14	16
3089.0	Interpolated	16	25	31	36	42
2662.0	G1033601A (48%)	37	58	72	84	97
2291.0	Interpolated	42	65	81	94	109
2014.0	Interpolated	46	71	88	102	118
1627.0	Interpolated	51	80	99	115	133
1195.0	Interpolated	58	91	113	131	151
972.0	Interpolated	63	97	121	140	162
620.0	Interpolated	70	108	135	156	180
249.0	G1033304_0000_J	78	121	151	175	202

For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.07 was used and overbank n-values were set at 0.05 to 0.11. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-36-01 includes the following stream crossings:

- Roadway Culvert Crossing –One (1) [Kingwood Drive – 2 – 72" RCP]
- Low Water Pedestrian Crossing – One (1) [Clubs of Kingwood Golf Course]

5.2.2.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 50.9 feet near the confluence with Bear Branch to 54.3 feet at the upper limits of the model.

The Existing Conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 52**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event.

Table 52. HCFCD Unit G103-36-01 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year
2	0	100-Year

5.2.3. HCFCD UNIT G103-36-02

HCFCD Unit G103-36-02 is a 0.9 mile long tributary to HCFCD Unit G103-36-00. At Woodland Hills Drive, flow from a storm sewer empties and flows east overland along steep terrain. It appears that overtime the flow has eroded a small natural channel section before the flow hits the low lying area next to the Kingwood County Club golf course. At this point, the flow drains overland and eventually into HCFCD Unit G103-36-02 which is a pond/lake water hazard for the golf course. Historical aerials in the area show the channel constructed by 1978 with most of the current development constructed by that time.

Based on available aerials, the channel geometry and alignment has not changed since 1978. Recent storms have flooded structures in the watershed. No structures were recorded to have suffered flood damage during the 2015 or 2016 Memorial Day or 2016 Tax Day floods. A total of 52 structures flooded during Hurricane Harvey in 2017 and 1 structure flooded during Tropical Storm Imelda in 2019. The high number of flooded structures during Hurricane Harvey can be attributed to the water surface elevation along the West Fork San Jacinto River and Lake Houston.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 53**.

Table 53. Summary of HCFCD Unit G103-36-02 Characteristics

HCFCD Unit G103-36-02	Reach 1
Condition	Manmade
Longitudinal slope (ft/ft)	.0029
Depth (ft)	2.0 – 6.5
Top width (ft)	20 – 720
Side slope (H:V)	1.8:1 – 3.3:1
Maintenance berm	No
ROW (ft)	50
Owner	Other
Construction Date	Before 1978

5.2.3.1 Hydrologic Analysis

The topology along HCFCD Unit G103-36-02 drains east towards Bear Branch and drains a total of 0.6 square miles through the Kingwood area and ultimately outfalls into Bear Branch. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-36-02 is a mix of single-family residential, commercial, and undeveloped land with some open space along the Clubs of Kingwood Golf Course. The land use Basin Development Factor (BDF) is a mix of Pre-1984 Storm Sewer with some undeveloped natural areas and some open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.3.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. HCFCD G103-36-02 was included in the HCFCD Unit G103-36-00 (Bear Branch) HEC-RAS model. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 54**.

Table 54. HCFCD G103-36-02 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
4656.0	G1033602A (25%)	60	92	114	131	151
4600.0	Interpolated	63	97	120	138	159
4049.0	Interpolated	105	162	200	231	265
3169.0	G1033602A	237	366	453	521	598
2400.0	G1033602_0001_J	373	576	711	818	937
1560.0	Interpolated	183	302	405	485	576
756.0	G1033602_0000_J	92	163	236	294	361

For the channel portion of the cross sections, a Manning's n-value of 0.02 to 0.06 was used and overbank n-values were set at 0.05 to 0.11. The HEC-RAS cross section layout is shown on **Exhibit 9**.

5.2.3.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 50.9 feet near the confluence with Bear Branch to 60.0 feet at the upper limits of the model.

The Existing Conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 55**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel inundates the golf course and low lying areas, however as the golf course is at an elevation only slightly above the standing water elevation and poses no structural flooding risk the channel was determined to have a 100-year level of service. The results also show that the ponding inundation limits are mostly located within the West Fork San Jacinto 100-year floodplain with a Base Flood Elevation of 56-57 feet.

Table 55. HCFCD Unit G103-36-02 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.2.4. HCFCD UNIT G103-36-02.1

HCFCD Unit G103-36-02.1 is a 0.5 mile long tributary to HCFCD Unit G103-36-02 located entirely within Harris County. The channel begins north of Kingwood Drive and drains south along the Kingwood County Club before connecting with HCFCD Unit G103-36-02. Historical aerials in the area show the channel constructed by 1978 with most of the current development constructed by that time.

Based on available aerials, the channel geometry and alignment has not changed since 1978. Recent storms have flooded structures in the watershed. No structures were recorded to have suffered flood damage during the 2015 or 2016 Memorial Day or 2016 Tax Day floods. A total of 30 structures flooded

during Hurricane Harvey in 2017 and 2 structures flooded during Tropical Storm Imelda in 2019. The high number of flooded structures during Hurricane Harvey can be attributed to the water surface elevation along the West Fork San Jacinto River and Lake Houston.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 56**.

Table 56. Summary of HCFCD Unit G103-36-02.1 Characteristics

HCFCD Unit G103-36-02.1	Reach 1
Condition	Manmade
Longitudinal slope (ft/ft)	.0016
Depth (ft)	3.0 – 4.5
Top width (ft)	25 – 50
Side slope (H:V)	1.0:1 – 4.0:1
Maintenance berm	No
ROW (ft)	100
Owner	Public
Construction Date	Before 1978

5.2.4.1 Hydrologic Analysis

The topology along G103-36-02.1 drains southeast towards HCFCD Unit G103-36-02. HCFCD Unit G103-36-02.1 drains a total of 105 acres through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**.

The land use along HCFCD G103-36-02.1 is an almost entirely single-family residential. The land use Basin Development Factor (BDF) is a mix of Pre-1984 Storm Sewer and Roadside Ditch. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.4.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. HCFCD G103-36-02.1 was included in the Bear Branch HEC-RAS model. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 57**.

Table 57. HCFCD G103-36-02.1 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
2446.0	G10336021A (12%)	17	26	31	36	41
2314.0	Interpolated	19	30	36	42	48
2224.0	Interpolated	21	33	40	46	53
2159.0	Interpolated	23	35	43	50	57
2045.0	Interpolated	26	40	49	56	64
1927.0	Interpolated	30	45	56	64	73
1687.0	Interpolated	38	59	72	83	95
1493.0	Interpolated	48	73	90	103	118
1225.0	Interpolated	64	98	120	138	158
1009.0	Interpolated	81	124	153	175	200
831.0	Interpolated	98	151	186	213	243
515.0	G10336021A	139	213	262	301	344

For the channel portion of the cross sections, a Manning's n-value of 0.05 was used and overbank n-values were set at 0.11. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-36-02.1 includes the following stream crossings:

- Roadway Culvert Crossing – Two (2) [Kingwood Drive Westbound – 54" RCP, Kingwood Drive Eastbound – 54" RCP and 48" RCP]

5.2.4.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 50.9 feet near the confluence with G103-36-02 to 54.8 feet at the upper limits of the model.

The Existing Conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 58**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event.

Table 58. HCFCD Unit G103-36-02.1 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.2.5. HCFCD UNIT G103-36-03

HCFCD Unit G103-36-03 is a 0.4 mile long tributary to HCFCD Unit G103-36-00. The channel begins north of Royal Circle Drive and drains south across Kingwood Drive and through the Kingwood County Club before connecting with HCFCD Unit G103-36-00 within the golf course water body. Historical aerials in the area show the channel constructed by 1978 with most of the current development constructed by that time.

Based on available aerials, the channel geometry and alignment has not changed since 1978. The only storm event that resulted in recorded flooded structures was Hurricane Harvey in 2017 which flooded 99 structures. No flooded structures were recorded in the 2015 Memorial Day floods, the 2016 Tax Day Floods, the 2016 Memorial Day Floods, or Tropical Storm Imelda in 2019. The high number of flooded structures during Hurricane Harvey can be attributed to the water surface elevation along the West Fork San Jacinto River and Lake Houston.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 59**.

Table 59. Summary of HCFCD Unit G103-36-03 Characteristics

HCFCD Unit G103-36-03	Reach 1
Condition	Manmade
Longitudinal slope (ft/ft)	.0022
Depth (ft)	> 1.7
Top width (ft)	25 – 165
Side slope (H:V)	3.3:1
Maintenance berm	No
ROW (ft)	100
Owner	Public
Construction Date	Before 1978

5.2.5.1 Hydrologic Analysis

The topology along HCFCD Unit G103-36-03 drains southeast. HCFCD Unit G103-36-03 drains a total of 53 acres through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-36-03 is single-family residential. The land use Basin Development Factor (BDF) is a mix of Pre-1984 Storm Sewer, Roadside Ditch drainage with some undeveloped natural areas. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.5.2 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. HCFCD G103-36-03 was included in the HCFCD Unit G103-36-00 (Bear Branch) HEC-RAS model. The existing cross sections were created following the

methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 60**.

Table 60. HCFCD G103-36-03 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
2695.0	G1033603A (13%)	8	12	14	17	19
2129.0	G1033603A (38%)	22	34	42	49	56
1676.0	Interpolated	31	47	59	67	77
1362.0	Interpolated	38	59	73	85	97
986.0	Interpolated	50	77	96	111	128
790.0	G1033603A	58	89	111	128	147

For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.01 was used and overbank n-values were set at 0.1 to 0.11. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-36-03 includes the following stream crossings:

- Roadway Culvert Crossing – Three (3) Royal Circle Drive – 24" RCP, Kingwood Drive Westbound – 42" RCP, Kingwood Drive Eastbound – 48" RCP]
- Pedestrian Bridge Crossing – One (1) [Clubs of Kingwood Golf Course]

5.2.5.3 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 51.0 feet near the confluence with Bear Branch 53.9 feet at the upper limits of the model.

The Existing Conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 61**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a less than 2-year level of service with water overtopping all the roadway crossings. While the roadway is overtopped, the stream inundation does not contain any structures as the topography is very steep along the channel.

Table 61. HCFCD Unit G103-36-03 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.2.6. HCFCD UNIT G103-39-00

5.2.6.1 Stream Description

HCFCD Unit G103-39-00 is a 1.3 mile long natural channel. The channel begins near Sycamore Lane and travels south crossing Hamblen Road and Sunrise Trail before heading east and southeast into the West Fork San Jacinto River. Historical aerials in the area show the channel in 1978 with some development and most of the roads in the watershed constructed. Minor development continued in the watershed, but the overall level of development has been constant since 1989.

Based on available aerials, the channel geometry and alignment has not changed since 1978. No recorded structural flooding occurred during the 2015 Memorial Day storm. Four structures flooded during the Tax Day Floods of 2016 and during the Memorial Day 2016 floods. A total of 113 structures flooded during Hurricane Harvey in 2017 and 2 structures flooded during Tropical Storm Imelda in 2019. The flooding during Hurricane Harvey is likely attributed to the channel's proximity to the West Fork San Jacinto River.

For purposes of presenting the data, the stream was segmented into 3 reaches defined as:

- Reach 1 – Runs from the beginning of the channel to Hamblen Road.
- Reach 2 – Runs from Hamblen Road to Indian Hill Trail
- Reach 3 – Runs from Indian Hill Trail to the confluence with the West Fork San Jacinto River.

General characteristics of this stream can be seen in **Table 62**.

Table 62. Summary of HCFCD Unit G103-39-00 Characteristics

HCFCD Unit G103-39-00	Reach 1	Reach 2	Reach 3
Condition	Natural	Natural	Natural
Longitudinal slope (ft/ft)	0.006	0.006	.001
Depth (ft)	6.5 – 10	3.5 – 10.5	>3.0
Top width (ft)	20 – 55	20 – 100	25 – 80
Side slope (H:V)	--	--	--
Maintenance berm	No	No	No
ROW (ft)	100	--	--
Owner	Other	--	--
Construction Date	Before 1978	Before 1978	Before 1978

5.2.6.2 Hydrologic Analysis

The topology along HCFCD Unit G103-39-00 drains southwest towards the West Fork San Jacinto River. G103-39-00 drains a total of 0.3 square miles and ultimately outfalls into the West Fork San Jacinto River. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD Unit G103-39-00 is a mostly single-family residential with some commercial, and undeveloped land. The land use Basin Development Factor (BDF) is almost entirely Roadside Ditch drainage with some undeveloped natural areas and some open space along Reach 2 and Reach 3. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph

parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.6.3 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 63**. The downstream boundary condition was established as normal depth.

Table 63. HCFCD G103-39-00 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
5778.0	G1033900A	75	117	145	167	192
5362.0	Interpolated	84	130	161	185	212
5031.0	Interpolated	91	141	174	201	230
4667.0	Interpolated	100	155	191	219	252
4201.0	Interpolated	112	175	215	246	282
3862.0	Interpolated	122	191	234	267	306
3454.0	Interpolated	135	212	259	295	338
3244.0	G1033900_0001_J	143	223	273	311	356
2825.0	Interpolated	131	206	252	289	332
2426.0	Interpolated	121	190	234	269	310
1864.0	Interpolated	108	170	211	244	282
1575.0	Interpolated	101	161	200	232	268
1336.0	Interpolated	97	154	192	222	258
711.0	Interpolated	85	136	171	199	232
14.0	G1033900_0000_J	74	119	150	176	206

For the channel portion of the cross sections, a Manning's n-value of 0.06 was used and overbank n-values were set at 0.06 to 0.125. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-39-00 includes the following stream crossings:

- Roadway Culvert Crossing – Two (2) [Hamblen Road – 48" RCP, Sunrise Trail – 48" RCP]

5.2.6.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 48.6 feet near the confluence with West Fork San Jacinto River to 70.5 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 64**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are

shown on **Exhibit 9**. The results show that the existing channel upstream of Hamblen Road has a 100-year level of service due to the steep slope of the channel. Hamblen road is overtopped in the 50-year event and Sunrise Trail is overtopped in the 2-year event resulting in a less than 2-year level of service. Downstream of Sunrise Trail, the existing channel has wide 100-year inundation limits as this area is a low lying area near the West Fork San Jacinto River. This area is located within the West Fork San Jacinto River 100-year floodplain with base flood elevations of 59-60 feet. There is a potential of 4 flooded structures during the Atlas 14 100-year 24-hour rainfall storm event located within the stream inundation limits.

Table 64. HCFCD Unit G103-39-00 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	< 2-Year
2	1	2-Year
3	3	< 2-Year

5.2.7. HCFCD UNIT G103-46-00

5.2.7.1 Stream Description

HCFCD Unit G103-46-00 is a 1.1 mile long man made channel. The channel begins next to Forest Cove Drive and heads southeast crossing Hamblen Road as a grass lined channel. The stream then crosses Forest Cove Drive where it changes to a concrete lined channel that discharges into the West Fork San Jacinto River. Historical aerials in the area show the channel constructed in 1978 with some development adjacent to the channel.

Based on available aerials, the channel geometry and alignment has not changed since 1978. No recorded structural flooding occurred during the 2015 Memorial Day Storm or the 2016 Tax Day Floods. The 2016 Memorial Day Storm flooded 9 structures. A total of 80 structures flooded during Hurricane Harvey in 2017. The flooding during Hurricane Harvey is likely attributed to the channel's proximity to the West Fork San Jacinto River. No structures flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was analyzed as a single reach maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 65**.

Table 65. Summary of HCFCD Unit G103-46-00 Characteristics

HCFCD Unit G103-46-00	Reach 1
Condition	Improved
Longitudinal slope (ft/ft)	0.0028
Depth (ft)	3.5 – 8.0
Top width (ft)	25 – 60
Side slope (H:V)	2.3:1 – 5.5:1
Maintenance berm	No
ROW (ft)	35 - 85
Owner	HCFCD
Construction Date	Before 1978

5.2.7.2 Hydrologic Analysis

The topology along HCFCD G103-46-00 drains south towards the West Fork San Jacinto River. HCFCD Unit G103-46-00 drains a total of 0.3 square miles through the Kingwood area and ultimately outfalls into the West Fork San Jacinto River. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along HCFCD G103-46-00 is a mix of single-family residential and undeveloped land. The land use Basin Development Factor (BDF) is primarily Roadside Ditch drainage with some undeveloped natural areas and some open space. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. Routing of the hydrographs was performed within the HEC-HMS model following the methodology of **Section 2.0.** The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.7.3 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 66**. The downstream boundary condition was established as normal depth.

Table 66. HCFCD G103-46-00 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
3867.0	G1034600A	47	71	86	99	112
3521.0	Interpolated	95	143	174	199	227
3229.0	Interpolated	172	259	316	361	412
2988.0	Interpolated	179	252	305	345	391
2710.0	Interpolated	187	244	293	327	368
2485.0	Interpolated	194	238	283	313	350
2359.0	G1034600C	198	234	278	305	341
2102.0	Interpolated	201	247	293	324	362
1962.0	Interpolated	203	255	302	334	374
1699.0	Interpolated	206	269	319	356	398
1427.0	G1034600_0001_J	210	285	338	379	424
1253.0	G1034600_0000_J	212	296	350	394	442

For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.015 was used and overbank n-values were set at 0.1 to 0.125. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-46-00 includes the following stream crossings:

- Roadway Culvert Crossing – Two (2) [Hamblen Road – 48" RCP & 6'x6' RBC, Forest Cove Drive – 2 – 84" RCP]

The 6'x6' RBC appears to have been added at Hamblen Road at a later date than the 48" RCP and is located at the bank at a higher elevation.

5.2.7.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 45.3 feet near the confluence with West Fork San Jacinto River to 54.7 feet at the upper limits of the model.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 67**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel does not have a 100-year level of service with a potential of 5 flooded structures during the Atlas 14 100-year 24-hour rainfall storm event. The channel has a less than 2-year level of service with inundation outside of the ROW. The results show that Hamblen Road restricts the flow upstream and is overtopped in the 50-year event. Downstream of Hamblen Road, the water is contained within the channel ROW.

Table 67. HCFCD Unit G103-46-00 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	5	< 2-Year

5.2.8. HCFCD UNIT G103-46-01

5.2.8.1 Stream Description

HCFCD Unit G103-46-01 is a 0.6 mile long man-made channel. The channel begins at Sweet Gum Lane as a grass lined ditch that drains south into HCFCD Unit G103-46-00 via a 42" RCP storm sewer pipe. Historical aerials in the area show the channel constructed in 1989 with no major changes in development shown in the watershed since that time.

Based on available aerials, the channel geometry and alignment has not changed since 1989. No recorded structural flooding occurred during the 2015 or 2016 Memorial Day Storms, the 2016 Tax Day Floods, or during Tropical Storm Imelda in 2019. A total of 51 structures flooded during Hurricane Harvey in 2017. The flooding during Hurricane Harvey is likely attributed to the channel's proximity to the West Fork San Jacinto River.

For purposes of presenting the data, the stream was segmented into 2 reaches defined as:

- Reach 1 – From Sweet Gum Lane to Cypress Lane.
- Reach 2 – From Cypress Lane to HCFCD Unit G103-46-00.

General characteristics of this stream can be seen in **Table 68**.

Table 68. Summary of HCFCD Unit G103-46-01 Characteristics

HCFCD Unit G103-46-01	Reach 1	Reach 2
Condition	Man-made	Enclosed Storm Sewer System
Longitudinal slope (ft/ft)	0.008	N/A
Depth (ft)	2.5 – 6.0	--
Top width (ft)	25 - 45	--
Side slope (H:V)	2.5:1 – 5.0:1	--
Maintenance berm	No	--
ROW (ft)	--	50
Owner	--	Public/Other
Construction Date	Before 1989	Before 1989

5.2.8.2 Hydrologic Analysis

The topology along HCFCD Unit G103-46-01 drains south and southeast G103-46-00. G103-46-01 drains a total of 0.2 square miles through the Kingwood area. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2**.

The land use along G103-46-01 is a single-family residential with a land use Basin Development Factor (BDF) of Roadside Ditch Drainage. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for

the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.8.3 Hydraulic Analysis

New HEC-RAS and FHWA HY-8 models were created for this analysis. The HY-8 model analyzed the pipe outfall from Cypress Lane into HCFCD Unit G103-46-00. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 69**. The downstream boundary condition was developed as a rating curve obtained from the analysis of the outfall pipe in HY-8.

Table 69. HCFCD G103-46-01 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
2529.0	G1034601A (15%)	21	33	40	46	53
2278.0	Interpolated	26	39	49	56	64
2082.0	Interpolated	30	46	56	65	74
1880.0	Interpolated	34	53	65	75	86
1560.0	Interpolated	44	68	83	96	110
1350.0	Interpolated	51	79	98	112	129
1083.0	Interpolated	63	97	119	137	157
804.0	Interpolated	77	119	147	169	194
525.0	Interpolated	95	147	181	209	239
173.0	Interpolated	124	192	236	272	311
5.0	G1034601A	141	217	268	308	353

For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.06 was used and overbank n-values were set at 0.06 to 0.125. The HEC-RAS cross section layout is shown on **Exhibit 9**.

Stream Crossings

HCFCD Unit G103-46-01 includes the following stream crossings:

- Roadway Culvert Crossing – Four (4) [Mistletoe Ln – 2 – 24" RCP, Walnut Ln – 36" RCP, Magnolia Ln – 36" RCP, Sycamore Ln – 36" RCP]

5.2.8.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 53.3 feet near the near the confluence with G103-46-00 to 84.8 feet at the upper limits of the model in Montgomery County.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 70**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that HCFCD Unit G103-46-00 has a less than 2-year level of service with all roadway crossings overtopped in the 2-year event. No structures are located within the 100-year

stream inundation limits and outside of the roadway crossings is maintained within the area along the channel.

Table 70. HCFCD Unit G103-46-01 Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	< 2-Year
2	0	< 2-Year

5.2.9. HCFCD UNIT G103-80-03.1A (MILLS BRANCH)

5.2.9.1 Stream Description

Mills Branch (HCFCD Unit G103-80-03.1A) is a tributary to East Fork San Jacinto River, HCFCD Unit G103-80-00, and Caney Creek HCFCD Unit G103-80-03. Inside Harris County, the channel has a length of approximately 1.5 miles from just south of the Montgomery County boundary at Mills Branch Road draining east towards the outfall into White Oak Creek (HCFCD Unit G103-80-03.2) a branch of the East Fork San Jacinto River, HCFCD Unit G103-80-00. Historical aerials show that much of the development within the Mills Branch watershed within Harris County has occurred after 1984. Some of the development within Mills Branch watershed was constructed without detention mitigation, and more recent development of the Royal Brook Subdivision does have detention. Based on available aerials, Mills Branch is a natural channel with some minor improvements near bridge structures such as the clearing of trees and channel improvements constructed along with the development within the watershed. When the North Kingwood Subdivision was constructed, a portion of the channel upstream of Mills Branch Road was removed from the channel watershed in 2004 and diverted to Taylor Gully that is located west and south of Mills Branch. The HCFCD stream shapefile was updated to reflect this change. The entire channel is generally in its natural condition.

Within Mills Branch watershed Hurricane Harvey in 2017 was responsible for 3 flooded structures while no structures were found to be flooded during Tropical Storm Imelda in 2019. Mills Branch is a FEMA studied stream with the 100-year regulatory floodplain in the project area located in the FEMA Flood Insurance Rate Map (FIRM) for Harris County, Texas and Incorporated Areas, Map Number 48201C0305L, and 48201C0310L, with the Effective Date of June 18, 2007. The 100-year regulatory floodplain areas upstream of Mills Branch Road blend with the data for Taylor Gully (G103-80-03.1B). The FEMA effective floodplains are shown on **Exhibit 3**.

For purposes of presenting the data, the stream was not split into several reaches maintaining the HCFCD reach limits established in the Kingwood Area Drainage Assessment. General characteristics of this stream can be seen in **Table 71**.

Table 71. Summary of HCFCD Unit G103-80-3.1A (Mills Branch) Characteristics

HCFCD Unit G103-80-04	Reach 1
Condition	Natural
Longitudinal slope (ft/ft)	.0025
Depth (ft)	2-10
Top width (ft)	25-50
Bottom width (ft)	1 - 10
Side slope (H:V)	2:1 –3:1
Maintenance berm	No
ROW (ft)	Unknown
Owner	Easements/Private
Construction Date	Before 1978

5.2.9.2 Hydrologic Analysis

The topology along Mills Branch drains east towards White Oak Creek (G103-80-00) a tributary of the West Fork San Jacinto River. Mills Branch drains a total of 0.45 square miles through the northern most section of the Kingwood area and ultimately outfalls into the West Fork San Jacinto River. As noted above the areas upstream of Mills Branch Road were taken out of the effective drainage area map as those areas were redirected to Taylor Gully in 2004. Approximately 10% of the drainage area, 0.1 square miles, is located outside of Harris County within Montgomery County. A portion of the County Colony Park neighborhood in Montgomery County that lies between Ford Road, and Lake Houston Road is shown to sheet flow south based on the 2018 LiDAR, but the neighborhood is serviced by a storm sewer system that drains north to another tributary of White Oak Creek. For the purposes of this study the neighborhood boundaries were used as the watershed divide for this area. The drainage area and hydrologic parameters for this subbasin were revised following the methodology discussed in **Section 2**. A comparison of the FEMA drainage areas and the revised drainage areas is shown on **Exhibit 7**.

The land use along Mills Branch is a generally single-family residential, or undeveloped land. The land use Basin Development Factor (BDF) within Harris County is primarily Post-1984 Storm Sewer with a mix of undeveloped natural areas along the channel and some open space in areas along Mills Branch Road. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

A hydrologic analysis was performed to determine the runoff hydrographs and peak flows along Mills Branch for five (5) Atlas 14 frequencies which include the 2-, 10-, 25-, 50- and 100-year storm events. A comparison of the FEMA effective and the existing condition 100-year peak flows is shown in **Table 72**. The results show a decrease in 100-year peak flows ranging from approximately 75% at Mills Branch Road, to no difference at the downstream end of the channel at Hueni Road. The large difference in peak flows at Mills Branch is due to the reduction of drainage area at the upstream end of the model at Mills Branch. The North Kingwood Forest neighborhood shifted much of the upper Mills Branch watershed to Taylor Gully, and drainage contributing to the culverts at Mills Branch Road is limited to just the ROW areas along

Mills Branch Road. The revised rainfall data results approximate the effective flows at the lower half of the channel.

Table 72. Peak Flow Comparison for HCFCD Unit G103-80-03.1A (Mills Branch)

Item		Reach 1
100-Yr Flow (cfs)	FEMA	178 – 725
	Revised (Atlas 14)	4 – 750

5.2.9.3 Hydraulic Analysis

The HCFCD model obtained for Mills Branch for this study was originally submitted by Cobb Findley as part Royal Brook at Kingwood Bridge Crossing Impact Analysis in 2014. This HEC-RAS model was used as the base model for the Mills Branch analysis. This base model included the recently constructed bridges at West Lake Houston Parkway at STA. 59+00 and a 5-7'x4' culvert at Morning Creek Springs Lane. The model was converted to an unsteady model and the existing cross sections revised following the methodology discussed in **Section 2.0**. Runoff hydrographs from the HEC-HMS model were input into the HEC-RAS model at their respective flow locations. For subbasins located along the channel with multiple outfall locations, the runoff hydrograph was entered as uniform lateral inflow hydrographs. A summary of the hydrograph distribution is provided in **Table 73**. The FEMA effective downstream boundary condition was maintained as normal depth.

Table 73. HCFCD G103-80-03.1A (Mills Branch) Hydrologic Input Summary

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Q500 (cfs)
7664.52	Flow Hydrograph	G103-80-03.1A_4 (10%)	2	3	4	5	6
7608.93	Uniform Lateral Inflow	G103-80-03.1A_4 (90%)	18	27	37	42	56
7480.20	Uniform Lateral Inflow	G103-80-03.1A_3	112	174	248	285	392
5776.91	Uniform Lateral Inflow	G103-80-03.1A_2	121	181	249	282	360
4086.73	Uniform Lateral Inflow	G103-80-03.1A_1	133	204	289	331	450

The model cross sections were revised following the methodology discussed in **Section 2.0**. There is no standing water surface elevation from Lake Houston at White Oak Creek. The cross-section data from the Royal Brook model was used to supplement the 2018 LiDAR data. The Manning's coefficient n-values from the FEMA effective model were maintained. For the channel portion of the cross sections, a Manning's n-value of 0.04 to 0.06 was used, depending on the location along the reach. Overbank n-values ranging from 0.06 to 0.12 (0.99 for ineffective areas) were used. The HEC-RAS cross section layout is shown on **Exhibit 9**.

<u>Stream Crossings</u>

Mills Branch within the project area includes the following stream crossings:

- Roadway Culvert Crossing – Three (3) [Mills Branch Drive, Morning Creek Springs, Sand Pit Road]
- Roadway Bridge Crossing – Two (2) [W. Lake Houston Parkway, Hueni Road]
- Pedestrian Culvert Crossing – One (1) [Downstream of W. Lake Houston Parkway] – Not modeled as flow conditions in the channel are lower than the bridge structure.
- Low Water Crossing – None

The Royal Oaks HEC-RAS model did not include a pedestrian bridge crossing just downstream of W. Lake Houston Blvd as it is a single span structure that was constructed higher than the WSEL's of all modeled storm events.

Based on information gathered from the field reconnaissance the bridge and culvert layouts in the Royal Oaks models were confirmed, except for the areas around Hueni Road. The Sand Pit Road culvert was added to the model based on the field measurements. This culvert lies within private property. In addition, the bridge for Hueni Road did not match the model. It appeared that the bridge was updated to a single span structure after Hurricane Harvey. The following is a summary of the revisions to the stream crossings:

- Sand Pit Road Culvert (River Station 1029) – This culvert was added based on field estimates of dimensions.
    - The HDPE culvert estimated length 50 feet
    - Culvert size 84-inches (7-feet)
    - Gravel Road embankment elevations estimated from 2018 with overflow at approximate elevation of 59-feet.

- Hueni Road (River Station 764.02) – The FEMA effective model analyzed this crossing as a three-span bridge with two sets of bents. Field conditions show that this structure was recently reconstructed to a single span. Field measurements were used to estimate the existing span lengths, and bridge widths, and 2018 LiDAR data was used to verify the Hueni Road pavement elevations. The FEMA effective bridge sections and bridge length remained the same and the following updates were made.
    - Converted to single span bridge, with low chord at elevation of 56-feet, and high chord at a minimum elevation of 59.66-feet that is the same as the effective RAS model
    - Bridge Width – 27.12-feet – Remains the same as effective RAS

5.2.9.4 Results

A comparison of the FEMA effective/ Royal Oaks Update and existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 54.3 feet near the confluence with White Oak Creek to 69.6 feet just upstream of Mills Branch Road within the existing roadside ditch as this is the new terminus of the channel since the North Kingwood Subdivision was constructed. The FEMA effective model has water surface elevations (pre-Royal Oaks) ranged from 54.3 feet at the confluence with White Oak Creek to 71.8 feet upstream of Mills Branch Road. The largest difference in water surface elevation occurs at Mills Branch Road due to the significant flow reduction upstream of Mills Branch Road. The unsteady HEC-RAS model producing water surface elevations that are up to 2.2 feet lower than the FEMA effective model.

The Existing Conditions 100-year floodplain was developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 74**. The existing level of service was also identified for each reach along the stream. The 100-year floodplain, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel does have a 100-year level of service with no potential flooded structures during the Atlas 14 100-year 24-hour rainfall storm event.

Table 74. HCFCD Unit G103-80-03.1A (Mills Branch) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year

5.2.10. HCFCD UNIT G103-80-04 (BLACKLAND GULLY)

5.2.10.1 Stream Description

Blackland Gully (HCFCD Unit G103-80-04) is a 0.6 mile long channel. The channel begins near Maple Knob Court as a grass lined channel that drains southeast into the East Fork San Jacinto River. Historical aerials in the area show the vicinity of the channel being cleared in 1989 with the channel constructed by 1995. Most of the area south of the channel was developed by 1995 and all of the current development in the watershed would be constructed by 2002.

Based on available aerials, the channel geometry and alignment has not changed since 1995. No recorded structural flooding occurred during the 2015 or 2016 Memorial Day Storms or the 2016 Tax Day Floods. A total of 34 structures flooded during Hurricane Harvey in 2017. The flooding during Hurricane Harvey is likely attributed to the channel's proximity to the East Fork San Jacinto River. A total of four structures in the watershed were recorded to have flooded during Tropical Storm Imelda in 2019.

For purposes of presenting the data, the stream was segmented into 2 reaches defined as:

- Reach 1 – From the beginning of the channel to High Valley Drive.
- Reach 2 – From High Valley Drive to the East Fork San Jacinto River.

General characteristics of this stream can be seen in **Table 75**.

Table 75. Summary of HCFCD Unit G103-80-04 Characteristics

HCFCD Unit G103-80-04	Reach 1	Reach 2
Condition	Improved natural	Natural
Longitudinal slope (ft/ft)	0.005	0.005
Depth (ft)	8 - 12	>10
Top width (ft)	65 - 120	95 - 180
Side slope (H:V)	1.0:1 – 3.0:1	--
Maintenance berm	Yes	No
ROW (ft)	150	150 - 260
Owner	Public	Public
Construction Date	Before 1995	Before 1995

5.2.10.2 Hydrologic Analysis

The topology along Blackland Gully drains northeast towards the East Fork San Jacinto River. Blackland Gully drains a total of 0.4 square miles through the Kingwood area and ultimately outfalls into the East Fork San Jacinto River. The drainage area and hydrologic parameters for this subbasin were determined following the methodology discussed in **Section 2.0**.

The land use along Blackland Gully is a mix of single-family residential and undeveloped land. The land use Basin Development Factor (BDF) within Harris County is a mix of Post-1984 Storm Sewer and Undeveloped Areas. The land use and conveyance BDF factors are shown in **Exhibit 8.** HEC-HMS was used to develop runoff hydrographs for the identified subbasins. The hydrologic calculations for the Clark Unit Hydrograph parameters time of concentration (TC) and storage coefficient (R) and HEC-HMS output are provided in **Appendix B**.

5.2.10.3 Hydraulic Analysis

A new HEC-RAS model was created for this analysis. The existing cross sections were created following the methodology discussed in **Section 2.0**. The flow distribution was calculated following the methodology listed in **Section 2.0** incorporating the storage routing methodology from **Section 2.0**. A summary of the hydrograph distribution is provided in **Table 76**. The downstream boundary condition was established as normal depth.

Table 76. HCFCD G103-80-04 Existing Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
3049.0	G1038004A (32%)	104	160	197	227	260
2828.0	Interpolated	118	181	223	257	294
2522.0	Interpolated	140	215	265	305	349
2407.0	Interpolated	149	229	283	325	372
2218.0	Interpolated	166	255	314	362	414
1990.0	Interpolated	188	290	357	411	471
1816.0	Interpolated	208	320	394	453	519
1607.0	Interpolated	234	359	443	510	584
1474.0	Interpolated	252	387	478	549	629
1220.0	Interpolated	291	447	551	634	726
1022.0	G1038004A	325	499	616	708	811

For the channel portion of the cross sections, a Manning's n-value of 0.04 was used and overbank n-values were set at 0.06 to 0.085. The HEC-RAS cross section layout is shown on **Exhibit 9**.

<u>Stream Crossings</u>

Blackland Gully includes the following stream crossings:

- Roadway Bridge Crossing – Two (2) [Hidden Lakes Drive, High Valley Drive]

5.2.10.4 Results

The existing condition water surface elevations and HEC-RAS output are shown in **Appendix C.** The 100-year water surface elevation for existing conditions ranges from 47.7 feet near the confluence with East Fork San Jacinto River to 56.7 feet at the upper limits of the model in Montgomery County.

The existing conditions 100-year ponding inundation limits were developed utilizing RAS-Mapper within the HEC-RAS software. Additionally, a 100-year potential flooded structure inventory analysis was performed and is summarized in **Table 77**. The existing level of service was also identified for each reach along the stream. The 100-year ponding inundation limits, level of service and structure inventory are shown on **Exhibit 9**. The results show that the existing channel has a 100-year level of service with no flooded structures during the Atlas 14 100-year 24-hour rainfall storm event.

Table 77. HCFCD Unit G103-80-04 (Blackland Gully) Structure Inventory Summary

Reach	100-Year Flooded Structures	Level of Service
1	0	100-Year
2	0	100-Year

6. Improvement Analysis

This section presents the proposed improvements to provide structural flooding protection for the 100-year frequency event within the Kingwood Area. Drainage improvements considered to the open channel system include:

- Improved drainage channels including widening, deepening, and/or lining for increased conveyance capacity.
- Improved conveyance capacity of existing roadway crossings through lengthening or raising existing bridge structures or additional culverts.
- Watershed diversions using enclosed conduits (following existing roadway alignments or other public ROW) or along existing streams.
- Property buy-outs

As per direction from HCFCD, the improvement analysis was performed assuming improvements to the local drainage system by revising the land use basin development factor to post-1984 storm sewers within the Kingwood Area. The assumption regarding the future improvement of the local drainage system by the City of Houston was made to make sure that the proposed improvements needed to upsize the open channel drainage system in Kingwood would take into account local storm sewer and roadside ditch improvements that would add additional flows to these channels. No improvements within Montgomery County were accounted for except for Northpark Drive which is currently being analyzed for roadway and drainage improvements. No evaluation of the local drainage systems or the impacts associated with a potential rise in water surface elevation associated with the increase in peak flows was performed. The scope for this project only includes a structure inventory analysis to determine the potential "at risk structures" located within the 100-year stream inundation. The scope for this project does not include an evaluation of other potential impacts associated with increases in water levels from increased peak flows due to assumed local drainage improvements within existing channels found to have a 100-year level-of-service with no "at risk structures". *It is recommended after this study is completed that a more detailed study be performed by the City of Houston to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.* The proposed hydrologic calculations are provided in **Appendix D** and shown on **Exhibit 10**.

Channels and streams that were found to have an existing 100-year level-of-service were reevaluated utilizing the proposed peak flows. If the stream was still determined to have a 100-year level-of-service with no structural flooding within the 100-year stream inundation limits, no improvements are proposed.

The results of the proposed improvements are presented and discussed. As a result of any reduction in water surface elevations, a structural benefit analysis was performed to determine the number of benefitted structures. As the analysis was performed assuming improvement to local drainage systems, the benefitted structures were identified as either directly benefitted or indirectly benefitted. Directly benefitted structures are those structures identified to have been located within the existing 100-year stream inundation that are then removed due to the proposed improvements. The indirectly benefitted structures are those historically flooded structures (Ike, Memorial Day, Tax Day Harvey, Imelda) that may benefit from local drainage improvements. They were selected based on engineering judgement to be located outside of the influence of the existing riverine floodplains that will not change as a result of the

proposed improvements. *The determination of the benefitted structures is just an approximation for comparison purposes. In order to determine the actual benefitted structures, a more detailed analysis would need to be performed.*

6.1. HCFCD MAINTAINED STREAMS

6.1.1. HCFCD UNIT G103-33-00 (BENS BRANCH) & HCFCD UNIT G103-38-00 (KINGWOOD DIVERSION DITCH)

6.1.1.1 Improvement Option 1

When HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was originally constructed, right-of-way was obtained to allow for future channel improvements to divert flow from HCFCD Unit G103-33-00 (Bens Branch) to handle additional runoff as development happened within the watershed. Improvement Option 1 analyzes channel enlargement for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) and diversion of up to the 100-year flow from HCFCD Unit G103-33-00 (Bens Branch). A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11** and channel typical sections are shown on **Exhibit 12**. The proposed channel sections maintain a 30-foot maintenance berm on both sides of the channel. The improvements included the following:

- HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) Reach 1 (From the confluence with HCFCD Unit G103-33-00 [Bens Branch] to Woodland Hills Drive)
    - Construction of a concrete control structure to divert the majority of the 100-year hydrograph from upstream of the confluence down HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). Analysis of the control structure was outside the scope for this project; therefore, the existing model was revised and the connection between HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was removed with all flow upstream continuing down HCFCD Unit G103-38-00 (Kingwood Diversion Ditch).
    - Dropping the channel flowline elevation 2.5 feet south of Walnut Lane and maintaining a constant slope upstream (.0008 ft/ft) to the confluence with HCFCD Unit G103-33-00 (Bens Branch).
    - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width ranging from 20-70 feet and depths ranging from 10-24 feet.
    - Construct a concrete-lined trapezoidal channel section with 2H:1V sides slopes and a bottom width of 60-70 feet and depths ranging from 14-29 feet from south of Walnut Lane to the downstream side of Deer Ridge Estates Blvd. The proposed channel sections matches the existing banks at Deer Ridge Estates Blvd. This portion of the existing channel is steep with a 12 foot drop in channel flowline over 1,750 feet with the slope ranging from .0024 ft/ft to .015 ft/ft. This drop in the existing channels results in high velocities and erosion of the existing channel banks just upstream of Deer Ridge Estates Blvd; therefore concrete-lining of the proposed channel sections is proposed. A drop structure could also be constructed, however due to the depths and available ROW it is anticipated that it would still require concrete-lining of the channel section.
    - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width of 140 feet and a depth of 12 feet along the existing stream alignment and construct

a new outfall into the West Fork San Jacinto River just upstream of the existing crossing of Woodland Hills Drive. No improvements are recommended at Woodland Hills Drive or further downstream.

- Based on the new channel sections, the following changes are proposed to the existing roadway crossings:
  - Northpark Drive – The existing bridge will span the proposed channel section; however, the existing low chord elevation infringes on the water surface elevation. It is proposed that the low chord of the bridge be raised above the 100-year water surface elevation. Based on discussions with Lake Houston Redevelopment Authority TIRZ Number 10, the Northpark Drive project currently under design will raise the existing low chord above the 100-year water surface elevation; therefore, this item was not included in the preparation of the construction cost.
  - Kingwood Drive – Existing bridge to remain.
  - Pedestrian Bridge (Lake Village Drive) – Replace the existing bridge to span the proposed channel.
  - Walnut Lane Bridge – Replace the existing bridge to span the proposed channel.
  - Deer Ridge Estates Blvd. – Existing bridge to remain.
  - Woodland Hills Drive – Existing bridge to remain.

- HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) Reach 2 (From Woodland Hills Drive to confluence with West Fork San Jacinto River – Existing channel to remain.

The proposed channel improvements will require purchase of right-of-way (ROW) for the channel section and new outfall into West Fork San Jacinto River downstream of Deer Ridge Estates Blvd. Additionally, there are two locations where the existing ROW narrows and would require purchase of additional ROW. Based on the HCFCD ROW shapefile and Harris County Appraisal District (HCAD) parcel data, at both locations there is a gap between the HCFCD ROW and parcels bounding the channel. Purchasing the land up to the parcel boundaries would be adequate to encompass the proposed channel sections. Total additional ROW required is 12.8 acres. The additional ROW acquisition is shown on **Exhibit 11**.

A summary of the hydrograph distribution is provided in **Table 78** and **Table 79**. The HEC-HMS output is in **Appendix D.**

Table 78. HCFCD G103-33-00 (Ben's Branch) Proposed Hydrologic Input Summary (Option 1)

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
29615	Flow Hydrograph	G1033300_0009_J	860	1480	1946	2353	3307
29024.31 - 27513.68	Uniform Lateral Inflow	G1033300A	254	401	502	584	677
27441.69	Lateral Inflow	G1033303A	110	166	203	231	262
26458.74 - 24159.50	Uniform Lateral Inflow	G1033300B	156	245	306	355	411
24209.16	Lateral Inflow	G1033302A	265	411	509	587	675
23234.05 - 21847.04	Uniform Lateral Inflow	G1033300C	161	254	318	371	430
21221.31 - 19400.18	Uniform Lateral Inflow	G1033300D	170	270	339	396	459
18617.86 - 16519.62	Uniform Lateral Inflow	G1033300E	117	186	233	271	314
15455.73 - 13023.86	Uniform Lateral Inflow	G1033300F	179	277	343	396	455
14299.67	Lateral Inflow	G1033301_0000_J	854	1339	1669	1934	2235
12941.61 - 11521.57	Uniform Lateral Inflow	G1033300G	117	180	222	256	293
9501.098 - 7739.881	Uniform Lateral Inflow	G1033300H	178	278	347	403	466
7739.88	Lateral Inflow	G1033304_0000_J	606	911	1111	1269	1450
6455.492 - 4371.619	Uniform Lateral Inflow	G1033300I	172	273	342	399	462

Table 79. HCFCD G103-38-00 (Kingwood Diversion Ditch) Proposed Hydrologic Input Summary

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
20789	Lateral Inflow	G1033800A	139	211	259	296	338
20553 - 17548	Uniform Lateral Inflow	G1033800B	104	162	201	231	266
17382 - 14289	Uniform Lateral Inflow	G1033800D	241	378	473	549	636
17382	Lateral Inflow	G1033800C	282	451	571	671	785
13880 - 11022	Uniform Lateral Inflow	G1033800E	264	413	515	598	691
13880	Lateral Inflow	G1033802_0000_J	413	641	795	917	1052
10572	Lateral Inflow	G1033801_0000_J	457	707	874	1008	1156
10572 - 3313	Uniform Lateral Inflow	G1033800F	423	659	818	945	1088
3245 - 1451	Uniform Lateral Inflow	G1033800G	153	257	333	398	473

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the HEC-RAS results is shown in **Table 80** . Based on the results, even with the increased flows associated with full offsite conveyance within the Kingwood Area, the diversion of flow down HCFCD

Unit G103-38-00 (Kingwood Diversion Ditch) results in a drop in water surface elevation ranging from 3 feet at the Montgomery County boundary to 0.4 feet at the outfall into West Fork San Jacinto River. At the confluence there is a 2,900 cfs reduction in peak flows, however due to the increased flow from local drainage, there is only a decrease of 843 cfs at the outfall. Along HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) the proposed channel improvements contain the flow within channel banks with a reduction in water surface elevation ranging from 1.8 feet to 0.1 feet. Based on the reduction in water surface elevations, there will be no impact to the local drainage systems. The minor reduction in water level at the Montgomery County boundary is not anticipated to result in any adverse impact to water levels within Montgomery County. *A more detailed analysis during the design phase will be required to ensure no impacts to Montgomery County.*

Table 80. HEC-RAS Summary for HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch)

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-33-00 (Bens Branch)	Confluence	R1	2883	0	-2883	73.99	70.91	-3.08
	Northpark Drive		3182	479	-2703	72.99	70.87	-2.12
	Woodland Hills Drive		3383	904	-2479	71.21	68.42	-2.79
	Tree Lane	R2	4294	2347	-1947	65.36	62.85	-2.51
	Kingwood Drive	R3	5602	4112	-1491	54.73	54.03	-0.70
	West Lake Houston Pkwy		5683	4407	-1275	50.74	49.97	-0.77
	West Fork San Jacinto	R4	6419	5575	-843	45.28	44.89	-0.39
HCFCD Unit G103-38-00 (Kingwood Diversion Ditch)	Confluence	R1	720	3311	2592	73.99	73.91	-0.08
	Northpark Drive		716	3315	2599	73.98	73.85	-0.13
	Kingwood Drive		2132	4833	2700	73.02	71.55	-1.47
	Pedestrian Bridge		2698	5201	2503	71.46	70.12	-1.34
	Walnut Lane		3834	6032	2198	66.04	64.60	-1.44
	Deer Ridge Estates Blvd.		4050	6236	2185	55.59	53.81	-1.78
	West Fork San Jacinto	R2	4847	6796	1949	45.78	44.86	-0.92

The reduction in water surface elevations associated with the proposed improvements results in the removal of 61 structures and 1 structure from the 100-year stream inundation of HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), respectively. The proposed improvements also allow for the construction of local drainage improvements that could benefit 313 structures and 281 historically flooded structures within HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), respectively. As the analysis assumes improvement of the local drainage systems including within the tributaries to HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), the indirectly benefited structures include all tributaries. **Table 81** provides a summary of the benefitted structures.

Table 81. Benefitted Structures HCFCD Unit G103-33-00 (Bens Branch) & HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) Improvement Option 1

Stream	Directly Benefited	Indirectly Benefited
G103-33-00 (Ben's Branch)	61	295
G103-38-00 (Ben's Branch Diversion)	1	281

While the proposed improvements offer significant reduction in water surface elevations, **Exhibit 11** shows 39 structures still located within HCFCD Unit G103-33-00 (Bens Branch) stream inundation. The Kingwood High School and Saint Martha Catholic School are included within the 39 structures; however, the results show significant reduction in flooding risk with a drop in 100-year water surface elevation of approximately 0.7 feet and 2.7 feet, respectively.

6.1.1.2 Improvement Option 2

The second improvement option analyzed for HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) maintains Improvement Option 1 and adds proposed channel improvements to HCFCD Unit G103-33-00 (Bens Branch). In evaluating the improvements to HCFCD Unit G103-33-00 (Bens Branch), every attempt was made to minimize the impact to the natural section located between Woodland Hills Drive and Rocky Woods Drive, however it was determined that channel enlargement was required to provide a 100-year flood protection for the areas upstream. A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11** and channel typical sections are shown on **Exhibit 12**. The proposed channel sections contain a 30-foot maintenance berm on both sides of the channel with the exception of downstream of Kingwood Drive which in existing does not contain a maintenance berm. The improvements included the following:

- HCFCD Unit G103-33-00 (Bens Branch) Reach 1 (From the confluence with HCFCD Unit G103-38-00 [Kingwood Diversion Ditch] to the confluence with HCFCD Unit G103-33-02)
    - Replace the existing 2–84” RCP at eastbound Northpark Drive with 2–9’x8’ RBC.
    - Remove low water crossing located between westbound and eastbound Northpark Drive.
- HCFCD Unit G103-33-00 (Bens Branch) Reach 2 (From confluence with HCFCD Unit G103-33-02 to Rocky Woods Drive)
    - The existing channel has a 3.0-foot drop in the flowline at Tree Lane. Drop the channel flowline elevation 2.6-feet on the upstream side of Tree Lane and maintain a constant slope upstream (0.0017 ft/ft) to the existing flowline at Woodland Hills Drive.
    - Based on the new channel sections, the following changes are proposed to the existing roadway crossings:
        - Low Water Pedestrian Crossing upstream of Tree Lane – Remove and replace with pedestrian bridge that spans the channel.
        - Tree Lane Bridge – Replace the existing bridge to span the proposed channel.
    - No improvements proposed downstream of Tree Lane.
- HCFCD Unit G103-33-00 (Bens Branch) Reach 3 (Rocky Woods Drive to the confluence with HCFCD Unit G103-33-04)

  - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width of 80-150 feet and depths ranging from 7-14 feet. The proposed channel typical section ties into the existing banks just upstream and downstream of West Lake Houston Parkway.
  - Based on the new channel sections, the following changes are proposed to the existing roadway crossings:
    - Kingwood Drive – Replace the existing bridge to span the proposed channel.
    - West Lake Houston Parkway – Existing bridge to remain as proposed channel section matches existing banks.
- HCFCD Unit G103-33-00 (Bens Branch) Reach 4 (Confluence with HCFCD Unit G103-33-04 to West Fork San Jacinto River)
  - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width of 150-feet and depths ranging from 7-14 feet.

The proposed channel improvements will require purchase of right-of-way (ROW) upstream of Tree Lane, from Rocky Woods Drive to Kingwood Drive and from the confluence with HCFCD Unit G103-33-04 to West Fork San Jacinto River. Total additional ROW required is 42.4 acres. The additional ROW acquisition is shown on **Exhibit 11**. A summary of the hydrograph distribution is provided in **Table 82**. The HEC-HMS output is in **Appendix D.**

Table 82. HCFCD G103-33-00 (Ben's Branch) Proposed Hydrologic Input Summary (Option 2)

Cross Section	Input Type	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
29615	Flow Hydrograph	G1033300_0009_J	860	1480	1946	2353	3307
29024.31 - 27513.68	Uniform Lateral Inflow	G1033300A	254	401	502	584	677
27441.69	Lateral Inflow	G1033303A	110	166	203	231	262
26458.74 - 24159.50	Uniform Lateral Inflow	G1033300B	156	245	306	355	411
24209.16	Lateral Inflow	G1033302A	265	411	509	587	675
23234.05 - 21847.04	Uniform Lateral Inflow	G1033300C	232	356	439	505	578
21221.31 - 19400.18	Uniform Lateral Inflow	G1033300D	239	368	455	525	602
18617.86 - 16519.62	Uniform Lateral Inflow	G1033300E	118	187	234	272	315
15455.73 - 13023.86	Uniform Lateral Inflow	G1033300F	179	277	343	396	455
14299.67	Lateral Inflow	G1033301_0000_J	854	1339	1669	1934	2235
12941.61 - 11521.57	Uniform Lateral Inflow	G1033300G	117	180	222	256	293
9501.098 - 7739.881	Uniform Lateral Inflow	G1033300H	178	278	347	403	466
7739.88	Lateral Inflow	G1033304_0000_J	606	911	1111	1269	1450
6455.492 - 4371.619	Uniform Lateral Inflow	G1033300I	172	273	342	399	462

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the peak flows and water surface elevations is provided in **Table 83**. Based on the results, the diversion of flow down HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) and the proposed channel improvements along HCFCD Unit G103-33-00 (Bens Branch) results in a drop in water surface elevation ranging from 5.6 feet at Woodland Hills Drive to 0.4 feet at the outfall into West Fork San Jacinto River. At the confluence there is a 2,900 cfs reduction in peak flows, however due to the increased flow from local drainage and the channel improvements, there is an increase of 1126 cfs at the outfall. Along HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) there are no changes from Improvement Option 1.

Table 83. HEC-RAS Summary for HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) Improvement Option 2

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-33-00 (Bens Branch)	Confluence	R1	2883	0	-2883	73.99	69.83	-4.16
	North Park Drive		3182	579	-2604	72.99	69.57	-3.42
	Woodland Hills Drive		3383	1150	-2234	71.21	65.62	-5.59
	Tree Lane	R2	4294	2836	-1458	65.36	61.44	-3.92
	Kingwood Drive	R3	5602	5336	-266	54.73	51.75	-2.98
	West Lake Houston Pkwy		5683	5830	148	50.74	48.03	-2.71
	West Fork San Jacinto	R4	6419	7544	1126	45.28	44.84	-0.44
HCFCD Unit G103-38-00 (Kingwood Diversion Ditch)	Confluence	R1	720	3311	2592	73.99	73.91	-0.08
	North Park Drive		716	3315	2599	73.98	73.85	-0.13
	Kingwood Drive		2132	4833	2700	73.02	71.55	-1.47
	Pedestrian Bridge		2698	5201	2503	71.46	70.12	-1.34
	Walnut Lane		3834	6032	2198	66.04	64.60	-1.44
	Deer Ridge Estates Blvd.		4050	6236	2185	55.59	53.81	-1.78
	West Fork San Jacinto	R2	4847	6796	1949	45.78	44.86	-0.92

The reduction in water surface elevations associated with the proposed improvements results in the removal of 39 additional structures including Kingwood High School and the Saint Martha Catholic School from the 100-year stream inundation of HCFCD Unit G103-33-00 (Bens Branch). **Table 84** provides a summary of the benefitted structures.

Table 84. Benefitted Structures HCFCD Unit G103-33-00 (Bens Branch) & HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) Improvement Option 2

Stream	Directly Benefited	Indirectly Benefited
G103-33-00 (Ben's Branch)	100	313
G103-38-00 (Kingwood Diversion Ditch)	1	281

6.1.1.3 Environmental Concerns

HCFCD Unit G103-33-00 (Bens Branch)

HCFCD Unit G103-33-00 (Bens Branch) is an improved channel from Northpark Drive to Woodland Hills Drive and from Rocky Woods Drive to the confluence with HCFCD Unit G103-33-04 downstream of West Lake Houston Parkway. The improvements appear to have been constructed between 1978 and 1989 based on historical aerials. Downstream of HCFCD Unit G103-33-04, the channel is part of the Deerwood Golf Course. From Woodland Hills Drive to Rocky Woods Drive, the channel is still a natural channel. Based on the Moonshine Hill Topo Map from 1916, the channel improvements have for the most part been constructed along the existing natural alignment of the channel.

The constructed channel was built as a grass lined trapezoidal channel with sections of concrete slope paving at Woodland Hills Drive, Tree Lane, Kingwood Drive and West Lake Houston Parkway. Side slopes are steeper than current HCFCD standards with slopes ranging from 2:1 to 3:1. The proposed improvements include improvements to the improved channel section from Rocky Woods Drive to the confluence with the West Fork San Jacinto River and the natural channel from the confluence with HCFCD Unit G103-33-02 to Tree Lane.

If Bens Branch is determined to be jurisdictional, the proposed improvements may require an Individual Permit, if they exceed NWP limits for bank stabilization (500 LF and 1 CY/LF below OHWM) as they would most likely include work below the ordinary high water mark (OHWM). From an environmental permitting perspective, it may be more advantageous for the proposed improvements to the channel to stay a minimum of 1-foot above the ordinary high water elevation (OHWE). The resulting benched channel section would have a wider top width and may require additional ROW, but it would potentially avoid the cost and time associated with obtaining an Individual Permit.

HCFCD Unit G103-38-00 (Kingwood Diversion Ditch)

HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) is a manmade channel that extends from the confluence with the West Fork San Jacinto River east of Woodland Hills Drive to the confluence with HCFCD Unit G103-33-00 (Bens Branch) in Montgomery County. As evidenced on historical aerials from 1978, the channel was originally constructed sometime in the 1970's. Based on the Moonshine Hill Topo Map from 1916, the channel appears to be mostly constructed out uplands. Based on the 1961 Topo map, the only portion of the channel that was originally part of a stream network is the area around Woodland Hills Drive where a stream drained north across the existing channel alignment into what is now Deer Ridge Park and then drains southeast and connects to where the existing channel exists at Woodland Hills Drive to the outfall into the West Fork San Jacinto River.

The constructed channel was built as a grass lined trapezoidal channel with side slopes steeper than current HCFCD standards with slopes ranging from 2:1 to 3:1. East of Deer Ridge Estates Boulevard, the channel spoil was placed on the southern bank resulting in a berm of up to 6 feet in height compared to the natural ground. When the channel was originally constructed, additional ROW was purchased to allow for channel improvements in the future to relieve flow from HCFCD Unit G103-33-00 (Bens Branch). The channel connects to the existing flowline at the confluence with HCFCD Unit G103-33-00 (Bens Branch) and has the potential to receive base flow.

There are several potential environmental permitting issues that exist with improvements to the proposed channel. Several of the issues have the potential of requiring an Individual Permit which results in increases to the project cost and timeline. The following are considerations to be analyzed during the next phase of the project.

- Construction of a control structure at the confluence with HCFCD Unit G103-33-00 (Bens Branch) will need to allow the existing base flow to continue down Bens Branch. Additionally, design of the control structure should attempt to limit any impacts to the natural portion of the Bens Branch channel.
- The portion of the proposed channel downstream of Walnut Lane requires slope protection due to the steep slope of the channel and resulting high velocities. In order to reduce environmental permitting issues, it is recommended that buried rip rap be utilized within this portion of the channel; however, if this is deemed to be infeasible during the Preliminary Engineering phase, a concrete-lined section may be needed which would require an Individual Permit.
- Downstream of Deer Ridge Estates Boulevard, an additional outfall into the West Fork San Jacinto River is proposed just west of Woodland Hills Drive. This outfall was proposed west of Woodland Hills Drive to avoid impacting the natural stream; however, the outfall may need to be moved further west if it is determined to have a portion located in what was originally a natural stream.
- The proposed project also calls for lowering of the existing channel flowline from Walnut Lane to the confluence in Montgomery County. If this portion of the channel is determined to be jurisdictional, lowering of the flowline would require improvements to the channel section to stay a minimum of 1-foot above the ordinary high water mark (OHWM) to avoid triggering USACE permitting, most likely requiring additional ROW. If this is determined to not be feasible, an Individual Permit may be required.

6.1.2. HCFCD UNIT G103-33-04

6.1.2.1 Improvement Option

The improvement option for HCFCD Unit G103-33-04, a tributary to HCFCD Unit G103-33-00 (Bens Branch), cannot be constructed until the receiving channels have the necessary capacity. Therefore, the improvement option for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) must be constructed first. The existing analysis showed a less than 2-year level of service with significant ponding within the commercial parking lot upstream of Kingwood Drive. In order to provide a 100-year level of service, a channel enlargement improvement option was analyzed. A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11** and channel typical sections are shown on **Exhibit 12**. The proposed channel sections contain a 30-foot maintenance berm on both sides of the channel. The improvements included the following:

- Reach 1 (From upper limits to confluence with HCFCD Unit G103-33-00 Bens Branch)
    - Drop the channel flowline elevation 3.1 feet at the outfall into HCFCD Unit G103-33-00 (Bens Branch) and maintain a constant slope upstream (0.001 ft/ft).
    - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width of 25-feet upstream of Kingwood Drive and 40-feet downstream of Kingwood Drive with depths ranging from 5-7 feet.
    - Replace the existing 2 – 8'x5' RBC's at Kingwood Drive with 3 – 10'x6' RBC's.

The proposed channel improvements fit within the existing ROW except for downstream of Kingwood Drive near the confluence with HCFCD Unit G103-33-00 (Bens Branch). The additional ROW acquisition is shown on **Exhibit 11**.

A summary of the hydrograph distribution is provided in **Table 85**. The HEC-HMS output is in **Appendix D.**

Table 85. HCFCD G103-33-04 Proposed Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
5176.0	G1033304A	190	285	347	394	447
4874.0	Interpolated	204	305	371	421	476
4671.0	Interpolated	214	319	387	440	498
4223.0	Interpolated	237	353	427	485	548
3705.0	Interpolated	266	395	478	543	612
3353.0	Interpolated	288	428	517	586	660
3086.0	G1033304_0002_J	306	454	548	621	699
2748.0	G1033304_0001_J	586	875	1063	1204	1365
1229.0	Interpolated	600	901	1098	1252	1427
677.0	G1033304_0000_J	606	911	1111	1269	1450

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the peak flows and water surface elevations is provided in **Table 86**. Based on the results, the proposed channel contains the flow within the channel banks and results in a drop in water surface elevation ranging from 0.9 feet at the outfall into HCFCD Unit G103-33-00 (Bens Branch) to 1.9 feet at Kingwood Drive. At the outfall there is a 264 cfs increase in peak flows. 2,900 cfs reduction in peak flows, however due to the increased flow from local drainage, there is only an increase of 264 cfs at the outfall. Based on the reduction in water surface elevations, there will be no impact to the local drainage systems.

Table 86. 100-Year HEC-RAS Summary for HCFCD Unit G103-33-04

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-33-04 (Kings Crossing Ditch)	Upper Limits	R1	401	447	46	50.54	49.10	-1.44
	Kingwood Drive		520	699	179	50.47	48.55	-1.92
	HCFCD Unit G103-33-00		1186	1450	264	48.17	47.27	-0.9

The existing 100-year stream inundation does not contain any existing structures; however, the proposed project significantly reduces the ponding within the commercial development parking lot north of Kingwood Drive and allows for local drainage improvements that could benefit 18 historically flooded structures. **Table 87** provides a summary of the benefitted structures.

Table 87. Benefitted Structures HCFCD Unit G103-33-04

Stream	Directly Benefited	Indirectly Benefited
G103-33-04	0	18

6.1.2.2 Environmental Concerns

HCFCD Unit G103-33-04 is an improved channel that extends from the confluence with HCFCD Unit G103-33-00 (Bens Branch) to just east of West Lake Houston Parkway. Based on historical aerials, the channel appears to be under construction in 1978 and completed to today's condition by 1989. Before this time, the channel was a natural channel 500 feet downstream of Kingwood Drive based on Moonshine Hill Topo Map from 1916. The remaining portions of the channel appear to be converted uplands.

The constructed channel was built as a grass-lined trapezoidal channel with side slopes steeper than current HCFCD standards. The proposed improvements require lowering of the channel flowline from the confluence with HCFCD Unit G103-33-00 (Bens Branch) and the construction of a larger grass lined trapezoidal channel section. If the channel is determined to be jurisdictional, it may not be possible to lower the flowline elevation without requiring an Individual Permit or a NWP 27 for natural stable channel design (no concrete allowed), or NWP 43 (300 LF and 0.50 acres impact, concrete structures only, no lining). Alternatively, improvements to the channel section would need to stay a minimum of 1-foot above the ordinary high water mark (OHWM) to avoid triggering USACE permitting. The resulting benched channel section would have a wider top width and may require additional ROW; however, it may be more advantageous from an environmental permitting perspective.

6.1.3. HCFCD UNIT G103-38-01 & HCFCD UNIT G103-38-01.1

6.1.3.1 Improvement Option

The improvement option for HCFCD Unit G103-38-01 and HCFCD Unit G103-38-01.1, tributaries to HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), cannot be constructed until the receiving channels have the necessary capacity. Therefore, the improvement option for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) must be constructed first. The existing analysis showed a 100-year level of service for HCFCD Unit G103-38-01 and a 25-year level of service for HCFCD Unit G103-38-01.1. The streams were reanalyzed utilizing the proposed peak flows and HCFCD Unit G103-38-01 was found to still contain the 100-year water surface elevation within the channel banks. While the water surface elevations are contained within the channel bank for HCFCD Unit G103-38-01, the water surface elevation at the confluence with HCFCD Unit G103-38-01.1 is higher than the elevation within the overbank areas of HCFCD Unit G103-38-01.1. The result is flooding of the overbank areas along HCFCD Unit G103-38-01.1. In order to provide a 100-year level of service for HCFCD Unit G103-38-01.1, a channel enlargement improvement option was analyzed for both HCFCD Unit G103-38-01.1 and HCFCD Unit G103-38-01 downstream of the confluence with HCFCD Unit G103-38-01.1. A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11** and channel typical sections are shown on **Exhibit 12**. The improvements included the following:

- HCFCD Unit G103-38-01 Reach 1 (From upper limits to confluence with HCFCD Unit G103-38-01.1)
  - No improvements proposed.
- HCFCD Unit G103-38-01 Reach 2 (From the confluence with HCFCD Unit G103-38-01.1 to the outfall into HCFCD Unit G103-38-00 [Kingwood Diversion Ditch])

  - Modify the existing concrete lined channel section. The existing channel section has 2H:1V side slopes and a 4-foot deep low flow section with a bottom width of 8 feet. It is proposed that an additional bench section 4 feet deep with a bottom width of 8 feet be added be added to both sides of the existing low flow section. The proposed changes would not result in changes to the existing bank elevations.
- HCFCD Unit G103-38-01.1 Reach 1
  - Drop the channel flowline elevation 1.2 feet at the confluence with HCFCD Unit G103-38-01 and maintain a constant slope upstream (0.0015 ft/ft)
  - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width of 15-feet.

The proposed channel improvements fit within the existing ROW. A summary of the hydrograph distribution is provided in **Table 88** and **Table 89**. The HEC-HMS output is in **Appendix D.**

Table 88. HCFCD G103-38-01 Proposed Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
6994	G1033801A (10%)	29	46	57	65	75
6767	Interpolated	33	52	64	74	85
6539	Interpolated	38	59	73	84	97
6220	Interpolated	45	70	87	100	115
5765	Interpolated	58	90	112	129	148
5431	Interpolated	69	108	134	155	178
5125	Interpolated	82	128	159	183	211
4409	Interpolated	122	190	235	272	313
4010	Interpolated	152	236	293	339	390
3601	Interpolated	190	296	367	424	488
3246	Interpolated	231	360	447	516	594
3043	Interpolated	259	403	500	577	664
2814	G1033801A	293	457	567	655	753
2665	G1033801_0001_J	363	564	698	806	926
2167	Interpolated	380	590	730	842	968
1281	Interpolated	413	639	791	912	1047
512	Interpolated	443	685	847	977	1121
164	G1033801_0000_J	457	707	874	1008	1156

Table 89. HCFCD G103-38-01.1 Proposed Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
1580.0	G10338011A (51%)	39	59	72	83	94
1417.0	Interpolated	42	64	78	90	102
1236.0	Interpolated	46	70	86	98	112
1078.0	Interpolated	50	75	92	106	121
830.0	Interpolated	56	85	104	119	136
592.0	Interpolated	63	96	117	134	153
410.0	Interpolated	69	104	128	147	167
200.0	G10338011A	76	116	142	162	185

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the peak flows and water surface elevations is provided in **Table 90**. Based on the results, there is an increase in peak flows of 44 cfs for HCFCD Unit G103-38-01.1 and 237 cfs at the outfall into HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) associated with the proposed channel section and proposed peak flows. The result is an increase in water surface elevations; however, the proposed channel contains the flow within the channel banks.

Table 90. 100-Year HEC-RAS Summary for HCFCD Unit G103-38-01 and HCFCD Unit G103-38-01.1

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-38-01	Upper Limits	R1	59	75	16	77.25	77.81	0.56
	Chestnut Ridge Rd		247	313	66	75.77	76.14	0.37
	Confluence	R2	729	926	197	74.86	74.90	0.04
	HCFCD Unit G103-38-00		919	1156	237	71.42	73.04	1.62
HCFCD Unit G103-38-01.1	Upper Limits	R1	72	94	22	76.37	75.87	-0.5
	Confluence		141	185	44	75.34	75.48	0.14

The existing 100-year stream inundation does not contain any existing structures; however, the proposed project allows for local drainage improvements that could benefit 56 historically flooded structures. **Table 91** provides a summary of the benefitted structures.

Table 91. Benefitted Structures HCFCD Unit G103-38-01 and HCFCD Unit G103-38-01.1

Stream	Directly Benefited	Indirectly Benefited
G103-38-01	0	130
G103-38-01.1	0	26

6.1.4. HCFCD UNIT G103-80-03.1B (TAYLOR GULLY)

The primary structural flooding concerns are concentrated in the upper 1/3 of the channel that is upstream of topographic high point near the Mill Bridge Way bridge crossing. The top of bank elevations near this bridge crossing are approximately 76-feet then drop to near 71-feet in the areas upstream of Rustling Elms Drive. In addition, the roads Shady Maple Dr. and Village Springs Dr. that run parallel with Taylor Gully are low and act as parallel channels upstream of Rustling Elms Drive with low points at approximately 68-feet in elevation where street flooding begins. Structural flooding likely starts to occur near elevation 71-feet based on an assessment of the available 2018 LiDAR data. No slab elevations were surveyed for this study, and these elevations are approximate. The goal of proposed improvements along this channel is to reduce water surface elevations and reduce the risk of structural flooding along Taylor Gully. Flows from Montgomery County are based on hydrology discussed in previous sections.

A number of different improvement alternatives were evaluated for this study.

Option 1 – Channel improvements along Taylor Gully

Option 2 – Bypass Flows to Mills Branch Creek

Option 3 – Bypass Flows to Mills Branch Road

Option 4 – Potential Detention in Montgomery County

Existing ROW along the Taylor Gully corridor ranges from 140-feet near Montgomery County to a maximum of 190 to 200-feet near Mill Bridge Way where the channel is deeper. HCFCD records in this area show a ROW of only 150-feet, but dimensions from the HCAD parcel maps show the wider ROW dimensions, so for this review of alternatives it is assumed that the entire area from property boundaries are available for channel improvements along the channel.

A review of the existing Rustling Ridge culvert shows that it does not have adequate conveyance capacity for the existing flows beyond a 10-year storm frequency. Removal of this culvert is recommended in all options, and it was assumed that the replacement structure would be a bridge. Not replacing the bridge would reduce head losses at this location in the channel in range of 6-inches to 1-foot upstream depending on the storm frequency and reduce the cost of the project, but other factors such as evaluating the impact to emergency services and local mobility is important and beyond the scope of this analysis and would need additional evaluation.

At the downstream end of Taylor Gully there have been reports from residents of erosion issues at the confluence of White Oak Creek along the remaining natural channel section. HCFCD does own ROW that allows for construction of a channel that would direct outflows from Taylor Gully to the south vs. flowing northeast adverse to the flow of White Oak Creek. Discussions with HCFCD staff led to some environmental concerns See Section 6.1.4.6 with impacting the areas that are below normal water levels. For all options below it is recommended that HCFCD include a bypass channel as part of the next study phase above normal water levels, and also evaluate the reported erosion issues along the properties along Brook Shore Court that border White Oak Creek.

6.1.4.1 Improvement Option 1 – Channel Improvements

When HCFCD Unit G103-80-03.1B (Taylor Gully) was originally constructed, sufficient right-of-way was obtained, and the existing maintenance berms meet current guidelines. The existing channel side slopes

are steeper at 3:1 and are steeper than the current HCFCD standard 4:1 but appear to be stable with no visible signs of global bank instability. An existing 7 to 8-foot drop structure exist downstream of Mills Branch Road which provides opportunity to lower the flowline of the main channel upstream to Montgomery County. The length of channel from the drop structure to Montgomery County is approximately 11,100-LF (approximately 2-miles). A number of different channel improvement options were looked at as discussed below.

1. Grass lined trapezoidal channel –
    a. Deepen and keep existing 3:1 side slope – (steady state evaluation)
        i. Maximum deepening = 7.3-feet near Mill Bridge Road
        ii. Replace Rustling Ridge Culvert with a single span bridge
        iii. Average Channel Slope = 0.10%
        iv. Upstream Channel Elev. At Montgomery County = 58.51-ft
        v. Downstream Elev. At Drop Structure = 48.00-ft
        vi. Additional ROW = Additional 15-feet near Mills Branch Road
        vii. Elm Grove
            1. Exist. WSEL STA. 118+88.72 (100-yr / 500-yr) = 71.72 / 73.14-feet
            2. Prop. WSEL STA. 118+88.72 (100-yr / 500-yr) = 69.04 / 70.64-feet

    b. Deepen and change to 4:1 side slope – (steady state evaluation)
        i. Maximum Deepening = 4.60-feet near Mill Bridge Road
        ii. Replace Rustling Ridge Culvert with a single span bridge
        iii. Average Chanel Slope = 0.10%
        iv. Upstream Channel Elev. At Montgomery County = 60.00-ft
        v. Downstream Elev. At Drop Structure = 49.50-ft
        vi. Additional ROW = Additional 10 to 35-feet near Mills Branch Road
        vii. Elm Grove
            1. Exist. WSEL STA. 118+88.72 (100-yr / 500-yr) = 71.72 / 73.14-feet
            2. Prop. WSEL STA. 118+88.72 (100-yr / 500-yr) = 68.76 / 70.23-feet

2. Concrete line the existing channel – (steady state evaluation)
    a. Maximum Deepening = Clean-out match existing FL
    b. Average Chanel Slope = varies
    c. Upstream Channel Elev. At Montgomery County = approx. 57.00-ft (2018 LiDAR)
    d. Downstream Elev. At Drop Structure = approx. 52.70-ft (2018 LiDAR)
    e. Additional ROW = none
    f. Elm Grove
        i. Exist. WSEL STA. 118+88.72 (100-yr / 500-yr) = 71.72 / 73.14-feet
        ii. Prop. WSEL STA. 118+88.72 (100-yr / 500-yr) = 70.51 / 70.84-feet

3. Concrete low flow channel (Alt7 - unsteady) – This is the construction of a concrete rectangular channel in the center of the existing channel, and to maintain the existing 3:1 grass lined side slopes as much as possible. A number of different concrete sections were looked at with a 20-ft wide by 4-ft tall section providing the best results (Alt 7 – Unsteady State)

a. Maximum Deepening = approx. 5.8-feet
b. Replace Rustling Ridge Culvert with a bridge (single span)
c. Average Chanel Slope = 0.10% min
d. Upstream Channel Elev. At Montgomery County = approx. 57.00
e. Downstream Elev. At Drop Structure = approx. 49.50
f. Additional ROW = none
g. Elm Grove
    i. Exist. WSEL STA. 118+88.72 (100-yr / 500-yr) = 71.72 / 73.14-feet
    ii. Prop. WSEL STA. 118+88.72 (100-yr / 500-yr) = 69.57 / 71.34-feet

6.1.4.2 Improvement Option 2 - Bypass Flows to Mills Branch Creek

All diversion options are based on keeping the existing infrastructure on Taylor Gully in place in Harris County. The flow to divert is determined by looking at the existing rating curve at STA. 118+88.72. Based on this X-Section the 100-yr flow needs to be reduced by approximately 50% from a flow of approximately 1,400 cfs to approximately 700 cfs to reduce WSEL's upstream of Rustling Ridge to an elevation below 71-feet that puts homes at risk of structural flooding.

The older channel for Mills Branch originally drained portions of this area that are west of Mills Branch Road, but recent developments have filled in the old channel, and drained it to Taylor Gully with detention. In addition, there is a pipeline easement that runs along the north side of this new development. A diversion channel would need to be in portions of Montgomery County and Harris County to match up with the existing Mills Branch Channel upstream of Lake Houston Parkway.

The primary concerns with this route relate to the existing flowline elevations for Mills Branch Creek that are higher in relation to Taylor Gully, and to match flowlines the diversion at Taylor Gully would need to be at an elevation of approximately 67-feet that is only about 4-feet from the home elevations in Elm Grove. A 5-foot deep channel would need to have a 25-foot bottom width at a slope of 0.12%. In addition, the diversion channel would need to go through a higher zone that would have a 15-foot depth. Downstream at all the culvert and bridge crossings the flow would roughly double in flow, and the recently constructed bridge structures would all need to be replaced to double conveyance. Considering these concerns and the likely need to adjust the existing petroleum pipelines this option is not recommended.

6.1.4.3 Improvement Option 3 - Bypass Flows to Mills Branch Road

The option matches Option 2 to Mills Branch Road with the use of box culvert diversion vs. open channel. In addition, road improvements are planned for Mills Branch Road from the Montgomery County line south to near Kingwood Drive. It was suggested that there may be a potential to oversize the storm sewer under Mills Branch Road to allow the diversion of flow along Mills Branch Road, then back to Mills Branch downstream of the existing channel drop structure that is downstream. With the need to divert approximately 700 cfs, the box culverts would need to be at a size of 2-10'x10'. Excavation for the box culverts would need to be deep at approximately 20-25-feet. This depth creates some construction difficulties when staging road construction for box culverts of this size. Cost for pre-cast box culverts are generally more expensive that channels, and there is a premium for this depth. This route would also cross the existing pipeline easement and a pipeline relocation is likely that would add additional cost. Considering these design issues this route is not recommended.

6.1.4.4 Improvement Option 4 – Additional Detention in Montgomery County

The option considers the approximation of detention necessary to reduce flows from Montgomery County by approximately 1/2 that results in a similar flow as the proposed flow diversions in Option 2 and 3. An approximation of detention volume necessary for mitigation of the peak flows was done based on the Atlas 14 rainfall depth and the small watershed method for a total drainage area of 1,248-acres, and a rainfall excess of 15.5-inches for the 100-year storm event. The calculated volume is approximately 650 ac-ft. Considering approximately 156.3-ac-ft of storage was planned for Woodridge Village, then an additional 500 ac-ft of additional storage would be required to reduce flows to Harris County by roughly 50%. The cost for this option is dependent on the cost for obtaining ROW in Montgomery County. However, there may be opportunity to both deepen Taylor Gully and excavate more depth in the existing basins in Montgomery County. With this scenario less ROW would be required. This option has better potential for mitigation of channel improvement impacts in Harris County vs. a standalone option. The cost is not significantly lower than other options due to the significant amount of excavation required, and there is uncertainty in the cost of ROW in Montgomery County.

6.1.4.5 Recommended Improvement Option

The recommended option for HCFCD Unit G103-80-03.1B (Taylor Gully) is improvement option 1 with the concrete low flow structure, and the proposed improvements at the downstream confluence with White Oak Creek. The reduction in water surface elevations associated with the proposed improvements results in the removal of 387 structures from the 100-year stream inundation of HCFCD Unit G103-80-03.1B (Taylor Gully). The proposed improvements also allow for the construction of local drainage improvements that could benefit 62 structures within HCFCD Unit G103-80-03.1B (Taylor Gully). **Table 92** provides a summary of the benefitted structures.

Table 92. Benefitted Structures – HCFCD Unit G103-80-03.1B (Taylor Gully)

Stream	Directly Benefited	Indirectly Benefited
G103-80-03.1B (Taylor Gully)	387	62

This recommend option offers significant reduction in water surface elevations. **Exhibit 11** shows the resulting inundation for the 100-year storm event. The concrete low flow option would require less channel slope impacts as the existing channel banks would generally remain the same with the proposed improvements primarily in the center 20-feet bottom width of the channel. The channel banks will be smoothed to the top of the 6-foot tall side walls and any existing silt will be removed. Concrete slope paving will be needed in some areas that are deeper between W. Lake Houston and Mill Bridge Way. In terms of constructability a cast-in-place low flow channel would be slow to construct and based on preliminary estimates could take 2-years to construct. This option will have less impact on existing bridge structures as the concrete low flow channel would fit between the existing bridge spans.

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the HEC-RAS results is in **Table 93** below. Results for the proposed alternative show significant reduction in flooding risk with a drop in 100-year water surface elevation of approximately 2 to 3-feet in the Elm Grove Area at the upstream end of the channel in Harris County.

Table 93. HEC-RAS Summary for HCFCD Unit G103-80-03.1B (Taylor Gully)

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-80-03.1B (Taylor Gully)	Confluence	R3	2953	3285	332	51.82	52.33	0.51
	Maple Bend	R2	2787	3130	343	57.59	57.96	0.37
	Mills Branch	R2	2324	2684	360	65.76	64.03	-1.73
	Mill Bridge Way	R2	1680	1937	257	69.54	66.93	-2.61
	W. Lake Houston	R2	1592	1625	33	71.04	68.27	-2.77
	Rustling Elms	R2	1552	1566	14	71.50	69.11	-2.39
	Bassingham	R1	1217	1065	-152	71.72	69.57	-2.15

It is worth mentioning that the 3:1 trapezoidal channel improvements are worth considering in subsequent studies (Option 1.a), as it may allow for some alternative channel configurations that would take less time to construct. For this study, this option was studied based on a traditional 3:1 trapezoid channel that matches the existing channel top of bank, but a mid-bank maintenance shelf with lowered top of banks may allow more flow conveyance area and would be a less traditional approach, but would require more excavation. In addition, this option may result in more exposure for existing bridge columns depending on design. The use of 3:1 slope is not the current standard in Harris County, but may be possible in this area due to the stability of the existing 3:1 slope. Additional investigation of soil conditions, and the proximity to the groundwater below the existing channel would also be a factor for all options that will need to be considered during the design phase.

6.1.4.6 Environmental Concerns

HCFCD Unit G103-80-03.1B (Taylor Gully) is an improved channel that extends from the confluence with White Oak Creek northwest towards Montgomery County. The channel was constructed in the mid 1970's based on available evidence including aerial photos from the 1970's and available USGS topographic maps of the area.

Prior to the construction of the current Taylor Gully channel the upper potions of the watershed appear to have drained to Mills Branch (HCFCD Unit # G103-80-03.1A) based on the 1920 and 1961 USGS topographic maps. The current high area just north of the Mill Bridge Way bridge crossing represented the drainage divide prior to construction of the channel. Taylor Gully extended to just upstream of Mills Branch Road and was appears ill-defined upstream of this Mills Branch Road based on the 1920 and 1961 USGS topographic maps. The outfall of Taylor Gully appears to split and drain to both White Oak Creek (HCFCD Unit # G103-80-03.1) and Caney Creek (HCFCD Unit # G103-80-03) via separate channels.

Portions of the old Taylor Gully channel exist today as low areas and oxbows adjacent to the current channel downstream of Mills Branch Road. Taylor Gully was constructed channel as a grass-lined trapezoidal channel with sections of concrete slope paving at bridges, and on the approach to a concrete drop structure. Slopes are steeper at 3:1 than current HCFCD standards. Based on the HCFCD Kingwood Area Drainage Assessment, Reach 1 is the upper portion of the channel downstream of the Montgomery County Line, Reach 2 is the main section of the channel from just upstream of Rustling Elms Drive to near Willow Wood Trail Road, and Reach 3 is a short natural channel segment that remains to the confluence of White Oak Creek.

There are several potential environmental permitting issues that exist with improvements to the proposed channel. Several of the issues have the potential of requiring an Individual Permit which results in increases to the project cost and timeline. The following are considerations to be analyzed during the next phase of the project.

- A few options are being considered for improving the channel from the existing concrete drop structure.
    - Construction of a deeper low flow 20-ft wide, by 4-ft deep concrete channel from the existing concrete drop structure to the Montgomery County Line.
    - Construction of a lowered channel flowline from the existing concrete drop structure upstream to the Montgomery County Line using a deeper 3:1 grass lined channel.
        - The grass lined channel would have the same linear impact but may score higher on USACE's stream condition assessment criteria when compared to the concrete low flow channel improvement options.
    - Each option would likely exceed the limits for nationwide permits and may require an individual permit.
- Construction of an additional channel connection to White Oak Creek that follows the current HCFCD ROW.
    - This area has not been developed and is located within floodplain areas of Caney Creek and White Oak Creek. Discussions with HCFCD Environmental Staff noted that there would likely need to be some review of wetlands, archeological, threatened and endangered species, and USACE permitting issues in this area.
    - The lower portions of the channel typically have water and may be considered Waters of the US.
    - New channel can be constructed as a high level overflow. In this case the existing natural channel can remain to maintain base flows of the channel to the current outfall location. The new channel would then be constructed above the Ordinary High Water Mark (OHWM)to minimize impacts to what may be considered Waters of the US.
    - Also need to consider erosion issues that lie within Waters of the US as areas along White Oak Creek downstream are impacting existing properties in this area.

6.2. STREAMS MAINTAINED BY OTHERS

6.2.1. HCFCD UNIT G103-36-00 (BEAR BRANCH)

6.2.1.1 Improvement Option

The existing analysis showed a 100-year level of service for HCFCD Unit G103-36-00 downstream of Kingwood Drive and a less than 2-year level of service upstream of Kingwood Drive with the major problem area being a natural low-lying area along the stream at Royal Circle Drive. This portion of the channel has had several structures flood during multiple recent storm events. In order to provide a 100-year level of service while accounting for local drainage improvements, a channel enlargement and roadway crossing improvement option was analyzed from Kingwood Drive upstream to Twin Grove Drive. A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11** and channel typical sections are shown on **Exhibit 12**. The improvements included the following:

- HCFCD Unit G103-36-00 Reach 1 (From Woodland Hills Drive to Kingwood Drive)

  - Construct a grass-lined trapezoidal channel section with 3H:1V side slopes and a bottom width of 60 feet and depths ranging from 3-6 feet.
  - Replace the existing 3 – 96" RCP at Kingwood Drive with 3 – 12'x8' RBC's.
- HCFCD Unit G103-36-00 Reach 2 (From Kingwood Drive to confluence with HCFCD Unit G103-36-01)
  - No improvements proposed.
- HCFCD Unit G103-36-00 Reach 3 (From confluence with HCFCD Unit G103-36-01 to Cotswold Manor Drive South)
  - No Improvements Proposed.
- HCFCD Unit G103-36-00 Reach 4 (From Cotswold Manor Drive South to outfall into West Fork San Jacinto River)
  - No improvements proposed.

The proposed channel improvements fit within the existing ROW. A summary of the hydrograph distribution is provided in **Table 94**. The HEC-HMS output is in **Appendix D.**

Table 94. HCFCD G103-36-00 Proposed Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
13795.0	G1033600A	299	459	566	650	744
13266.0	Interpolated	309	476	587	675	774
12902.0	Interpolated	316	487	602	693	796
12373.0	Interpolated	327	505	625	721	828
11848.0	Interpolated	338	523	648	749	862
11215.0	Interpolated	351	546	677	784	904
10713.0	Interpolated	362	564	701	813	939
10133.0	Interpolated	376	587	731	848	981
9511.0	Interpolated	391	612	763	888	1028
8868.0	Interpolated	407	639	798	930	1079
8217.0	Interpolated	424	667	835	975	1134
7595.0	Interpolated	440	696	872	1021	1188
7020.0	Interpolated	456	723	908	1064	1241
6495.0	Interpolated	472	749	942	1106	1291
6054.0	G1033600_0004_J	485	771	972	1142	1335
5640.0	G1033600_0003_J	614	992	1302	1544	1823
5123.0	Interpolated	618	1008	1326	1588	1891
4942.0	G1033600_0002A_J	619	1013	1335	1603	1915
4832.0	Interpolated	632	1044	1374	1652	1975
4713.0	Interpolated	647	1078	1419	1707	2041
4420.0	G1033600_0002_J	683	1168	1534	1850	2213
3087.0	Interpolated	702	1217	1600	1929	2310
2252.0	Interpolated	714	1249	1642	1981	2374
1506.0	G1033600_0001_J	725	1278	1681	2028	2432
1050.0	Interpolated	728	1307	1730	2079	2491
113.0	G1033600_0000_J	744	1342	1773	2135	2561

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the peak flows and water surface elevations is provided in **Table 95**. Based on the results, there is an increase in peak flows ranging from 130 cfs to 310 cfs associated with the proposed channel section and proposed peak flows which assume improvements to the local drainage systems. The result is an increase in water surface elevations for the majority of the stream, however, the limits of the 100-year stream inundation do not contain any existing structures and generally matches the existing stream inundation limits. The results show that the proposed channel section results in a drop of water surface elevation of 2.2 feet within the low lying area.

Table 95. 100-Year HEC-RAS Summary for HCFCD Unit G103-36-00 (Bear Branch)

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-36-00	Woodland Hills Drive	R1	614	744	130	67.80	68.60	0.80
	Twin Grove Drive		887	1079	192	56.21	53.99	-2.22
	Kingwood Drive		1018	1241	223	51.00	52.38	1.38
	Pine Bend Drive	R2	1707	1975	268	50.89	51.15	0.26
	Cotswold Manor Drive S	R3	2064	2374	310	48.02	48.36	0.34
	West Fork San Jacinto	R4	2252	2561	309	46.41	46.58	0.17

The reduction in water surface elevations associated with the proposed improvements results in the removal of 6 structures from the 100-year stream inundation of HCFCD Unit G103-36-00 (Bear Branch). Improvements to the local drainage improvements could benefit 600 additional structures. The scope of this project did not include an evaluation of the impacts associated with the rise in water surface elevations outside of the structure inventory analysis. *It is recommended after this study is completed that a more detailed study be performed by the City of Houston to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.* **Table 96** provides a summary of the benefitted structures.

Table 96. Benefitted Structures HCFCD Unit G103-36-00 (Bear Branch)

Stream	Directly Benefited	Indirectly Benefited
G103-36-00	6	60

6.2.1.2 Environmental Concerns

HCFCD Unit G103-36-00 is an improved natural channel that extends from the confluence with the West Fork San Jacinto River to Woodland Hills Drive. No maintenance of the channel upstream of Kingwood Drive has been performed resulting in overgrowth of trees and plants within the channel section. Downstream of Kingwood Drive, the channel is a water hazard for the Kingwood Golf Course. Based on

historical aerials, the channel improvements were constructed prior to 1978. Before this time, the channel was a natural channel upstream of Kingwood Drive with low lying ponding areas south of Kingwood Drive based on Moonshine Hill Topo Map from 1916.

The proposed improvements require construction of a larger grass-lined trapezoidal channel section upstream of Kingwood Drive. If this portion of the channel is determined to be jurisdictional, then the improvements to the channel section would need to stay a minimum of 1-foot above the ordinary high water mark (OHWM) or be less than 500 LF and 1 CY of fill/LF to avoid triggering USACE permitting. The resulting benched channel section would have a wider top width. The existing channel has a large ROW; therefore, a benched section may not require additional ROW.

6.2.2. HCFCD UNIT G103-36-03

6.2.2.1 Improvement Option

The existing analysis showed a less than 2-year level of service for HCFCD Unit G103-36-03 with the existing 100-year flow overtopping the roadway at each crossing. The results also showed that the existing 100-year stream inundation did not include any structures. In order to provide a 100-year level of service while accounting for local drainage improvements, roadway crossing improvements were analyzed. A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11**. The improvements included the following:

- HCFCD Unit G103-36-03 Reach 1 (From Royal Circle Drive to HCFCD Unit G103-36-02)
    - Royal Circle Drive – Replace the existing 24" RCP with 4 – 4'x2' RBC
    - Westbound Kingwood Drive – Replace the existing 36" RCP with 2 – 4'x3' RBC
    - Eastbound Kingwood Drive – Replace the existing 36" RCP with 2 – 6'x3' RBC

A summary of the hydrograph distribution is provided in **Table 97**. The HEC-HMS output is in **Appendix D.**

Table 97. HCFCD G103-36-03 Proposed Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
2695.0	G1033603A (13%)	10	15	19	21	24
2129.0	G1033603A (38%)	29	44	54	62	71
1676.0	Interpolated	41	61	75	86	98
1362.0	Interpolated	51	77	95	108	123
986.0	Interpolated	67	101	124	141	161
790.0	G1033603A	77	116	143	163	186

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the peak flows and water surface elevations is provided in **Table 98**. Based on the results, there is an increase in peak flows ranging from 5 cfs to 39 cfs associated with the change in offsite peak flows (local drainage improvements). The result of the proposed roadway crossing improvements is a decrease in water surface elevations at the roadway crossings ranging from 0.22 feet to 0.41 feet. *It is recommended after this study is completed that a more detailed study be performed by the City of Houston*

to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.

Table 98. 100-Year HEC-RAS Summary for HCFCD Unit G103-36-03

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-36-03	Royal Circle Drive	R1	19	24	5	53.92	53.51	-0.41
	Westbound Kingwood Drive		56	71	15	53.14	52.82	-0.32
	Eastbound Kingwood Drive		77	98	21	52.15	51.93	-0.22
	HCFCD Unit G103-36-02		147	186	39	50.96	51.22	0.26

6.2.3. HCFCD UNIT G103-46-01

6.2.3.1 Improvement Option

The existing analysis showed a less than 2-year level of service for HCFCD Unit G103-46-01 with the existing 100-year flow overtopping the roadway at each crossing. The results also showed that the existing 100-year stream inundation did not include any structures. In order to provide a 100-year level of service while accounting for local drainage improvements, roadway crossing improvements were analyzed. A plan view of the improvement option and the resulting 100-year inundation is shown on **Exhibit 11**. The improvements included the following:

- HCFCD Unit G103-46-01 Reach 1 (From Sweet Gum Lane to Cypress Lane)
  - Mistletoe Lane – Replace the existing 24" RCP with 4 – 4'x2' RBC
  - Walnut Lane – Replace the existing 36" RCP with 2 – 4'x3' RBC
  - Magnolia Lane – Replace the existing 36" RCP with 2 – 6'x3' RBC
  - Sycamore Lane – Replace the existing 36" RCP with 2 – 5'x4' RBC
- HCFCD Unit G103-46-01 Reach 2 (From Cypress Lane to confluence with HCFCD Unit G103-46-00)
  - Cypress Lane – Replace the existing 42" RCP with 3 – 6'x3' RBC

A summary of the hydrograph distribution is provided in **Table 99**. The HEC-HMS output is in **Appendix D.**

Table 99. HCFCD G103-46-01 Proposed Hydrologic Input Summary

Cross Section	HMS Node	Q2 (cfs)	Q10 (cfs)	Q25 (cfs)	Q50 (cfs)	Q100 (cfs)
2529.0	G1034601A (15%)	30	45	55	63	71
2278.0	Interpolated	36	54	66	75	86
2082.0	Interpolated	42	63	77	87	99
1880.0	Interpolated	49	73	89	102	115
1560.0	Interpolated	62	93	114	129	147
1350.0	Interpolated	73	109	133	152	172
1083.0	Interpolated	89	134	163	185	210
804.0	Interpolated	109	165	201	229	259
525.0	Interpolated	135	203	248	282	319
173.0	Interpolated	176	265	323	367	416
5.0	G1034601A	199	300	366	417	472

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and a plot comparing the existing and proposed 100-year water surface profile is provided in **Appendix E**. A summary of the peak flows and water surface elevations is provided in **Table 100**. Based on the results, there is an increase in peak flows ranging from 25 cfs to 119 cfs associated with the change in offsite peak flows (local drainage improvements). The result of the proposed roadway crossing improvements is a decrease in water surface elevations at the roadway crossings ranging from 0.4 feet to 1.6 feet. *It is recommended after this study is completed that a more detailed study be performed by the City of Houston to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.*

Table 100. 100-Year HEC-RAS Summary for HCFCD Unit G103-46-01

Stream	Location	Reach	Peak Flow (cfs)			Water Surface Elev (ft)		
			Ex	Prop	Diff	Ex	Prop	Diff
HCFCD Unit G103-46-01	Mistletoe Lane	R1	74	99	25	84.37	83.8	-0.57
	Walnut Lane		110	147	37	83.28	82.87	-0.41
	Magnolia Lane		157	210	53	80.13	78.74	-1.39
	Sycamore Lane		239	319	80	78.16	76.54	-1.62
	Cypress Lane	R2	353	472	119	69.62	68.35	-1.27

6.3. BUYOUTS

There are several streams in the Kingwood area that have a less than 100-year level of service where any channel or conveyance improvements would not reduce the risk for structural flooding. These streams are located within the floodplain of the West Fork San Jacinto River and are inundated by several feet of water with some locations experiencing 15 feet of flood depths when the West Fork San Jacinto River

reaches flood stage. As such, improvements constructed along these streams would be incapable of reducing the risk of flooding due to the close proximity to the West Fork San Jacinto River.

HCFCD has already identified areas along the West Fork San Jacinto River where they are pursuing buyouts to acquire at risk properties and remove the structures from within the West Fork San Jacinto River floodplain. Some of the streams studied are currently included within the existing targeted buyout area. It is recommended that the areas along the following streams be considered for buyout:

- HCFCD Unit G103-39-00
- HCFCD Unit G103-45-00
- HCFCD Unit G103-46-00 – South of Cypress Lane

6.4. NO IMPROVEMENTS

The existing level of service analysis identified several channels with a 100-year level of service. Some of these streams are located within newer portions of Kingwood that have been constructed with storm sewer systems; therefore, no changes were made to the peak flows based on the assumption of modifying the basin development factor to post-1984 storm sewers. Therefore, the following streams were found to have a 100-year level of service and no improvements are proposed:

- HCFCD Unit G103-41-00 (Sand Branch)
- HCFCD Unit G103-41-01 (50-year level of service)
- HCFCD Unit G103-80-04
- HCFCD Unit G103-80-01 (Green Tree Ditch)
- HCFCD Unit G103-80-01.1
- HCFCD Unit G103-80-03.1A (Mills Branch)

Of these streams, HCFCD Unit G103-41-01 was found to have a 50-year level of service; however, this tributary to Sand Branch is located within a golf course with the 100-year stream inundation contained to the golf course. As no structures are at risk, no improvements were proposed to this stream.

Other streams with an existing 100-year level of service located within older portions of Kingwood were reanalyzed utilizing the proposed peak flows assuming improvements to the local drainage systems. The proposed analysis found that the following streams were still found to have a 100-year level of service with no structures located within the 100-year stream inundation:

- HCFCD Unit G103-33-01
- HCFCD Unit G103-33-02
- HCFCD Unit G103-33-03
- HCFCD Unit G103-38-02
- HCFCD Unit G103-36-01
- HCFCD Unit G103-36-02
- HCFCD Unit G103-36-02.1

The HEC-RAS output, a comparison of the existing and proposed peak flows and water surface elevations and the HEC-RAS peak flow distribution is provided in **Appendix E**. While the analysis found these streams to have a 100-year level of service, the scope of this project did not include an evaluation of the impacts

associated with the rise in water surface elevations outside of a structure inventory analysis. *It is recommended after this study is completed that a more detailed study be performed by the City of Houston to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.*

7. Detention Estimate

Due to Harris County's current policy requirement (also adopted by HCFCD) that detention volume must be included for any projects that outfall into Lake Houston, a mitigation analysis was performed to determine potential detention needs due to increased runoff associated with the proposed channel improvements and the assumed local drainage improvements. Due to the scale of improvements analyzed throughout the Kingwood Area, detention would need to be provided regionally in large detention ponds; therefore, peak flow impacts and mitigation volume needs were measured at the following outfall locations out of the Kingwood Area:

- Outfall 1 – HCFCD Unit G103-33-00 and HCFCD Unit G103-38-00 confluence with West Fork San Jacinto River. Due to the interconnectivity of these streams, impacts were measured jointly out of the Kingwood Area.
- Outfall 2 – HCFCD Unit G103-80-03.1B (Taylor Gully) confluence with White Oak Creek.
- Outfall 3 – HCFCD Unit G103-46-01 confluence with HCFCD Unit G103-46-00 downstream of Palmetto Lane.
- Outfall 4 – HCFCD Unit G103-36-00 confluence with West Fork San Jacinto River west of West Lake Houston Parkway.

A detailed analysis of detention volume requirements for each alternative drainage improvements was not performed, but rather, the potential detention volume was calculated by comparing the difference between the existing and proposed outflow hydrograph at the identified outfall locations. A 20% contingency was applied to the resulting calculated volume.

The proposed outfall hydrographs include the peak flow increases associated with both the proposed channel improvement options and the assumed local drainage improvements; therefore, an additional unsteady HEC-RAS plan and HEC-HMS basin, identified as "Proposed Channel", was developed to estimate the potential impacts associated with only the improvement option. The HEC-HMS model "Proposed Channel" was developed by maintaining the existing land use basin development factors and revising the conveyance basin development factors for the proposed channel improvements. The HEC-HMS model also maintained the proposed storage-discharge relationships developed for the proposed channels. The HEC-RAS model was developed by utilizing the proposed geometry HEC-RAS files with the HEC-HMS flow files. The resulting peak flow increases, and potential detention volumes are, therefore, those associated with only the proposed improvement options. The potential detention volume requirements and peak flow increases associated with the local drainage improvements are estimated by the following: (1)Proposed – (2)Proposed Channel. For HCFCD Unit G103-46-01, no routing reach was developed for this analysis; therefore, it was not possible to determine the peak flow impacts and potential detention volumes associated with only the roadway crossing improvements. A summary of the peak flow increases and potential detention volume at each outfall location is shown in **Table 101** and **Table 102**. The mitigation calculations are provided in **Appendix F**.

Table 101. 100-Year Peak Flow Impact Summary

Outfall	Streams	100-Yr Peak Flow (cfs)			Peak Flow Impact (cfs)		
		Ex (1)	Prop Chan (2)	Prop (3)	Prop Chan (2-1)	Prop (3-1)	Local Impr (3-2)
HCFCD Maintained Streams							
1 (Option 1)	G103-33-00 (Bens Branch) G103-33-04 G103-38-00 (Kingwood Diversion Ditch) G103-38-01 G103-38-01.1	10,100	11,872	12,378	1,772	2,278	506
1 (Option 2)	G103-33-00 G103-33-04 G103-38-00 G103-38-01 G103-38-01.1	10,100	13,578	14,584	3,478	4,484	1,006
2	G103-80-03.1B (Taylor Gully)	2,953	3,285	3,285	332	332	0
Streams Maintained By Others							
3	G103-46-01	353	472	472	119	119	0
4	G103-36-00 (Bear Branch) G103-36-03	2,252	2,301	2,561	49	309	260

Table 102. 100-Year Potential Detention Volume Summary

Outfall	Streams	100-Yr Potential Detention (ac-ft)		
		Proposed Channel	Local Improvement	Total
HCFCD Maintained Streams				
1 (Option 1)	G103-33-00 (Bens Branch) G103-33-04 G103-38-00 (Kingwood Diversion Ditch) G103-38-01 G103-38-01.1	834.3	414.2	1248.5
1 (Option 2)	G103-33-00 G103-33-04 G103-38-00 G103-38-01 G103-38-01.1	486.3	54.6	540.9
2	G103-80-03.1B (Taylor Gully)	108.0	0.0	108.0
Streams Maintained By Others				
3	G103-46-01	0.0	19.3	19.3
4	G103-36-00 (Bear Branch) G103-36-03	18.0	105.5	123.5

8. Preliminary Cost Estimate

Preliminary cost estimates were developed for each of all improvement options. Unit costs were obtained from recent Harris County and TxDOT bid tabs. Costs were calculated for the removal of existing bridges, channel modifications, ROW acquisition and for the construction of detention ponds. As the scope of this project did not include identifying locations for detention ponds, the preliminary cost estimates do not include ROW acquisition for the detention ponds. Ancillary costs, contingency costs, and engineering fee estimates were calculated as a set percentage of the construction subtotal. The construction costs were subdivided based on the channel reaches. The preliminary drainage cost calculations are provided in **Appendix G**. A summary of construction costs is shown below in **Table 103**.

Table 103. Preliminary Construction Cost Summary

Stream	Construction Cost	Detention Cost	ROW Acquisition Cost	Total Cost
HCFCD Maintained Streams				
G103-38-00 Option 1	$25,428,000	$33,928,000	$3,582,000	$59,356,000
G103-33-00 Option 2	$24,229,000	$14,699,000	$11,827,000	$38,928,000
G103-33-04	$2,168,000	--	--	$2,168,000
G103-38-01	$2,157,000	--	--	$2,157,000
G103-38-01.1	$578,000	--	--	$578,000
G103-80-03.1B	$18,018,000	$3,122,000	--	$21,139,000
Streams Maintained By Others				
G103-36-00	$1,749,000	$3,357,000	--	$5,106,000
G103-36-03	$660,000	--	--	$660,000
G103-46-01	$2,309,000	$524,000	--	$2,833,000

9. Project Phasing

A detention mitigation plan will have to be developed and implemented for HCFCD Unit G103-33-00 (Bens Branch), HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), and HCFCD Unit G103-80-03.1B (Taylor Gully) prior to construction of channel improvements. The detention mitigation plan will also need to account for the recommended improvements to the tributaries of HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch). It is recommended that the improvement options be constructed and implemented in a phased approach from downstream to upstream. This will help to ensure that the receiving systems have the necessary capacity without some form of flow restriction which limits the benefit of the constructed improvements and does not result in downstream impacts during construction. Additionally, the improvement options for HCFCD Unit G103-38-01, HCFCD Unit G103-38-01.1 and HCFCD Unit G103-33-04, tributaries to HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), cannot be constructed until the receiving channels have the necessary capacity. Therefore, the improvement option for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) must be constructed first. Likewise, local drainage improvements cannot be constructed until after the detention mitigation plan and improvement options have been implemented for the receiving channel.

It is recommended that the improvement option to HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) be constructed prior to HCFCD Unit G103-33-00 (Bens Branch). Both alternatives require purchase of channel ROW, however except for the new outfall into the West Fork San Jacinto River, the ROW purchase for the improvements to HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) are relatively minor. The construction of the HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) improvements results in significant improvements associated with lowered water surface elevations along HCFCD Unit G103-33-00 (Bens Branch) and allows for the construction of local drainage improvements to a large portion of the Kingwood area which has historically experienced structural flooding.

While it is recommended that the improvement option to HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) be constructed first, the improvements to HCFCD Unit G103-33-00 (Bens Branch) for Reach 3 and Reach 4 from Rocky Wood Drive to the outfall into the West Fork San Jacinto River could be constructed first. Based on the results of the analysis, the peak flows utilized for the design of the channel are similar to existing (4% less at Kingwood Drive) or higher (17% higher at outfall into West Fork San Jacinto River); therefore, the construction of the proposed channel improvements could be constructed first to the benefit of the Kingwood High School and the subsequent downstream properties.

A summary of the improvement options and the necessary phasing of construction is provided in **Table 104**.

Table 104. Project Phasing Summary

Stream	Reach*	Improvement Description	Predecessors
HCFCD Maintained Streams			
G103-33-00 (Bens Branch)	R1	Flow Diversion, Culvert Replacement	G103-38-00 (Kingwood Diversion Ditch) R1
	R2	Channel modifications, bridge replacement, low water crossing removal	G103-38-00 (Kingwood Diversion Ditch) R1
	R3	Channel modifications, bridge replacement	
	R4	Channel modifications	
G103-33-04	R1	Channel modifications, culvert replacement	G103-33-00 (Bens Branch) R4
G103-38-00 (Kingwood Diversion Ditch)	R1	Channel Control Structure, Flow Diversion, Channel modifications, bridge replacement	
G103-38-01	R2	Revise existing concrete channel section	G103-38-00 (Kingwood Diversion Ditch) R1
G103-38-01.1	R1	Channel modifications	G103-38-01 R2
G103-80-03.1B (Taylor Gully)	R1	Channel Improvements	G103-80-03.1B (Taylor Gully) R2 and R3
	R2	Channel Improvements	G103-80-03.1B (Taylor Gully) R3
	R3	Channel Improvement, New Outlet	
Streams Maintained By Others			
G103-36-00	R1	Channel improvements	
G103-36-03	R1	Upsize Culverts	
G103-46-01	R1	Upsize Culverts	
	R2	Upsize Culverts	

*See Exhibit 4 for Reach extents.

10. Conclusion

The purpose of this study was to create a Conceptual Watershed Plan to evaluate and quantify the existing flooding problems along the streams within the Kingwood Project Area and develop strategies to eliminate existing flood problems while accounting for improved drainage infrastructure required to achieve a 100-year open channel level-of-service within the Kingwood Project Area. The study was performed utilizing the Atlas 14 rainfall data and HCFCD MAAPNext hydrologic methodology (see Section 2.3 for detailed discussion of this methodology). The drainage study included:

- Existing Open Channel Level of Service Analysis
- Channel Improvement Analysis
- Detention Estimate

The drainage study did not include analysis of the following:

- Detailed analysis of the Kingwood Area storm sewer systems and roadside ditches
- Detailed analysis of new development in the Kingwood Area and Montgomery County
- Analysis of HCFCD Unit G103-80-02 (White Oak Creek) and HCFCD Unit G103-80-03 (Caney Creek) along the northeastern boundary of Kingwood
- Analysis of HCFCD Unit G103-80-00 (East Fork San Jacinto River) along the eastern boundary of Kingwood
- Analysis of HCFCD Unit G103-00-00 (West Fork San Jacinto River) along the southern boundary of Kingwood.

Additionally, the acquisition of the Woodridge Village subdivision in Montgomery County upstream of HCFCD Unit G103-80-03.1B (Taylor Gully) for conversion to detention mitigation was proposed after the analysis for this drainage study had been completed. This analysis does not consider the benefits of detention at this site and it is recommended that the proposed Taylor Gully project in this study be reanalyzed to determine how the use of Woodridge Village for detention would modify the recommended plan.

The existing streams within the Kingwood Area are located within right-of-way (ROW) owned by either HCFCD, City of Houston, Public, and others (e.g. Harris County, utility districts, private entities, developers, neighborhood associations and communities). Some of these channels are entirely owned by entities other than HCFCD.

In order to effectively quantify the extent and frequency of flooding within the Kingwood Area, the existing conditions modeling was performed. The base models for the hydrologic and hydraulic analyses are identified as the FEMA Effective HEC-HMS and HEC-RAS models for San Jacinto River watershed. Hydrologic analysis for this project was performed using the HEC-HMS Version 4.2.1. The MAAPNext hydrologic methodology for developing runoff hydrographs was utilized for this study with the Atlas 14 rainfall amounts. The USACE HEC-RAS model, Version 5.0.7, was used to perform the hydraulic analysis along the streams in the project area. The FEMA Effective HEC-RAS models for HCFCD Unit G103-33-00 (Bens Branch), HCFCD Unit G103-80-03.1A (Mills Branch), and HCFCD Unit G103-80-03.1B (Taylor Gully) were simulated in unsteady state. Additionally, the HCFCD Unit G103-33-00 model was extended into Montgomery County to just upstream of the confluence with HCFCD Unit G103-38-00 (Kingwood

Diversion Ditch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) was also added to the model. For all other streams, a steady state HEC-RAS model was developed.

The data from the hydraulic models was used to develop the frequency event floodplains for the Kingwood Area utilizing RAS Mapper within the HEC-RAS program. The channel level of service was determined for each stream's reach based on whether the frequency event inundation limits were contained to the streams ROW or the wooded trails and areas next to the stream. Additionally, the streams were evaluated to determine whether the roadway crossings were overtopped during a specific frequency event. A structure inventory analysis was performed for the 100-year storm event to identify structures located within the 100-year stream inundation. A structure inventory file supplied by HCFCD was used and an average structure ground elevation was estimated from 2018 LiDAR data. For every instance where the average elevation of a structure fell below the computed water surface elevation of the 100-year storm event, that structure was considered "flooded" and tallied into a count of "structures at risk." The results of the existing condition level of service analysis are presented in the summary table at the end of this section.

Improvements to provide structural flooding protection for the 100-year frequency event within the Kingwood Area were analyzed. As per direction from HCFCD, the improvement analysis was performed assuming improvements to the local drainage system (generally City of Houston maintained storm sewer and roadside ditch systems) to the current standards within the Kingwood Area and a portion of Northpark Drive within Montgomery County. The assumption regarding the future improvement of the local drainage system by the City of Houston was made to make sure that the proposed improvements needed to upsize the open channel drainage system in Kingwood would take into account local storm sewer and roadside ditch improvements that would add additional flows to these channels. The scope for this project only includes a structure inventory analysis to determine the potential "at risk structures" located within the 100-year stream inundation. The scope for this project does not include an evaluation of other potential impacts associated with increases in water levels from increased peak flows due to assumed local drainage improvements within existing channels found to have a 100-year level-of-service with no "at risk structures". *It is recommended after this study is completed that a more detailed study be performed by the City of Houston to determine the acceptability/feasibility of the local drainage improvements and impacts associated with a potential rise in water surface elevation in the receiving systems.*

Channels and streams that were found to have an existing 100-year level-of-service were reevaluated utilizing the proposed peak flows based on assumed future storm sewer and overland flow improvements. If the stream was still determined to have a 100-year level-of-service with no structural flooding within the 100-year stream inundation limits, no improvements are proposed.

Drainage improvements considered for the open channel system include:

- Improved drainage channels including widening, deepening, and/or lining for increased conveyance capacity.
- Improved conveyance capacity of existing roadway crossings through lengthening or raising existing bridge structures or additional culverts.
- Watershed diversions using enclosed conduits (following existing roadway alignments or other public ROW) or along existing streams.

- Property buy-outs

A structural benefit analysis was performed as a result of any expected lowering of water surface elevations from recommended improvements. “Structures at risk” identified as flooding from a 100-year event were deemed to “benefit” if a drop in the water surface elevations allowed the “structures at risk” to no longer be located in the 100-year inundation as a result of recommended improvements. These structures are noted on accompanying maps as “removed,” meaning their footprints are no longer within the 100-year stream inundation.

Preliminary cost estimates were developed for each improvement option. The construction costs were subdivided based on the channel reaches. The results of the proposed improvements and preliminary cost estimates are summarized in the summary table at the end of this section.

Due to Harris County’s current policy requirement (also adopted by HCFCD) that detention volume must be included for any projects that outfall into Lake Houston, a mitigation analysis was performed to determine potential detention needs due to increased runoff associated with the proposed channel improvements and the assumed local drainage improvements. Due to the scale of improvements analyzed throughout the Kingwood Area, detention would need to be provided regionally in large detention ponds; therefore, peak flow impacts and mitigation volume needs were measured at the outfall locations out of the Kingwood Area.

A detailed analysis of detention volume requirements for each alternative drainage improvement was not performed, but rather, the potential detention volume was calculated by comparing the difference between the existing and proposed outflow hydrograph at the identified outfall locations. A 20% contingency was applied to the resulting calculated volume. A summary of the potential detention needs are provided in the summary table at the end of this section.

A detention mitigation plan will have to be developed and implemented before construction can begin on the open channel improvements. It is recommended that the improvement options be constructed from downstream to upstream to ensure that the receiving systems have the necessary capacity without some form of flow restriction which limits the benefit of the constructed improvements and to ensure that no downstream impacts occur. Additionally, the improvement options for HCFCD Unit G103-38-01, HCFCD Unit G103-38-01.1 and HCFCD Unit G103-33-04, tributaries to HCFCD Unit G103-33-00 (Bens Branch) and HCFCD Unit G103-38-00 (Kingwood Diversion Ditch), cannot be constructed until the receiving channels have the necessary capacity. Therefore, the improvement option for HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) must be constructed first. Likewise, local drainage improvements cannot be constructed until after the detention mitigation plan and improvement options have been implemented for the receiving channel.

Based on the results of this study, it is recommended that both the HCFCD Unit G103-38-00 (Kingwood Diversion Ditch) and HCFCD Unit G103-80-03.1B (Taylor Gully) recommended projects move to engineering design so that a Preliminary Engineering (30% plan design) can be completed subject to input from Kingwood area residents. Additionally, it is recommended that the proposed Taylor Gully project in this study be reanalyzed to determine how the use of Woodridge Village for detention would modify the recommended plan.

Stream	Reach*	Existing Channel Description					Recommended Improvement							
		Channel Type (Natural/Improved/ Concrete)	Maint. Berm	ROW	Owner	Level of Service	Improvement Description	ROW Required	Add. ROW Required	Construction Cost Estimate (Including ROW)	Total Benefited Structures	Detention Estimate Channel Improvement		
												Channel	Local	Constr. Cost (W/O ROW)
		(--)	(--)	(ft)	(--)	(--)	(--)	(ft)	(ac)	($)	(--)	(ac-ft)	(ac-ft)	(ac-ft)
HARRIS COUNTY FLOOD CONTROL MAINTAINED STREAMS														
G103-33-00 (Ben's Branch)	R1	Improved	No	100-120	HCFCD Public	<2-Yr	Flow Diversion, Culvert Replacement			$179,000	8	540.9		$14,699,000
	R2	Natural	No	100	Other	2-Yr	Channel modifications, bridge replacement, low water crossing removal	180	19.2	$8,651,000	2			
	R3	Improved	No	160-260	HCFCD	<2-Yr	Channel modifications, bridge replacement	200-260	2.4	$6,355,000	29			
	R4	Improved	No	--	COH Private	2-Yr	Channel modifications	270-300	20.8	$9,045,000	18			
G103-33-01	R1	Improved	Yes	140-150	HCFCD	100-Yr	NO IMPROVEMENT							
G103-33-02	R1	Improved	Yes	100-150	HCFCD	100-Yr	NO IMPROVEMENT							
G103-33-03	R1	Improved	Yes	80	HCFCD	100-Yr	NO IMPROVEMENT							
G103-33-04	R1	Improved	No	110-130	HCFCD	<2-Yr	Channel modifications, culvert replacement	110-140	0.5	$2,168,000	18			
G103-38-00 (Ben's Branch Diversion)	R1	Improved	Yes	195-300	HCFCD	100-Yr	Channel Control Structure, Flow Diversion, Channel modifications, bridge replacement	210-340	12.8	$25,428,000	282	834.3	414.2	$33,928,000
	R1-R4	G103-33-00 (Ben's Branch)					NO IMPROVEMENTS CONSTRUCTED				356			
	R2	Improved	No	140-300	COH	<2-Yr	NO IMPROVEMENT							
G103-38-01	R1	Improved	Yes	50	Public	100-Yr	NO IMPROVEMENT							
	R2	Concrete	Yes	90	HCFCD Other	100-Yr	Revise existing concrete channel section			$2,157,000	130			
G103-38-01.1	R1	Improved	Yes	80	HCFCD Public	25-Yr	Channel modifications			$578,000	26			
G103-38-02	R1	Improved/Concrete	No	130-160	HCFCD	100-Yr	NO IMPROVEMENT							
G103-41-00	R1	Improved	Yes	130	HCFCD Public	100yr	NO IMPROVEMENT							
	R2	Improved	Yes	130	Private	>100yr	NO IMPROVEMENT							
G103-41-01	R1	Improved	Yes	110 - 130	HCFCD Public	50yr	NO IMPROVEMENT							
G103-45-00	R1	Improved	No	60-85	HCFCD	<2-yr	TARGETED BUYOUT AREA							
G103-80-01	R1	Natural Channel	Yes	130-145	HCFCD Public	100yr	NO IMPROVEMENT							
G103-80-03.1B (Taylor Gully)	R1	Improved	Yes	140	HCFCD	10yr	Channel Improvements			$2,600,000	132	115.6		$3,122,000
	R2	Improved	Yes	140-150	HCFCD	10yr	Channel Improvements			$14,938,000	317			
	R3	Natural Channel	No	150	HCFCD	100yr	Channel Improvement, New Outlet			$480,000	0			

Stream	Reach*	Existing Channel Description					Recommended Improvement							
		Channel Type (Natural/Improved/ Concrete)	Maint. Berm	ROW	Owner	Level of Service	Improvement Description	ROW Required	Add. ROW Required	Construction Cost Estimate (Including ROW)	Total Benefited Structures	Detention Estimate Channel Improvement		
												Channel	Local	Construction Cost (Without ROW)
		(--)	(--)	(ft)	(--)	(--)	(--)	(ft)	(ac)	($)	(--)	(ac-ft)	(ac-ft)	(ac-ft)
STREAMS MAINTAINED BY OTHERS														
G103-36-00	R1	Natural	No	90-180	Public	<2-Yr	Channel improvements			$1,749,000	66	18.0	105.5	$3,357,000
	R2	Improved	No	130-210	Other	100-Yr	NO IMPROVEMENT							
	R3	Improved	No	135	Other	100-Yr	NO IMPROVEMENT							
	R4	Improved	No	135	Other	100-Yr	NO IMPROVEMENT							
G103-36-01	R1	Natural	No	20-70	Other	100-Yr	NO IMPROVEMENT							
	R2	Natural	No	--	Other	100-Yr	NO IMPROVEMENT							
G103-36-02	R1	Improved/Natural	No	50	Other	100-Yr	NO IMPROVEMENT							
G103-36-02.1	R1	Improved	No	100	Public	100-Yr	NO IMPROVEMENT							
G103-36-03	R1	Improved	No	100	Public	<2-Yr	Upsize Culverts			$660,000				
G103-39-00	R1	Natural	No	100	Other	100-Yr	NO IMPROVEMENT							
	R2	Natural	No	--	--	<2-Yr	Targeted Buyout Area							
	R3	Natural	No	--	--	<2-Yr	Targeted Buyout Area							
G103-46-00	R1	Improved	No	35-85	HCFCD Other	<2-Yr	Targeted Buyout Area							
G103-46-01	R1	Improved	No	--	--	<2-Yr	Upsize Culverts			$889,000	52		19.3	$524,000
	R2	Concrete	--	50	Public Other	<2-Yr	Upsize Culverts			$1,420,000	3			
G103-80-03.1A (Mills Branch)	R1	Natural	No	--	--	100yr	NO IMPROVEMENT							
G103-80-04	R1	Improved	Yes	150	Public	100-Yr	NO IMPROVEMENT							
	R2	Natural	No	150-260	Public	100-Yr	NO IMPROVEMENT							

*See Exhibit 4 for Reach extents.

Kingwood Drainage Study

HARRIS COUNTY
BOND PROGRAM 2018

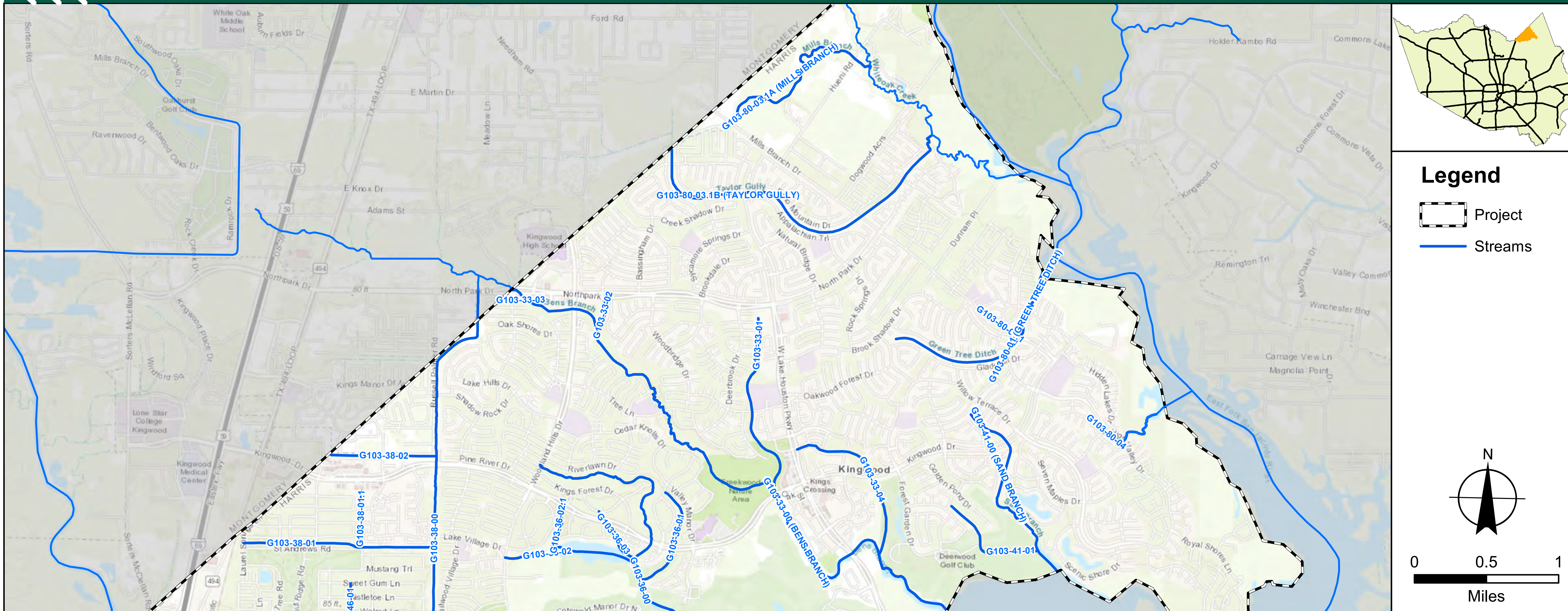


Exhibit 1
Project Area

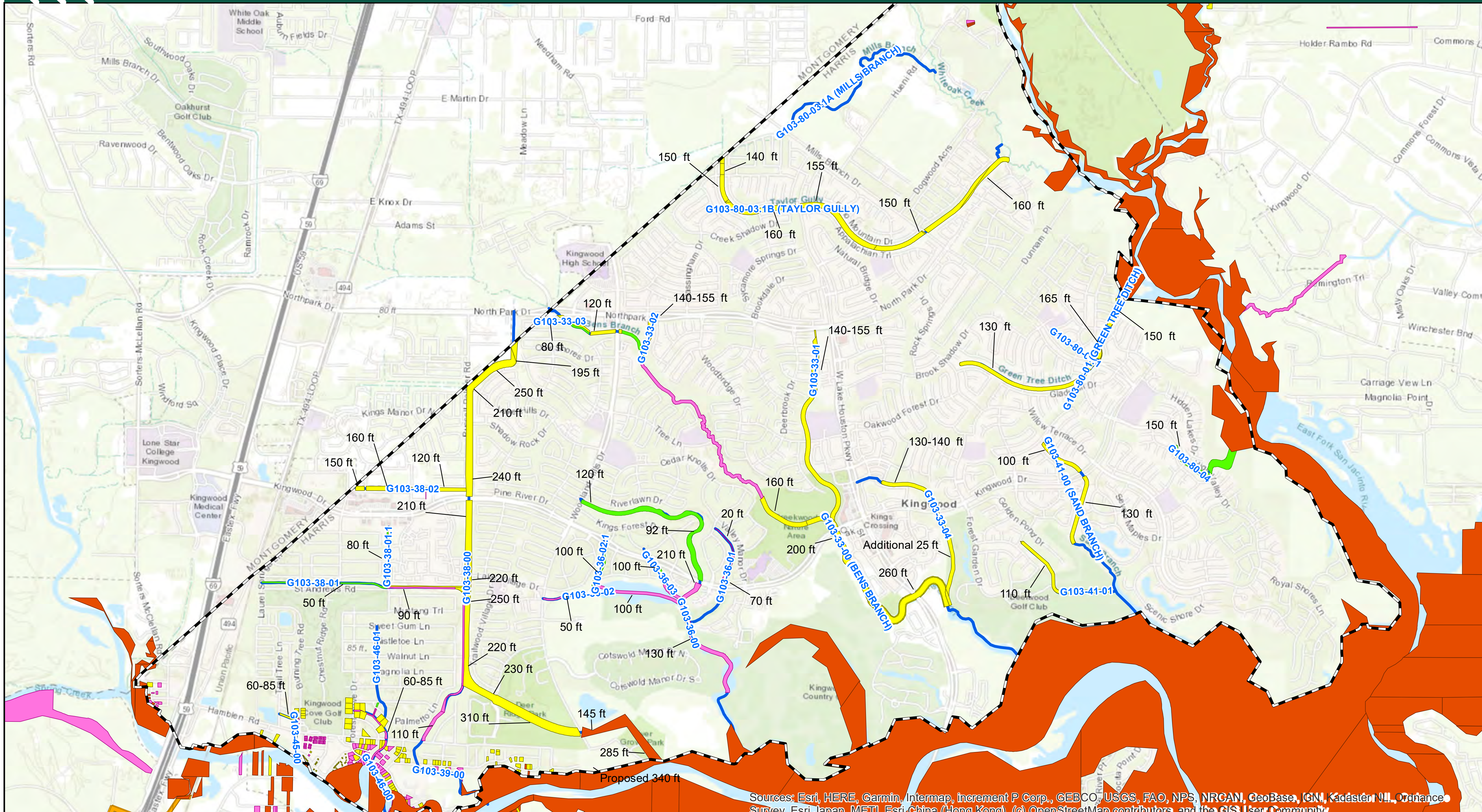
May 2020

www.hcfcd.org/2018bondprogram

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- Project
- **ROW (Acquired Grantee)**
- H.C.F.C.D.
- City of Houston
- State of Texas
- Public
- Others
- Streams

N

0 0.5 1

Miles

Exhibit 2
Channel Right-Of-Way

Gauge Engineering

NEEL-SCHAFFER

May 2020

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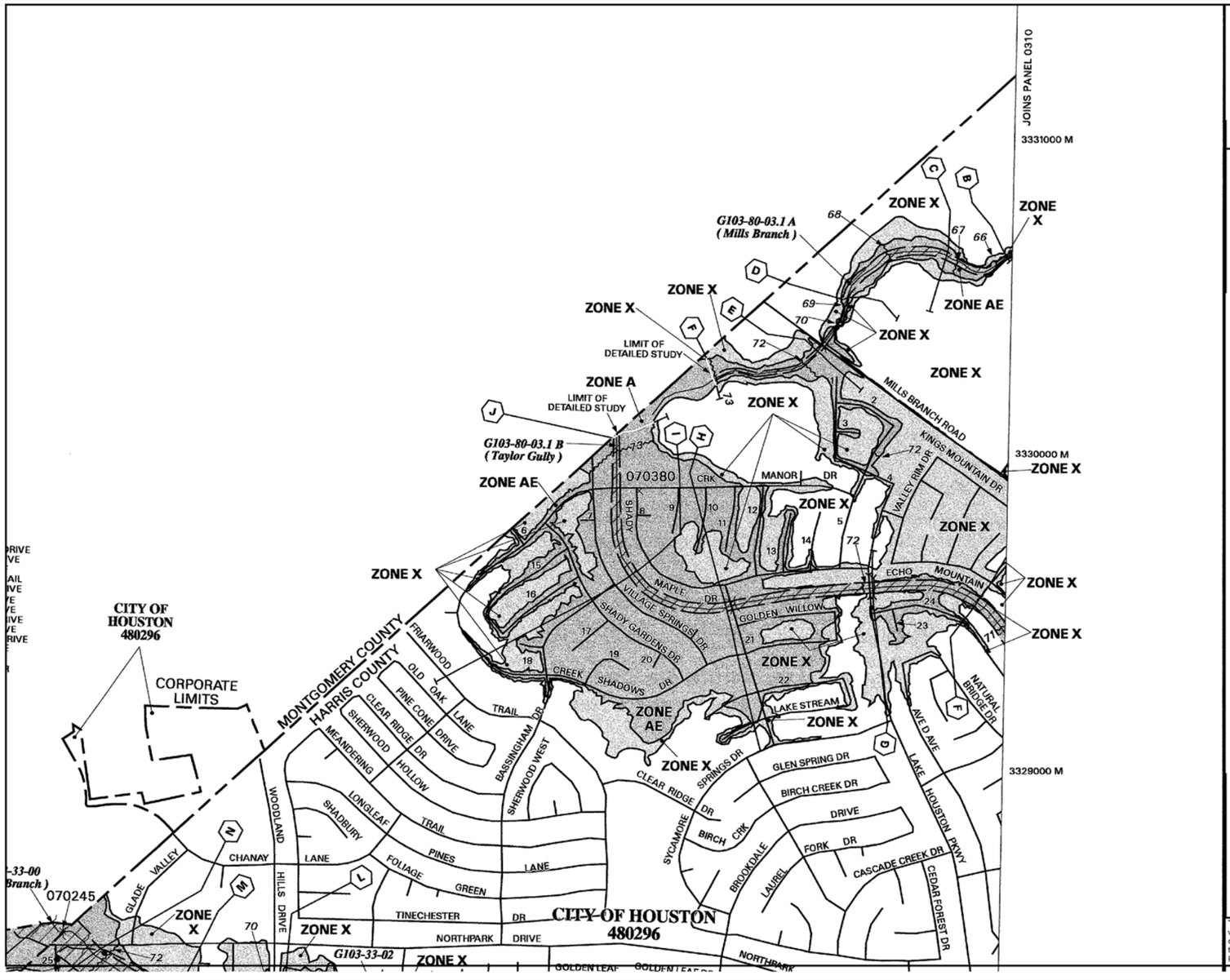
HARRIS COUNTY FLOOD CONTROL DISTRICT



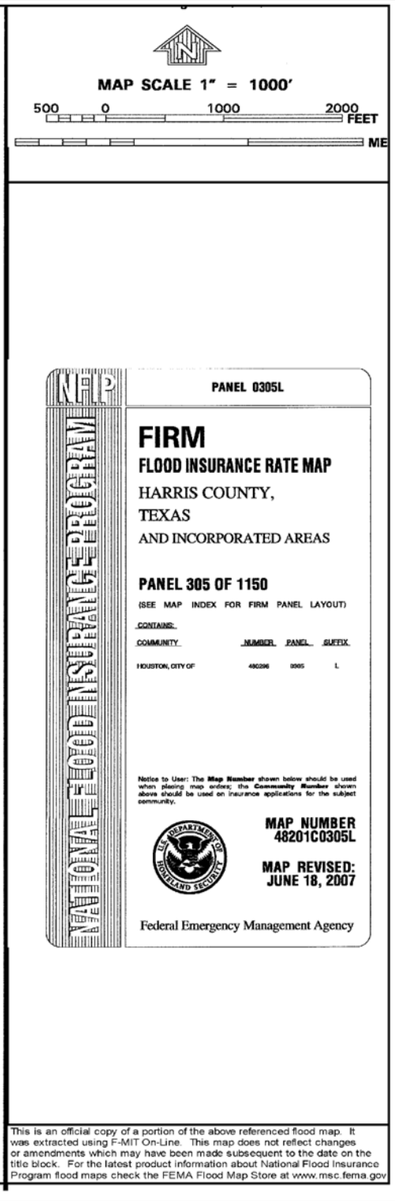


Exhibit 3-A
FEMA FIRM Map

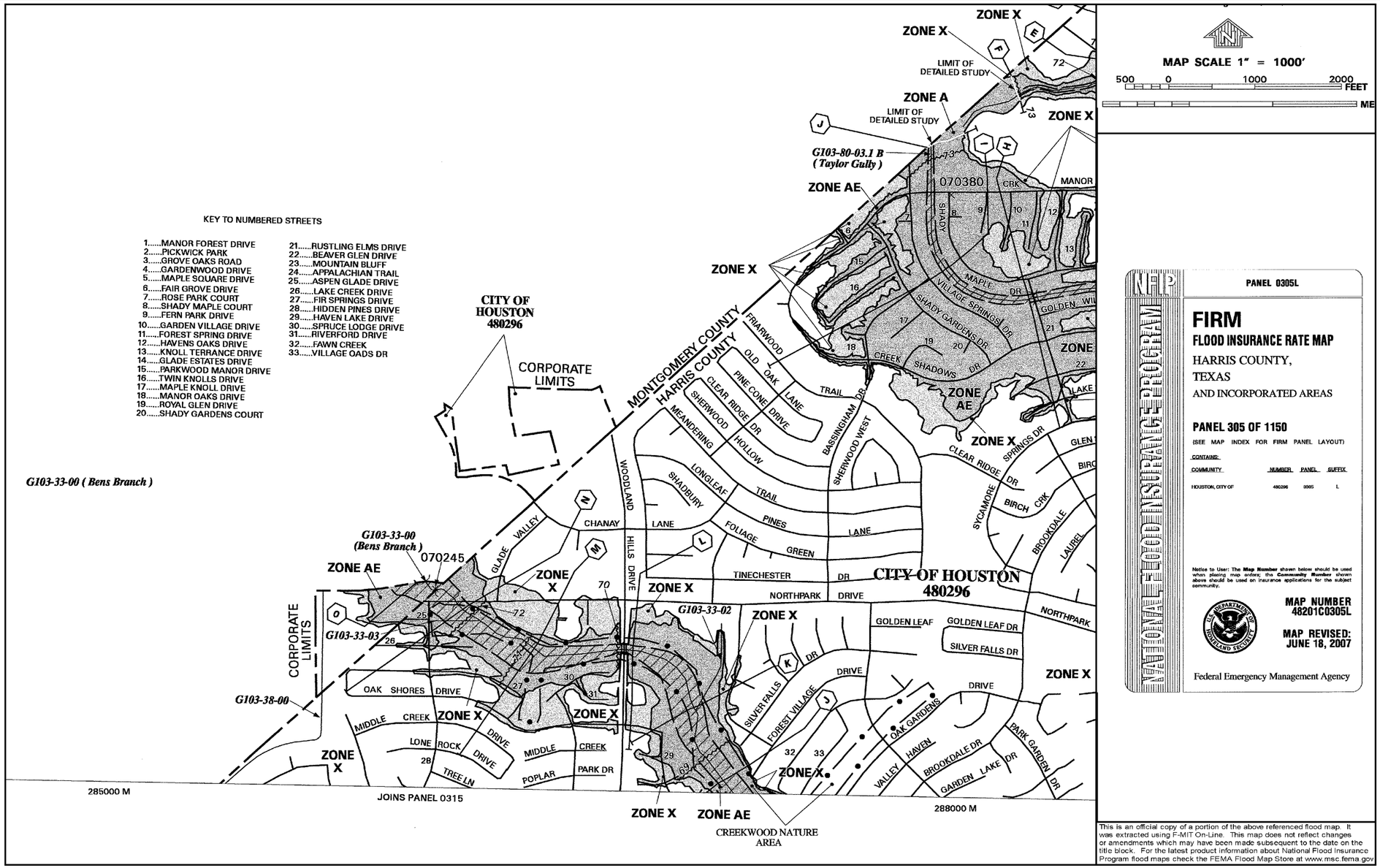


Exhibit 3-B
FEMA FIRM Map

Gauge ENGINEERING

NEEL-SCHAFFER

Exhibit 3-C
FEMA FIRM Map

Gauge ENGINEERING
NEEL-SCHAFFER

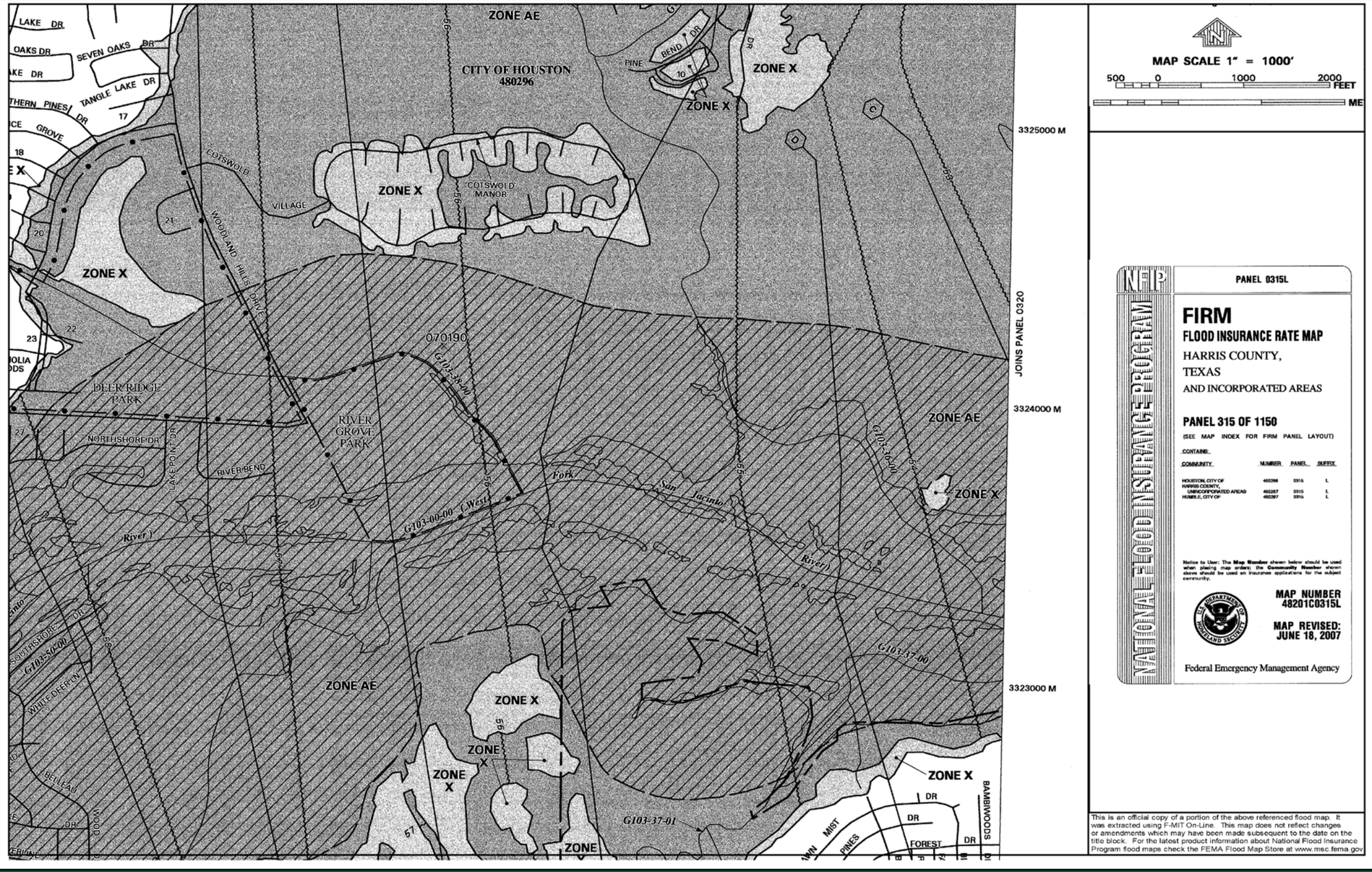
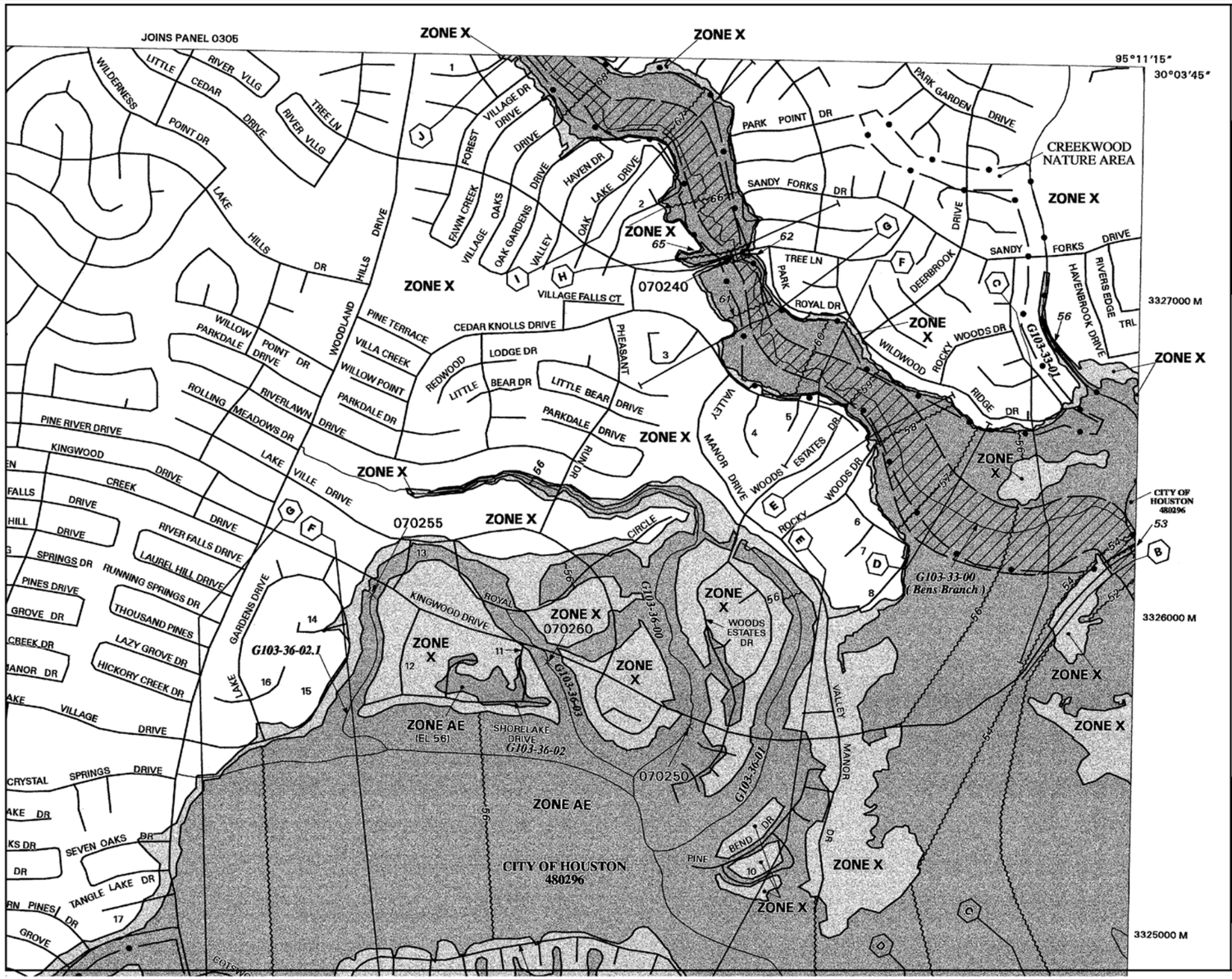


Exhibit 3-D
FEMA FIRM Map

Gauge ENGINEERING

NEEL-SCHAFFER



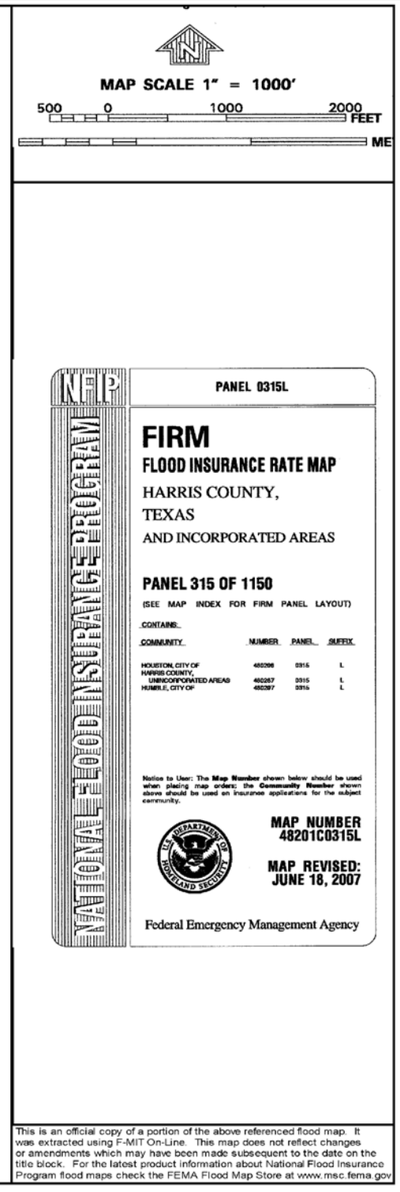
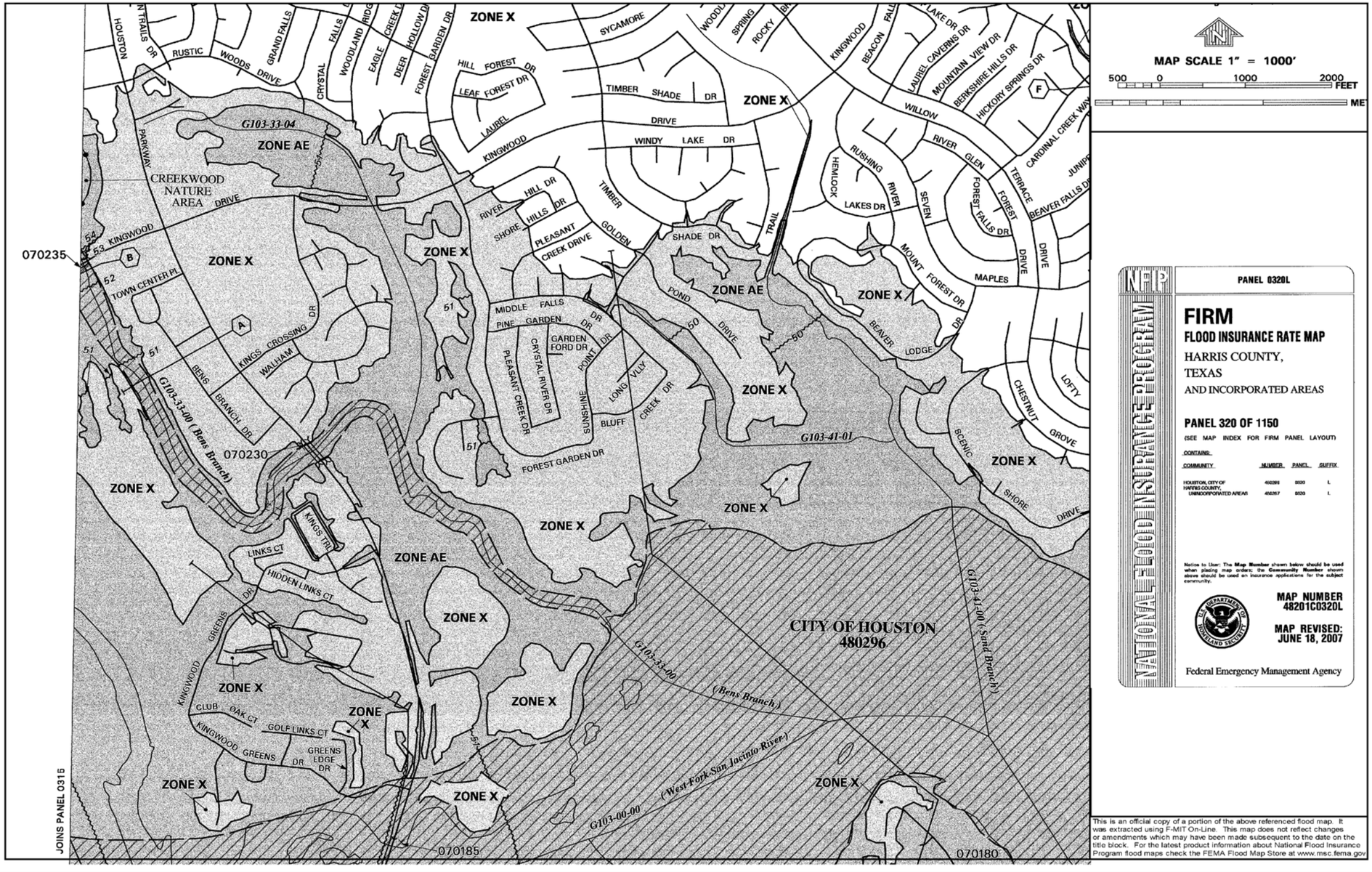


Exhibit 3-E
FEMA FIRM Map

Gauge ENGINEERING
NEEL-SCHAFFER



PANEL 0320L

FIRM

FLOOD INSURANCE RATE MAP

HARRIS COUNTY, TEXAS AND INCORPORATED AREAS

PANEL 320 OF 1150

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
HOUSTON, CITY OF	480296	0320	L
HARRIS COUNTY UNINCORPORATED AREAS	480287	0320	L

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER 48201C0320L

MAP REVISED: JUNE 18, 2007

Federal Emergency Management Agency

This is an official copy of a portion of the above referenced flood map. It was extracted using F-MIT On-Line. This map does not reflect changes or amendments which may have been made subsequent to the date on the title block. For the latest product information about National Flood Insurance Program flood maps check the FEMA Flood Map Store at www.msc.fema.gov

Exhibit 3-F
FEMA FIRM Map

Gauge ENGINEERING

NEEL-SCHAFFER

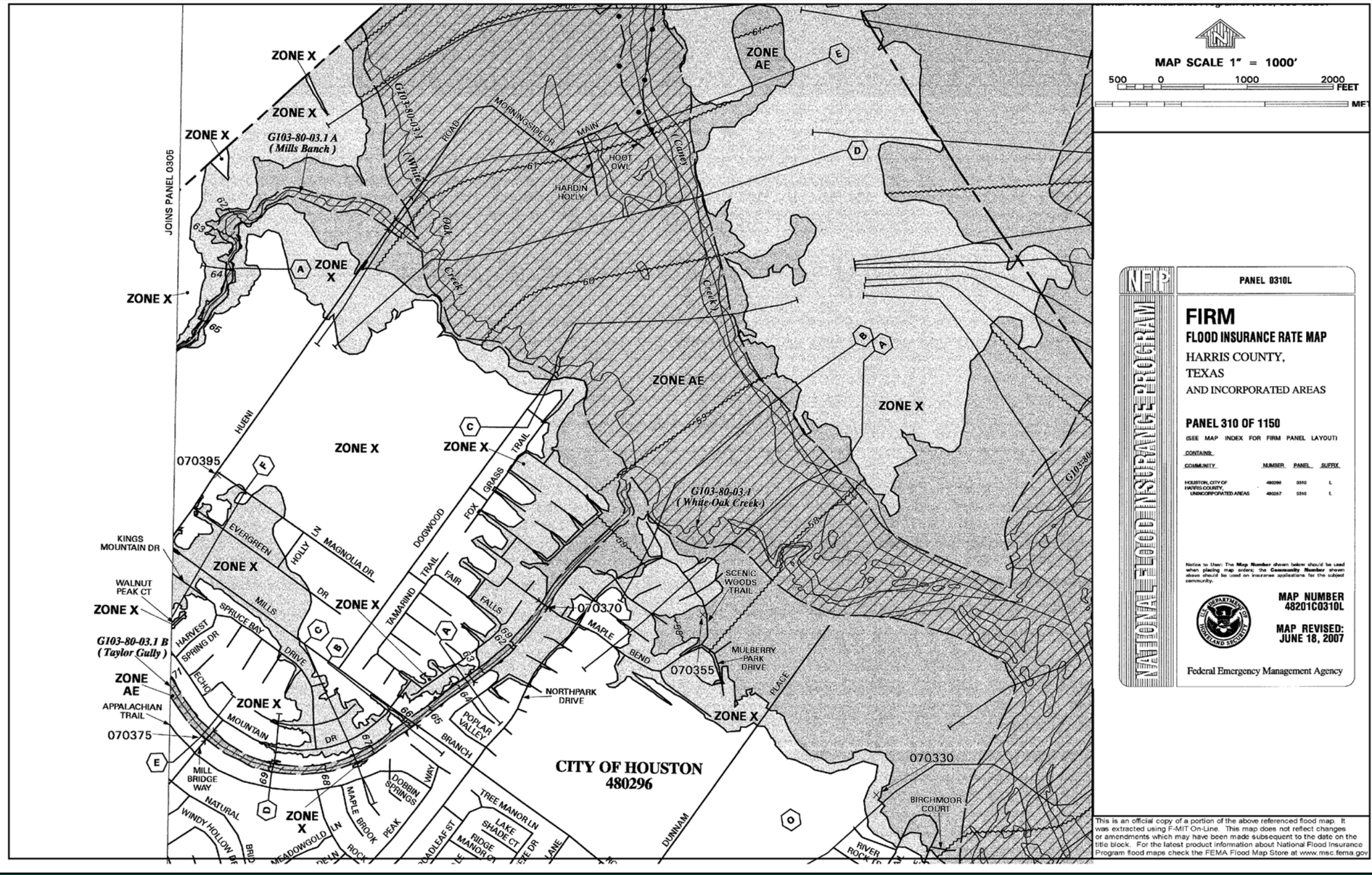


Exhibit 3-G
FEMA FIRM Map

Gauge ENGINEERING

NEEL-SCHAFFER

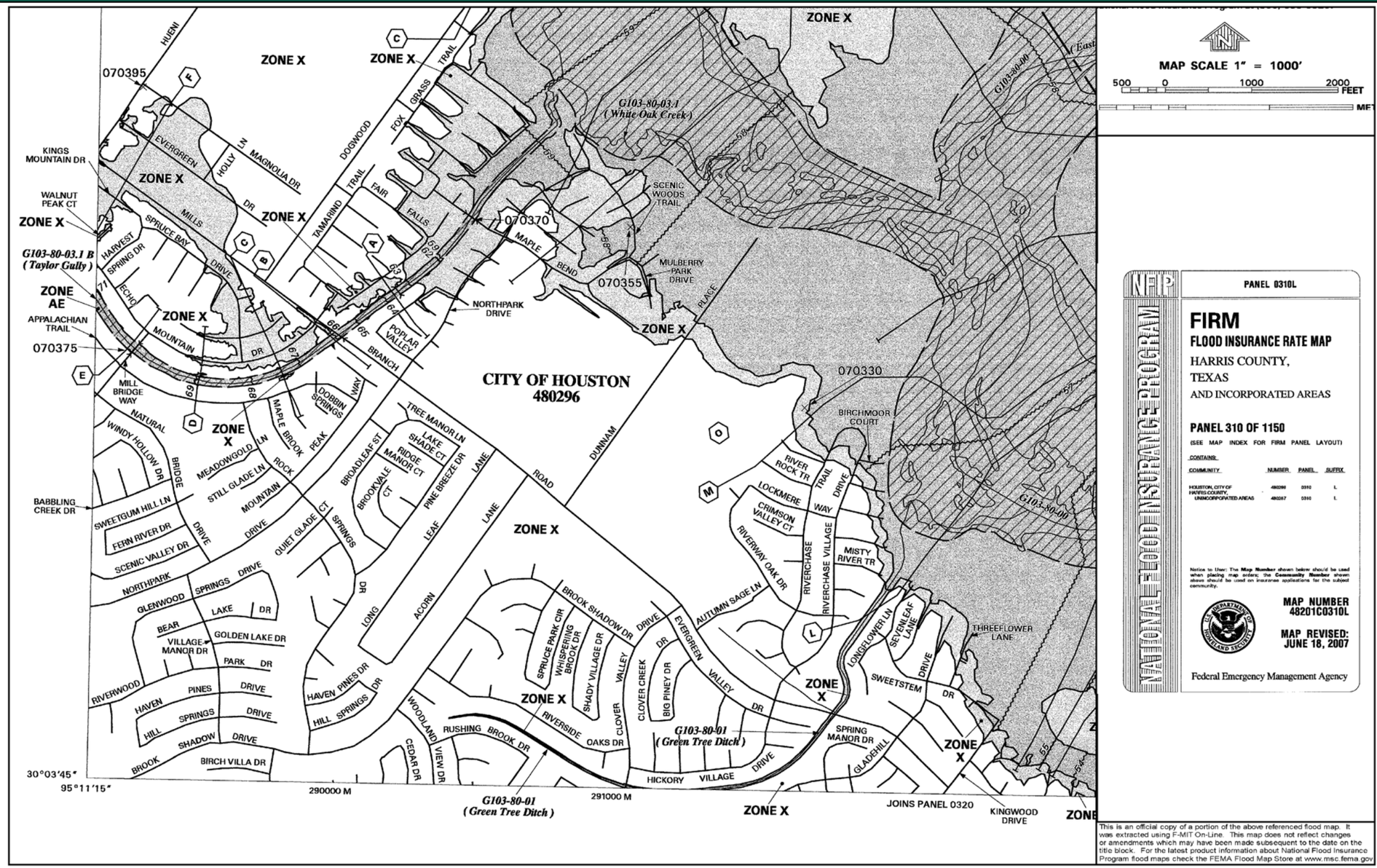


Exhibit 3-H
FEMA FIRM Map

Gauge ENGINEERING

NEEL-SCHAFFER

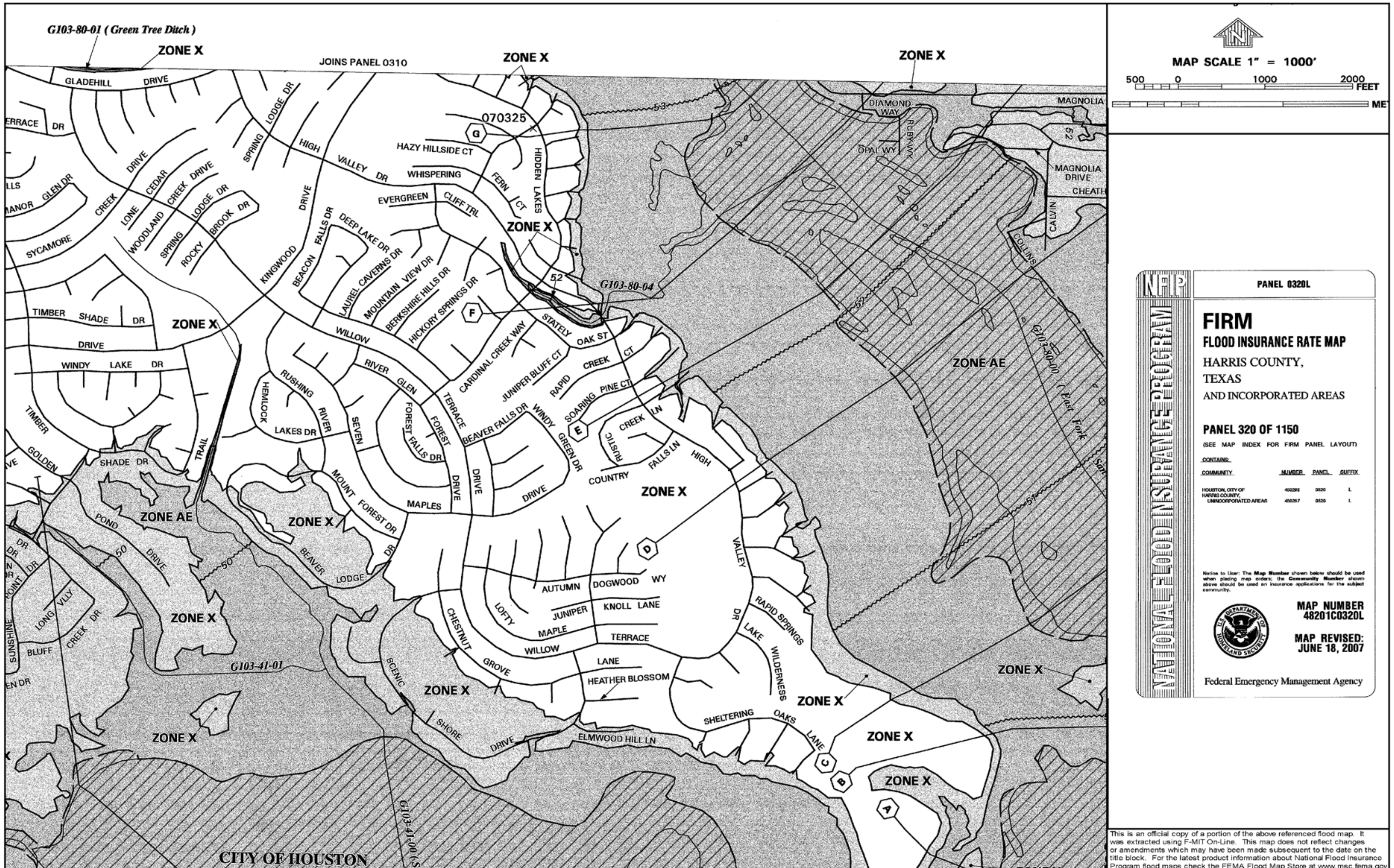
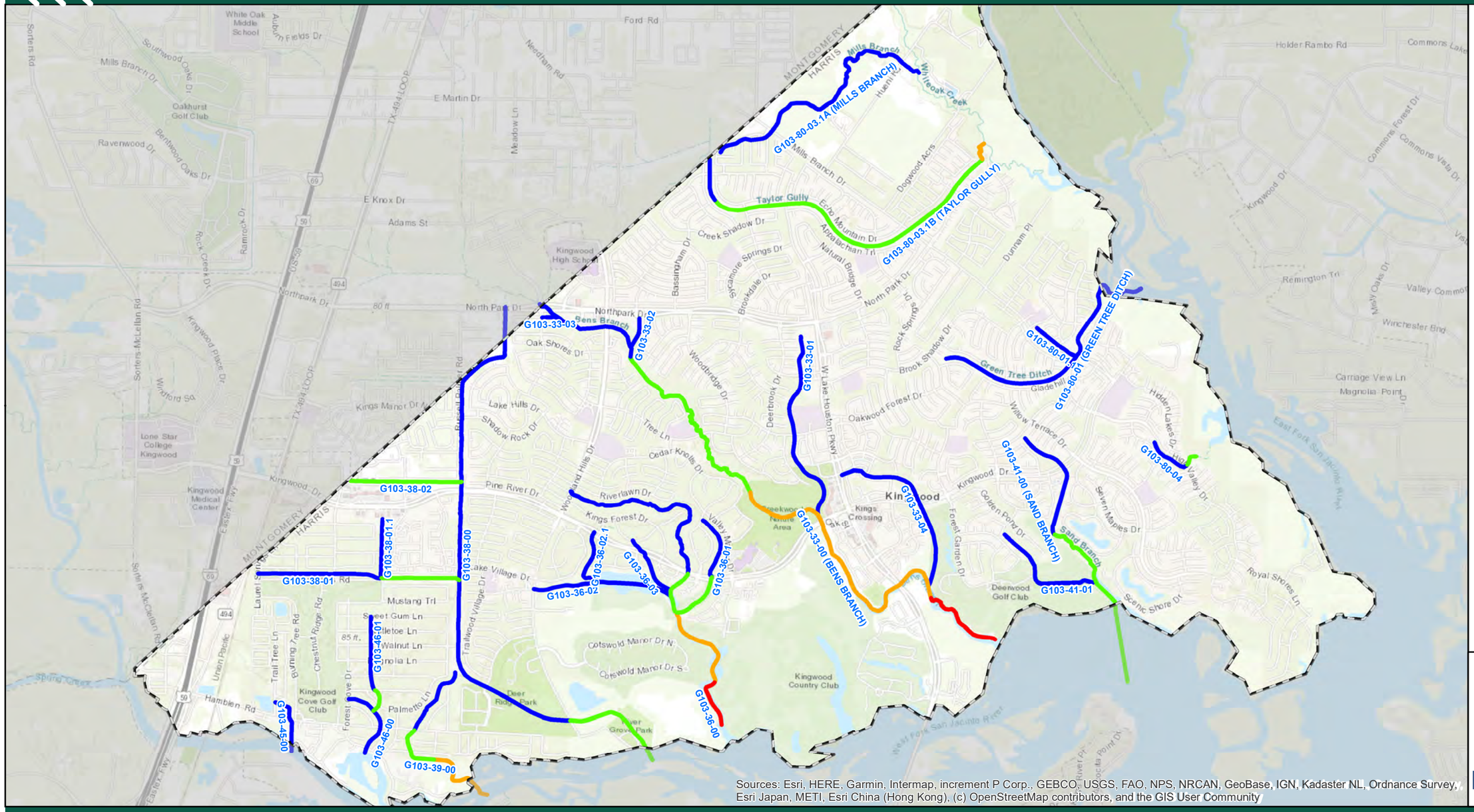


Exhibit 3-I
FEMA FIRM Map



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Legend

Project Area

Stream Segment

- Reach 1
- Reach 2
- Reach 3
- Reach 4

N

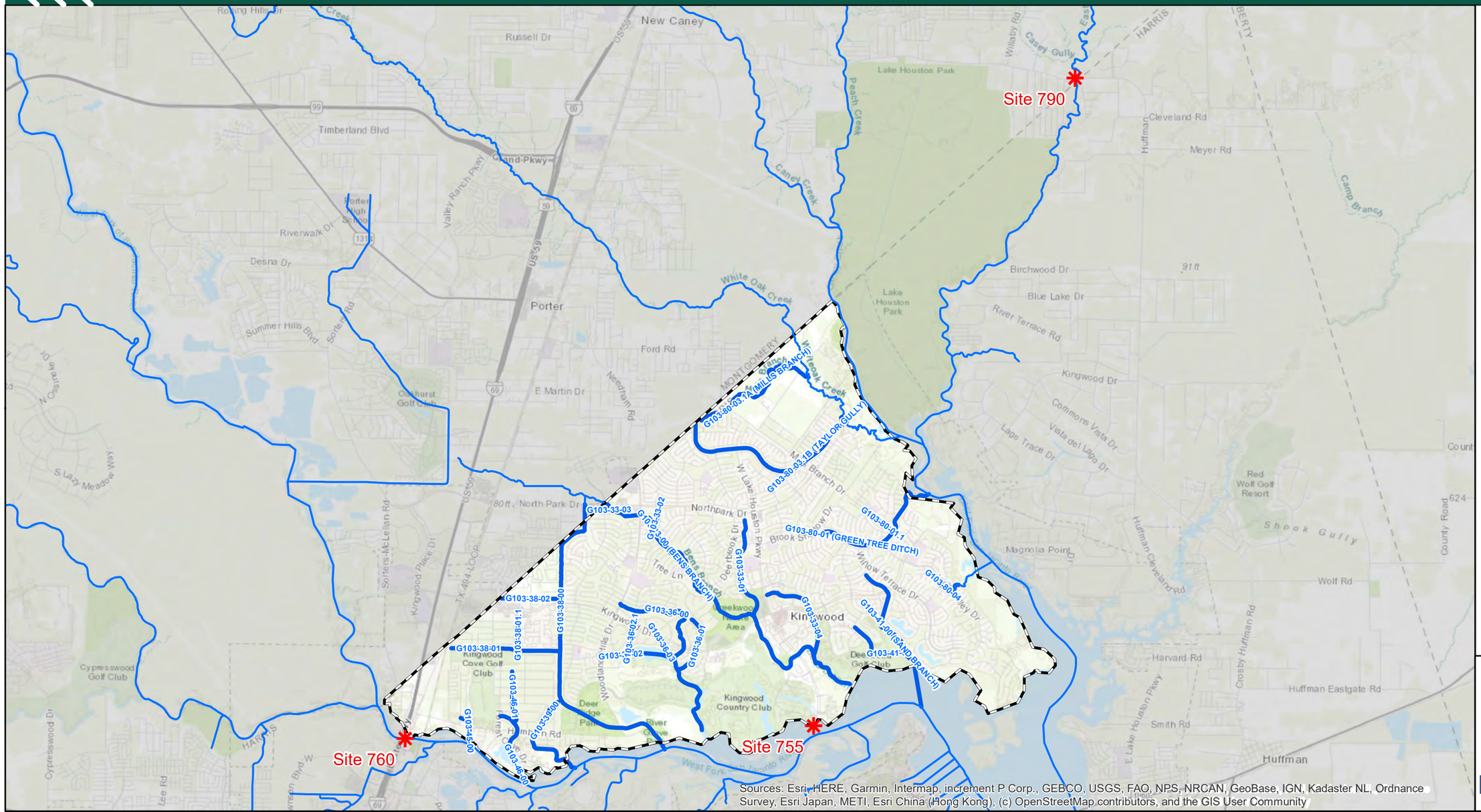
0 0.5 1

Miles

Exhibit 4
Stream Segmentation

Gauge ENGINEERING

NEEL-SCHAFFER



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Legend

- Harris County FWS Gage
- Project Area
- Stream

Exhibit 5
Harris County
FWS Gages

Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

2D Overland Flow Analysis Summary

HARRIS COUNTY

BOND PROGRAM 2018

Extreme event overflow from southern end of subdivision.

Overland Flow split Zone from Bens Branch to Taylor Gully

SSIA 1

See Exhibit 6-B

See Exhibit 6-C

Montgomery Co.

Harris Co.

G103-80-03-1A (Mills Branch)

G103-80-03-1B (Taylor Gully)

NORTH KINGWOOD FOREST

ELM GROVE ELEM

Legend

- Streams
- Storm Sewers - Exist
- Flow Paths
- County Boundary
- 1% AEP Floodplain

SSIA = Recommended Storm Sewer Investigation Area

Watershed Divide - Ridge Line

Extreme Event Overland Flow Investegation Zone

N

0 500 1,000

Feet

2D Overland Flow Analysis Summary

Exhibit 6-A

Gauge ENGINEERING

NEEL-SCHAFFER

July 6, 2020

www.hcfcd.org/2018bondprogram

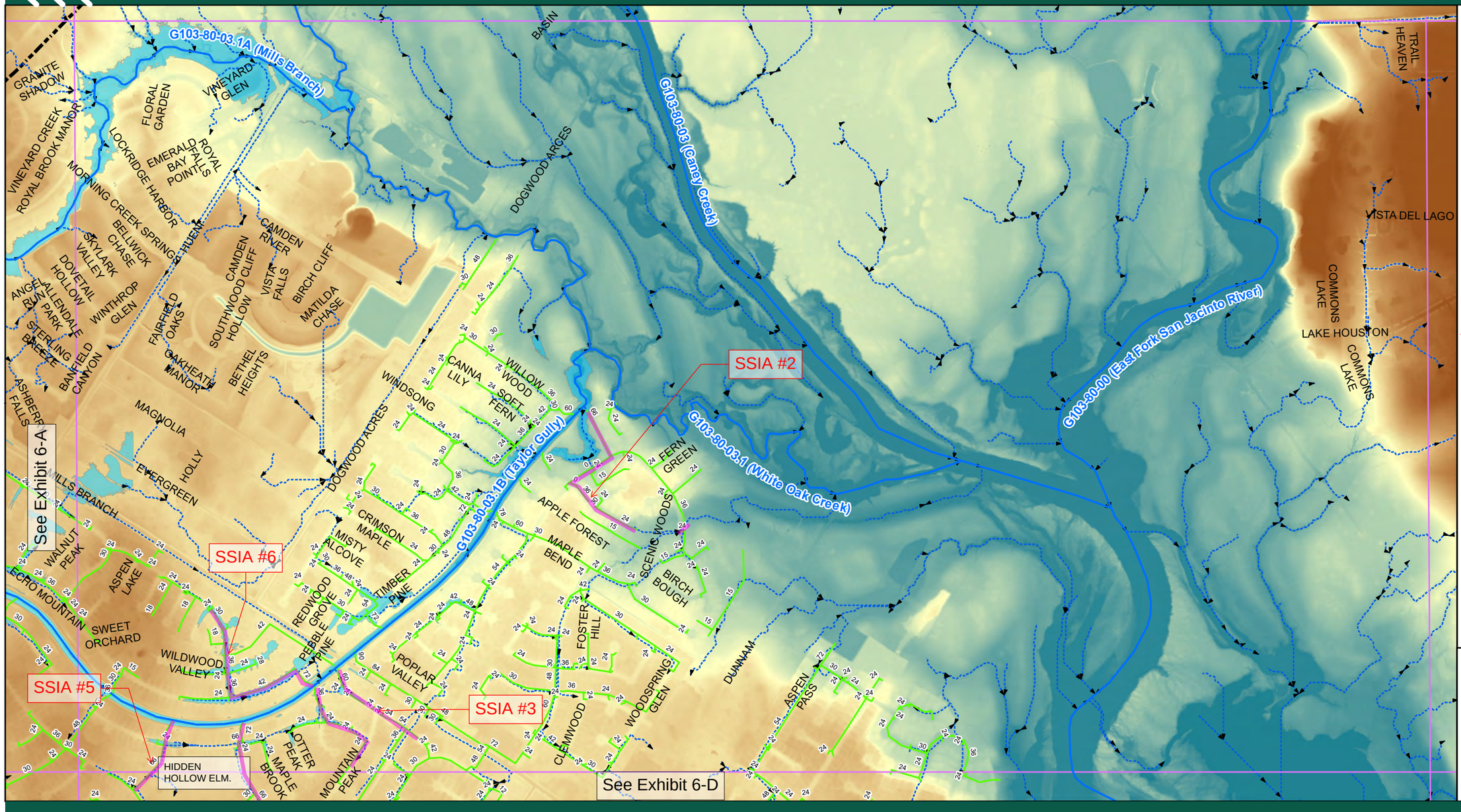
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

2D Overland Flow Analysis Summary

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- Streams
- Storm Sewers - Exist
- Flow Paths
- County Boundary
- 1% AEP

SSIA = Recommended Storm Sewer Investigation Area

Extreme Event Overland Flow Investegation Zone

N

0 500 1,000

Feet

2D Overland Flow Analysis Summary

Exhibit 6-B

Gauge ENGINEERING

NEEL-SCHAFFER

July 6, 2020

www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

2D Overland Flow Analysis Summary

HARRIS COUNTY

BOND PROGRAM 2018

Legend

- Streams
- Storm Sewers - Exist
- Flow Paths
- County Boundary
- 1% AEP

SSIA = Recommended Storm Sewer Investigation Area

Extreme Event Overland Flow Investegation Zone

N

0 500 1,000

Feet

2D Overland Flow Analysis Summary
Exhibit 6-C

Gauge ENGINEERING

NEEL-SCHAFFER

July 6, 2020

www.hcfcd.org/2018bondprogram

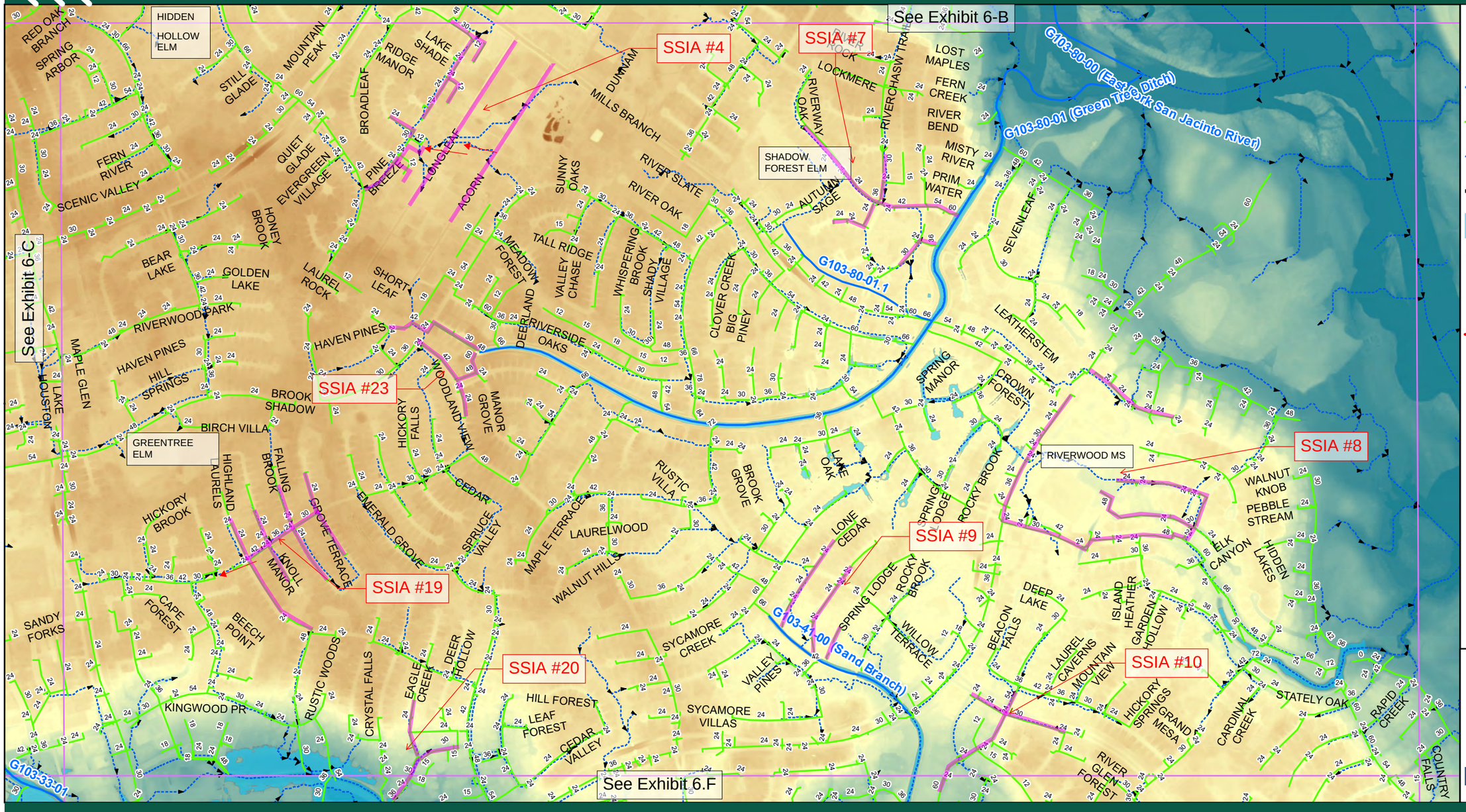
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

2D Overland Flow Analysis Summary

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- Streams
- Storm Sewers - Exist
- Flow Paths
- County Boundary
- 1% AEP

SSIA = Recommended Storm Sewer Investigation Area

Extreme Event Overland Flow Investegation Zone

N

0 500 1,000

Feet

2D Overland Flow Analysis Summary
Exhibit 6.D

Gauge ENGINEERING

NEEL-SCHAFFER

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www.hcfcd.org/2018bondprogram

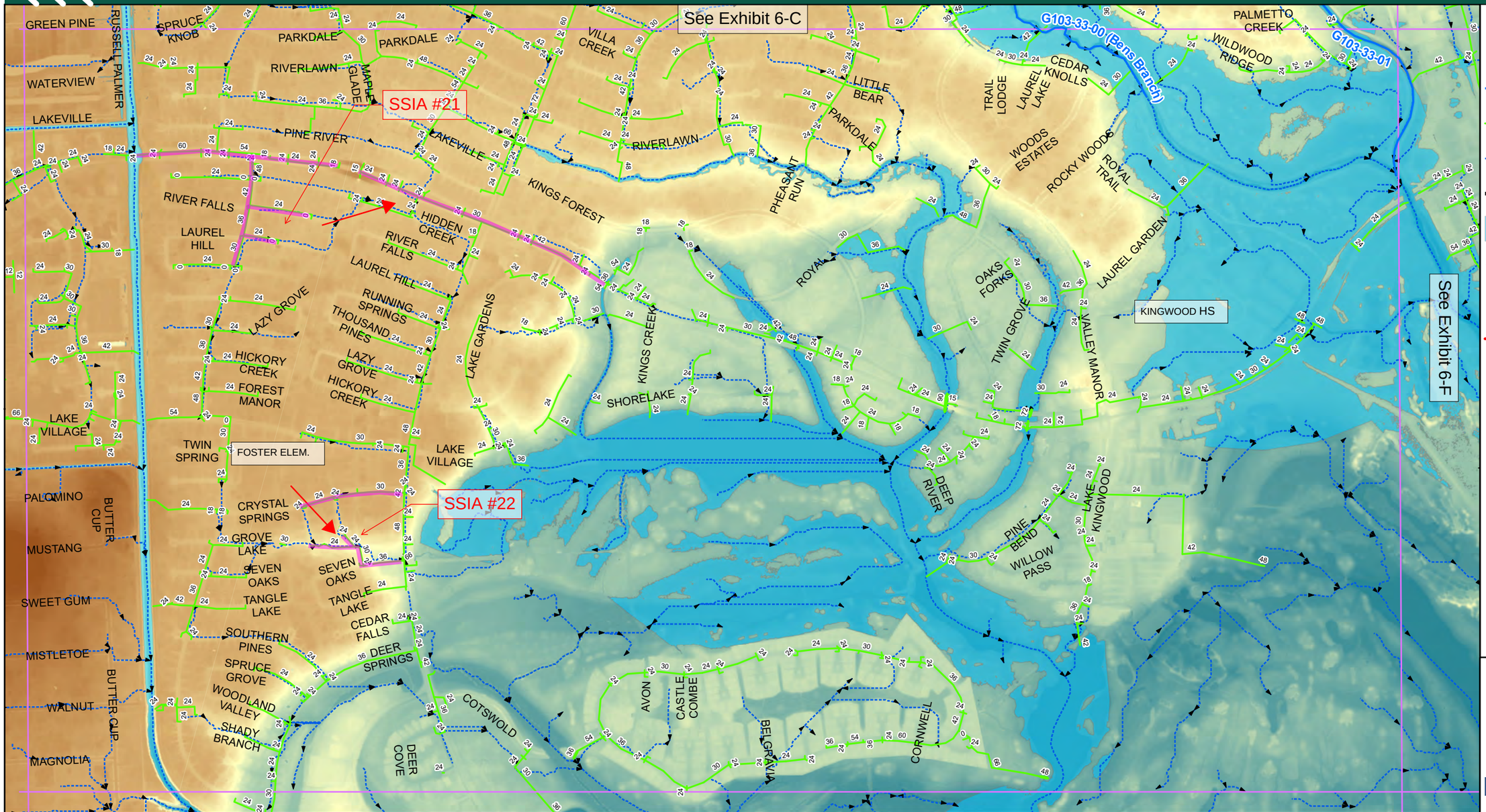
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

2D Overland Flow Analysis Summary

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- Streams
- Storm Sewers - Exist
- Flow Paths
- County Boundary
- 1% AEP Floodplain

SSIA = Recommended Storm Sewer Investigation Area

Extreme Event Overland Flow Investegation Zone

N

0 500 1,000

Feet

2D Overland Flow Analysis Summary

Exhibit 6-E

Gauge ENGINEERING

NEEL-SCHAFFER

July 6, 2020

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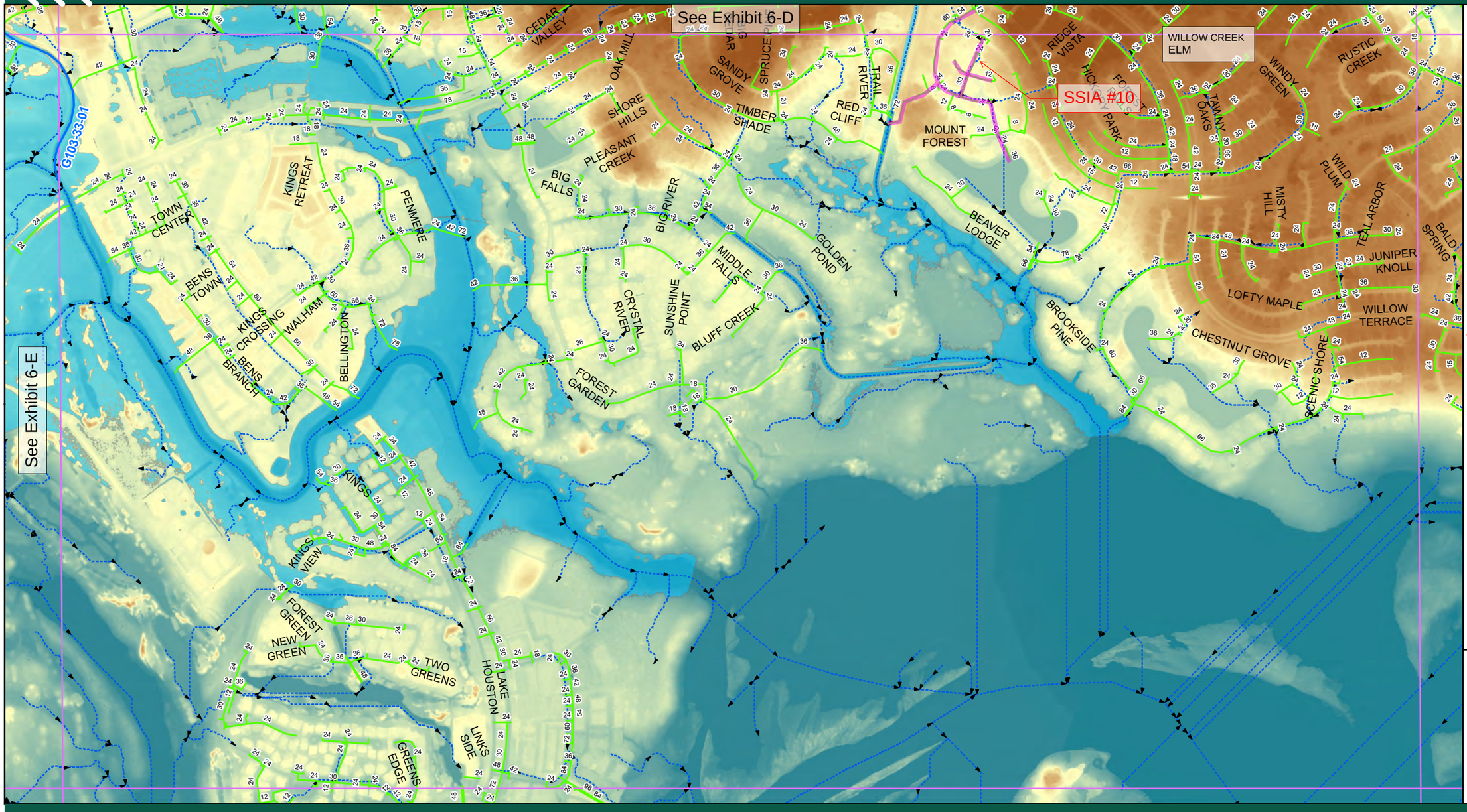
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

2D Overland Flow Analysis Summary

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- Streams
- Storm Sewers - Exist
- Flow Paths
- County Boundary
- 1% AEP Floodplain

SSIA = Recommended Storm Sewer Investigation Area

Extreme Event Overland Flow Investegation Zone

N

0 500 1,000

Feet

2D Overland Flow Analysis Summary

Exhibit 6-F

Gauge ENGINEERING

NEEL-SCHAFFER

July 6, 2020

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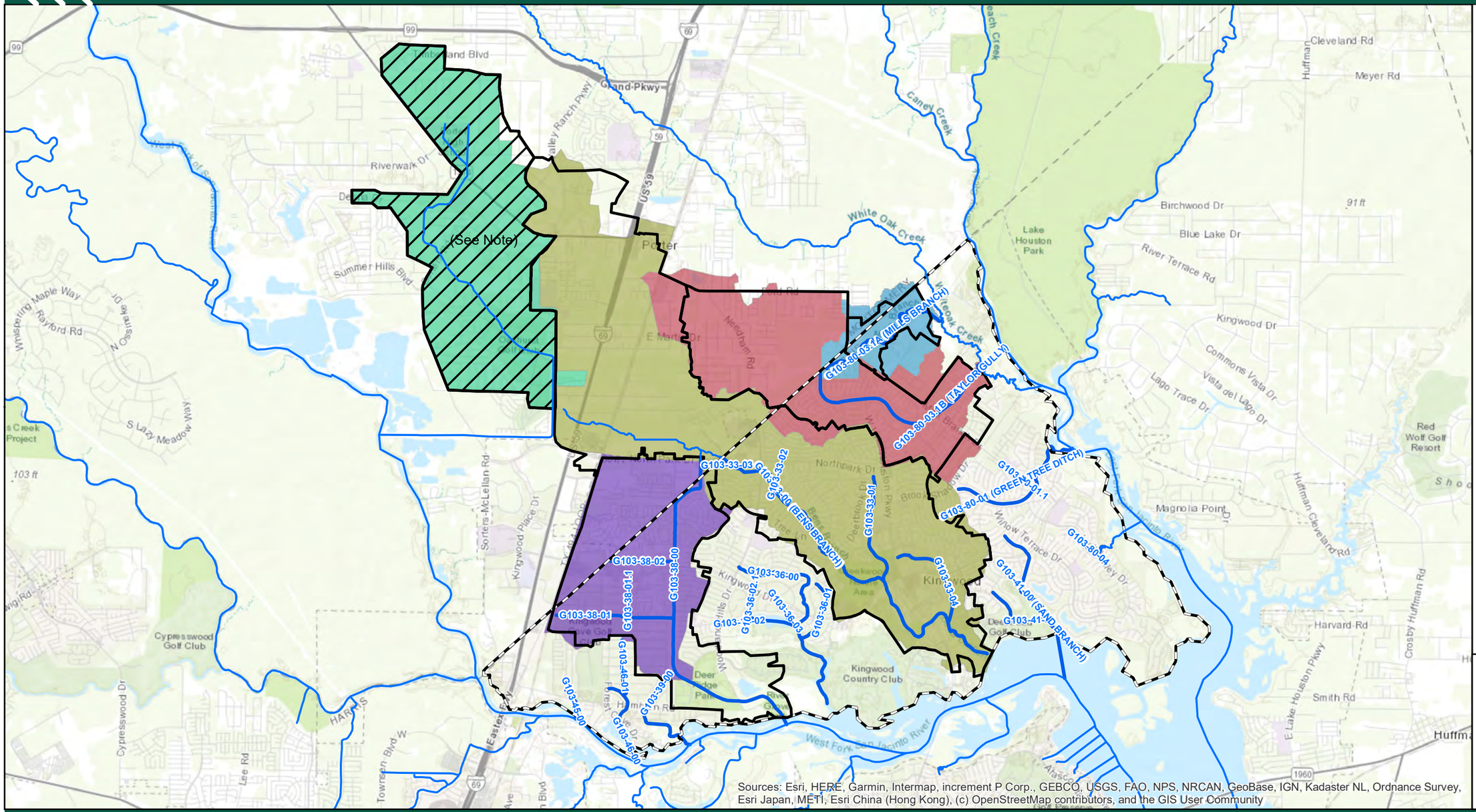
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- Revised Watershed Boundaries
- Overflow Area
- Project Area
- Streams

FEMA Watersheds

- G103-33-00 (Bens Branch)
- G103-38-00 (Kingwood Diversion Ditch)
- G103-80-03.1A (Mills Branch)
- G103-80-03.1B (Taylor Gully)
- Overflow

Note: Historically, this area drained to Bens Branch; however a channel was constructed in the early 1990's that rerouted this area to drain to the West Fork San Jacinto River. During high rainfall events, some of the water still drains towards Bens Branch due to out of bank flooding following the existing topography.

N

0 0.75 1.5

Miles

Exhibit 7
FEMA Drainage Area Comparison

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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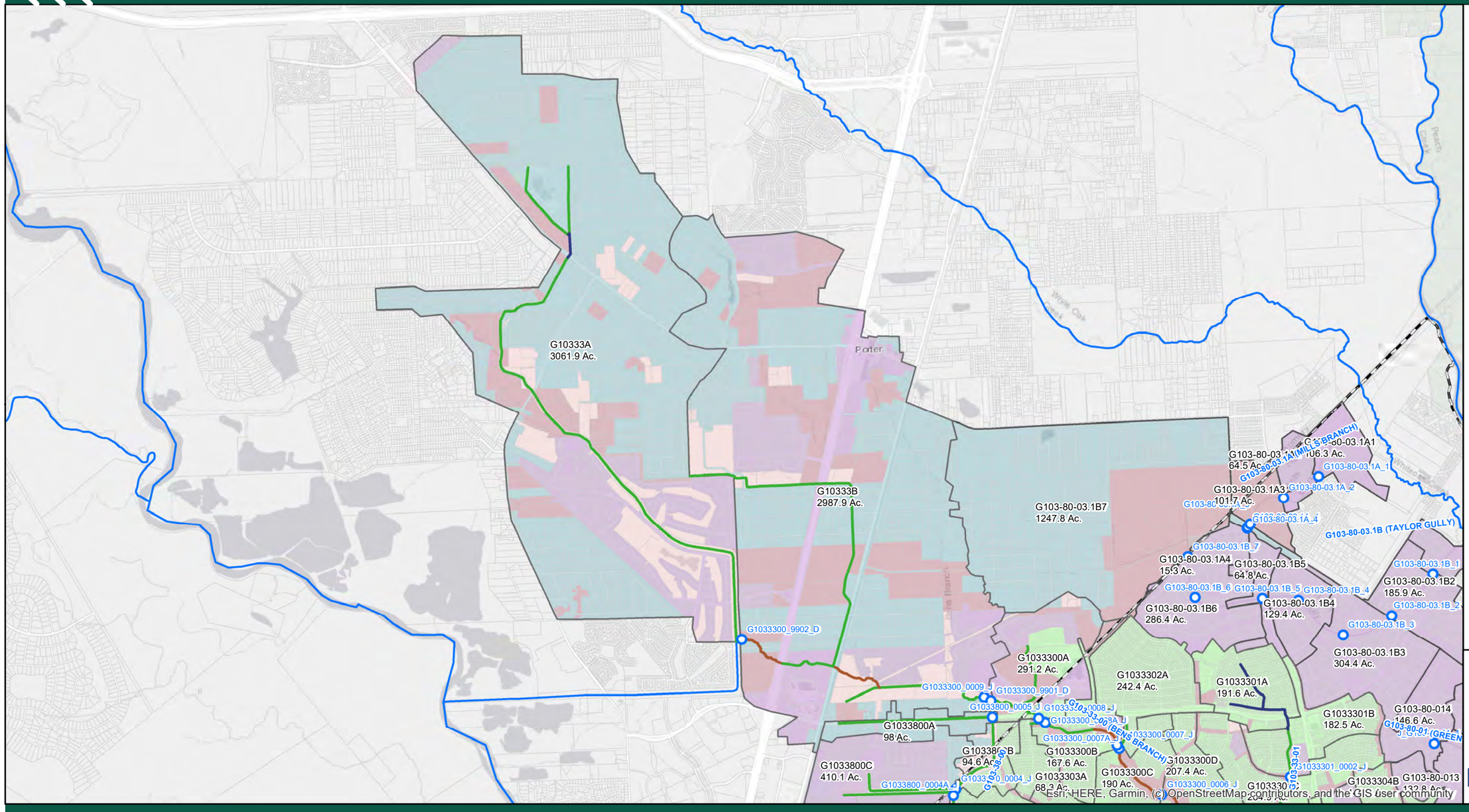
HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural

Streams

- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 1,750 3,500

Feet

Exhibit 8-A
Existing Hydrologic Analysis Map

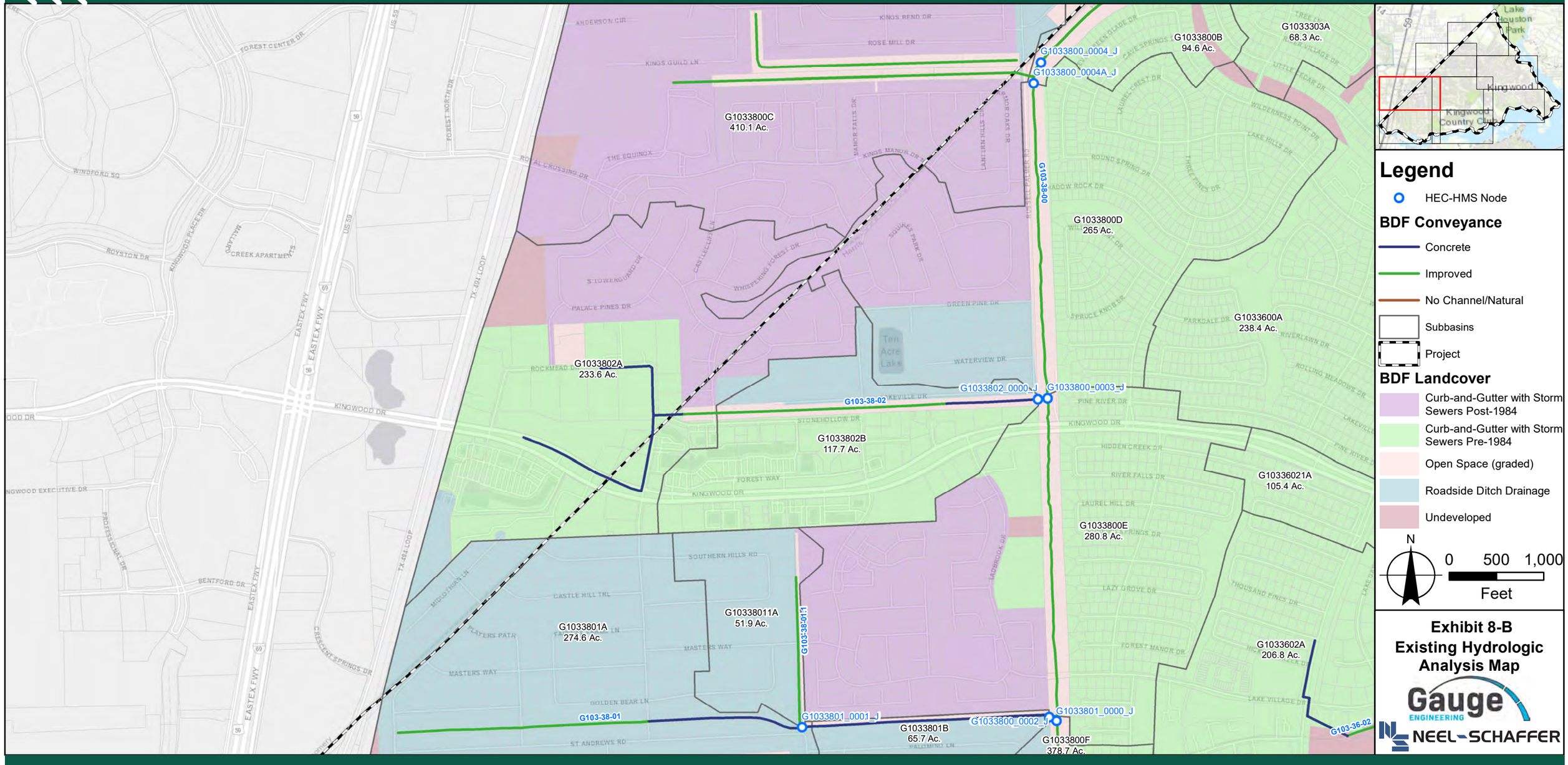
Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 8-B
Existing Hydrologic Analysis Map

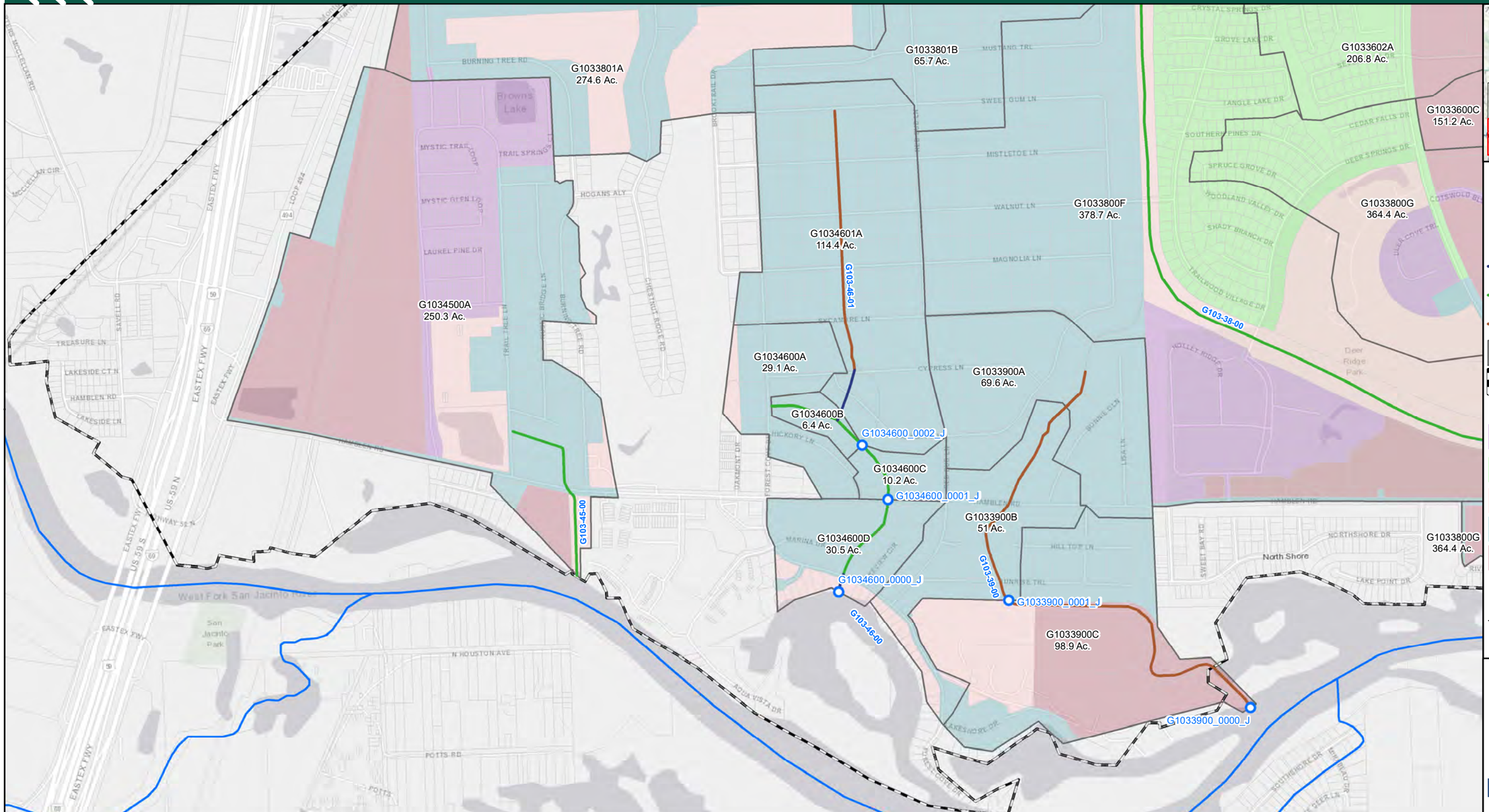
Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 8-C
Existing Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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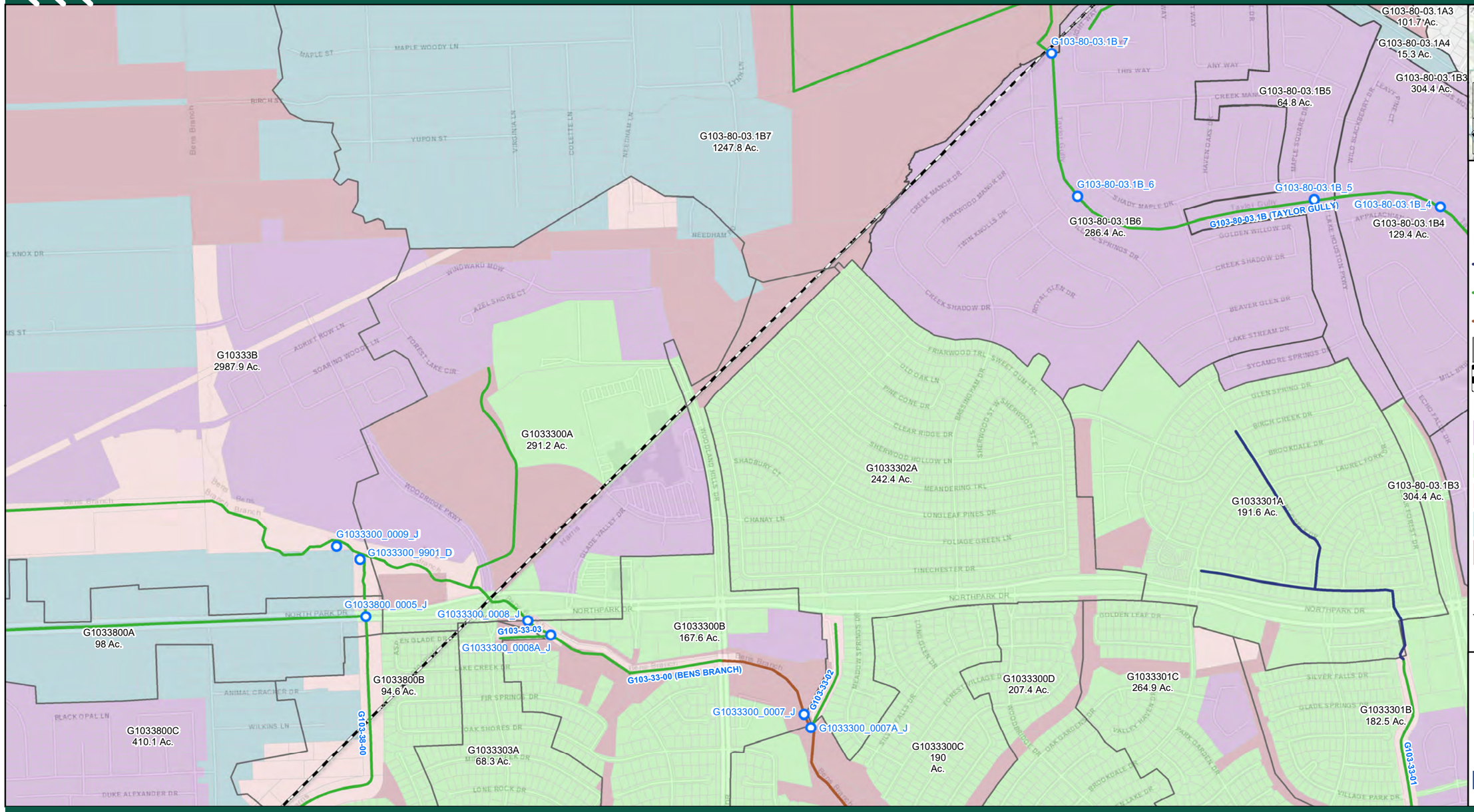
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 8-D
Existing Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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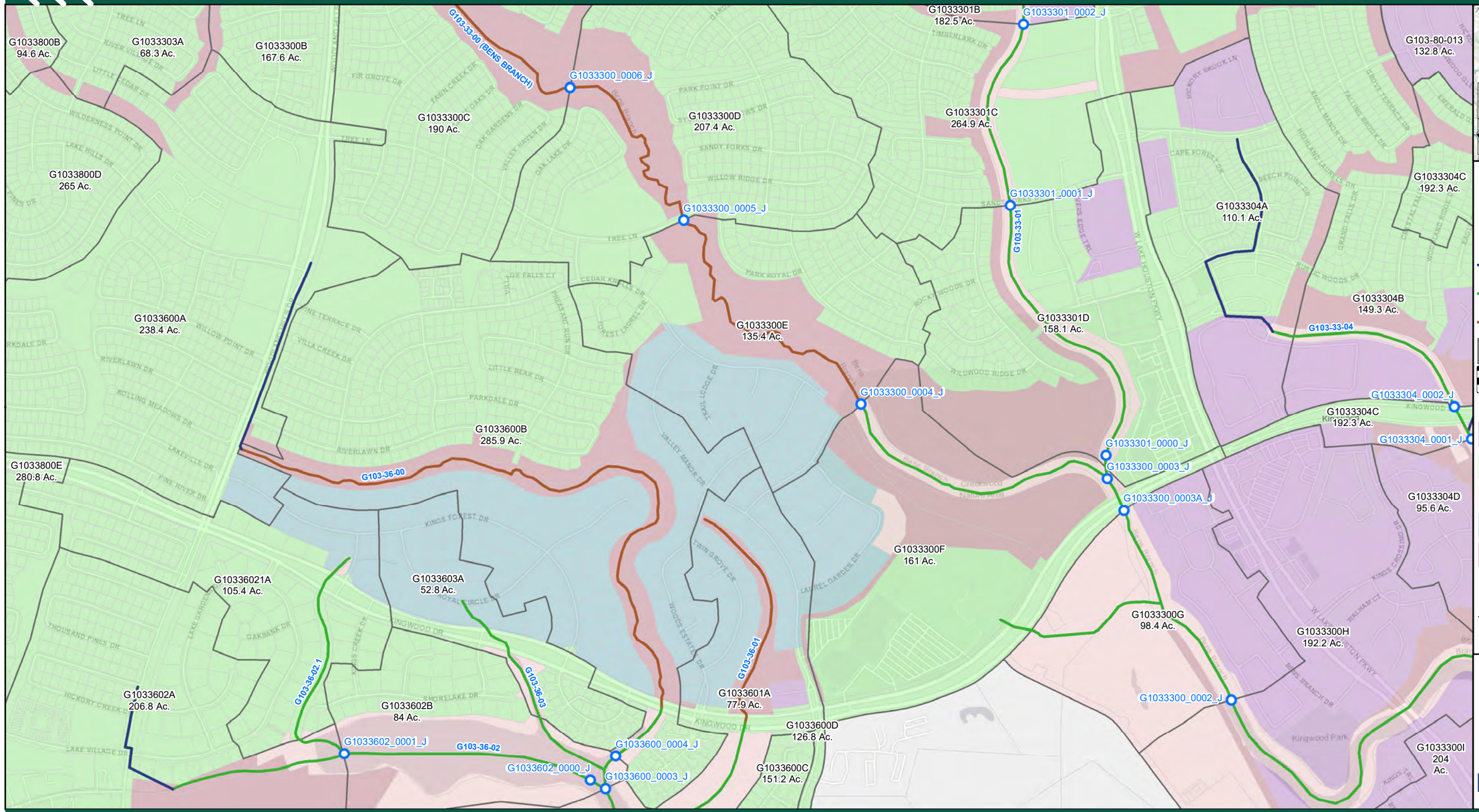
HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 8-E
Existing Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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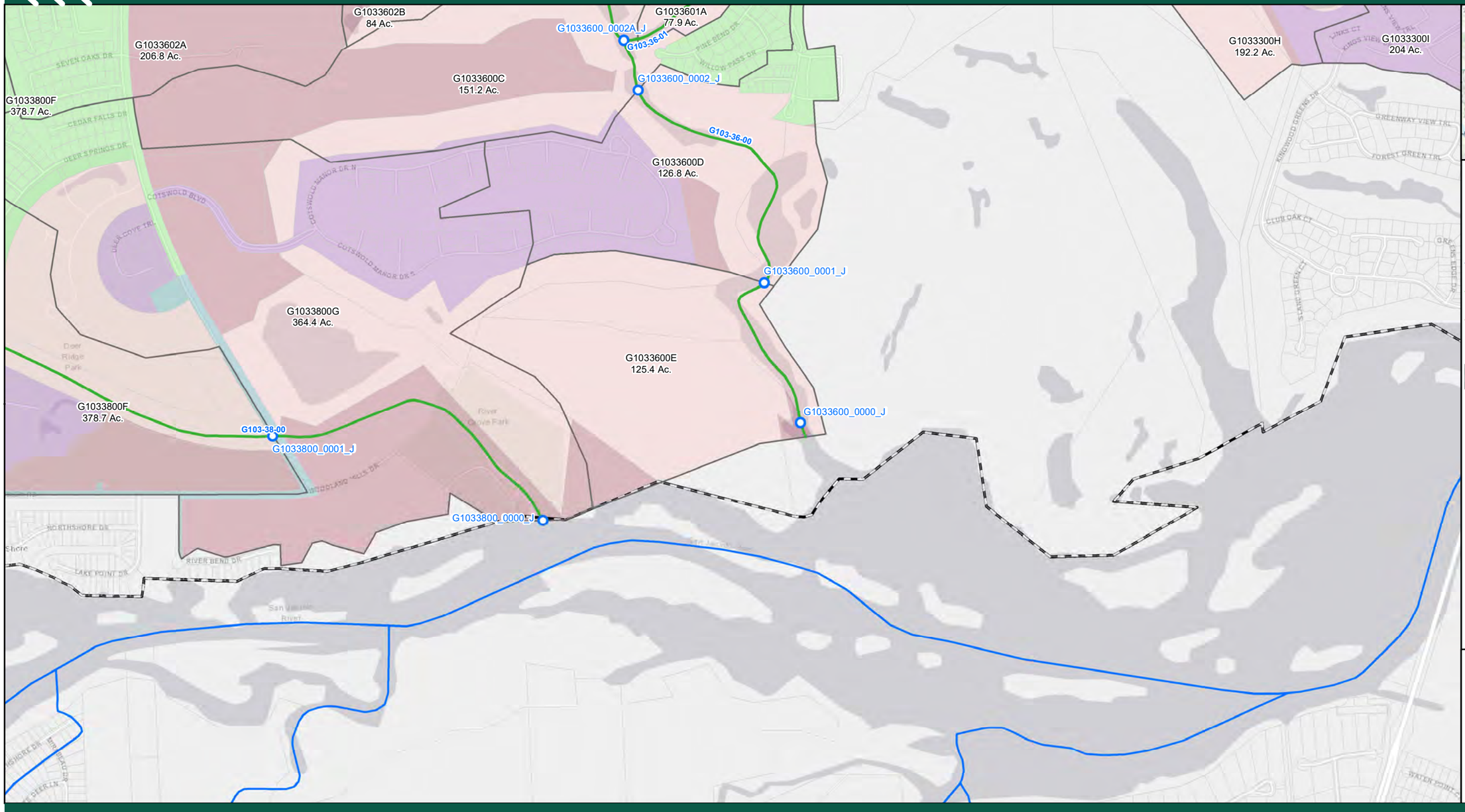
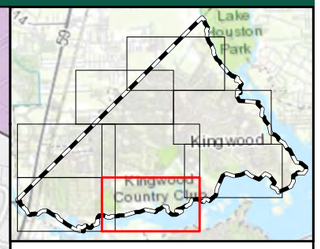
HARRIS COUNTY FLOOD CONTROL DISTRICT





Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

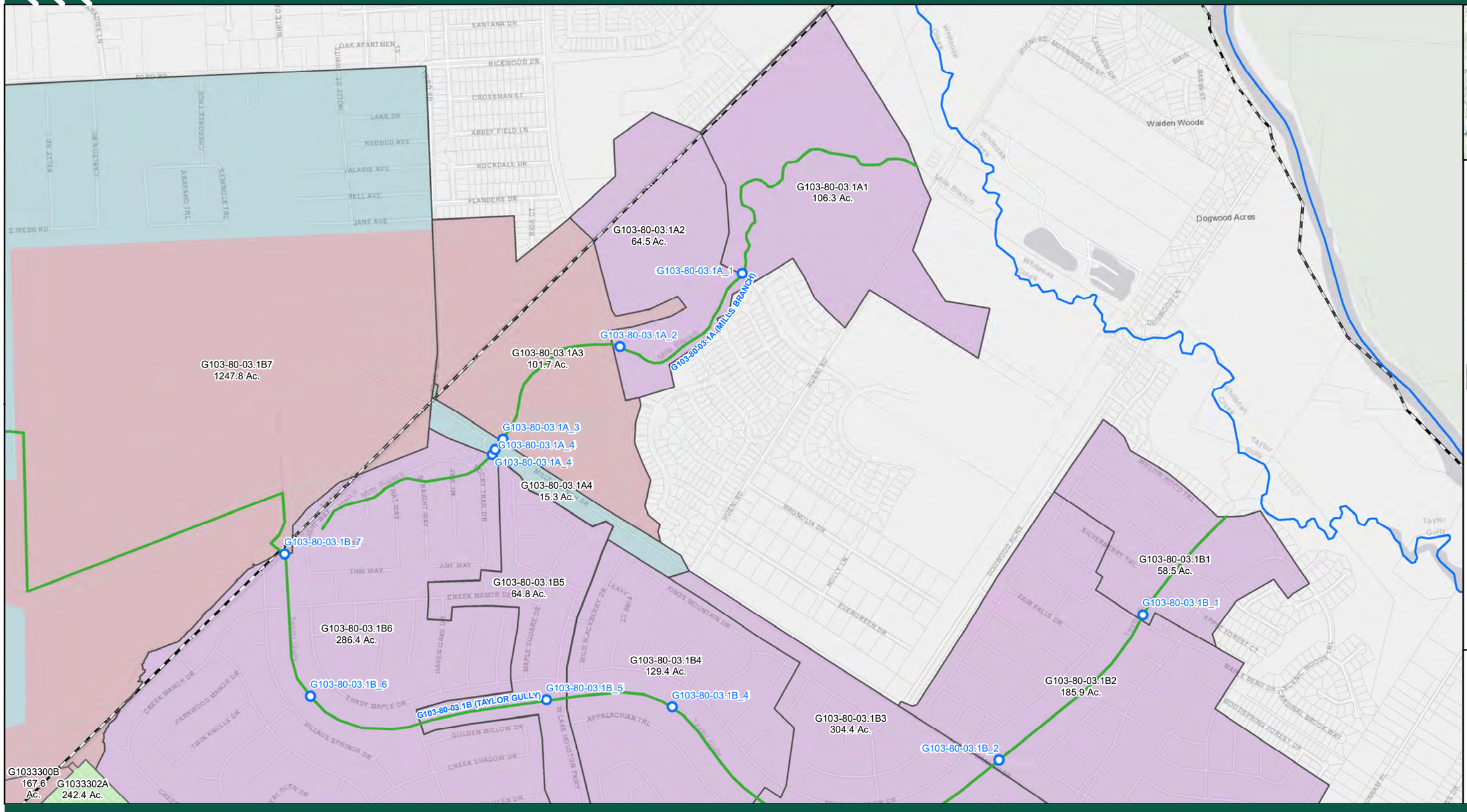
0 500 1,000

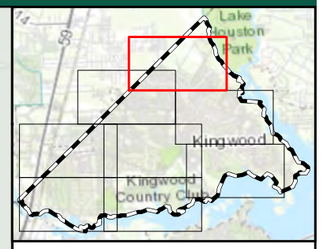
Feet

Exhibit 8-F
Existing Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER





Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

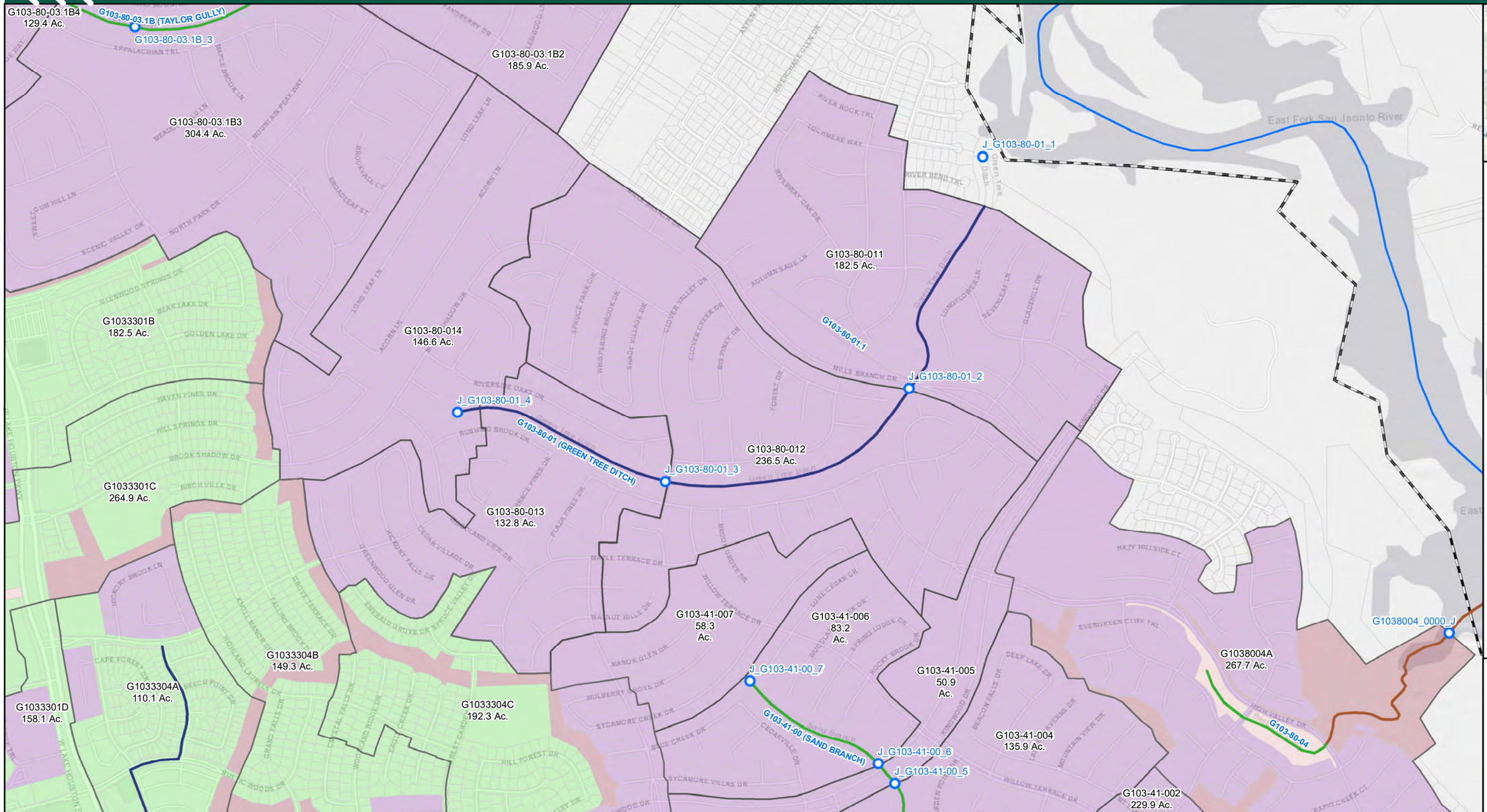
Exhibit 8-G
Existing Hydrologic Analysis Map

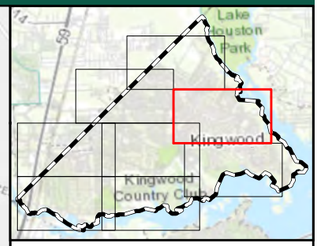
Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018





Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 8-H
Existing Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

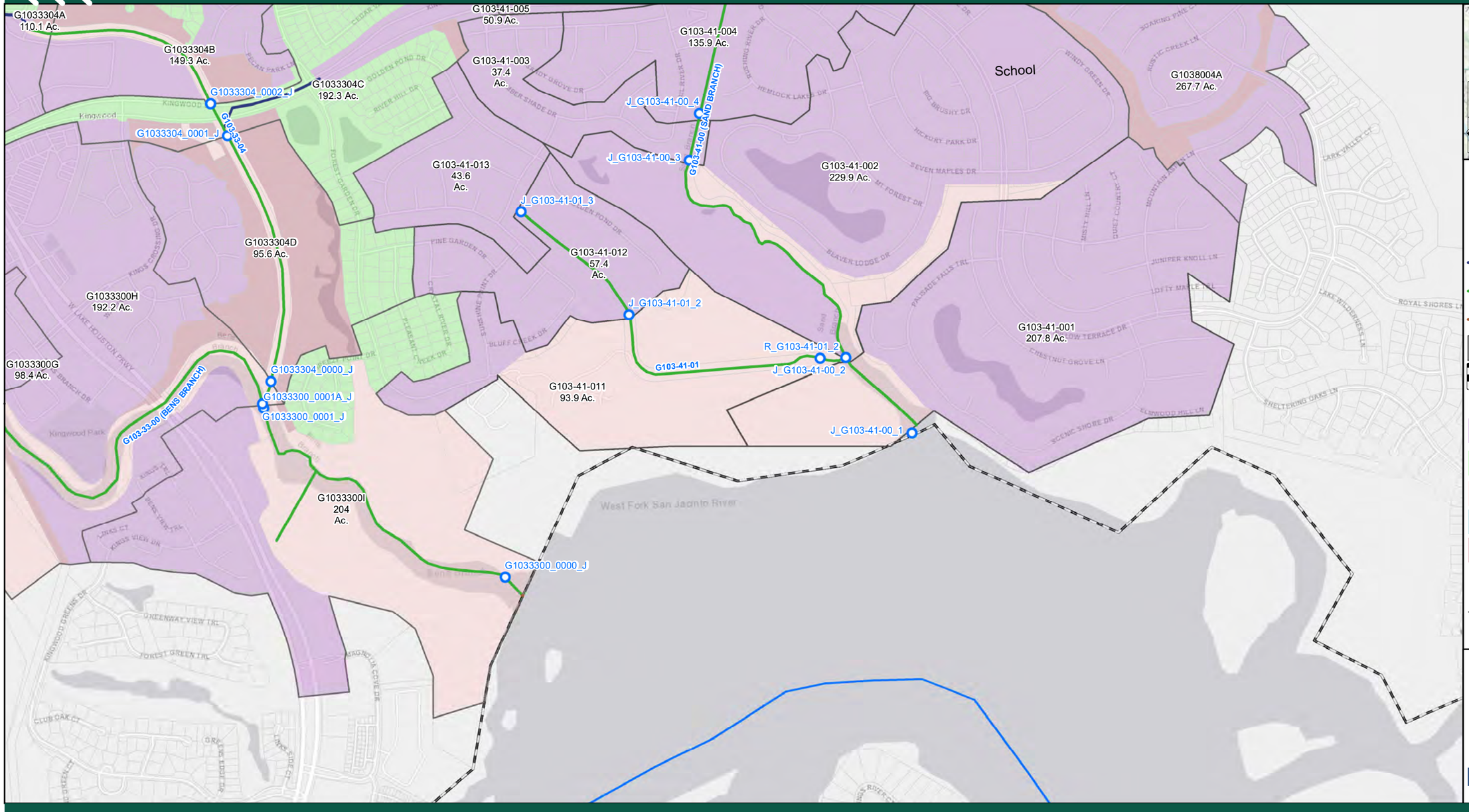
July 2020

www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project

BDF Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 8-I
Existing Hydrologic Analysis Map

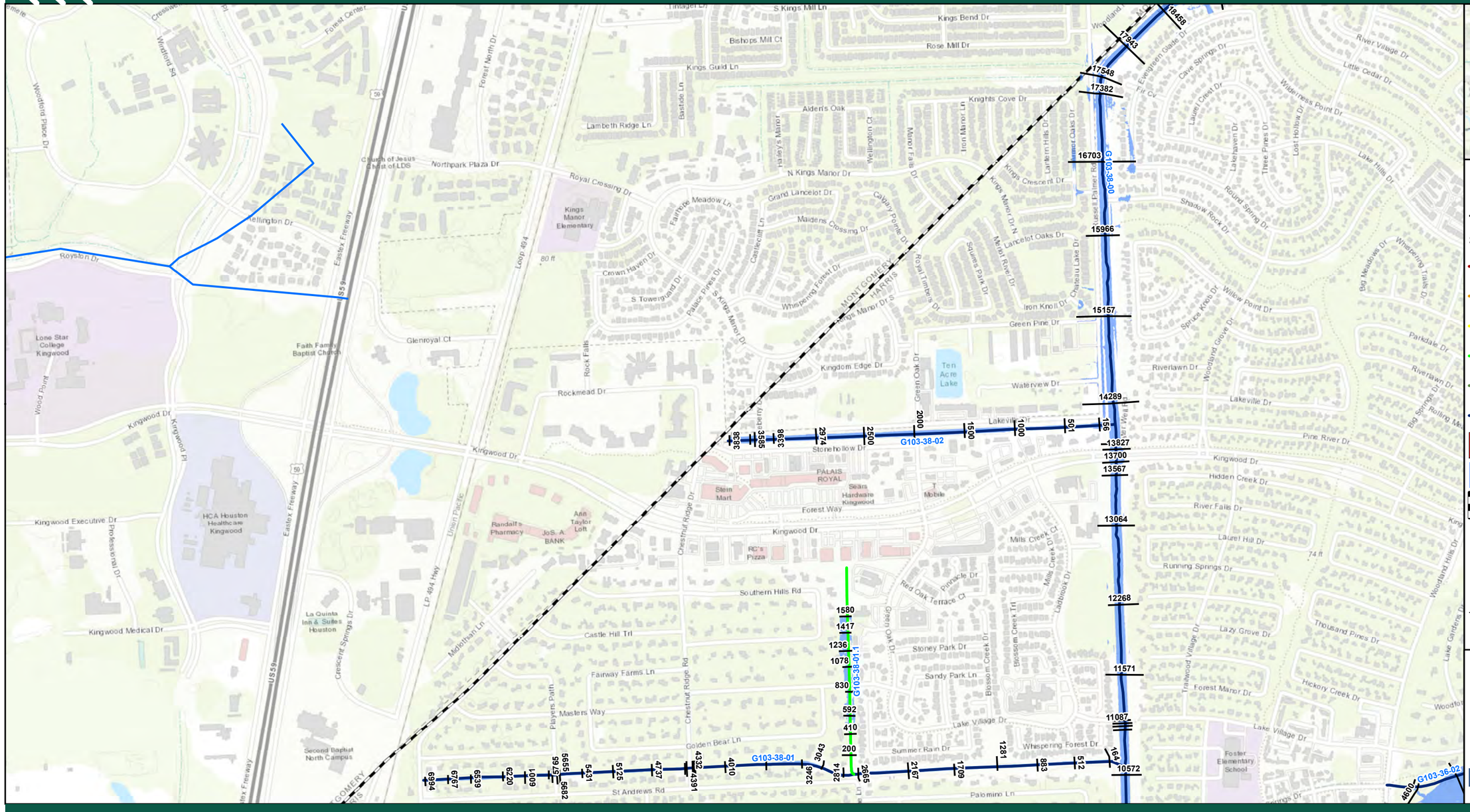
Gauge ENGINEERING

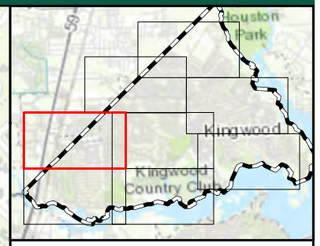
NEEL-SCHAFFER

July 2020

www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT





Legend

- HEC-RAS Cross Sections

Stream Level of Service

- < 2-Yr (50% AEP)
- 2-Yr (50% AEP)
- 10-Yr (10% AEP)
- 25-Yr (4% AEP)
- 50-Yr (2% AEP)
- 100-Yr (1% AEP)
- 100-Yr Flooded Structures
- 100-Yr Inundation
- Project Area

N

0 500 1,000

Feet

Exhibit 9-A
Existing Level of Service

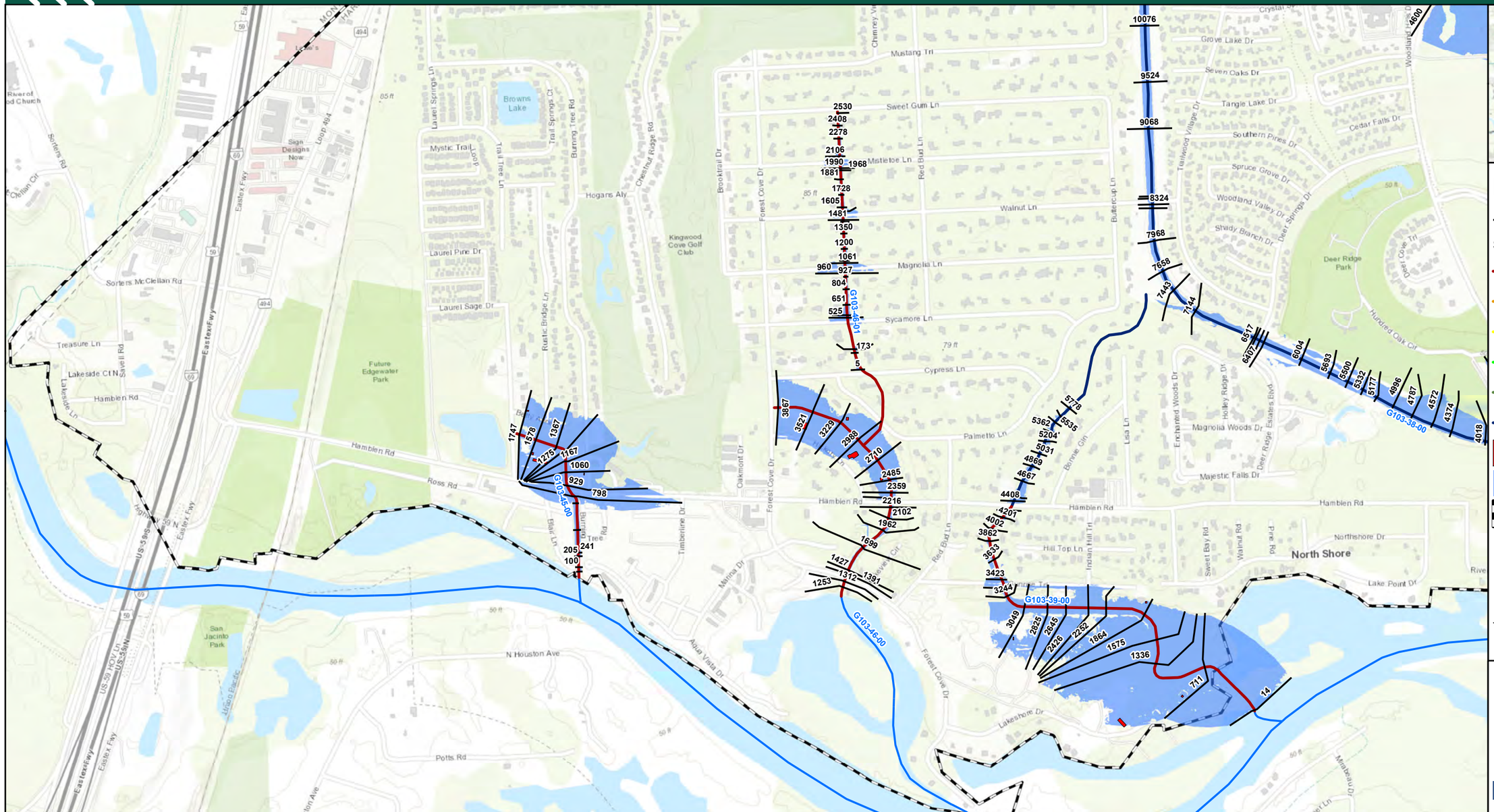
Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- HEC-RAS Cross Sections

Stream Level of Service

- < 2-Yr (50% AEP)
- 2-Yr (50% AEP)
- 10-Yr (10% AEP)
- 25-Yr (4% AEP)
- 50-Yr (2% AEP)
- 100-Yr (1% AEP)
- 100-Yr Flooded Structures
- 100-Yr Inundation
- Project Area

N

0 500 1,000

Feet

Exhibit 9-B
Existing Level of Service

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

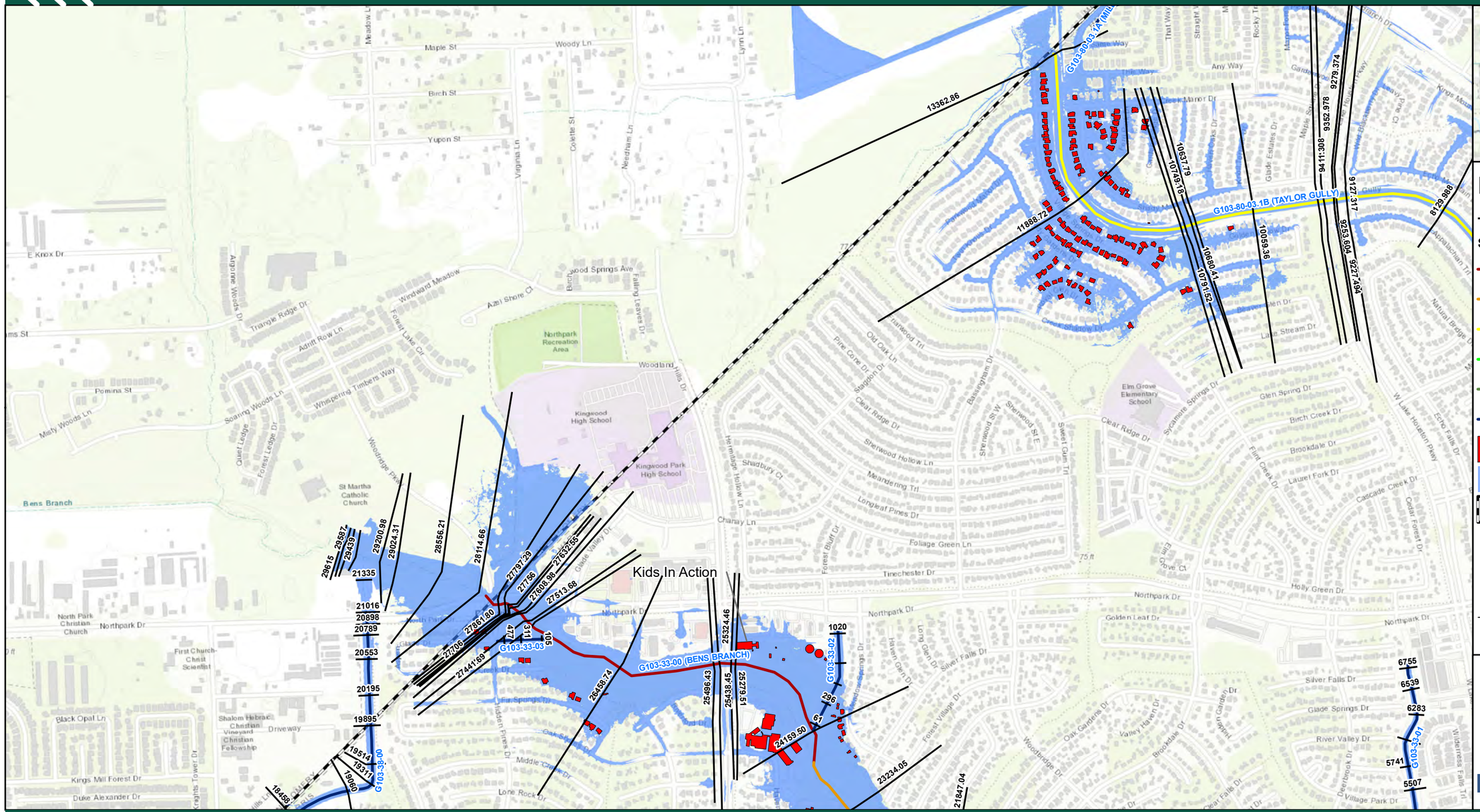
www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018



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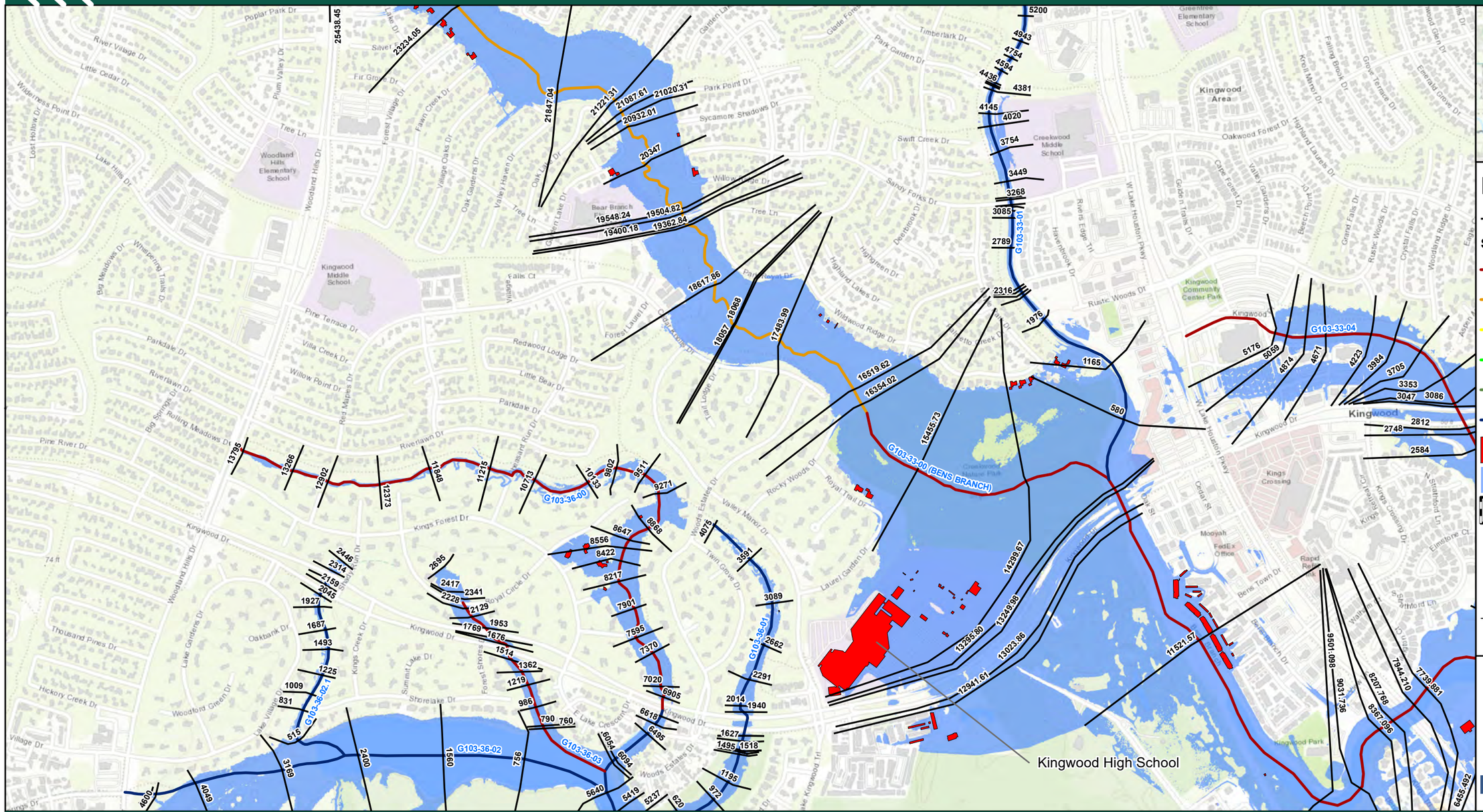
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-RAS Cross Sections

Stream Level of Service

- < 2-Yr (50% AEP)
- 2-Yr (50% AEP)
- 10-Yr (10% AEP)
- 25-Yr (4% AEP)
- 50-Yr (2% AEP)
- 100-Yr (1% AEP)
- 100-Yr Flooded Structures
- 100-Yr Inundation
- Project Area

N

0 500 1,000

Feet

Exhibit 9-D
Existing Level of Service

Gauge ENGINEERING

NEEL-SCHAFFER

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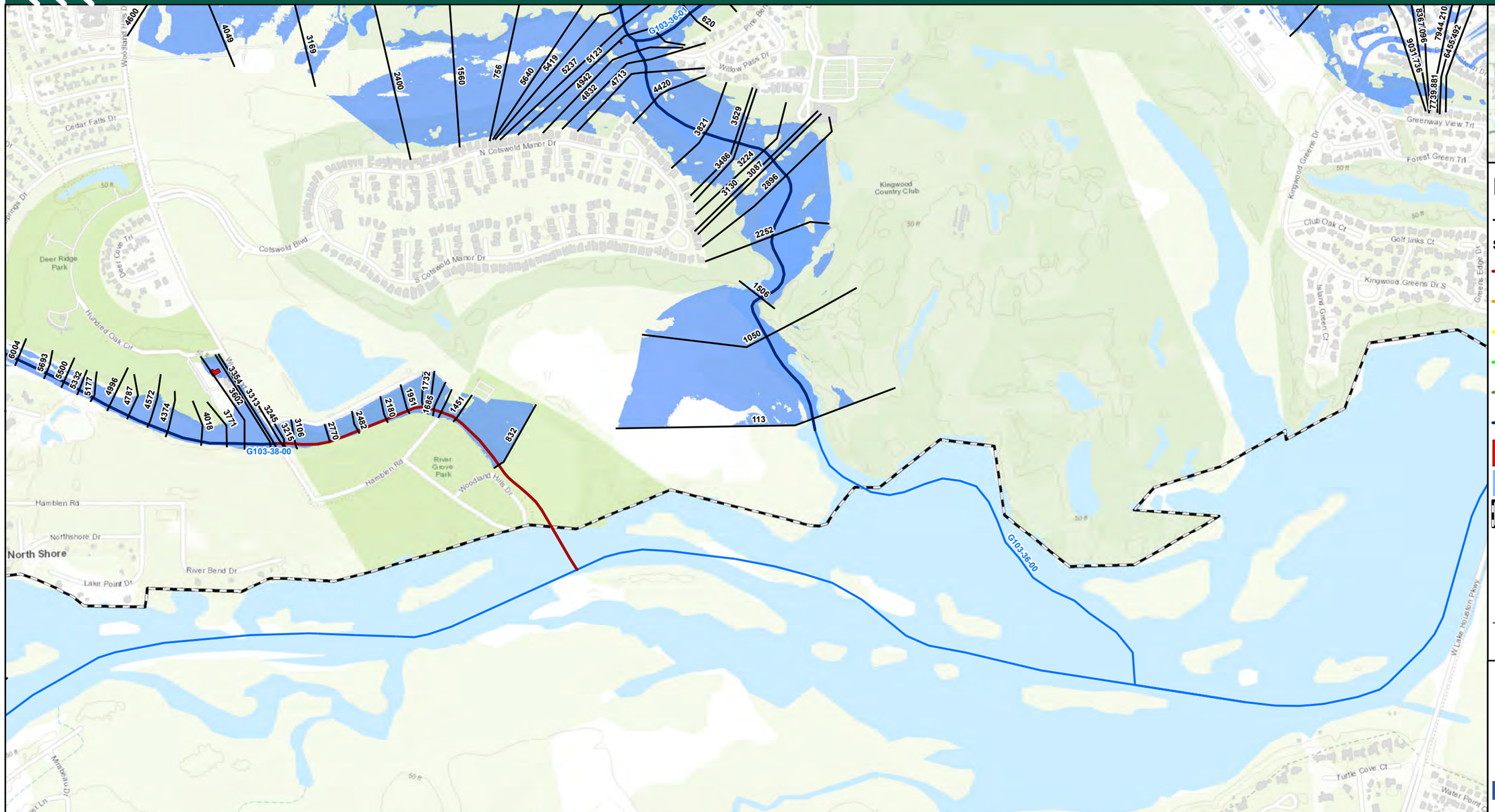
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-RAS Cross Sections

Stream Level of Service

- < 2-Yr (50% AEP)
- 2-Yr (50% AEP)
- 10-Yr (10% AEP)
- 25-Yr (4% AEP)
- 50-Yr (2% AEP)
- 100-Yr (1% AEP)
- 100-Yr Flooded Structures
- 100-Yr Inundation
- Project Area

N

0 500 1,000

Feet

Exhibit 9-E
Existing Level of Service

Gauge ENGINEERING

NEEL-SCHAFFER

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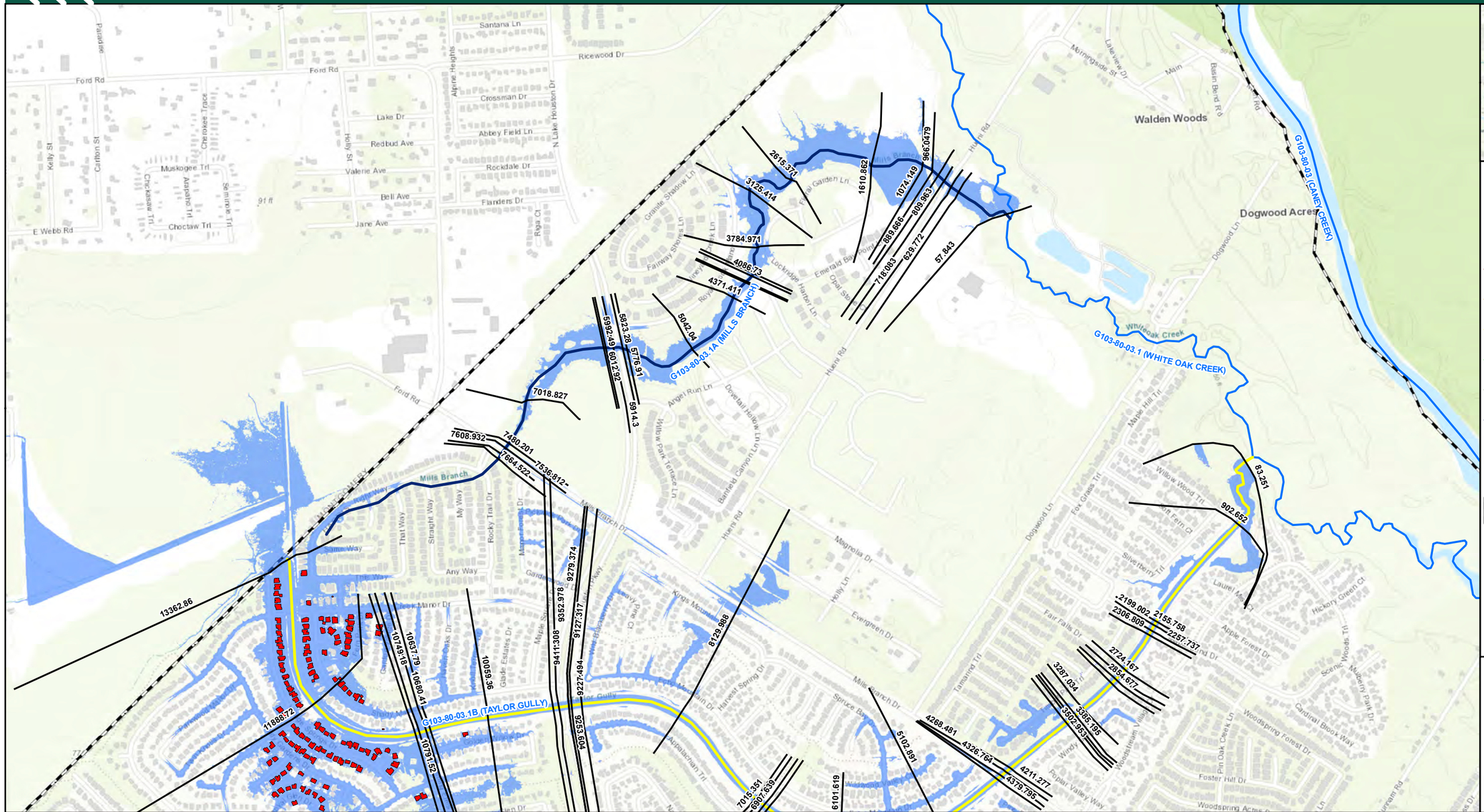
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-RAS Cross Sections

Stream Level of Service

- < 2-Yr (50% AEP)
- 2-Yr (50% AEP)
- 10-Yr (10% AEP)
- 25-Yr (4% AEP)
- 50-Yr (2% AEP)
- 100-Yr (1% AEP)
- 100-Yr Flooded Structures
- 100-Yr Inundation
- Project Area

N

0 500 1,000

Feet

Exhibit 9-F
Existing Level of Service

Gauge ENGINEERING

NEEL-SCHAFFER

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HARRIS COUNTY FLOOD CONTROL DISTRICT

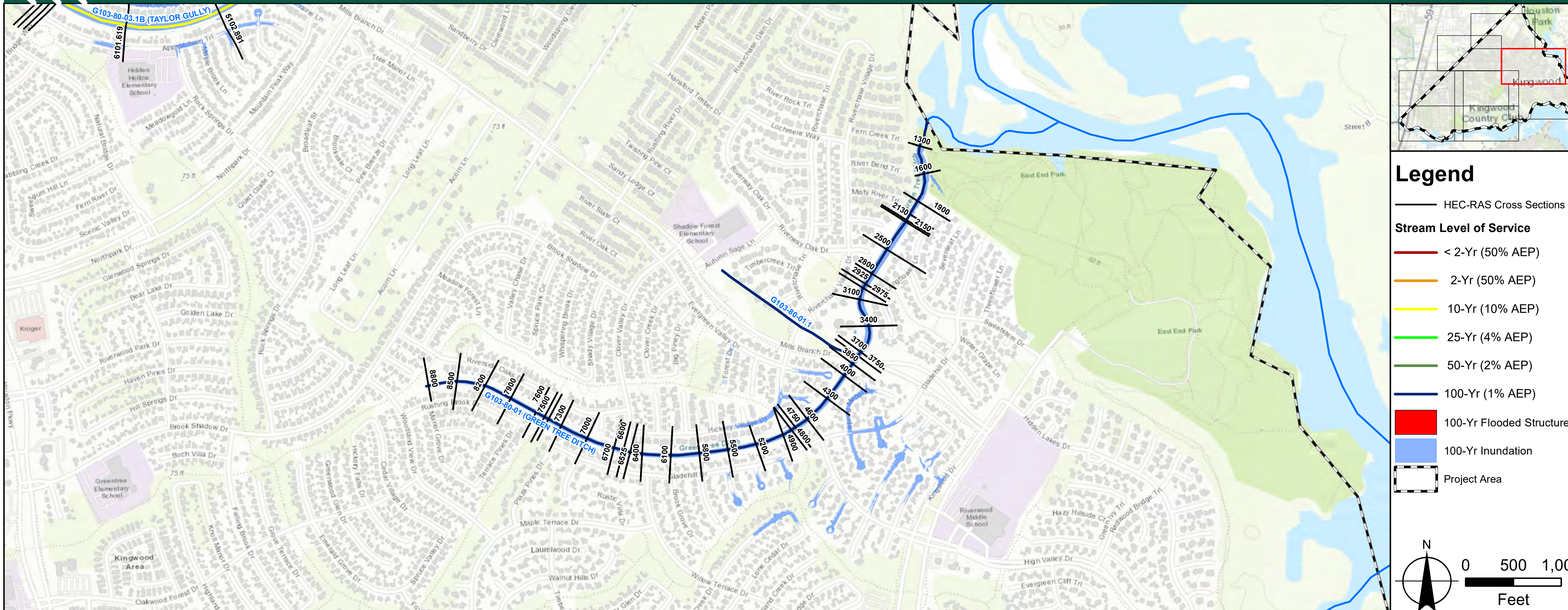


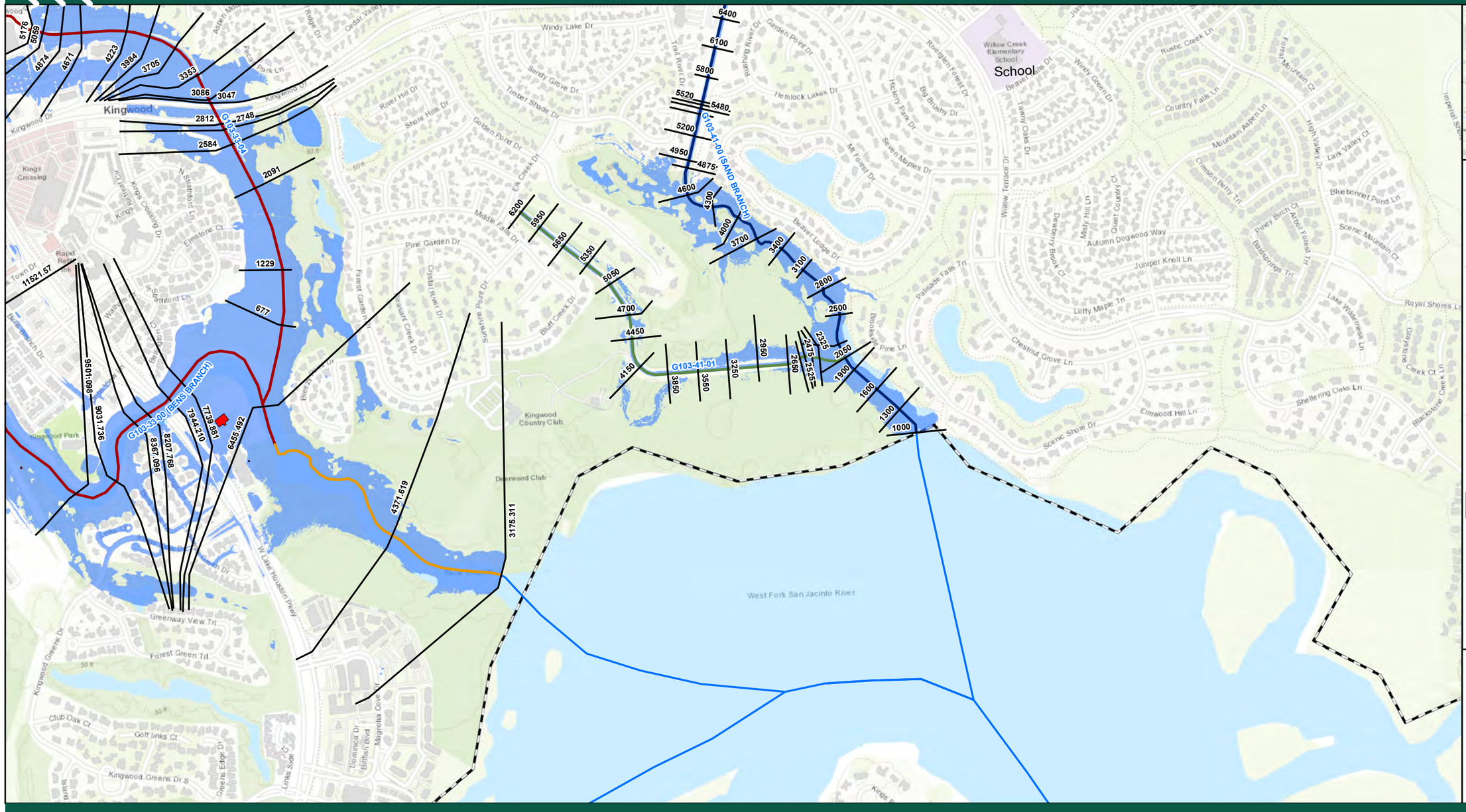
Exhibit 9-G
Existing Level of Service

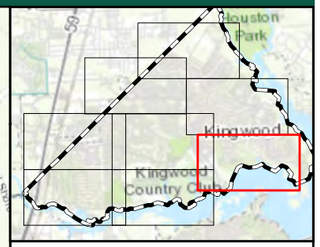
Gauge Engineering
Neel-Schaffer

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018





Legend

- HEC-RAS Cross Sections

Stream Level of Service

- < 2-Yr (50% AEP)
- 2-Yr (50% AEP)
- 10-Yr (10% AEP)
- 25-Yr (4% AEP)
- 50-Yr (2% AEP)
- 100-Yr (1% AEP)
- 100-Yr Flooded Structures
- 100-Yr Inundation
- Project Area

N

0 500 1,000

Feet

Exhibit 9-H
Existing Level of Service

Gauge ENGINEERING

NEEL-SCHAFFER

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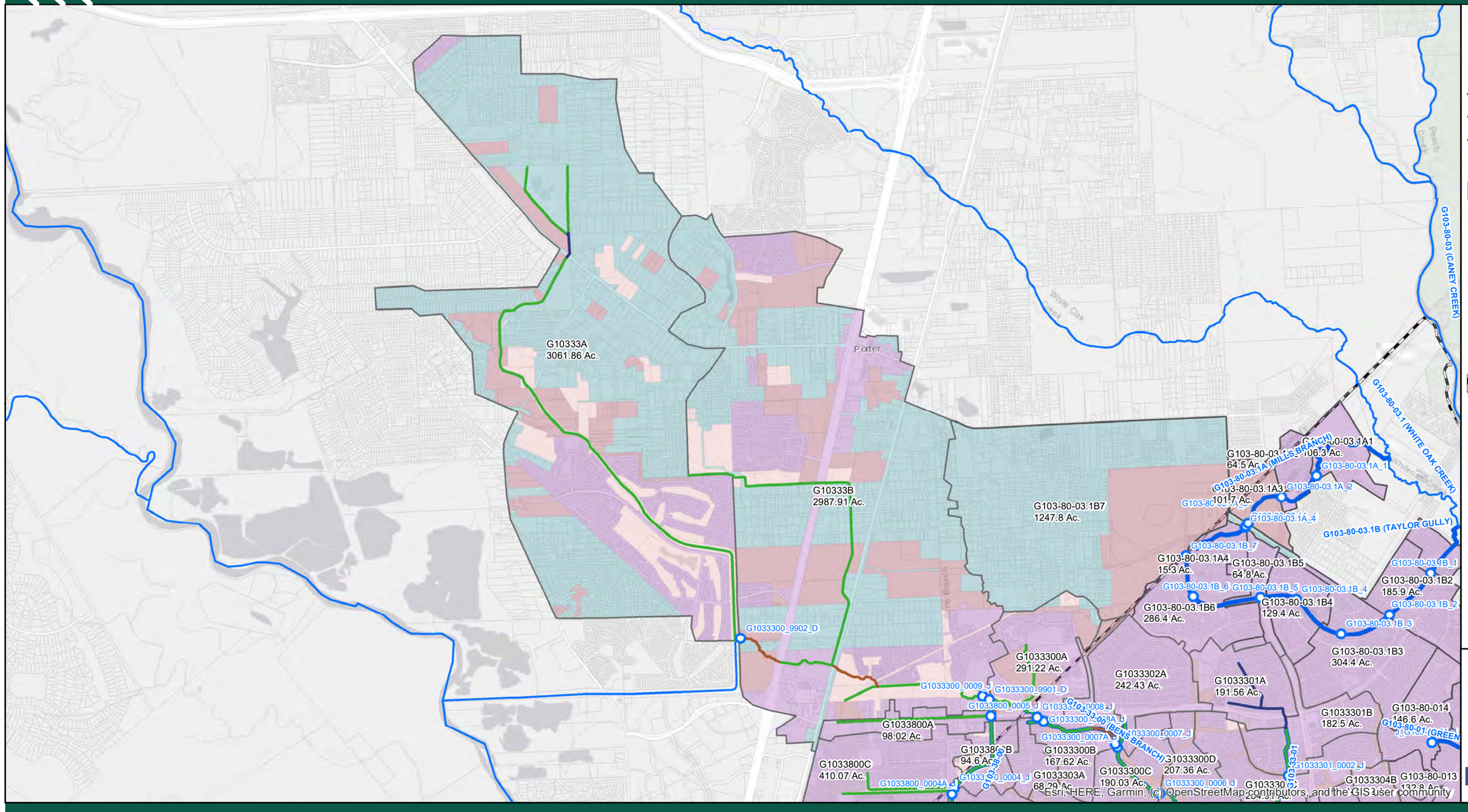
HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Streams
- Subbasins

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped
- Project Area

N

0 1,750 3,500

Feet

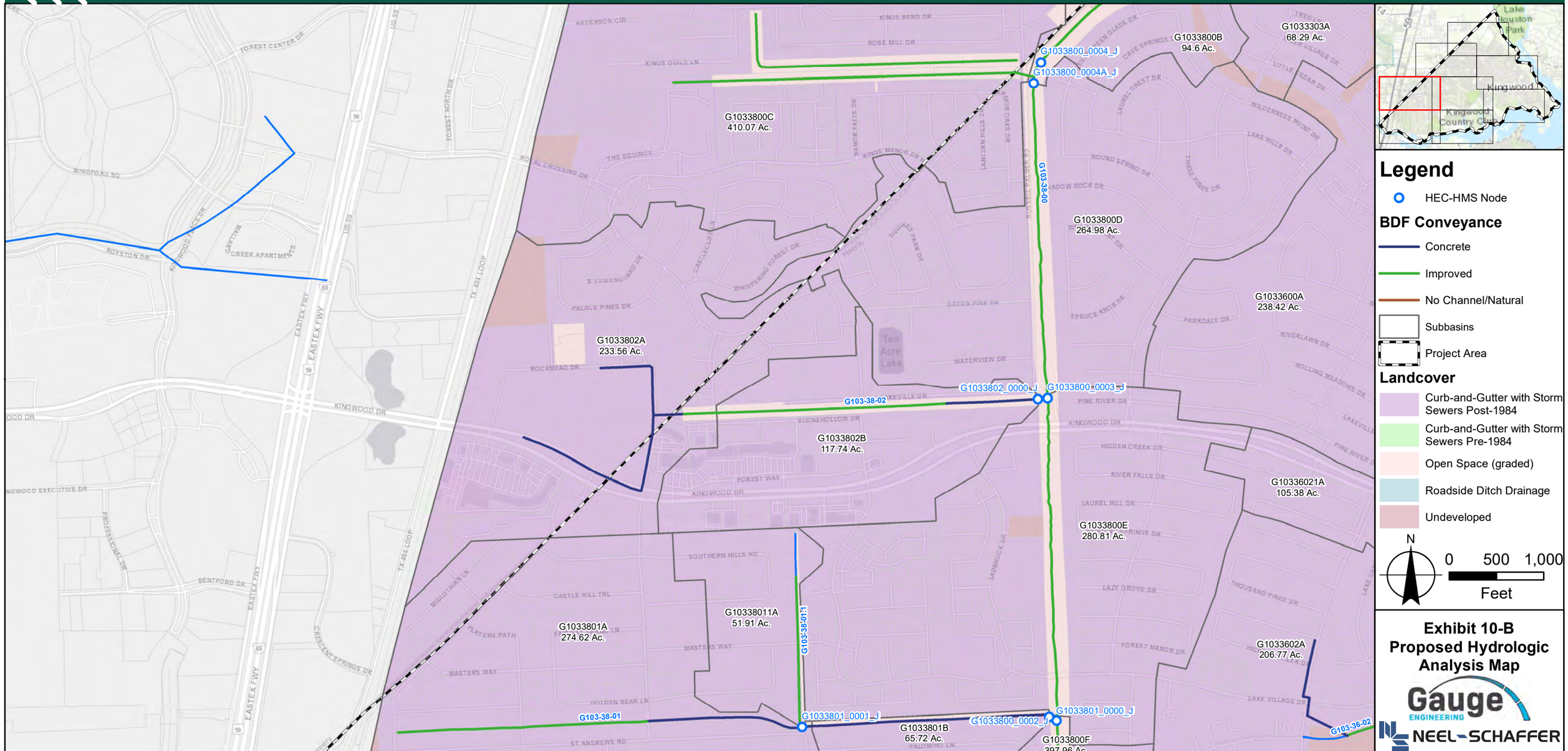
Exhibit 10-A
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-B
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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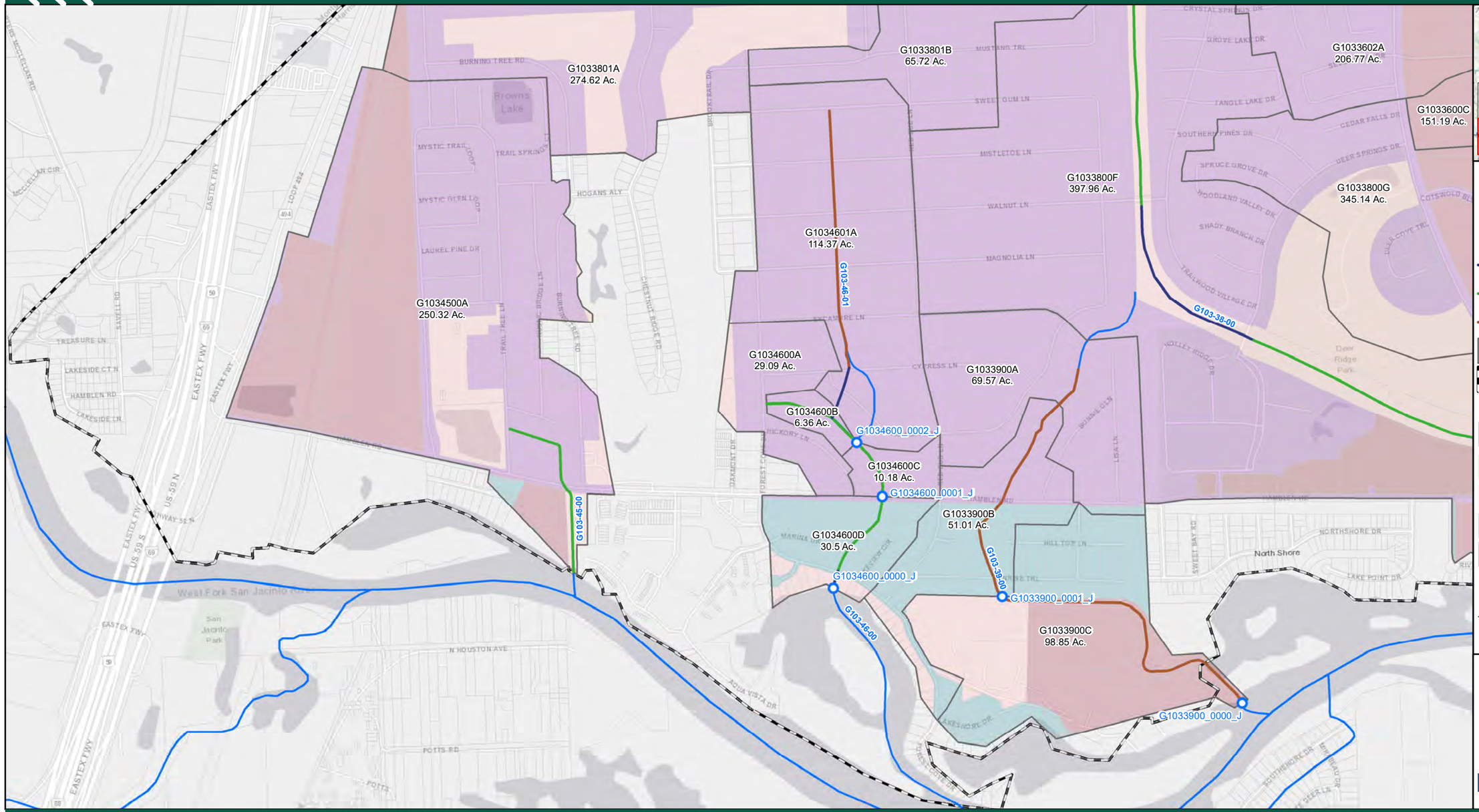
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-C
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

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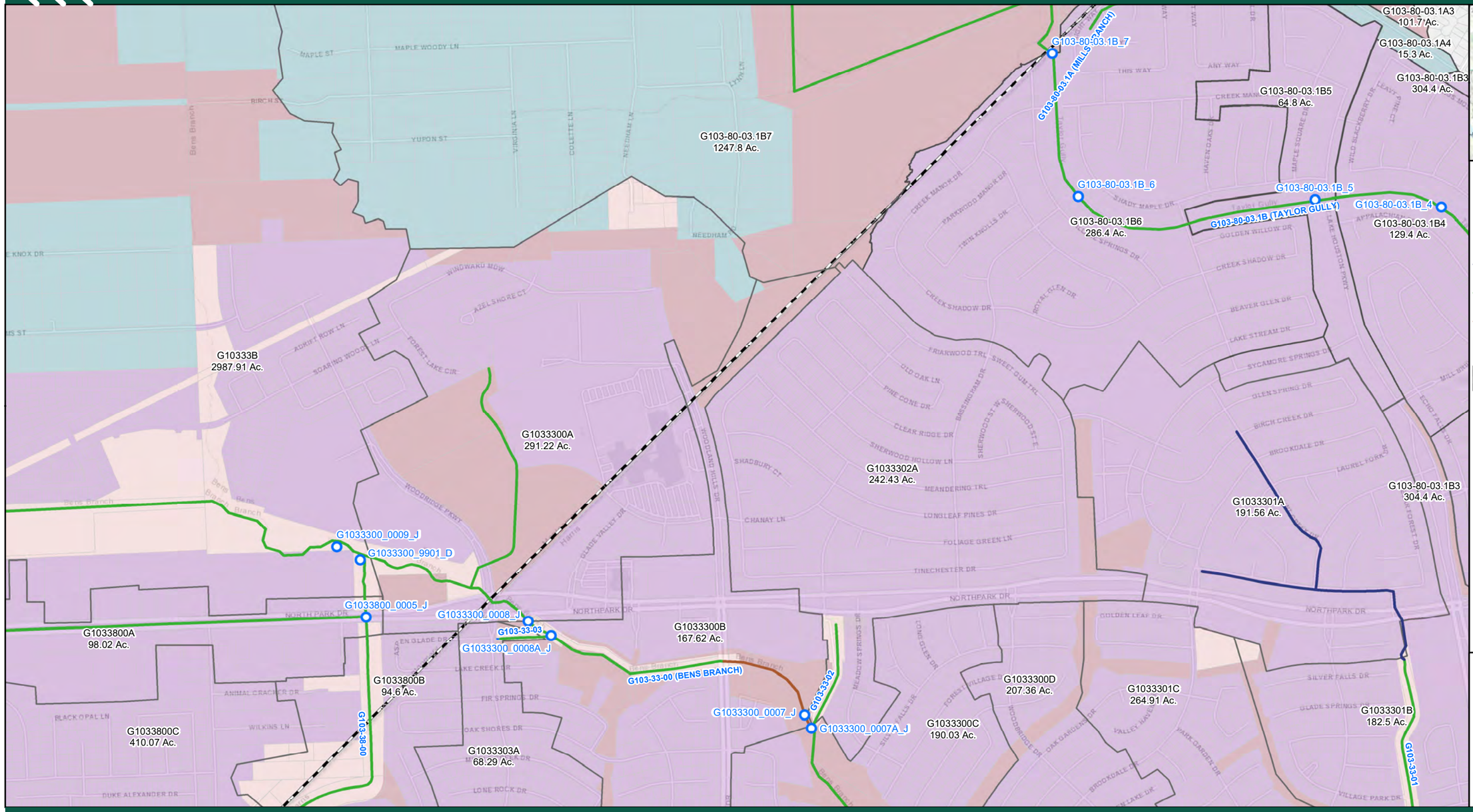
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-D
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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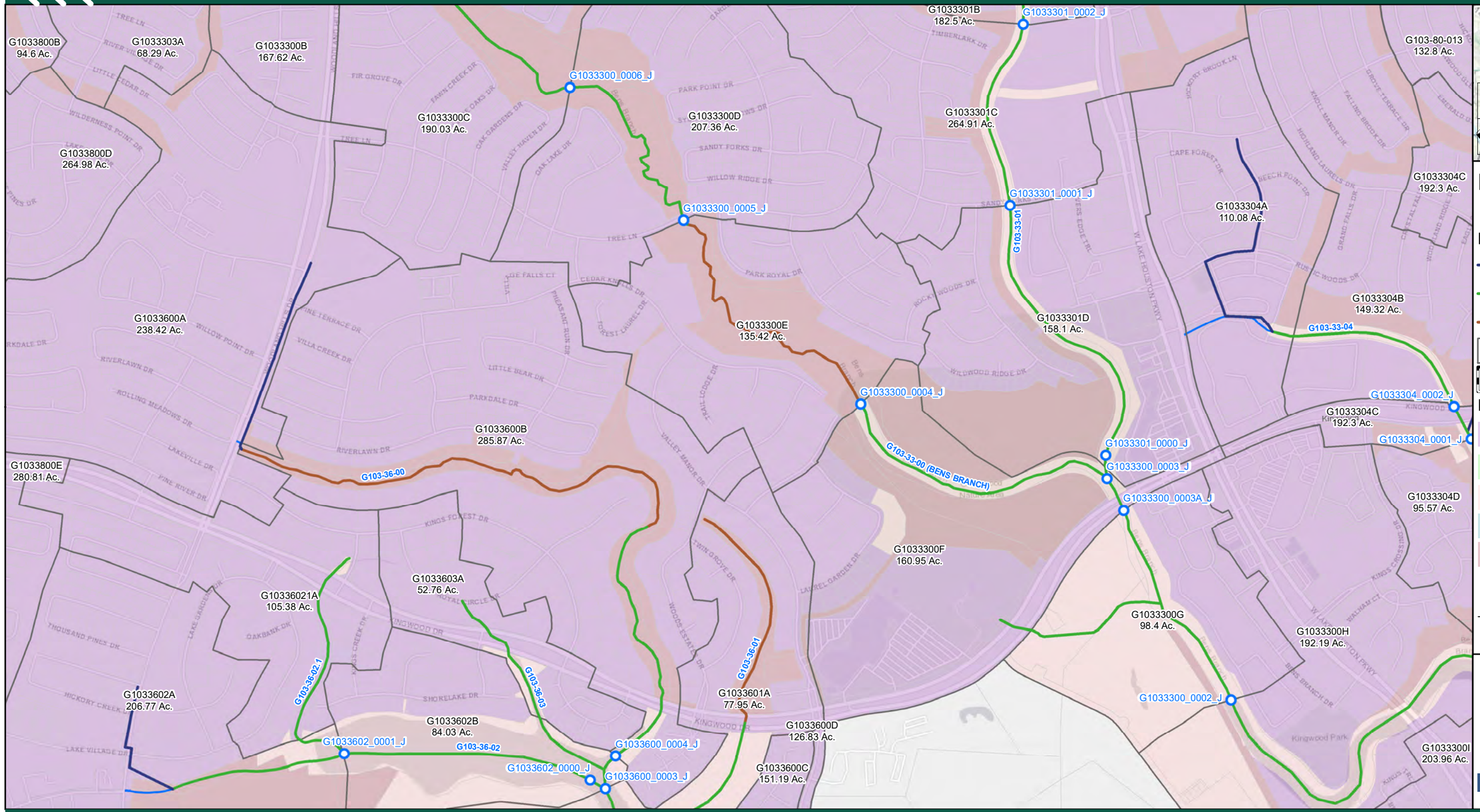
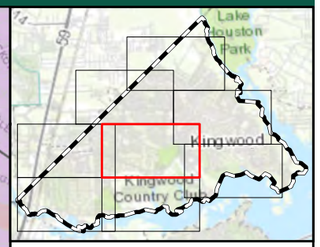
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018





Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-E
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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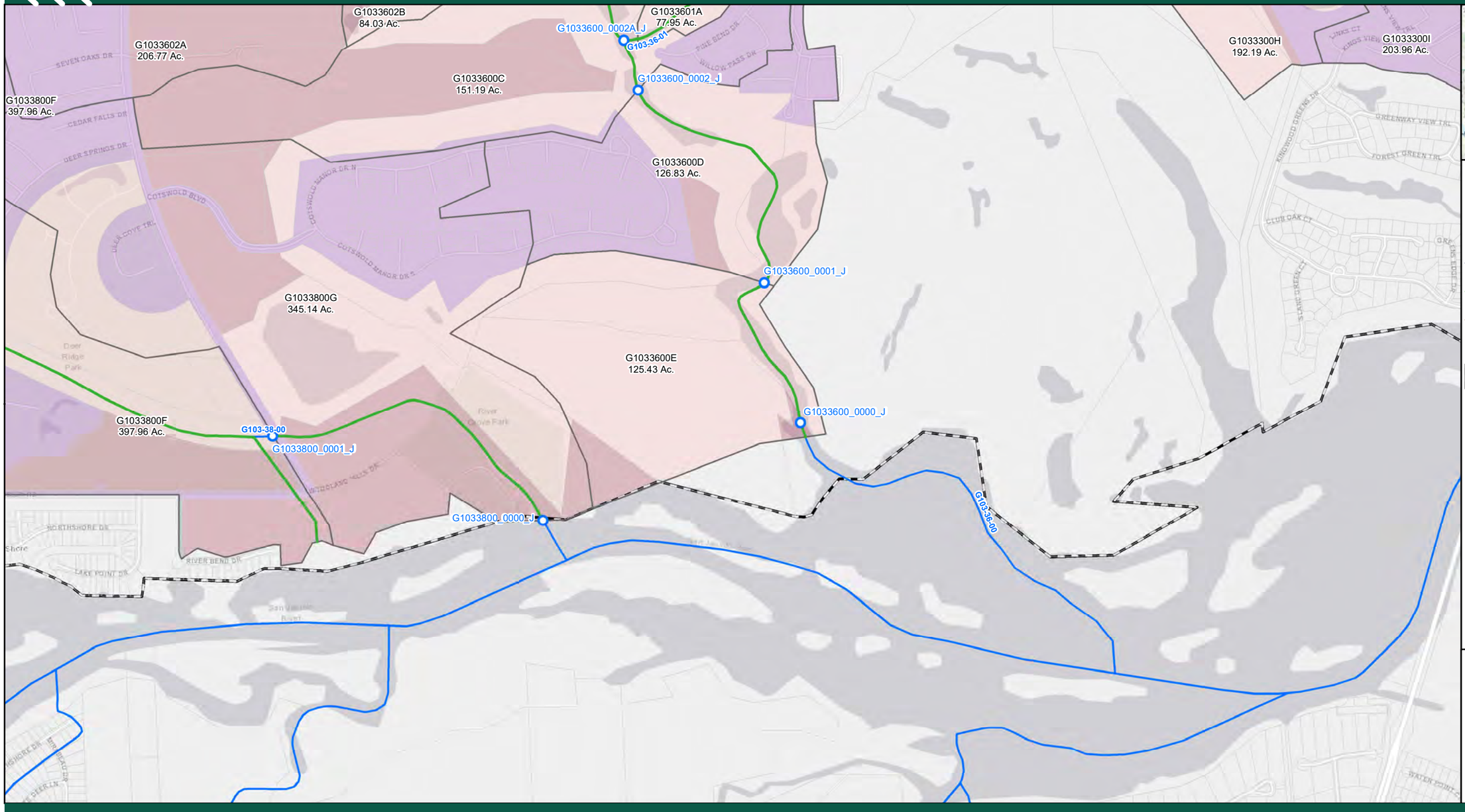
HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

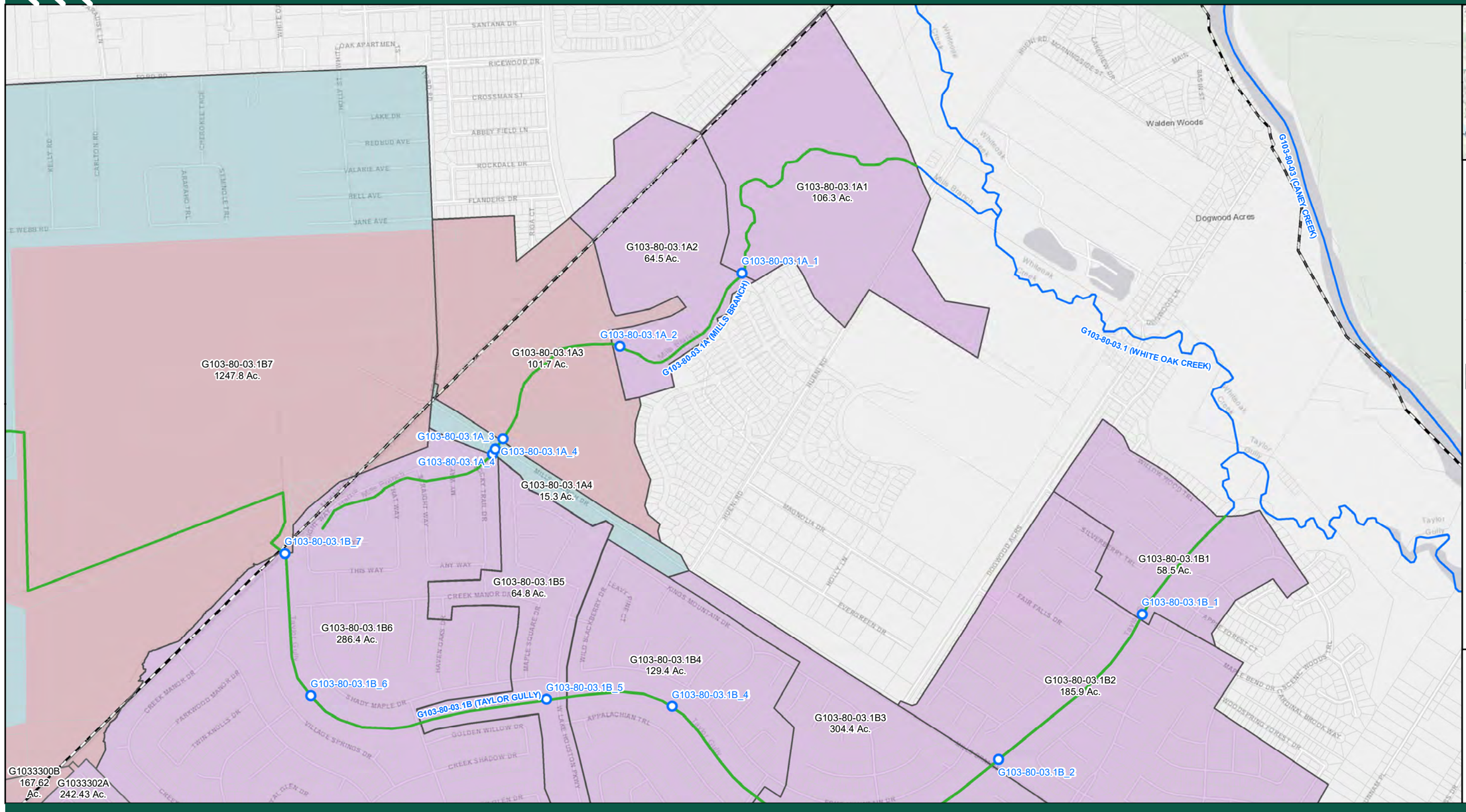
0 500 1,000

Feet

Exhibit 10-F
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-G
Proposed Hydrologic Analysis Map

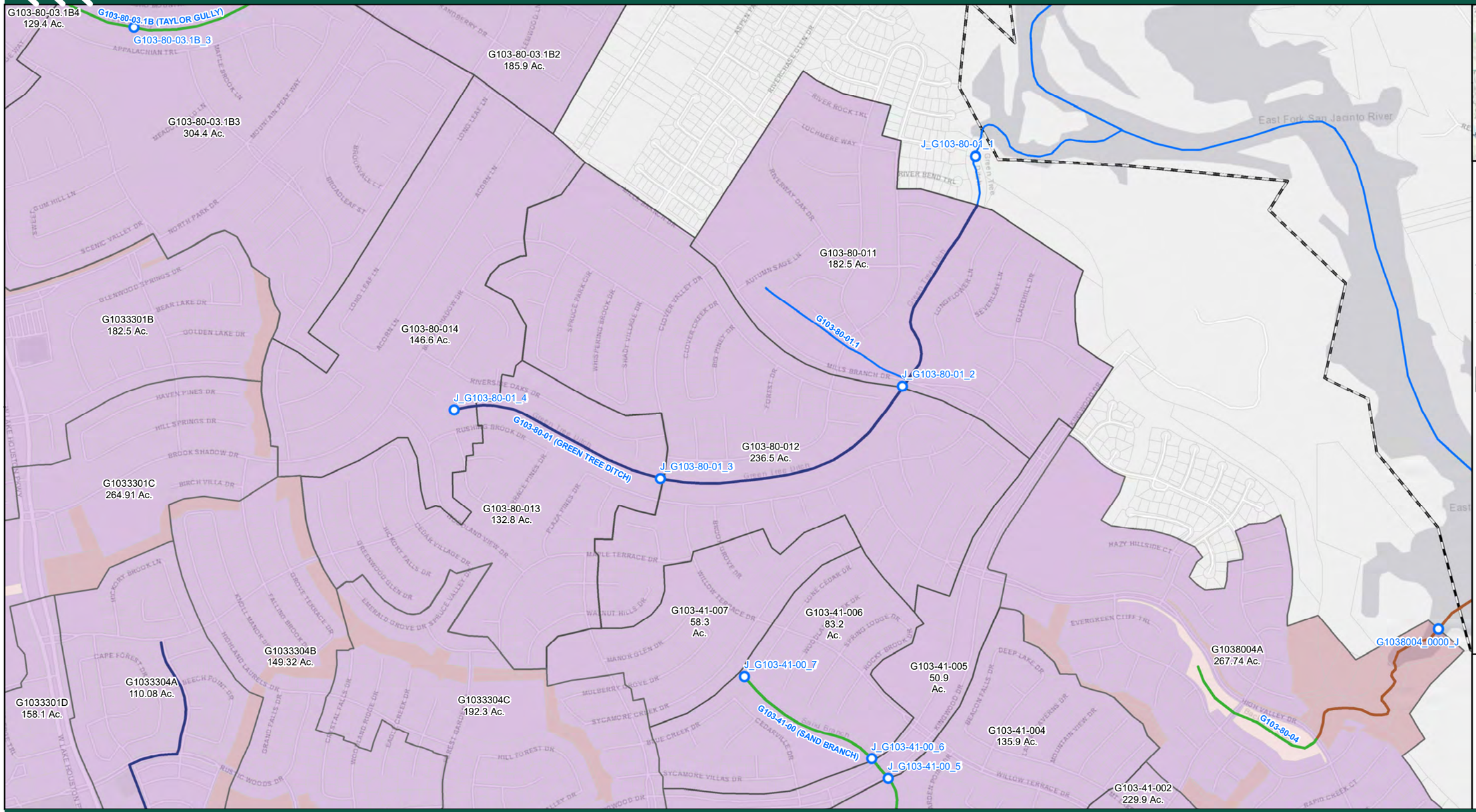
Gauge ENGINEERING

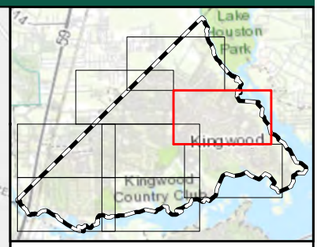
NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018





Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-H
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

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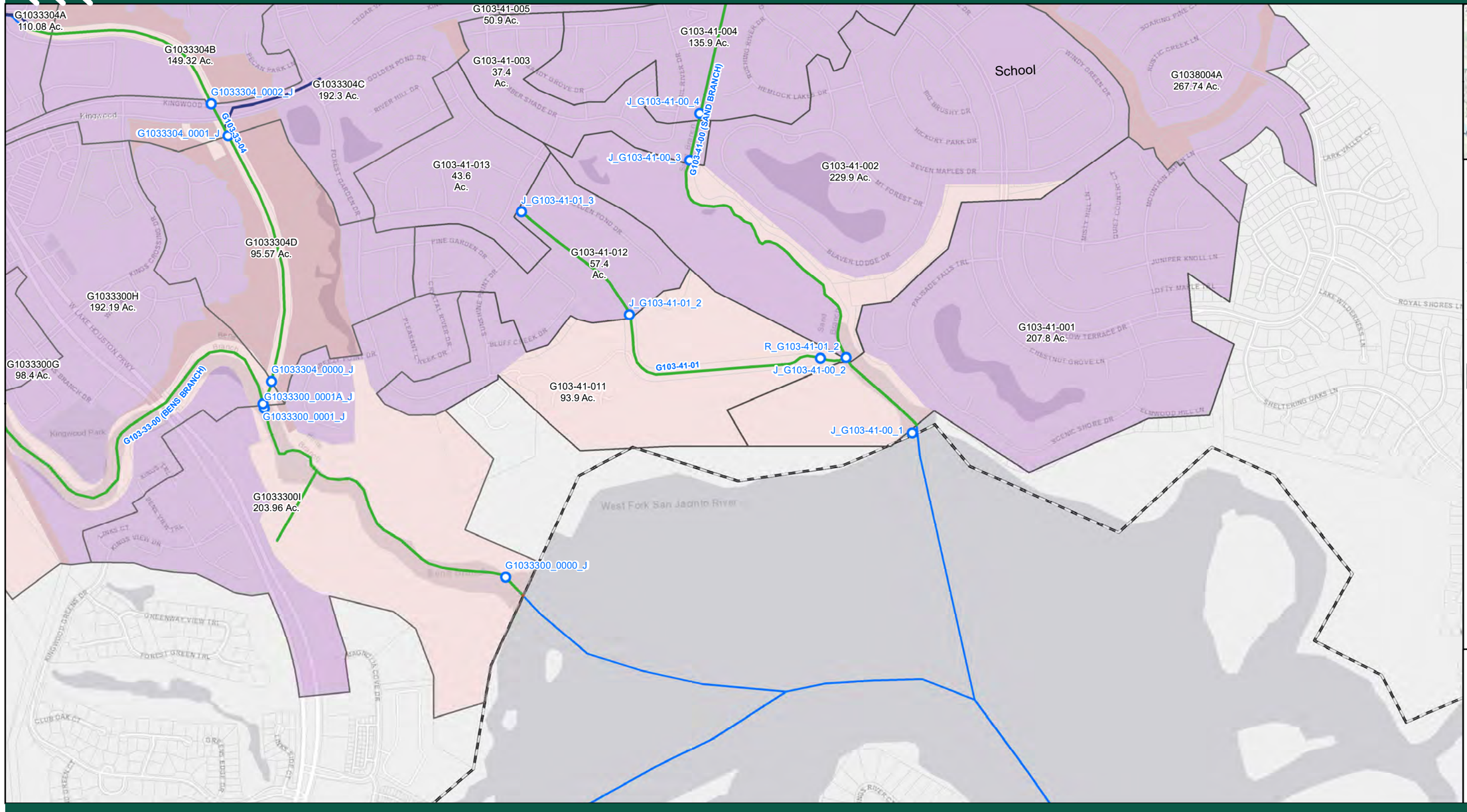
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

- HEC-HMS Node

BDF Conveyance

- Concrete
- Improved
- No Channel/Natural
- Subbasins
- Project Area

Landcover

- Curb-and-Gutter with Storm Sewers Post-1984
- Curb-and-Gutter with Storm Sewers Pre-1984
- Open Space (graded)
- Roadside Ditch Drainage
- Undeveloped

N

0 500 1,000

Feet

Exhibit 10-I
Proposed Hydrologic Analysis Map

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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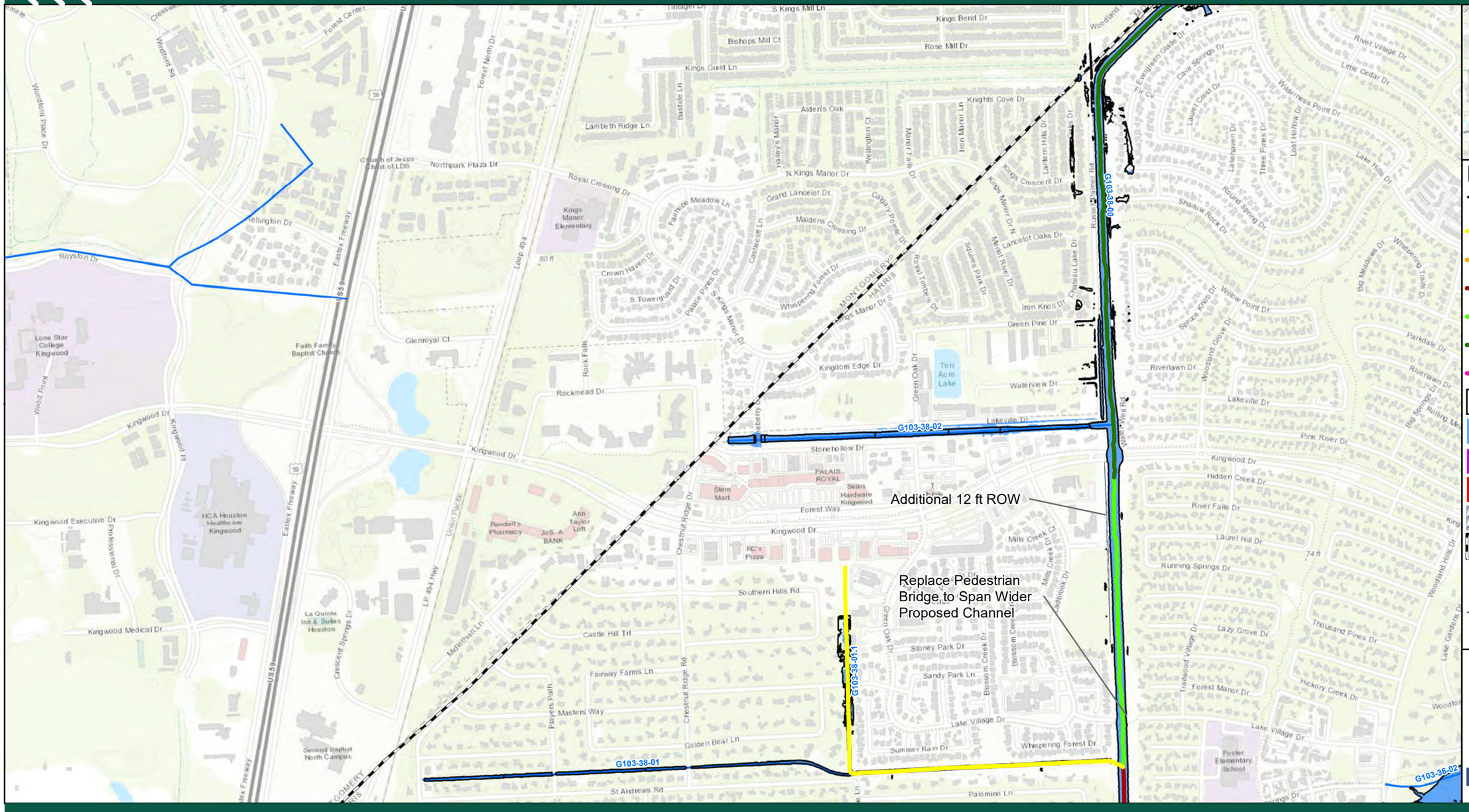
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018



Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6

- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

0 500 1,000

Feet

Exhibit 11-A
Improvement Option Layout

Gauge Engineering

NEEL-SCHAFFER

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HARRIS COUNTY FLOOD CONTROL DISTRICT

Existing: 24"
Proposed:4-4'x2'

Existing: 36"
Proposed:2-6'x3'

Existing: 42"
Proposed:3-6'x3'

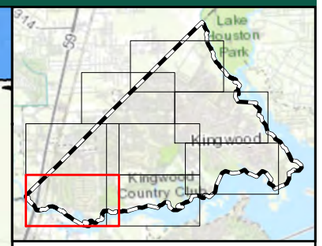
Existing: 122' Bridge
Proposed: 142' Bridge
Drop Channel Flowline 2.7 ft

Existing: 36"
Proposed:2-4'x3'

Existing: 36"
Proposed:2-5'x4'

Additional 12 ft ROW

G103-45-00
G103-46-00
G103-38-00



Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6

- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

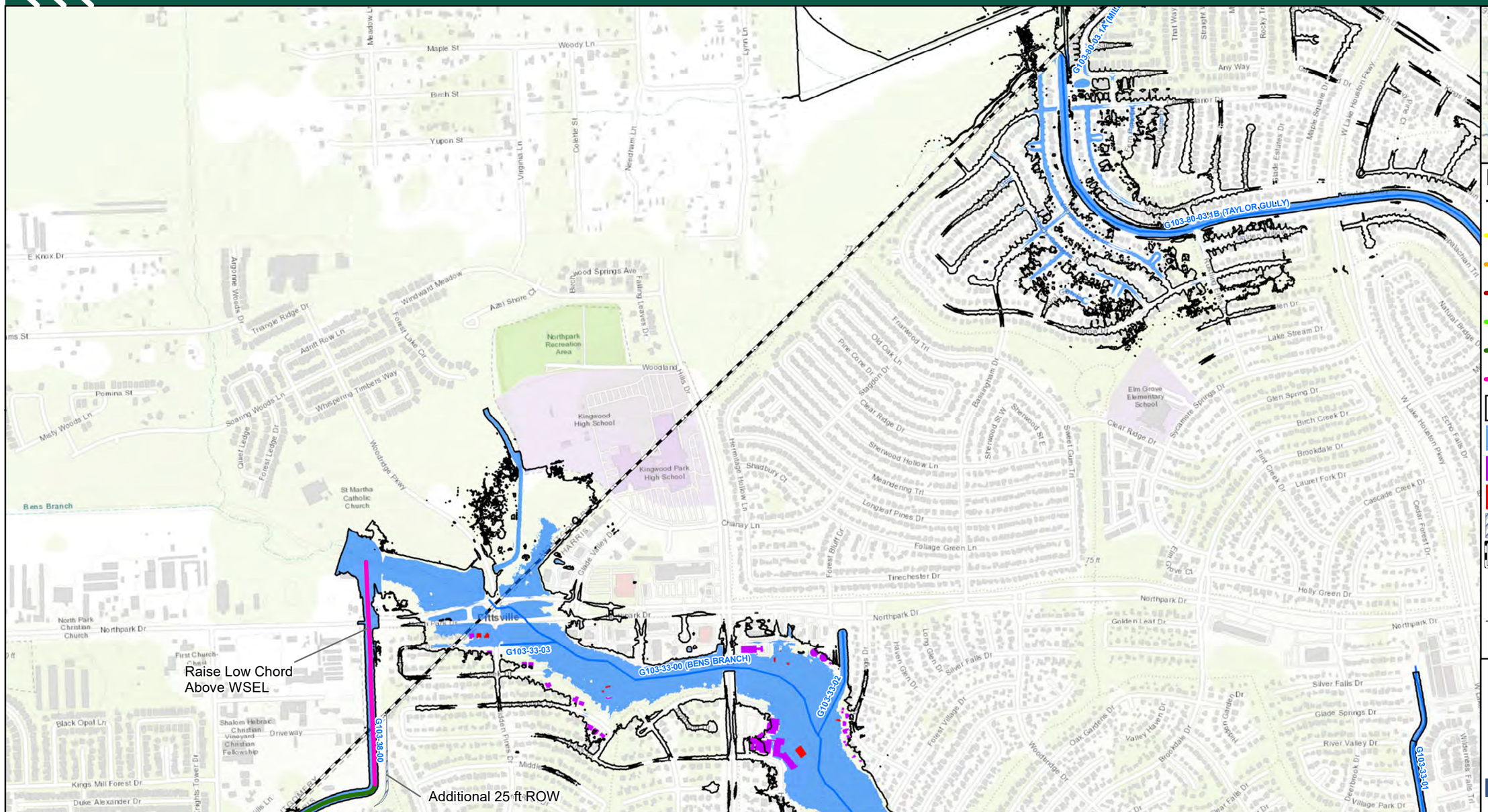
0 500 1,000

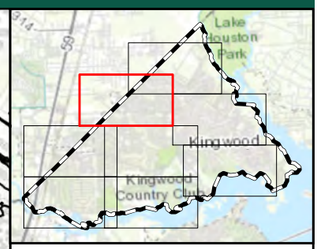
Feet

Exhibit 11-B
Improvement Option Layout

Gauge ENGINEERING

NEEL-SCHAFFER





Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6
- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

0 500 1,000

Feet

Exhibit 11-C
Improvement Option Layout

Gauge ENGINEERING

NEEL-SCHAFFER

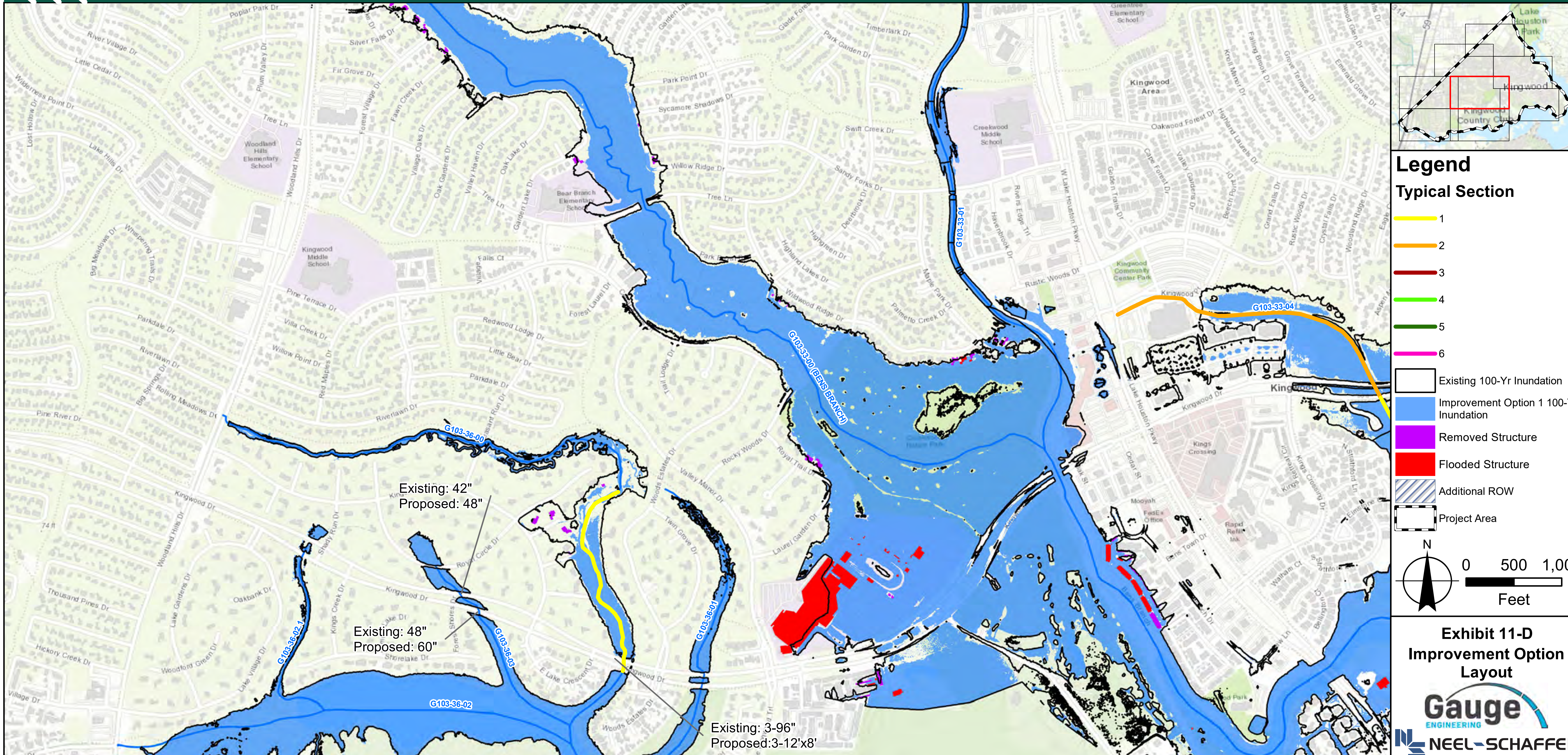


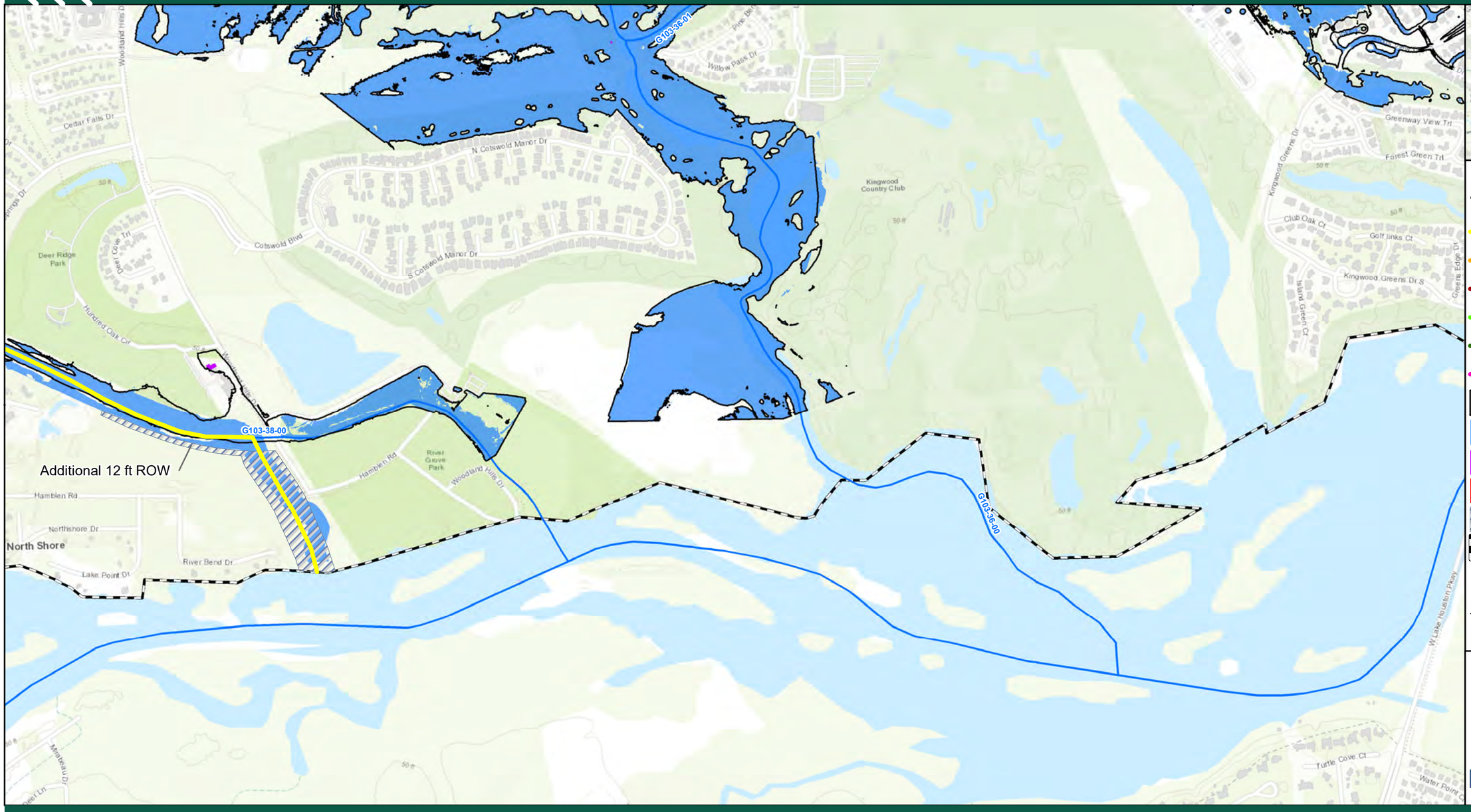
Exhibit 11-D
Improvement Option Layout

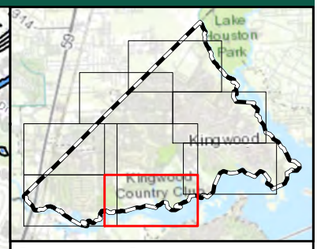
Gauge ENGINEERING
NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018





Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6

- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

0 500 1,000

Feet

Exhibit 11-E
Improvement Option Layout

Gauge ENGINEERING

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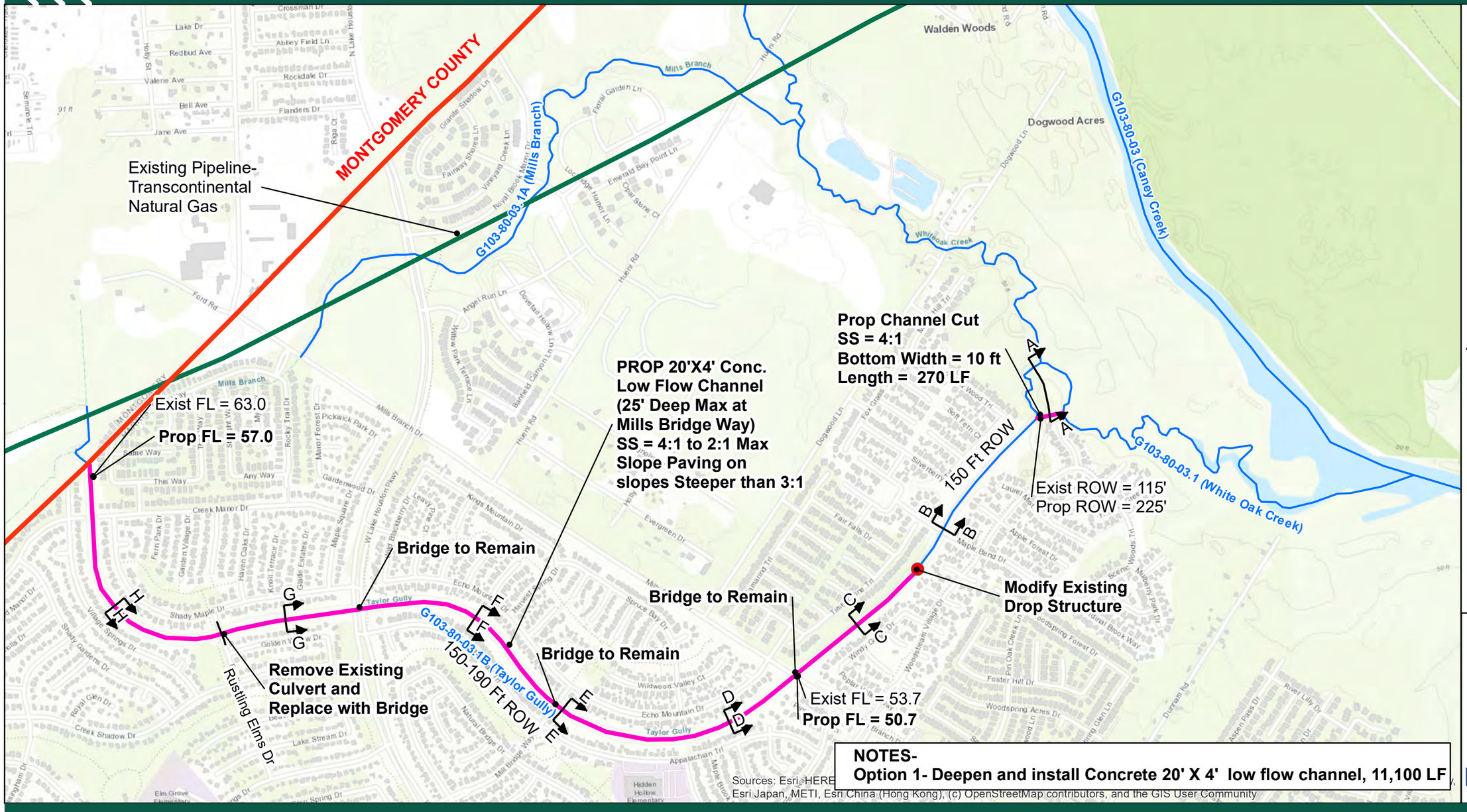
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

Taylor Gully Improvement Option 1

HARRIS COUNTY

BOND PROGRAM 2018



Legend

- County Boundary
- Natural Gas Pipeline

Alt Name

- Option 1
- Streams
- Typical Section Location

N

0 500 1,000

Feet

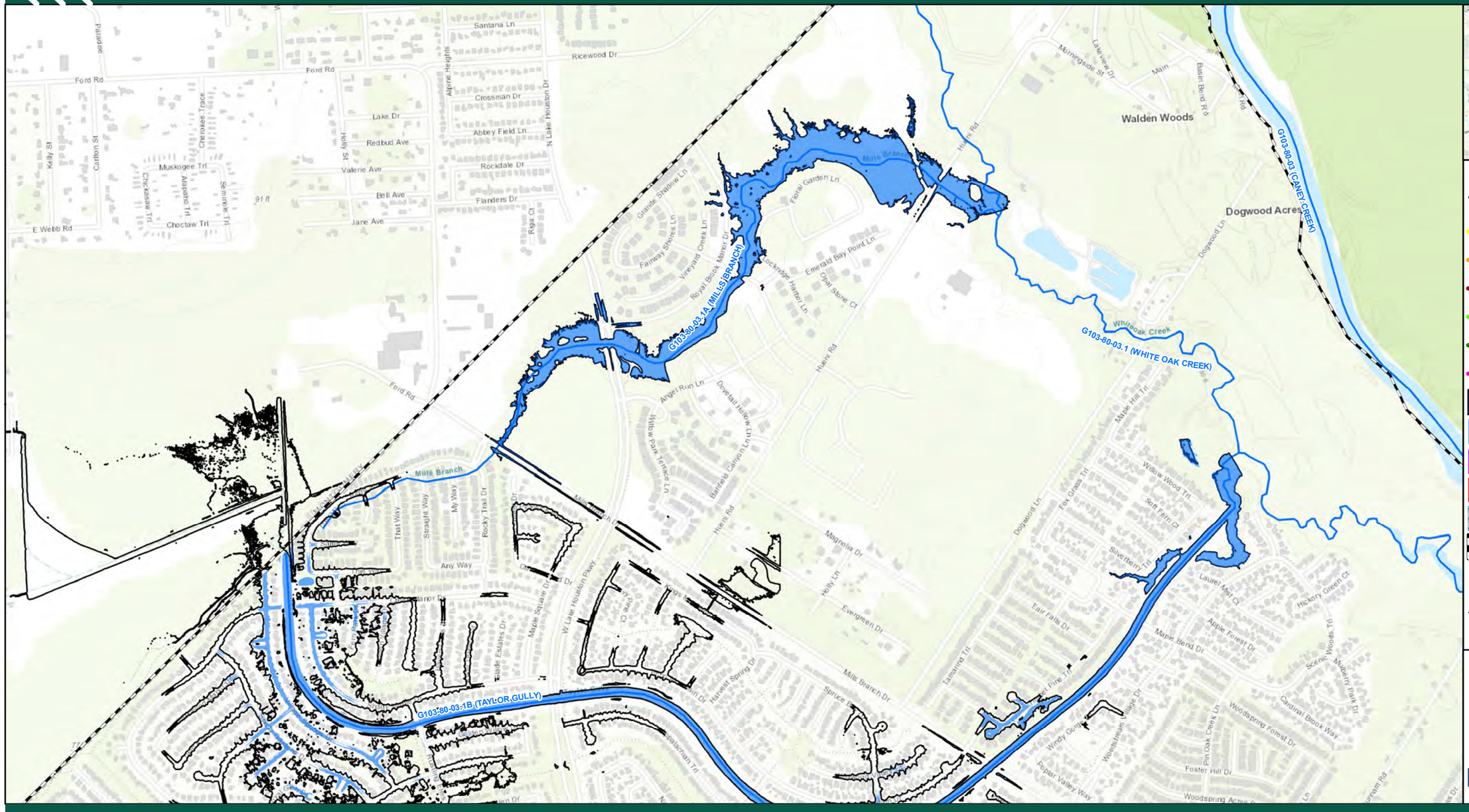
Taylor Gully Improvement Options OPTION 1

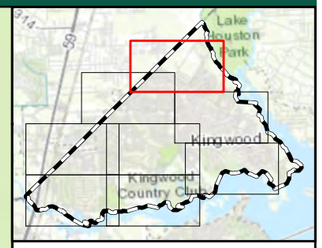
Exhibit 11-F

Gauge ENGINEERING

NEEL-SCHAFFER

NOTES-
Option 1- Deepen and install Concrete 20' X 4' low flow channel, 11,100 LF





Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6
- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

0 500 1,000

Feet

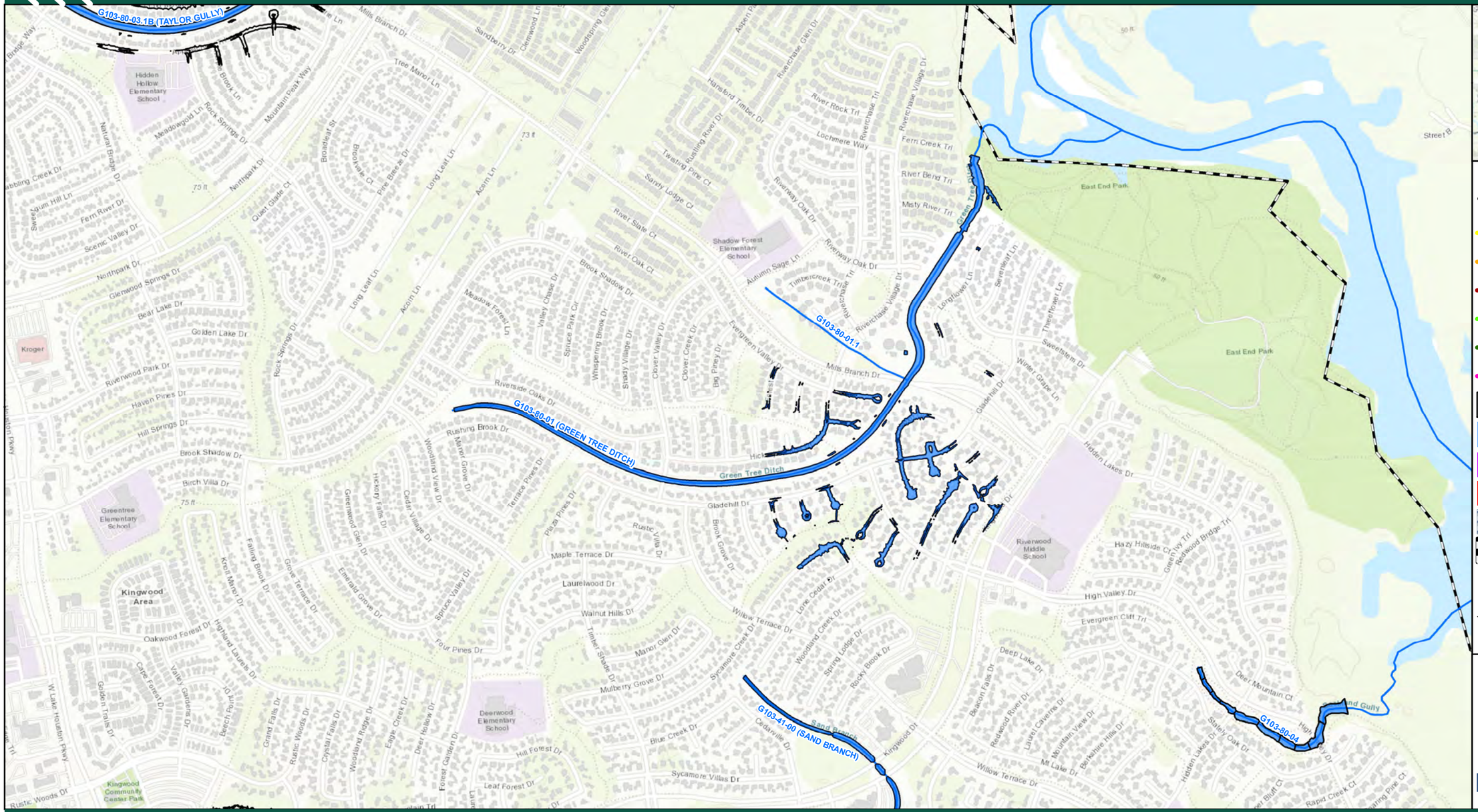
Exhibit 11-G
Improvement Option Layout

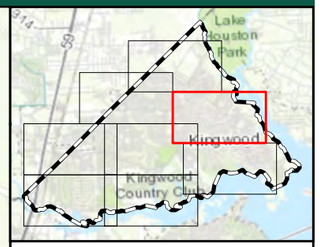
Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY BOND PROGRAM 2018





Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6
- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

0 500 1,000

Feet

Exhibit 11-H
Improvement Option Layout

Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

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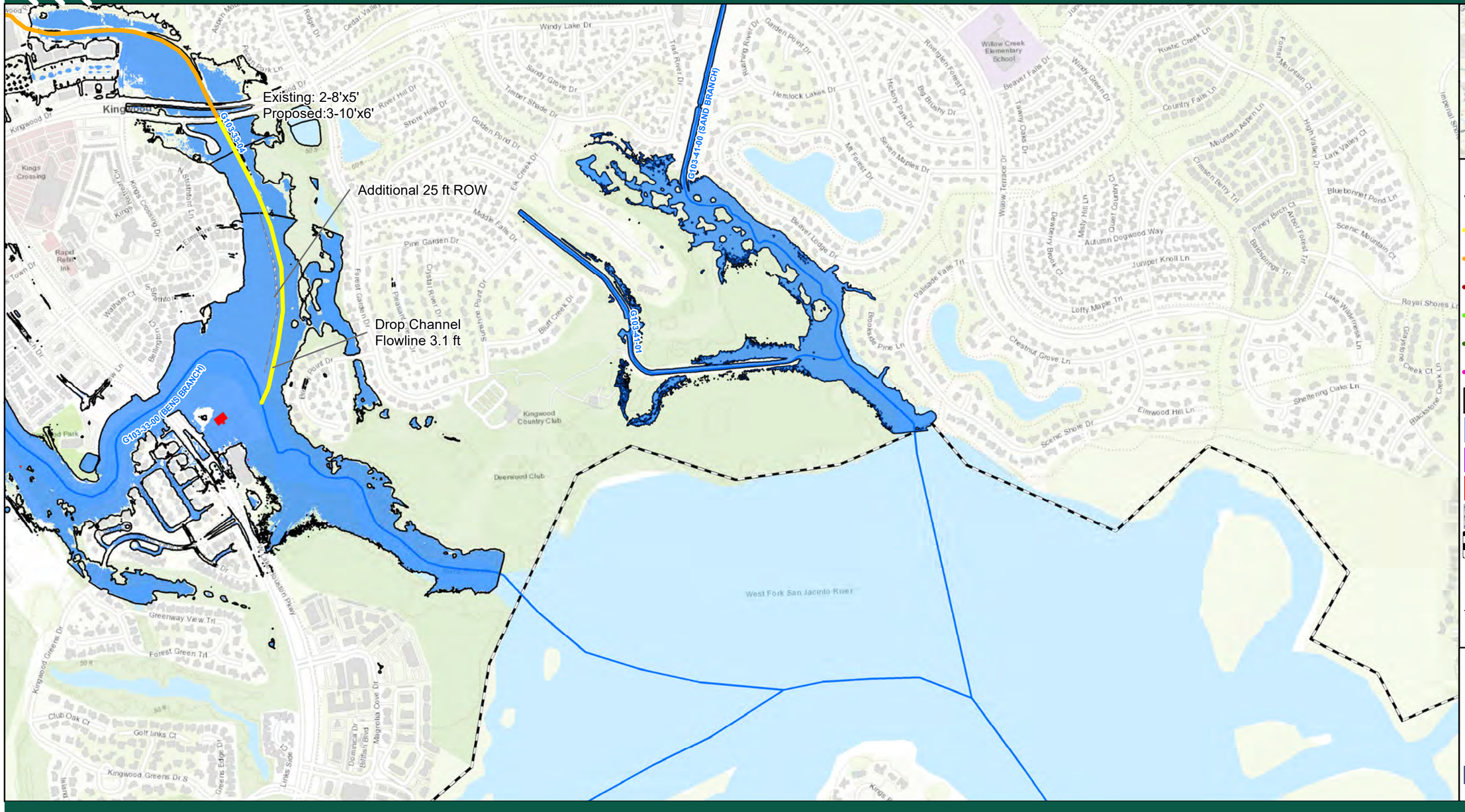
HARRIS COUNTY FLOOD CONTROL DISTRICT

Kingwood Drainage Study

HARRIS COUNTY

BOND PROGRAM 2018



Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6

- Existing 100-Yr Inundation
- Improvement Option 1 100-Yr Inundation
- Removed Structure
- Flooded Structure
- Additional ROW
- Project Area

N

0 500 1,000

Feet

Exhibit 11-I
Improvement Option Layout

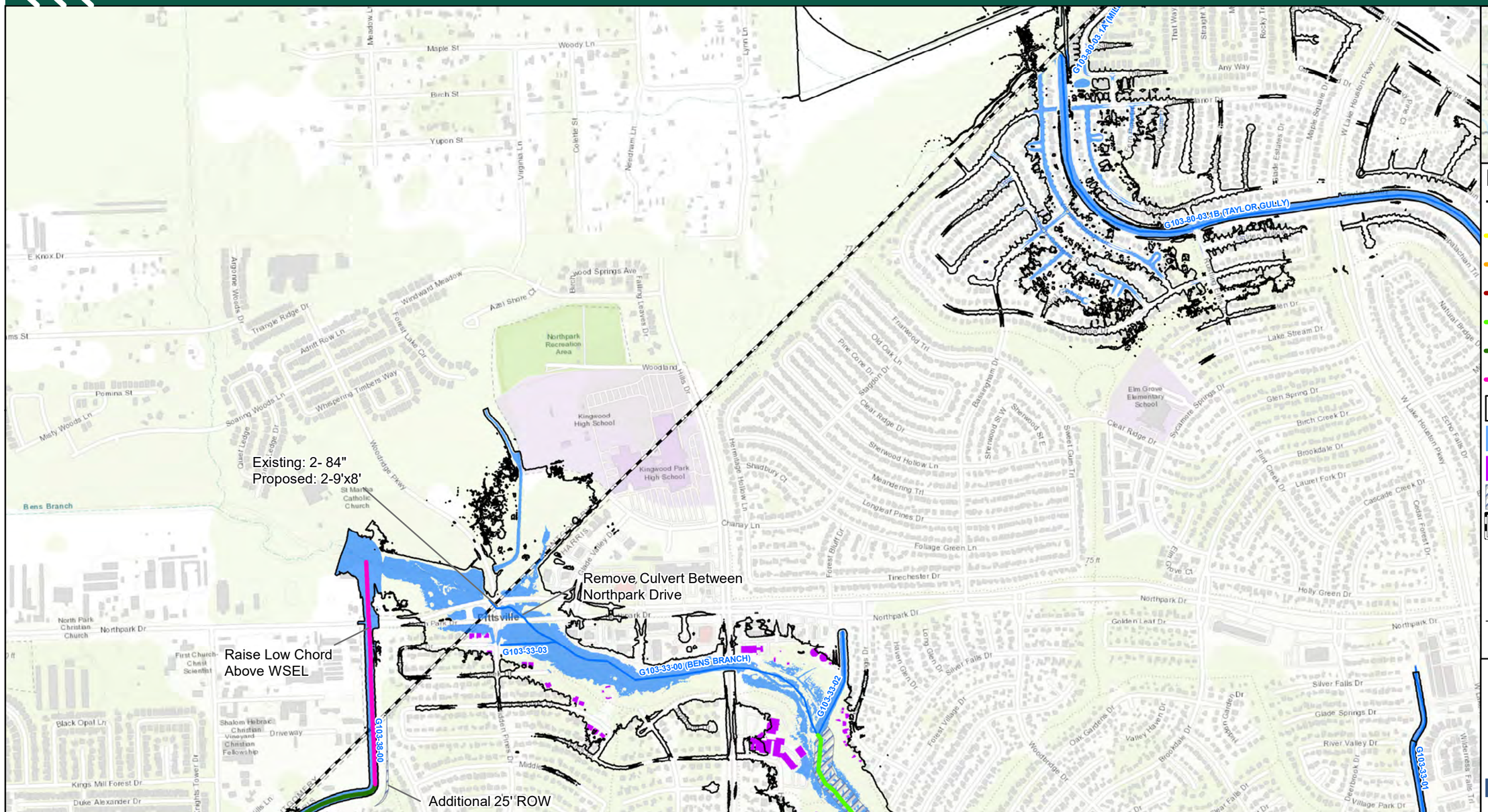
Gauge ENGINEERING

NEEL-SCHAFFER

July 2020

www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT



Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6

- Existing 100-Yr Inundation
- Improvement Option 2 100-Yr Inundation
- Removed Structure
- Additional ROW
- Project

N

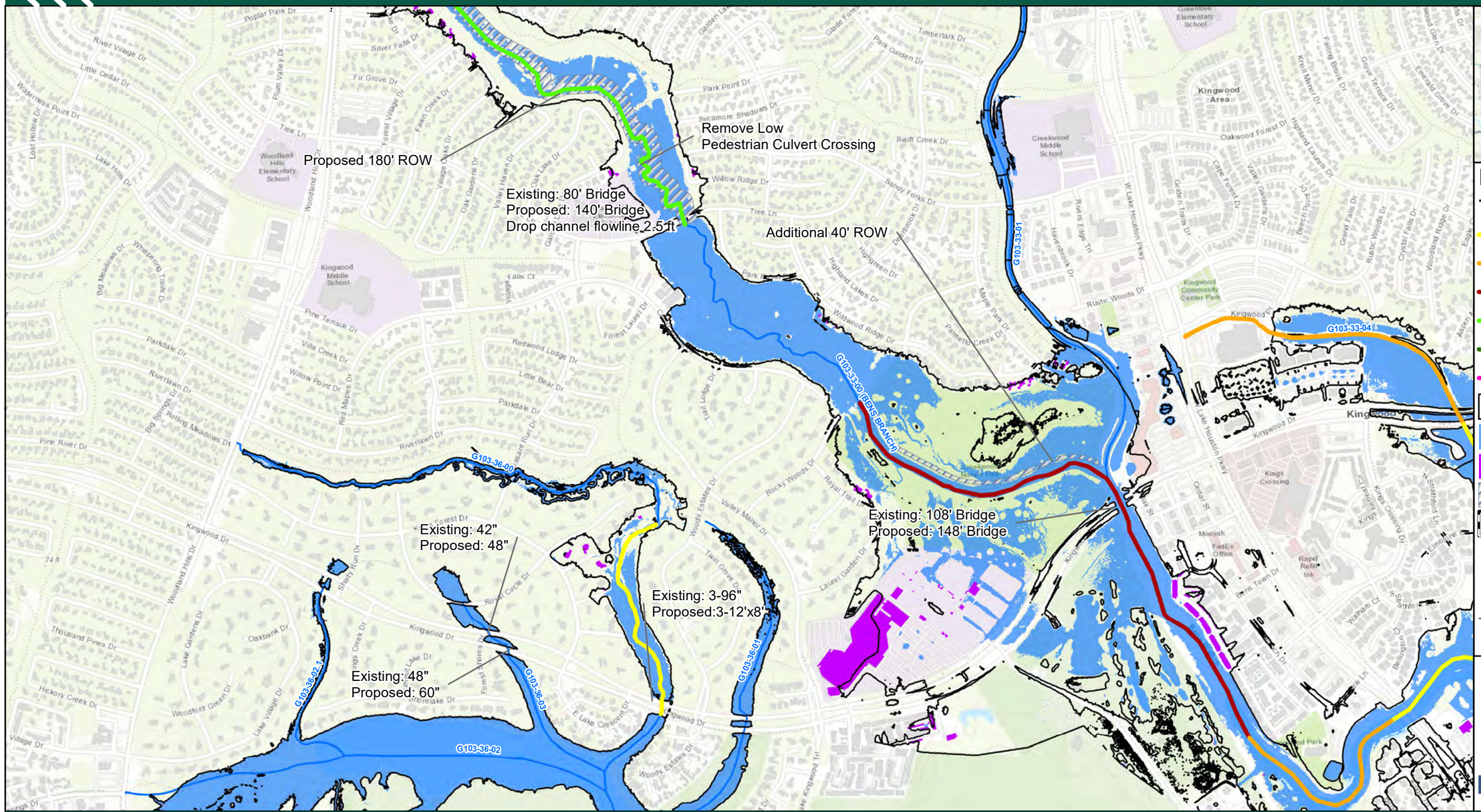
0 500 1,000

Feet

Exhibit 11-J
Improvement Option Layout

Gauge ENGINEERING

NEEL-SCHAFFER



Legend

Typical Section

- 1
- 2
- 3
- 4
- 5
- 6

- Existing 100-Yr Inundation
- Improvement Option 2 100-Yr Inundation
- Removed Structure
- Additional ROW
- Project

N

0 500 1,000

Feet

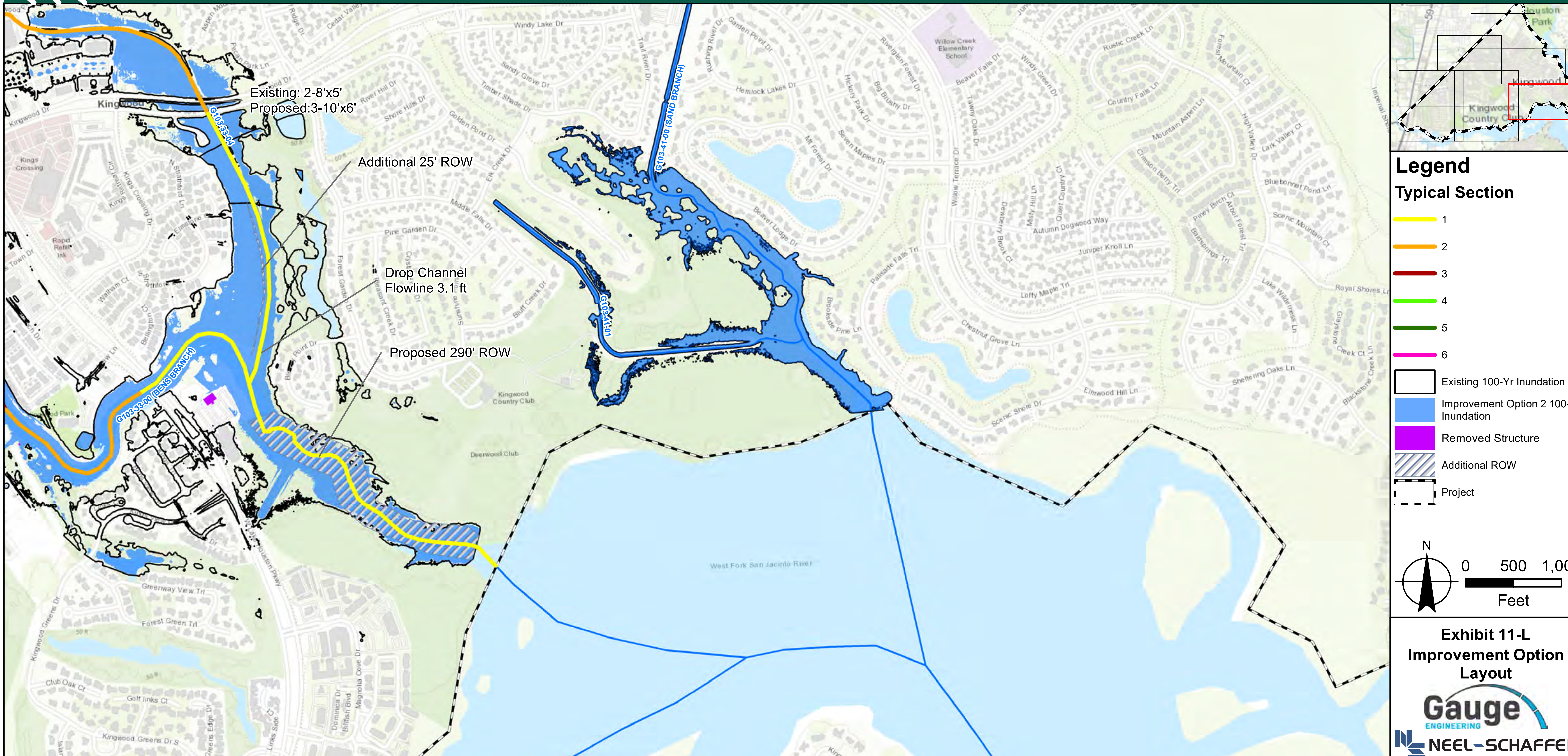
Exhibit 11-K
Improvement Option Layout

Gauge ENGINEERING

NEEL-SCHAFFER

Kingwood Drainage Study

HARRIS COUNTY
BOND PROGRAM 2018

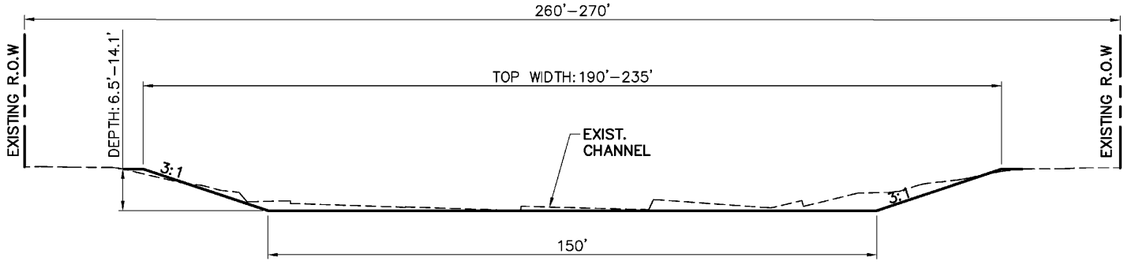


July 2020

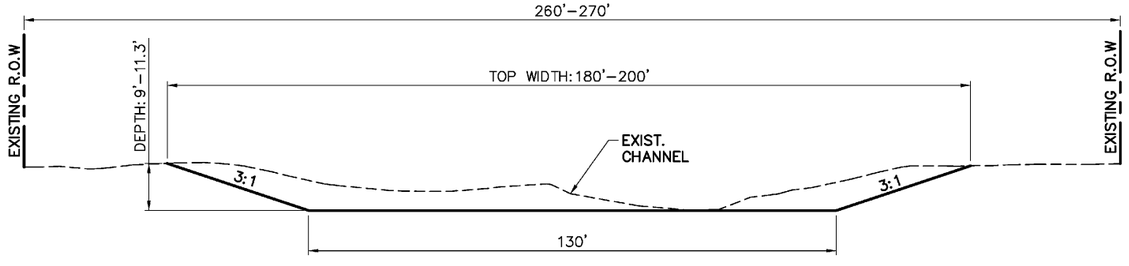
www.hcfcd.org/2018bondprogram

HARRIS COUNTY FLOOD CONTROL DISTRICT

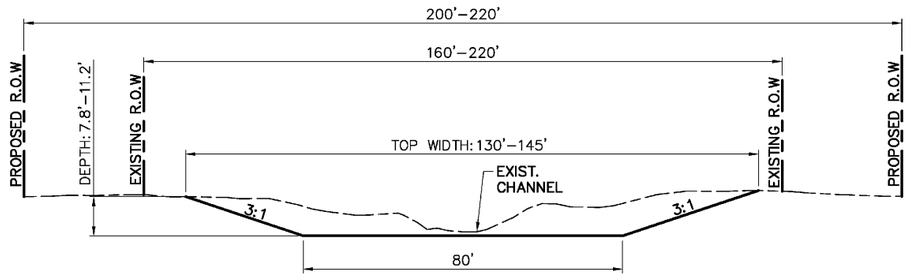
PROPOSED
CHANNEL TYPICAL SECTION 1
G103–33–00



PROPOSED
CHANNEL TYPICAL SECTION 2
G103–33–00



PROPOSED
CHANNEL TYPICAL SECTION 3
G103–33–00



PROPOSED
CHANNEL TYPICAL SECTION 4
G103–33–00

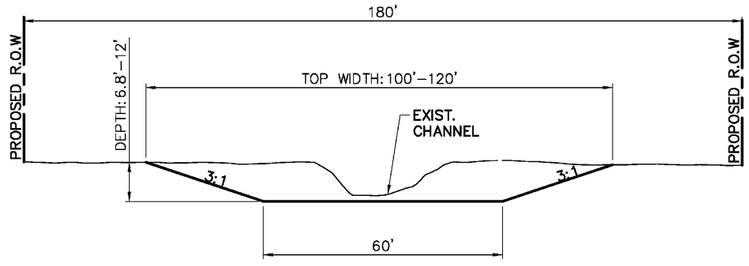
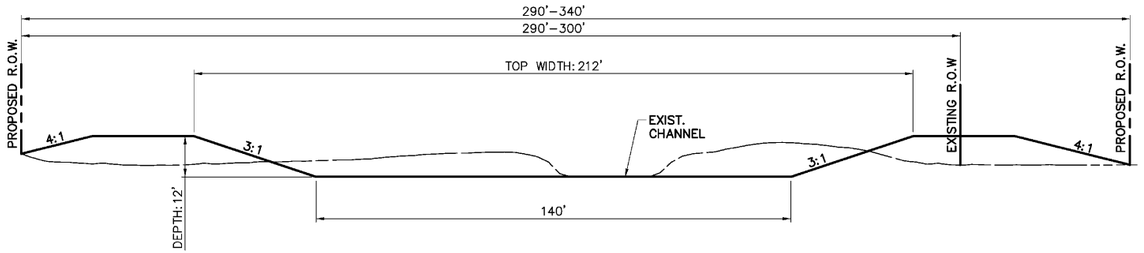


Exhibit 12-A
Proposed Typical Sections

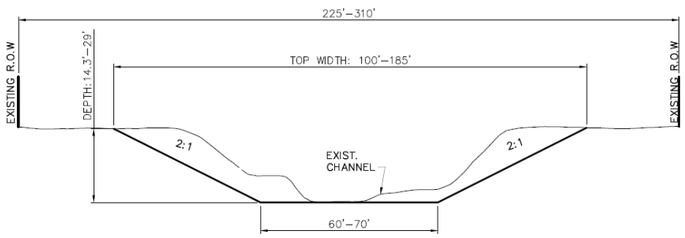
Gauge ENGINEERING

NEEL-SCHAFFER

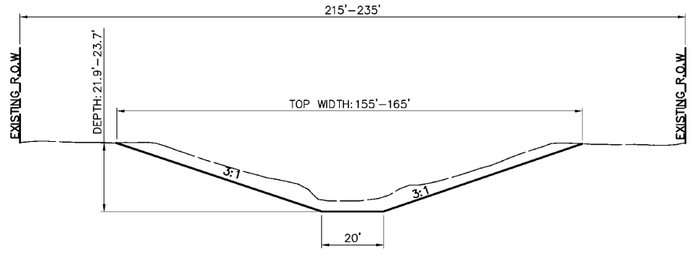
PROPOSED
CHANNEL TYPICAL SECTION 1
G103–38–00



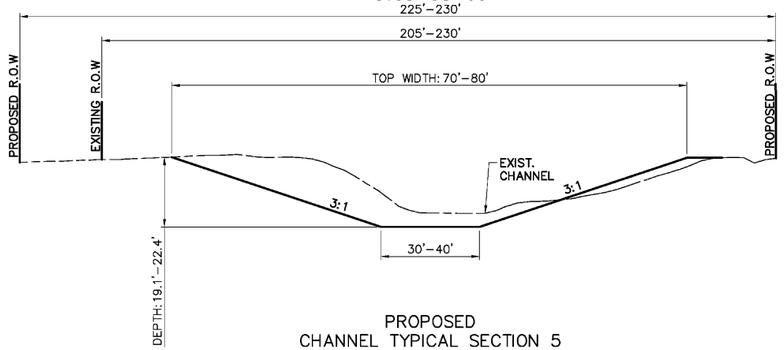
PROPOSED
CHANNEL TYPICAL SECTION 2
G103–38–00



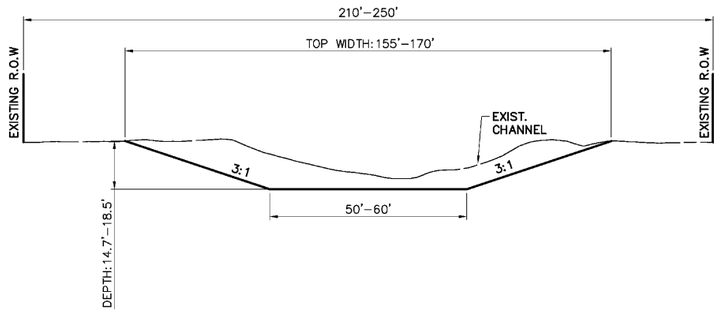
PROPOSED
CHANNEL TYPICAL SECTION 3
G103–38–00



PROPOSED
CHANNEL TYPICAL SECTION 4
G103–38–00



PROPOSED
CHANNEL TYPICAL SECTION 5
G103–38–00



PROPOSED
CHANNEL TYPICAL SECTION 6
G103–38–00

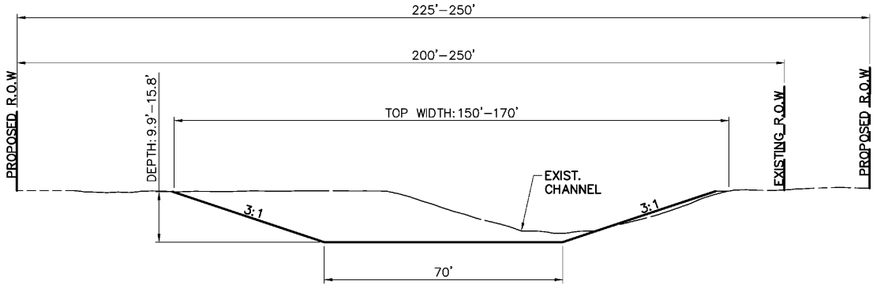
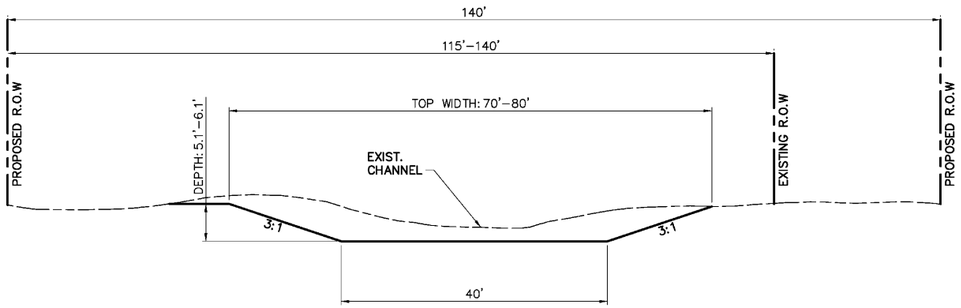


Exhibit12-B
Proposed Typical Sections

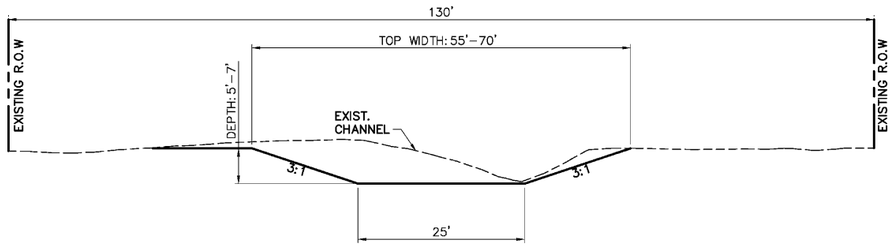
Gauge ENGINEERING

NEEL-SCHAFFER

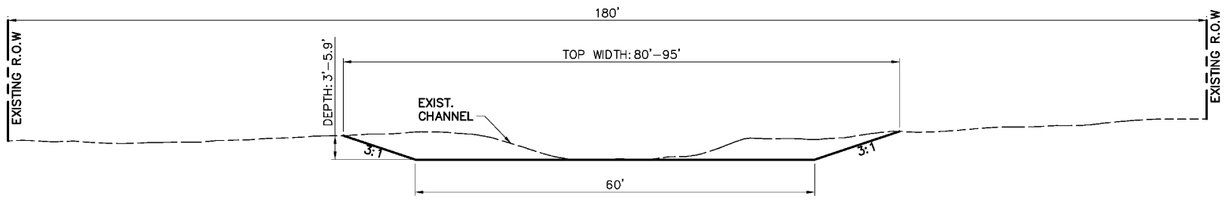
PROPOSED
CHANNEL TYPICAL SECTION 1
G103–33–04



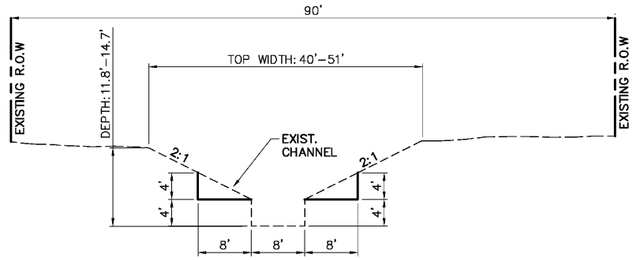
PROPOSED
CHANNEL TYPICAL SECTION 2
G103–33–04



PROPOSED
CHANNEL TYPICAL SECTION
G103–36–00



PROPOSED
CHANNEL TYPICAL SECTION 1
G103–38–01



PROPOSED
CHANNEL TYPICAL SECTION 1
G103–38–01.1

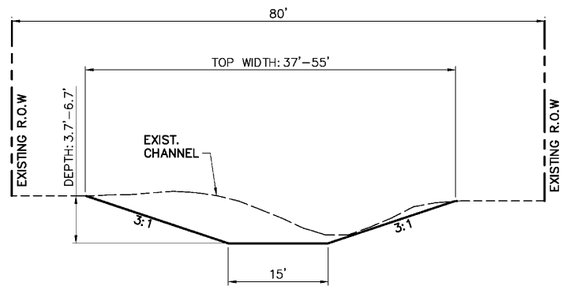
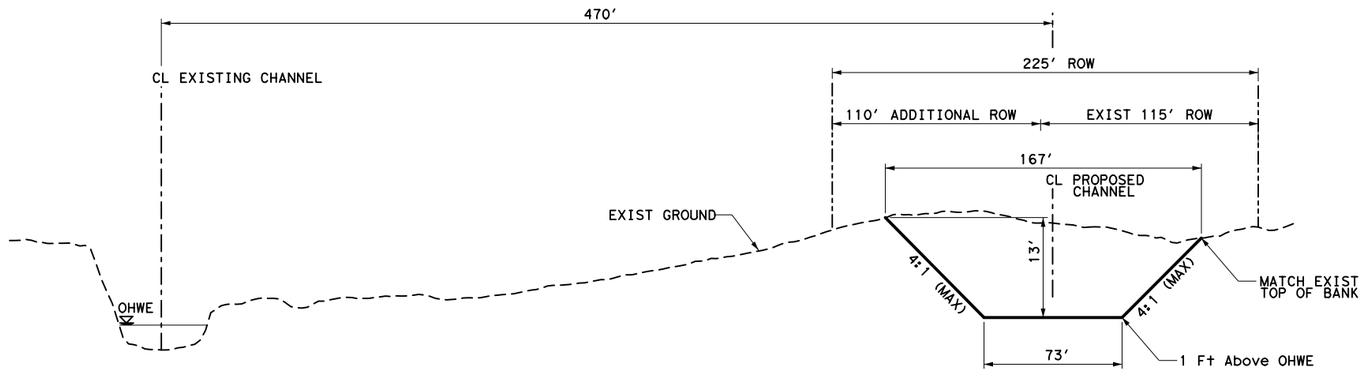


Exhibit 12-C
Proposed Typical Sections

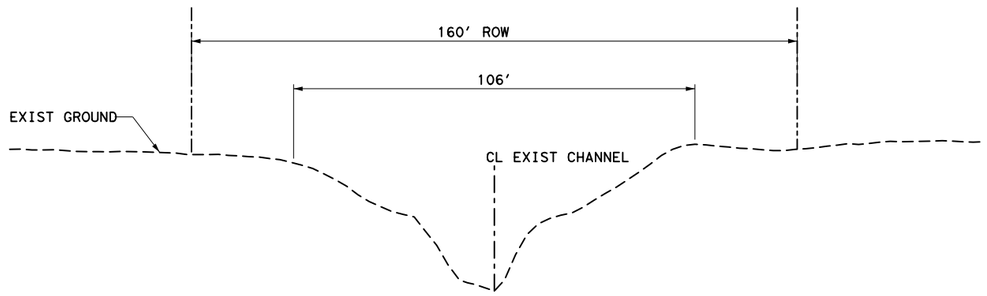
Gauge ENGINEERING

NEEL-SCHAFFER

0′ 40′ 80′
SCALE IN FEET



SECTION A-A
SCALE: 1"=80′-H
1"=20′-V



NO PROP. CHANNEL IMPROVEMENTS
FROM DROP STRUCTURE TO END OF REACH 2

SECTION B-B
SCALE: 1"=40′-H
1"=20′-V

KINGWOOD DRAINAGE STUDY

HARRIS COUNTY BOND PROGRAM 2018

TAYLOR GULLY OPTION 1, TYPICAL SECTIONS
SHEET 1 OF 4

PREPARED:

CHECKED:

APPROVED:

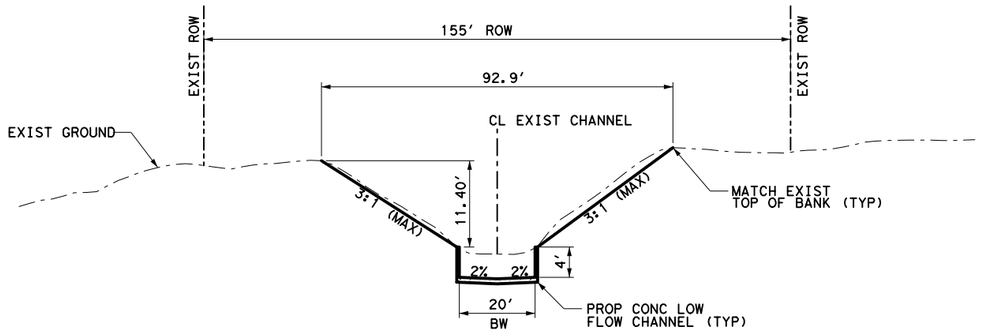
Gauge ENGINEERING
3200 Wilcrest Drive, Suite 220
Houston, TX 77042
www.GaugeEngineering.com
Texas PE Firm Reg. #F-20017

HARRIS COUNTY FLOOD CONTROL DISTRICT
9900 Northwest Freeway
Houston, Texas 77092

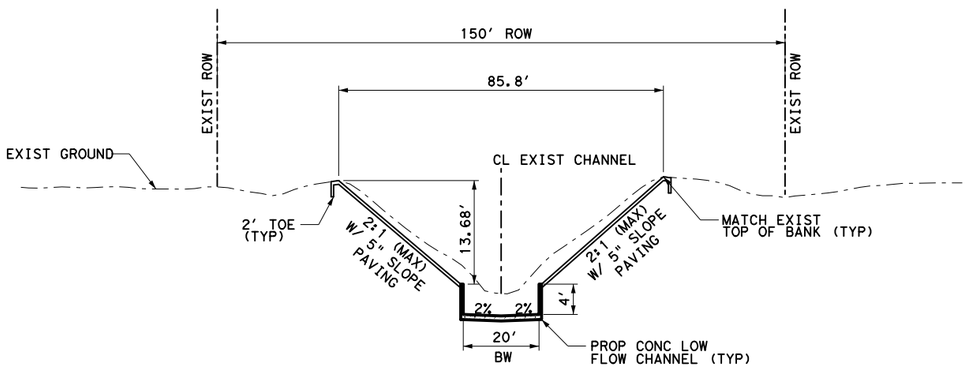
DATE: MARCH 2020
SCALE: 1":40'

EXHIBIT
12-D

INTERIM REVIEW
Not intended for construction, bidding or permit purposes.
Engineer: BRIAN R. WHITNEY
P.E. Serial No.: 81591
Date: MARCH 2020



SECTION C-C
SCALE: 1"=40'-H
1"=20'-V



SECTION D-D
SCALE: 1"=40'-H
1"=20'-V

0' 40' 80'
SCALE IN FEET

KINGWOOD DRAINAGE STUDY

HARRIS COUNTY BOND PROGRAM 2018

TAYLOR GULLY OPTION 1. TYPICAL SECTIONS
SHEET 2 OF 4

PREPARED:

CHECKED:

APPROVED:

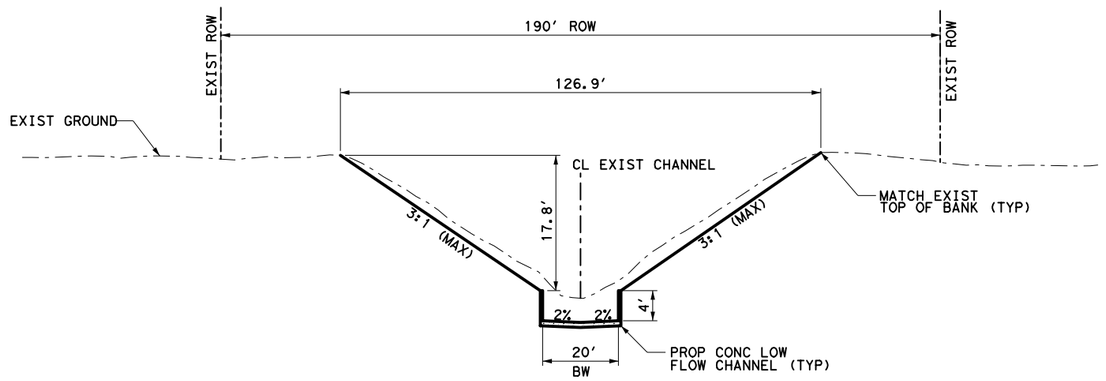
Gauge ENGINEERING
3200 Wilcrest Drive, Suite 220
Houston, TX 77042
www.GaugeEngineering.com
Texas PE Firm Reg. #F-20017

HARRIS COUNTY FLOOD CONTROL DISTRICT
9900 Northwest Freeway
Houston, Texas 77092

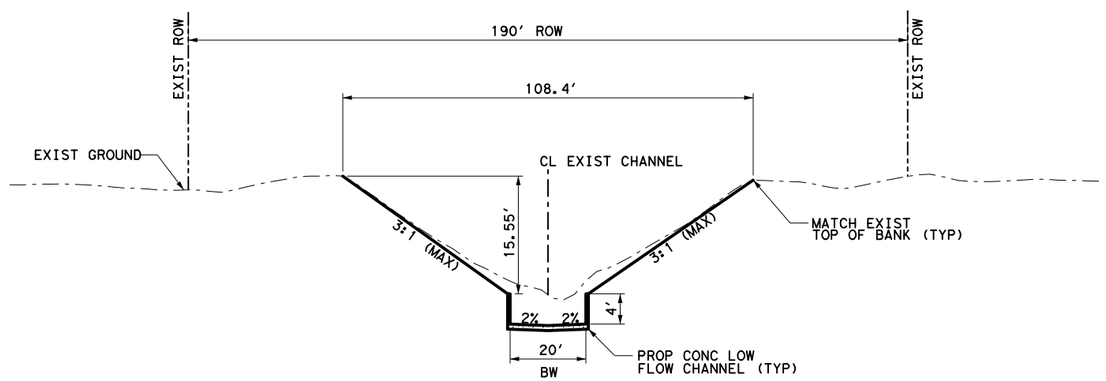
DATE: MARCH 2020
SCALE: 1":40'

EXHIBIT
12-E

INTERIM REVIEW
Not intended for construction, bidding or permit purposes.
Engineer: BRIAN R. WHITNEY
P.E. Serial No.: 81591
Date: MARCH 2020



SECTION E-E
SCALE: 1"=40'-H
1"=20'-V



SECTION F-F
SCALE: 1"=40'-H
1"=20'-V

0' 40' 80'
SCALE IN FEET

KINGWOOD DRAINAGE STUDY

HARRIS COUNTY BOND PROGRAM 2018

TAYLOR GULLY OPTION 1. TYPICAL SECTIONS
SHEET 3 OF 4

PREPARED:
CHECKED:
APPROVED:

Gauge ENGINEERING
3200 Wilcrest Drive, Suite 220
Houston, TX 77042
www.GaugeEngineering.com
Texas PE Firm Reg. #F-20017

HARRIS COUNTY FLOOD CONTROL DISTRICT
9900 Northwest Freeway
Houston, Texas 77092

DATE: MARCH 2020
SCALE: 1":40'

EXHIBIT
12-F

INTERIM REVIEW
Not intended for construction, bidding or permit purposes.
Engineer: BRIAN R. WHITNEY
P.E. Serial No.: 81591
Date: MARCH 2020

Design Filename: P:\Neel Schaffer\1030-Kingwood Watershed Study\4-0-Production-Working\4-1-CAD\Drainage\PR*DRN*03.dgn

Pen Table:KINGWOOD.tbl
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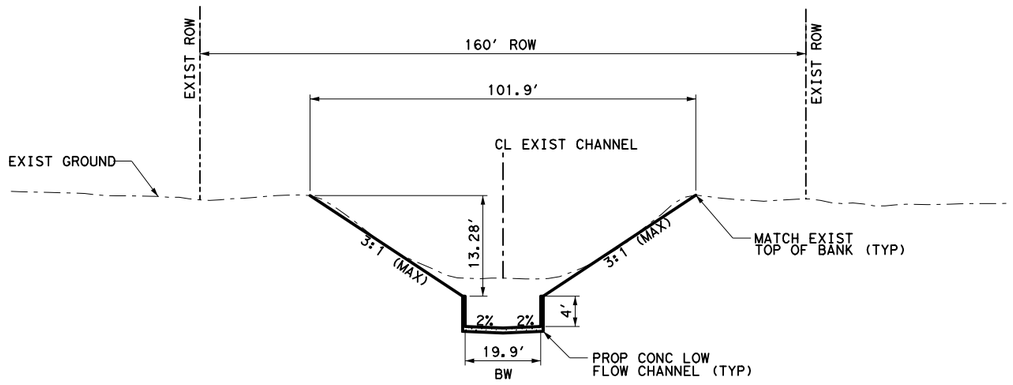
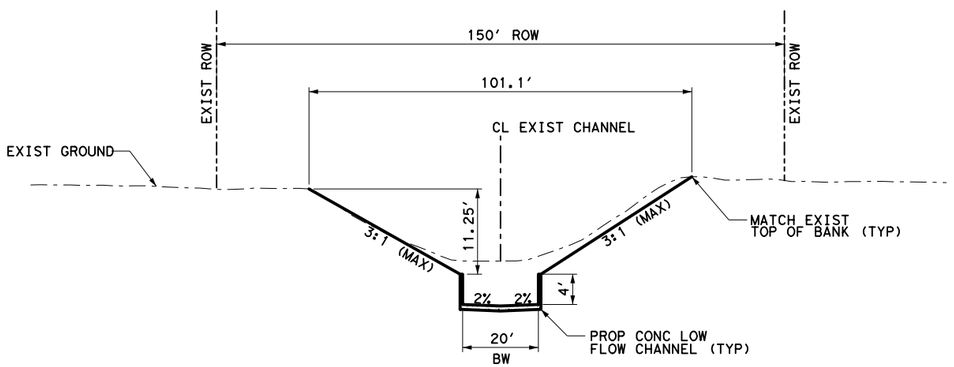


SECTION G-G
SCALE: 1"=40'-H
1"=20'-V



SECTION H-H
SCALE: 1"=40'-H
1"=20'-V

0' 40' 80'
SCALE IN FEET

KINGWOOD DRAINAGE STUDY

HARRIS COUNTY BOND PROGRAM 2018

TAYLOR GULLY OPTION 1. TYPICAL SECTIONS
SHEET 4 OF 4

PREPARED:
CHECKED:
APPROVED:

Gauge ENGINEERING
3200 Wilcrest Drive, Suite 220
Houston, TX 77042
www.GaugeEngineering.com
Texas PE Firm Reg. #F-20017

HARRIS COUNTY FLOOD CONTROL DISTRICT
9900 Northwest Freeway
Houston, Texas 77092

DATE: MARCH 2020
SCALE: 1":40'

EXHIBIT
12-G

INTERIM REVIEW
Not intended for construction, bidding or permit purposes.
Engineer: BRIAN R. WHITNEY
P.E. Serial No.: 81591
Date: MARCH 2020