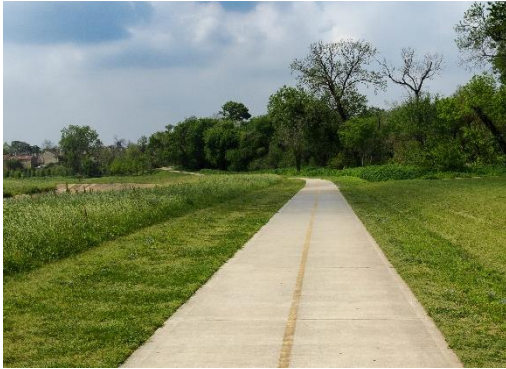




LOWER WHITE OAK BAYOU CHANNEL RESTORATION STUDY

Prepared for:



October 2017

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Prepared for:

Harris County Flood Control District




2017/10/11
FREESE AND NICHOLS, INC.
TEXAS REGISTERED
ENGINEERING FIRM
F-2144

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TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
1.0 INTRODUCTION.....	5
2.0 OVERVIEW OF STUDY APPROACH AND STAKEHOLDER PROCESS	7
3.0 EXISTING CHANNEL CONDITION	9
4.0 DEVELOPMENT OF CONSTRAINTS, OPPORTUNITIES, OBJECTIVES, AND METRICS	13
5.0 IDENTIFICATION OF ALTERNATIVE CHANNEL CONCEPTS	17
5.1 Alternative 1: Low-Impact Alternative	17
5.2 Alternative 2: Expansion North of Channel	18
5.3 Alternative 3: Expansion North and South of Channel.....	18
6.0 EVALUATION AND COMPARISON OF IDENTIFIED ALTERNATIVES.....	21
6.1 Natural Channel Design and Environment.....	21
6.1.1 Geomorphology	21
6.1.2 Water Quality Enhancement.....	24
6.1.3 Habitat Enhancement.....	25
6.2 Engineering and H&H.....	25
6.2.1 Hydraulic Performance and Flood Damage Benefits	25
6.2.2 Project Costs	28
6.2.3 Permitting.....	29
6.2.4 Implementation Timeline	30
6.3 Urban Design.....	30
6.3.1 Enhancement of Recreation and Green Space	30
6.3.2 Population Served.....	31
6.4 Economic Development.....	31
6.4.1 Proximity Benefits to Property Values	32
6.4.2 Acreage Contributing to Increased Economic Benefits.....	32
6.4.3 Recreation Benefits	33
7.0 RESULTS OF PROJECT METRIC EVALUATION AND COMPARISON OF IDENTIFIED ALTERNATIVES	35
7.1 Natural Channel Design and Environment.....	35
7.2 Engineering and H&H.....	36
7.3 Urban Design.....	40
7.4 Economic Development.....	41

8.0	POTENTIAL FOR RESTORATION UPSTREAM OF STUDY AREA	43
9.0	RECOMMENDATIONS AND PATH FORWARD	45
10.0	REFERENCES	49

LIST OF FIGURES

Figure 1:	Typical View of White Oak Bayou Downstream from Taylor Street Bridge	9
Figure 2:	Identified Constraints, Opportunities, Objectives, and Metrics for White Oak Bayou Channel Restoration Study	15
Figure 3:	Dimensions for Geomorphic Channel Cross-Sections	23
Figure 4:	Representative Detention Projects Completed by HCFCD	37

LIST OF TABLES

Table ES-1:	Overview of Features for Baseline and Studied Alternatives	3
Table 1:	Study Participants Represented	7
Table 2:	GIS Data Collected for White Oak Bayou	10
Table 3:	Identified COH CIP Projects in the Project Watershed	27
Table 4:	Natural Channel Design and Environment Metrics for All Alternatives	35
Table 5:	Engineering and H&H Metrics for All Alternatives	36
Table 6:	Project Development Metrics for All Alternatives	38
Table 7:	Urban Design Metrics for All Alternatives	40
Table 8:	Economic Development Metrics for All Alternatives	42
Table 9:	Assumed Width Requirements for Restoration of Upstream Cross-Sections	43
Table 10:	Overview of Features for Studied Alternatives	45

Exhibits

Exhibit 1	Location Map
Exhibit 2	Field Investigation
Exhibit 3	Constraints Map
Exhibit 4	Channel Alternative Alignment #1 Plan View
Exhibit 5	Channel Alternative Alignment #1 Graphic Rendering
Exhibit 6	Channel Alternative Alignment #2 Plan View
Exhibit 7	Channel Alternative Alignment #2 Graphic Rendering
Exhibit 8	Channel Alternative Alignment #3 Plan View
Exhibit 9	Channel Alternative Alignment #3 Graphic Rendering
Exhibit 10	Upstream Implementation Potential

APPENDICES

Appendix A	Conceptual Level Stability Analysis
Appendix B	Flood Risk Management Analysis
Appendix C	Cost Estimation and Project Implementation

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EXECUTIVE SUMMARY

Between the years of 1964 and 1976, the U.S. Army Corps of Engineers (USACE) performed a series of projects to rectify approximately 9.5 miles of White Oak Bayou in order to prevent erosion throughout the main stem that may negatively impact the Houston Ship Channel downstream. The project to clear, straighten, enlarge, and partially line the portion of the bayou below Taylor Street was completed in 1965. The bayou suffers from significant impairment of its water quality (AECOM, 2010). After more than 50 years of service, the concrete channel armoring that was installed is showing signs of age and its deterioration is requiring increased maintenance efforts by the Harris County Flood Control District (HCFCF). At the same time, the channel holds the potential for an enhanced environmental and economic function for the channel through restoration of many of its natural features with no adverse impact to existing flood levels. This study focuses on identifying the potential for restoration of a section of the concrete lined White Oak Bayou downstream of Taylor Street to the end of the concrete lining just upstream of Hogan Street. Three alternatives are presented for creating a more natural, stable channel with enhanced value and the various benefits and costs of each option are considered. Finally, consideration is given to the potential continuation of the project to upstream reaches of White Oak Bayou.

A study team comprised of various stakeholders including the Memorial Heights Redevelopment Authority (MHRA), HCFCF, and the City of Houston (COH) was formed to consider potential alternatives and develop a methodology to assess the values and benefits of each option. Constraints, opportunities, benefits, and metrics were identified in four separate categories: natural channel design and environment, engineering and hydrology/hydraulics, urban design, and economic development. The metrics identified provide insight into the capability of each alternative to provide benefit in terms of flood damage reduction, environmental enhancement, recreational value, and potential socioeconomic uplift.

Alternative 1 considers a limited scale option that constrained development to within the existing HCFCF right-of-way (ROW) and minimized impact to the current trail alignment through the greenway. Alternative 2 is envisioned as a means of expanding the overall project footprint by incorporating green space to the north of the channel and realigning and adding to existing trails. Alternative 3 builds upon Alternative 2 by incorporating the area to the south of the channel that is owned by the Texas Department of Transportation (TxDOT).

Evaluation of the three alternatives demonstrate a somewhat similar benefit for Alternatives 2 and 3 in respect to natural channel design and environment, with both options providing channel width for geomorphic floodplain and adequate room for water quality features adequate for outfalls in the immediate area. These benefits are found to be greatly in excess of those provided by Alternative 1.

Benefits in the engineering and hydrology and hydraulics (H&H) categories are mostly confined to the addition of linear detention associated with each option, with Alternatives 1, 2, and 3 providing progressively more detention due to the progressive increase in excavated volume in each alternative. Benefits to water surface elevations under the one percent flood event are found to be marginal and comparable across the studied alternatives and no alternative was found to worsen these impacts.

Both urban design and economic development impacts are difficult to quantify and require expertise and study beyond the scope of this report. Nevertheless, relative impacts of the alternatives are indicated by the measures chosen.

Urban design benefits are also found to progress incrementally from Alternatives 1 through 3. These benefits are mostly derived from the addition of trails associated with each alternative. However, the proposed trail alignments serve as a recommendation and the actual access and recreational benefits associated with each alternative will vary greatly based on final design. Opportunities exist to provide urban design benefits to Alternatives 1 and 2 that are more comparable to Alternative 3, such as the addition of trail facilities on the south side of the channel to provide additional connectivity and access. In this way, additional recreational and access value can be added to the south side of the channel without dramatic reshaping of the south bank of the channel. Furthermore, this effort may be accomplished through agreement without necessitating the acquisition of property or right-of-way in this area.

Economic development benefit is found to be similar for Alternatives 2 and 3; both of which were greater than Alternative 1 due to the increased acreage contributing to environmental benefits. However, estimated benefits to overall property values, users within proximity, and recreation are found to be similar across all three project options.

Estimated project costs and schedules for all project options are evaluated and considered. In addition, baseline costs for either the incremental or complete replacement of the existing channel lining are analyzed to provide a comparison to the studied alternatives. Estimated costs for all alternatives are found to be higher than the costs for either of the baseline scenarios. However, costs for the three

alternatives are impacted by the uncertainty related to stability of the channel. Further study may limit the need for additional armoring that increased these costs considerably. In addition, the baseline alternatives of retaining the concrete lining lack the other benefits identified in the review of project metrics.

Conditions upstream were also examined to determine the potential for the removal of the concrete lining through this reach as well. A planning level analysis was conducted by reviewing the width of various channel cross-sections through the study reach and comparing those to the available width of channel and green space through other sections of White Oak Bayou. It was found that the entire reach of the channel upstream of Taylor Street and downstream of the I-610 loop may have available space to support some level of soft-engineered channel without concrete lining. However, actual implementation will require the use of property outside of the existing channel footprint and actual potential will be dependent on local characteristics in addition to the consideration of cross-section width evaluated in this study.

Comprehensive results of all options including the baseline replacement of the existing concrete lining are shown below in *Table ES-1*. Although there are potentially greater costs related to the implementation of the proposed alternatives, the added benefits in other focus areas provide opportunities beyond the current channel configuration which are not replicated by the baseline option to replace the concrete lining as it is today. Furthermore, the costs for alternatives may be reduced in subsequent phases of study due to additional information related to soil conditions and the need for substantial armoring in the modified channel.

Table ES-1: Overview of Features for Baseline and Studied Alternatives

Focus Area	Baseline Replacement	Alternative		
		1 (Limited Scale)	2 (North)	3 (North/South)
Natural Channel Design and Environment	-	●	● ● ●	● ● ●
Engineering and H&H	-	●	● ●	● ● ●
Urban Design	-	●	● ●	● ● ●
Economic Development	-	● ●	● ● ●	● ● ●
Project Cost and Development	△	△ △	△ △ △	△ △ △ △

● – Identified benefits from restoration

△ – Identified obstacles to restoration

This study represents a first step to identify potential benefits and issues to consider in implementation of the channel restoration project. Future efforts should include:

- Identify Stakeholders to Participate in Development of the Project,
- Revisit Objectives and Metrics Based on This Study and Stakeholder Group,
- Identify the Realistic Footprint of the Project,
- Conduct Preliminary Engineering and Planning, and
- Project Design, Permitting, and Execution.

1.0 INTRODUCTION

White Oak Bayou (Harris County Flood Control District [HCFCF] Unit E100-00-00) is a significant channel in Harris County and a tributary to Buffalo Bayou and the Houston Ship Channel. Although originally a natural channel with numerous meanders for habitat and other environmental functions, the bayou was channelized by the U.S. Army Corps of Engineers (USACE) between 1964 and 1976 in an effort to prevent erosion along the main stem that may adversely affect the Ship Channel downstream. This channelization, including clearing, straightening, enlarging, and partially lining the bayou, occurred between a point upstream of Hogan Street near the I-10/I-45 interchange the confluence with Cole Creek (HCFCF Unit E117-00-00) upstream of the I-610 loop. Over time, this channel has required maintenance and occasional replacement of the concrete panels lining it in order to maintain the integrity of the structure due to the impacts of hydrostatic uplift. These repairs are made on an as-needed basis by HCFCF and have increased over time as the channel reaches the end of its design life. *Exhibit 1* illustrates the alignment of White Oak Bayou within the I-610 loop.

The Memorial Heights Reinvestment Authority (MHRA) is a local government authority financed through Tax Increment Reinvestment Zone 5 (TIRZ 5), within defined boundaries in the City of Houston and is charged with creating and supporting an environment attractive to private investment in its area by implementing public infrastructure improvements that will result in the long-term stability and viability of the area. These improvements may include, among others, creating pedestrian-safe environments, public open space, hike and bike trails, rehabilitation of cultural and public facilities, and drainage and detention facilities. The extent of the MHRA within the White Oak Bayou project area is shown in *Exhibit 1*.

A critical component of MHRA's work has been the optimal use of lands with multiple uses such as White Oak Bayou. In corridors such as these, traditional purposes such as flood control and drainage can be preserved without detriment while simultaneously enhancing recreation and outdoor aesthetics. The MHRA, in cooperation with HCFCF developed a scope of work to explore channel restoration concepts on lower White Oak Bayou downstream of Taylor Street to Hogan Street, including the terminus of the concrete-lined extent of the bayou. This study reach represents approximately 1.0 mile of some 9.5 miles of concrete-lined channel along White Oak Bayou. Freese and Nichols, Inc. (FNI) was retained to provide professional services in conducting the channel restoration study.

Numerous studies have demonstrated the potential benefit from channel restoration projects and several of these have focused on the vibrant bayou system of the Houston area. Such research has contributed

to efforts by the Bayou Greenways Initiative (BGI) to provide 80 miles of urban trails through the extensive channels along Brays, Buffalo, Greens, Halls, Hunting, and Sims Bayous as well as Clear and Cypress Creeks. White Oak Bayou has also benefited from this initiative with the addition of trails that link users to other natural and semi-natural spaces throughout the Houston area. A study by Crompton (2012) has estimated benefits to the community ranging from approximately \$100- to \$140-million annually. A paper by Jones (2017) focuses specifically on the restoration of White Oak Bayou and identifies a range of benefits from \$2.9-million to \$3.7-million annually.

Similar improvements to green space have recently occurred within Buffalo Bayou Park along the Buffalo Bayou corridor and near the White Oak Bayou study site. In this section west of downtown, improvements have been made to enhance the recreational value of the area which has, in turn, provided uplift to the immediate area and outdoor recreation potential for both nearby residents and the greater-Houston area. Although specific uplift is difficult to assess for myriad reasons, a review of assessed, single- and multi-family residential values within ¼-mile of the park from 2012 when the project began and 2015 when the park opened demonstrate a 66 percent increase in overall value. From 2012, these values have increased 100 percent as of 2017 based on a review of data from the Harris County Appraisal District (HCAD).

This study aims to take another look at the potential for transforming lower White Oak Bayou, less from a direction of economic benefit and more from a standpoint of implementation. Although metrics will be evaluated to identify and weigh specific advantages of various alternatives for channel restoration, this study focuses on the means by which the concept can be implemented and also serves as a transition into a process whereby stakeholders may be identified and engaged to find common goals for a constructed project.

2.0 OVERVIEW OF STUDY APPROACH AND STAKEHOLDER PROCESS

The study is intended to build upon existing evaluations by presenting a fresh look at options to convert the existing channel to a more natural, ecologically and functionally rich system. This will involve several distinct efforts:

- Data collection and organization;
- Development of project constraints, opportunities, objectives, and metrics;
- Identification of alternative channel concepts;
- Evaluation and Comparison of alternative channel concepts; and
- Recommendations for implementation and further study.

In addition, this study will also utilize information gathered in the study reach below Taylor Street to consider the implementation of this concept upstream.

Execution of the study was performed as an interactive process among representatives from the MHRA, HCFCD, FNI and departments of the City of Houston (COH). The project included monthly status updates to review progress and guide the study as it evolved from the original Scope of Work in response to the information gathered during and gained from the project. Participants in the process included individuals representing the backgrounds shown in *Table 1*.

Table 1: Study Participants Represented

Participant	Background
Memorial-Heights Redevelopment Authority	Economic/Urban Development
	Leadership
Harris County Flood Control District (HCFCD)	Communications
	Flood Management
	Operations
	Precinct Coordination
City of Houston	Floodplain Administration
	Public Works and Engineering
	Resiliency
Freese and Nichols, Inc.	Environmental Services
	Resiliency
	Stormwater
	Urban Planning

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3.0 EXISTING CHANNEL CONDITION

The project study area consists of approximately 6,000 linear feet of channel from Hogan Street upstream to Taylor street. Within this reach, approximately 5,400 linear feet consist of concrete-lined trapezoidal channel. This section consists of an approximate 12-ft bottom width pilot channel with 1.5H:1V slopes increasing to an 8-ft bench on either side. From that point, the sides slope extends upward at a 2H:1V slope until the panels tie into the soil bank. It is this armoring that is targeted for removal through measures contained in the various alternatives considered in this study. Along the study reach, numerous outfalls discharge stormwater from systems within the area or drain backslope swales along the channel corridor. A typical view of White Oak Bayou can be seen in *Figure 1*.



Figure 1: Typical View of White Oak Bayou Downstream from Taylor Street Bridge

A review of property parcels in the project study area illustrates a significant tract of land that is not currently mapped by Harris County. It is understood through outside investigation that this property is owned by the Texas Department of Transportation (TxDOT) and has historically been used for the disposal of spoil material related to the channel rectification by USACE. Future cooperative efforts with TxDOT could potentially benefit the White Oak Bayou channel restoration if this property were included in the overall master plan. Potential benefits may include the opportunity to incorporate the land into accessible green space and the addition of linear detention in the channel through the removal of material that has been placed there. This tract is illustrated in *Exhibit 1*.

Existing spatial data for the study area was compiled into a comprehensive Geographic Information System (GIS) for White Oak Bayou. This data included the information listed in *Table 2*.

Table 2: GIS Data Collected for White Oak Bayou

Source	Dataset
City of Houston	Houston Greenway trails
	TIRZ boundaries
Harris County Appraisal District	Parcel data and appraised property values
Harris County Flood Control District	2016 aerial imagery
	2008 LiDAR
	HCFCF channel layer
	HCFCF right-of-way
	Historic aerial imagery
	National Wetlands Inventory wetlands
	Potential hazardous, toxic or radioactive waste
	Storm sewer lines
	COH Water lines
Texas Parks and Wildlife	Ecological Mapping System of Texas (EMST)
Texas Railroad Commission	Oil and Gas Wells
	Pipelines

In addition to desktop data sources that could be readily collected, field investigations were performed to gather additional information about the study area. This included the detailed identification of outfalls in the study reach in order to augment data available from the stormwater layer of the GIS. Field investigation also aided in the identification of potential wetland features and verification of the EMST dataset of land cover classes. A summary of information collected from field investigation is shown in *Exhibit 2*.

An ecological investigation of the study area identified information related to the stream, wetlands, open water bodies, and plant and animal species present. White Oak Bayou was found to be a heavily altered corridor as a result of the concrete lining and channelization as described, although some trees remain in the peripheral areas. Forested and emergent wetlands are present along portions of the project area, and are illustrated in *Exhibit 2*. These areas are made up of predominantly forested wetlands on both the north and south sides of the bayou. A mixture of interconnected forested and emergent wetlands was also found to be located on the south side of the channel. A small area of open water was present in each

of the two wetlands located on the north side of the bayou, although the depths of these waters likely does not exceed six feet. Five species are listed as threatened or endangered within Harris County. These include the interior least tern (*Sterna antillarum*), piping plover (*Charadrius melodus*), red knot (*Calidris canutus rufa*), West Indian manatee (*Trichechus manatus*), and Texas prairie-dawn (*Hymenoxys texana*). None of these species or their habitats were observed within the project area. The least tern, piping plover and red knot must only be considered for wind projects and would, therefore, not represent an issue for a project of this nature. As such, no adverse impacts to federally listed species or their habitats would be anticipated as a result of a project in the study area.

Much of the habitat within the project area was found to be greatly degraded. The bayou has been channelized and paved, although several species of fish were noted including carp (*Cyprinus carpio*), gar (*Lepisosteus spp.*) and striped mullet (*Mugil cephalus*). The terrestrial environment is largely mowed floodway and consists of invasive herbaceous species such as Johnsongrass (*Sorghum halapense*), Bermudagrass (*Cynodon dactylon*), and annual rye (*Lolium perenne*) along with native species such as firewheel (*Gaillardia pulchella*), frogfruit (*Phyla incisa*), white clover (*Trifolium repens*) and ragweed (*Ambrosia trifida*). Wooded areas exist along the periphery of the project area. These areas are fragmented, but serve as islands of habitat for woodland species in the area. Species present consist of sycamore (*Platanus occidentalis*), ash (*Fraxinus spp.*), water oak (*Quercus nigra*) and Shumard oak (*Q. shumardii*). Scattered Chinese tallow trees (*Triadica sebifera*) and Chinaberry (*Melia azedarach*) were noted in the wooded areas.

As part of the investigation, a review of available soil boring data was performed to estimate the characteristics of material within the study area. For this planning-level analysis, data was received from TxDOT detailing the seven boring locations that are roughly within the vicinity of the study reach. This limited information, focused primarily on the western portion of the study area, provided some information necessary to comprehend the stratigraphy of the area. Through the application of generalized parameters, a simple slope stability analysis was performed in order to confirm the feasibility of a proposed 3H:1V slope within the corridor. This detailed analysis is contained in *Appendix A* and confirms the likely potential to utilize 3H:1V slopes in the study reach. Although this analysis serves as a preliminary evaluation of constructability for the channel slopes, more detailed soil analysis is required for development of the project and confirmation of this planning-level concept.

The area around the study reach is within proximity of the proposed expansion of IH-45 which may constrain future designs of any proposed project. However, it is the intent of this preliminary study to provide feasible alternatives that are compatible with future alignments of the roadway while still achieving the goals of the project. The specific alignments of IH-45 will be considered in later phases and design as those specifics become clear.

4.0 DEVELOPMENT OF CONSTRAINTS, OPPORTUNITIES, OBJECTIVES, AND METRICS

The initial phase of the study focused on data collection and the preparatory effort of identifying constraints, opportunities, objectives, and metrics for the project. This process was conducted in order to provide for goals to be achieved by the project and identify means by which to judge the effectiveness of any proposed project alternatives. Consideration was given to four distinct focus areas:

- Natural Channel Design and Environment
- Engineering and Hydrology/Hydraulics (H&H)
- Urban Design
- Economic Development

Once these four Focus Areas were considered, the group identified the following as they applied to each of the Focus Areas:

- Constraints: Limitations or obstacles to the successful implementation of the project;
- Opportunities: Prospects for leveraging existing features, initiatives, and partnerships or the ability to address previously identified issues through project implementation;
- Objectives: High-level goals to work within identified constraints while capitalizing on opportunities;
- Metrics: Specific measures by which the attainment of goals can be evaluated, documented, and compared.

The Constraints, Opportunities, Objectives, and Metrics identified in this phase of the process are shown in *Figure 2*. A map of the study area along with constraints that could be located geographically is shown in *Exhibit 3*.

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	Constraints	Opportunities	Objectives/Metrics	
Natural Channel Design and Environment	- Lateral confinement limits of plan form. - Steep slopes along both sides of the bayou limits potential enhancements. - Valley slope and length.	- Improve channel stability. - Reduce sediment load from bank erosion. - Create floodplain sediment sinks. - Water quality improvement. - Reduce channel maintenance issues. - Enhance environmental quality and wildlife habitat. - Removal of exotic species and reestablishment of native species. - Capitalize on landscaped areas to reduce stormwater runoff help improve water quality and create a “greener” bayou.	- Provide stable channel configuration. - Provide stormwater quality enhancement. - Provide enhanced habitat features.	- Acreage of geomorphic floodplain provided. - Acreage of stormwater quality features added. - Acres of habitat added.
Engineering and H&H	- Removal of concrete lining may increase the potential for flood damages if not mitigated through other means. - Numerous road way and utility crossings of channel. - Existing park, trail, and recreational facilities limit development for flood protection. - Existing Hazardous, Toxic, Radioactive Waste projects, pipelines, and utilities present further confinement to project extents. - Navigability issues related to permitting.	- Decrease water surface elevations. - Improve local drainage. - Optimize floodplain storage and attenuation. - Protect critical infrastructure, facilities. - Explore opportunities to partner on mitigation projects with other entities. - Removal of 1% floodplain from homes.	- Reduce water surface elevations and increase floodplain storage. - Protect infrastructure and access .	- Acre-feet of linear detention added. - Population with reduction to likelihood of flooding - Number of structures with reduction to likelihood of flooding. - Average reduction in one percent water surface elevation within each major reach. - Approximate number of critical facilities and access routes benefited.
Urban Design	- High land values along the bayou present limitations. - Flood conveyance interests may compete with improved connectivity, recreational opportunities, and other potential enhancements. - Coordination needed with TxDOT to ensure compatibility with future potential projects.	- Enhance the character of parks and increase recreation through the use of native plants, signage, and other site amenities. - Utilize existing trails and projects along lower White Oak Bayou to enhance connectivity among projects and to surrounding community, environment, and infrastructure. - Roadway crossings and other features may provide enhanced visibility of the bayou. - Identify low impact development/green infrastructure improvements. - Increased access may improve issues with trash accumulation in some areas. - Develop designs that do not preclude future use. - Protect and provide means of educating the community about historic resources.	Enhance quality of life by integrating environmental sustainability and enhanced community character with flood damage reduction elements.	- Acres of concrete replaced with green space. - Linear feet of connected trails added. - Acres of additional green space made accessible. - Increased population within proximity.
Economic Development	- Limited undeveloped and undevelopable land in which to work without affecting economics. - Numerous avoidance issues related to historic resources, oil and gas facilities, and waste sites.	- Create reaches which contribute to economic development and sense of place. - Identify public/private partnerships	Enhance economic development by integrating environmental and community features with flood damage reduction elements.	- Number of users within proximity contributing to recreational use value, user health and transportation benefit. - Proximity benefits contributing to increased property values. - Acreage contributing to increased environmental benefits. - Increase in unit day value for recreation.

Figure 2: Identified Constraints, Opportunities, Objectives, and Metrics for White Oak Bayou Channel Restoration Study

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5.0 IDENTIFICATION OF ALTERNATIVE CHANNEL CONCEPTS

Three alternative concepts for the restored White Oak Bayou channel were considered for the study area. These concepts were carefully selected based on existing conditions and constraints identified at the site. Where possible, existing right-of-way (ROW) was utilized to minimize cost and necessary coordination for project implementation. These alternatives serve as options beyond the existing channel configuration. This baseline option may be maintained by HCFCFCD with ongoing replacement of failing concrete sections or replaced with a design identical to the current configuration.

5.1 ALTERNATIVE 1: LIMITED SCALE ALTERNATIVE

Alternative 1 was formulated in order to provide a limited scale option that achieved the goals of removing the concrete lining throughout the majority of the study reach while remaining within existing HCFCFCD ROW. Additionally, this alternative avoided adverse impacts to existing trail facilities. Intermediate benches in the channel side slope were added to allow for the replacement of trails at their existing location and current elevation where possible. Flow conditions from the current effective model were used along with HCFCFCD guidance to size a geomorphic channel. Where possible, a geomorphic floodplain was provided just above the channel bottom, although this area was not of adequate extent in this alternative to provide for stormwater quality features. No changes were made at bridge crossings in an effort to limit the cost of developing the project. An overview of Alternative 1 can be found in *Exhibit 4*. This alternative would avoid identified wetland locations within the project area. *Exhibit 5* provides a rendered view of the channel looking downstream from a point below Taylor Street.

Results of the preliminary geotechnical analysis suggested that a 3H:1V channel slope could be achieved and this guideline was used in the further refinement of the Alternative 1 configuration. However, due to the limited nature of information available concerning soil properties and sediment regime, it was assumed that the channel would be constructed with armoring features to protect channel slopes from erosion. This soft armoring features would include a combination of geotextile material, riprap, and other hard features interbedded with vegetation to provide a natural appearance. The sediment regime, or the amount of sediment conveyed by White Oak Bayou, affects both bed and bank erosion. When there is less sediment available than the transport capacity of the stream, the system is considered sediment-supply limited and there is excess energy. This excess energy often causes stream bed and bank erosion. Assuming the study reach of White Oak Bayou is sediment-supply limited because of the upstream concrete-lined sections, bed and bank erosion could occur if protective measures are not taken. A soft-

engineered option would be selected for this armoring in order to achieve a more natural aesthetic while still maintaining a stable channel alignment. Concrete armoring would be retained under bridge crossings as their geometry would not be modified.

The majority of trail features were retained in place wherever possible due to the use of intermediate benches. In other locations, trails would be replaced in the same location but at somewhat adjusted elevations.

5.2 ALTERNATIVE 2: EXPANSION NORTH OF CHANNEL

Alternative 2 expanded upon the concept in Alternative 1 by taking in additional space to the north of the current White Oak Bayou alignment. In addition to achieving the goal of removing the majority of the concrete lining through the study reach, this alternative expands the channel to incorporate area within the City of Houston's White Oak Parkway between Taylor Street and Houston Avenue. Below Houston Avenue, adjustments are made to the alignment to utilize existing HCFCFCD ROW but the channel does not further intrude upon Freed Park. *Exhibit 6* provides an overview of Alternative 2. This alternative would absorb the wetlands identified to the north of the channel but the large intermediate bench upstream of Houston Avenue can be configured in such a way to preserve this feature. *Exhibit 7* provides a rendered view of the channel looking downstream from a point below Taylor Street.

By utilizing the expanded width of the channel to the north, the larger geomorphic floodplain in Alternative 2 is able to accommodate water quality features sized appropriately for the major outfalls identified between Taylor Street and the I-10 and I-45 interchange. As with Alternative 1, limited information concerning soil stability suggests a conservative assumption of soft armoring throughout the channel until further data can support the removal of these features. Concrete lining will be retained at bridge crossings as these cross-sections will not be modified.

Existing trail features were enhanced in this alternative, more fully utilizing the space to the north of the channel and providing access to green space at a range of elevations in order to provide access through most channel flow conditions.

5.3 ALTERNATIVE 3: EXPANSION NORTH AND SOUTH OF CHANNEL

Alternative 3 was developed to expand upon Alternative 2 by also incorporating the TxDOT property to the south of the existing channel. This parcel has an uncharacteristically high elevation relative to

surrounding project area and, therefore, has great potential for enhancing linear detention through excavation and offsite disposal of material. Alternative 3 adds an intermediate bench to the south side of the channel which enhances slope stability while also providing green space which is accessible during low and moderate flow conditions. The configuration of Alternative 3 is shown in *Exhibit 8*. *Exhibit 9* provides a rendered view of the channel looking downstream from a point below Taylor Street.

Although additional water quality features were not required, the configuration of these features were realigned for Alternative 3 to provide more accessible green space in the channel bottom. As in other alternatives, soft armoring is anticipated throughout the study reach with the exception of concrete lining that will be required at bridge crossings. Further study may reduce this need for armoring, should flow and soil characteristics allow.

The incorporation of the TxDOT property into the project allowed for the establishment of trails to the south side of the channel and a significant increase of accessible green space. At this stage of study, the trails are expected to provide cross-channel access at Taylor Street and the existing crossing near Hogan Street at the upstream and downstream extents of the study area, respectively. Access to either side of the channel may also be provided through the development of additional crossings, although the potential for impacts to flood flows would have to be considered along with this possibility.

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6.0 EVALUATION AND COMPARISON OF IDENTIFIED ALTERNATIVES

Each identified alternative was studied in a parallel process in order to quantify the metrics for each option. This section summarizes the methodology and approach employed for this comparison. Additional information can also be found in Appendices B and C that provide additional information related to the study of hydraulic performance, flood damage benefits, and project costs and implementation.

6.1 NATURAL CHANNEL DESIGN AND ENVIRONMENT

Natural stable channel design is an integral part of the restoration of White Oak Bayou. In addition to providing aesthetic benefit to the study reach by allowing for the removal of the concrete lining, these techniques provide for a stable channel without concrete reinforcement of slopes and will enable the development of habitat and water quality features within the bottom of the channel. For this reason, geomorphology, water quality enhancement, and habitat enhancement will be discussed collectively in this section.

6.1.1 Geomorphology

Fluvial geomorphology, or simply geomorphology as it is referred to in this study, relates to the interaction of streams and the landscapes through which they flow. This consideration is essential, given the tendency of natural channels to meander under unstable conditions, in order to provide a robust design for lower White Oak Bayou. One of the primary goals of the initial channelization of White Oak Bayou was the need to provide a stable channel section that could accommodate high flow rates associated with a highly urbanized watershed. Through the use of geomorphologic design, this study intends to provide a comparable solution that does not sacrifice aesthetic, habitat, and water quality functions of the stream corridor. In total, such a design may also provide:

- Water quality improvement
- Reduction in flood discharge velocities
- Aquatic habitat and improved fish passage
- Riparian habitat and corridors for wildlife movement
- Recreational and educational amenities to the community
- Increased adjacent property values

- Floodplain sediment sinks
- “Greener” bayou

The geomorphologic design of the proposed channel alternatives was accomplished within the boundaries of the constraints set forth for each option. Consideration was also given to the performance of the stream in conveying flood flows. The one-percent event was modeled in HEC-RAS during the development of the overall geomorphic channel design in order to prevent any unintended impacts that would be associated with a rise in the water surface elevations under this flow condition.

Geomorphic design of the channel includes the sizing of several components of the channel, including riffle width and depth, and pool width and depth. These elements were specified based primarily upon the contributing drainage areas of White Oak Bayou at various points in the channel upstream and downstream of the confluence with Little White Oak Bayou. These drainage areas were used along with the regional curves presented in *Natural Stable Channel Design and Best Management Practices Guidance Manual for Corridor Channels* prepared by HCFCF to determine the top and bottom riffle depths as well as the mean and maximum riffle depths. These riffle depth dimensions were then used as input to hydraulic relationships values to determine pool dimensions. These values are shown below in *Figure 3*.

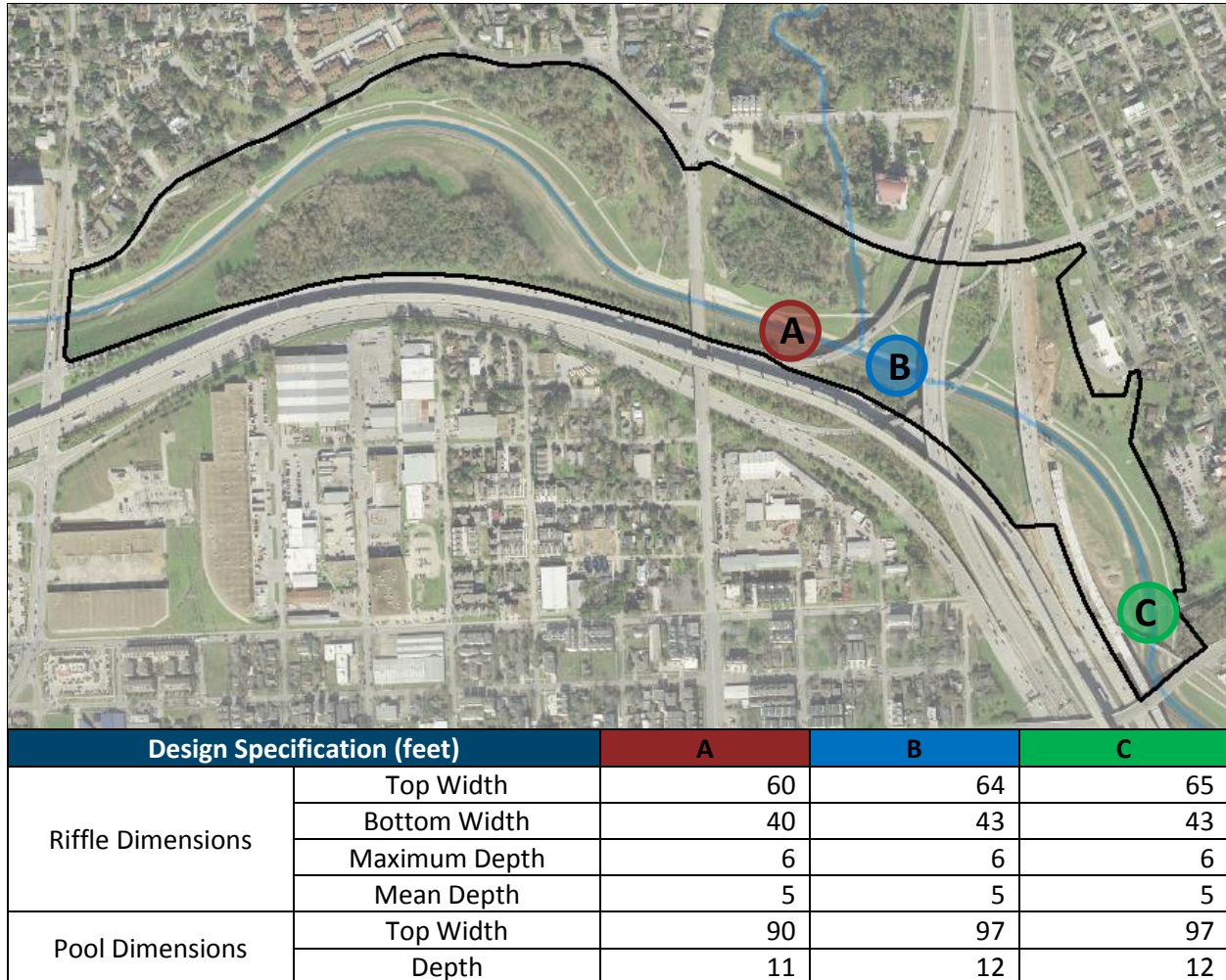


Figure 3: Dimensions for Geomorphic Channel Cross-Sections

In addition to the sizing of geomorphic channel components, consideration was also given to the sinuosity of the channel. As existing channel banks were removed to provide for increased conveyance area and inline volume within the corridor, the geomorphic channel was aligned in order to provide for a stable channel configuration while still providing a geomorphic floodplain and higher, intermediate benches throughout the study reach. These alignments are apparent in *Exhibits 4 through 6*.

In order to quantify and compare the degree to which a stable, geomorphic channel has been implemented, the total area within the study area dedicated to these features will be evaluated. This will include a total acreage of channel bottom and geomorphic floodplain present in each alternative.

6.1.2 Water Quality Enhancement

Water quality enhancement will be provided by the potential restoration of White Oak Bayou through two separate means. One series of benefits will originate from the development of water quality features adjacent to the channel while the actual restoration of the stream channel will provide different water quality services.

The development of water quality Best Management Practices (BMPs) in the overbank areas of the geomorphic channel will provide space for the treatment of inflows from storm sewer outfalls that currently discharge directly to White Oak Bayou. These wetland features may filter runoff entering the bayou, and reduce erosion at points of discharge.

Water quality features were sized for each outfall based on the calculated 10-year discharge, the 90 percent rainfall depth, and the area and percent impervious cover of the contributing watershed, based on the HEC-HMS model for White Oak Bayou augmented by review of storm sewer GIS and field-collected data. Acreages of the various components were divided among the deep pool, wet vegetated shelf, and dry vegetated shelf based on percentages of 25, 40, and 35 percent, respectively. For Alternatives 2 and 3, the identified acreage of water quality features could be accommodated within the geomorphic floodplain of the concepts. No features could be added to Alternative 1 due to the limited footprint of the alternative.

Conversion of the currently concrete-lined channel to a more natural configuration will also provide benefits to water quality through:

- Removal, uptake, and filtration of organic and inorganic nutrients by wetland biota,
- Processing of organic waste, and
- Diluting pollutant concentrations.

Although White Oak Bayou has historically shown high levels of bacteria within sampling data, limited information is available regarding sediment loading for White Oak Bayou. At this phase of study, it is difficult to identify specific water quality benefits resulting from the removal of the concrete lining and the installation of water quality features. This comparison will be made across all alternatives by comparing the total acreage of water quality features including deep pools and wet and dry shelves. Before and after testing of water quality impacts should be considered should a project be developed in order to more fully assess the potential of similar projects in the future.

6.1.3 Habitat Enhancement

Although any modification to the White Oak Bayou channel configuration would inherently necessitate changes to the existing land profile which may have impacts to the existing, low-value habitat, the removal of the concrete lining and implementation of water quality features will also provide habitat enhancement. These benefits include:

- Providing critical habitat during drought conditions, and
- Promoting biodiversity by creating habitat for mammals, amphibians, reptiles, birds, and insects.

To quantify the potential additional habitat added by the three alternatives, the total acreage of habitat added through the soft channel bottom, enhanced through the removal of concrete, plus the acreage of water quality wetlands were assessed for each alternative. It should be noted that these areas represent minimal increases in habitat compared to the potential for the overall site. Further enhancement may also be derived through the planting of native species in the redeveloped green spaces that will provide enhanced habitat over and beyond what is currently located at the site. A benefit of these strategies is that their cost of implementation is relatively low and can be developed alongside the planning of more costly aspects of the project. These specific practices will be identified during further developmental phases of the project.

6.2 ENGINEERING AND H&H

6.2.1 Hydraulic Performance and Flood Damage Benefits

Due to the sensitive nature of flooding within the White Oak Bayou corridor, ensuring no adverse impacts to existing flooding conditions was identified as a core goal of this study. It was recognized that no potential alternative that would increase water surface elevations under the one-percent flood condition could be considered a viable alternative. All three alternative channel configurations were modeled in HEC-RAS to determine the overall impact on water surface resulting from the increased channel roughness resulting from a grass-lined, vegetated channel as compared to the existing hybrid concrete/grass-lined section. Detailed information related to this analysis can be found in *Appendix B* of this report.

Several metrics related to hydraulics and flood performance were identified for the purpose of quantifying and comparing the benefits of each alternative. The metrics extracted from the hydraulic analysis include the following:

- Acre-feet of linear detention added,
- Population with reduction to likelihood of flooding,
- Number of structures with reduction to likelihood of flooding,
- Average reduction in one percent water surface elevation within each major reach, and
- Approximate number of critical facilities and access routes protected.

The acre-feet of linear detention added refers to the additional volume of flood storage present within the system after implementation of a project alternative. Although the alternatives resulted in only minor reductions in water surface elevations under the flood condition, the excavation of material from the project area resulted in additional flood storage being made available. This linear detention was calculated based on the floodplain volume within the study reach below the resultant water surface elevations from HEC-RAS and above the modified land surface. These volumes were compared against the current volumes using output from the base, unmodified hydraulic model and existing LiDAR elevations.

The benefit of linear detention, especially newly added floodplain volume located within a developed, urban area, is the potential for use as a regional detention solution for projects being developed within the watershed. A basic analysis of existing projects identified within the COH Capital Improvement Plan (CIP) was conducted to locate projects within the project area that could utilize detention created within the study reach. This list is provided to serve as a list of representative projects that could possibly utilize regional detention in White Oak Bayou and is not exhaustive of all projects that may be developed along with this regional initiative. The identified projects are shown below in *Table 3*.

Table 3: Identified COH CIP Projects in the Project Watershed

Reach/Location	Project Name/Description	Project Category	CIP Number
Hogan to Taylor (study reach)	Lorraine Paving and Drainage: West to Jensen Dr	Street	N-100028-0001
Hogan to Taylor (study reach)	Lorraine Paving and Drainage: Houston Ave to Hardy	Street	N-100028-0001
Hogan to Taylor (study reach)	Fulton Street Paving and Drainage: Quitman to Hogan Street	Street	N-000818-0001
Hogan to Taylor (study reach)	NSR 460: Storm water Improvements - Sub Project 1	Street	N-000389-0001
Hogan to Taylor (study reach)	NSR 460: Storm water Improvements - Sub Project 2	Street	N-000389-0002
Studemont to S. Heights	Houston Heights, John Brashear and Memorial Heights Paving and Drainage Project	Drainage	N-210001-0001
E. Shepherd to TC Jester	TC Jester Paving and Drainage: Washington to IH-10	Street	N-100002-0001

The extent of flooding for each project alternative was determined based on an analysis of floodplain extents as well as estimated structure elevations within the project area. An area from the downstream limit of the project reach up to the I-610 loop was examined. For each parcel identified to be within the 100-year floodplain, the mean elevation for the parcel was calculated based on HCAD extents and LiDAR. These elevations were compared to the water surface elevations generated by HEC-RAS for the baseline, existing condition as well as each proposed alternative. Parcels mapped with a level of inundation greater than 1.5-feet above the mean parcel elevation were considered to be “likely inundated.” Parcels with a level of inundation greater than 0.0-feet but less than 1.5-feet were considered “possibly inundated.” Any other parcels were considered not inundated. This approach provides consideration for the actual finished floor elevations of structures in the floodplain without detailed data for each site. This data was used to identify the inundation level of both residential and commercial parcels across all alternatives and also approximate the benefited population due to reduced inundation of residential parcels through the use of Census-derived information.

Reductions in water surface elevations were compared from the study reach to I-610. A simple comparison to the existing baseline model results was performed for the following representative reaches:

- Hogan to Taylor (study reach),

- Taylor to Studemont,
- Studemont to South Heights, South Heights to East Shepherd,
- East Shepherd to TC Jester,
- TC Jester to West 18th, and
- West 18th to I-610.

Finally, inundation of critical facilities and access routes was considered. The project GIS was used to locate educational institutions, government offices, and medical facilities within the project area as well as roadway intersections. The number of facilities impacted under each scenario was compared to provide an additional metric for the alternatives analysis.

6.2.2 Project Costs

A variety of project costs were developed as part of this analysis representing both multiple alternative and baseline Opinions of Probable Construction Costs (OPCCs). The following estimates were prepared for comparison of each potential option:

- **Baseline – Ongoing Maintenance:** This option considers the ongoing maintenance of the existing concrete lining, including the replacement of failing concrete panels as necessary. These costs are based on documented HCFCF costs and are applied to represent the total replacement of the study reach over a 50-year period assuming an inflation rate of two percent and total costs adjusted to a present-value cost.
- **Baseline – In-Kind Replacement:** This option provides an estimate of the complete replacement of the concrete lining within the study reach. Costs were developed from recent HCFCF bid tabs as well as selected values based on FNI experience.
- **Alternatives 1-3:** These options provide OPCCs for all three alternatives proposed within this study for comparison to the developed baselines.

Operations and Maintenance (O&M) costs for all baseline and alternative concepts were developed to provide additional comparison across options. These costs were developed to include the following items:

- Turf establishment for areas of sparse grass coverage,
- Mowing operations,
- Application of herbicide to control vegetative overgrowth,

- Planting and,
- Selective clearing.

It should be noted that these costs do not include any significant repair and rehabilitation of the concrete lining presented in the baseline cost estimates. For the Ongoing Maintenance case, it is assumed that these costs are included in the construction costs for panel replacement. For the In-Kind Replacement option, it is assumed that the complete replacement of the concrete lining will prevent the need for any significant maintenance of this armoring over a comparable 50-year period.

Detailed information related to the development of all project costs can be found in *Appendix C* of this report.

6.2.3 Permitting

Development of any proposed alternative will require the application for and securing of a Section 408 permit through USACE, which pertains to modifications to federally authorized civil works projects. Additionally, based on the results of the environmental survey, the proposed project would result in the discharge of fill material into waters/navigable waters of the U.S. and is therefore subject to Section 404/Section 10 permit regulations.

Because the project would remove the concrete lining in the channel and restore some degree of natural function, as well as enhance adjoining areas, the project may be able to be authorized under Nationwide Permit (NWP) 27, Aquatic Habitat Restoration, Establishment, and Enhancement Activities. Compensatory mitigation is not required for projects authorized under this NWP since these projects must result in net increases in ecological function.

Construction of the proposed channel modifications should comply with the Section 401 Water Quality Certification Conditions for NWPs that have been issued by the Texas Commission on Environmental Quality (TCEQ). These conditions should be incorporated into the contractor documents along with the permit terms and conditions. It should be noted in the plans and specifications that the construction contractor should implement Best Management Practices as specified by the TCEQ for Water Quality Certifications.

6.2.4 Implementation Timeline

Implementation for all alternatives as well as the baseline lining replacement were considered. Key components including field assessment such as survey and geotechnical work, design, permitting, and construction were considered for each individual project concept and assigned an estimated duration of project months.

6.3 URBAN DESIGN

Urban design metrics relate to the enhancement of public space and accessibility of resources developed or expanded by the proposed alternatives. These evaluations of project potential indicate the quality of life values added in addition to the benefits brought about in flood damage reduction and habitat enhancement.

6.3.1 Enhancement of Recreation and Green Space

The proposed project alternatives make use of green space adjacent to White Oak Bayou to provide multi-use areas that provide flood damage reduction while increasing accessibility to the neighboring community. Trails are already a significant component of the existing area and were a key component of this study due to their low cost and ease of implementation. Trail replacements and enhancements were considered for all three alternatives in this study. Although significant space is made available for public use, additional, active recreation amenities were not identified at this time, as the implementation of these projects would be subject to the identification of specific sponsors at later phases of the project and could vary widely based on community preferences and funding.

Trail elements that were expected to be impacted in Alternative 1 were restored in order to preserve the existing length of trail facilities. Wherever possible, this limited scale alternative also retained trails at their existing locations and elevations through the use of intermediate benches in the channel cross-section. Trails were added to Alternatives 2 and 3 in order to make use of the expanded footprint of the concepts. These trails provided access at all elevations including access to intermediate benches and the geomorphic floodplain which maximize access for a wide range of channel flow conditions. The alignments of all trail facilities are described in *Exhibits 4 through 6*.

Three metrics related to the enhancement of green space were developed:

- Acres of concrete replaced with green space,

- Linear feet of connected trails added, and
- Acres of additional green space made accessible.

The quantification of concrete replaced with green space for each alternative is simply derived from the acres of concrete lined channel that will be replaced with a soft-engineered alternative. The linear feet of connected trails were computed based on the total linear feet of trails within each project footprint. Finally, the acreage of additional green space made available is based on the green space located on an accessible side of the channel. For Alternatives 1 and 2, this accessible green space is located only on the north side of the channel. However, for Alternative 3, these acreages also include green space to the south of the channel due to the addition of new trail facilities. Notably, factors such as improved aesthetics and increased physical and visual access to a natural water course are not included due to the difficulty of quantifying these factors. They will, however, significantly impact the project's urban design impact.

6.3.2 Population Within Proximity

The population within proximity is represented by the population within various distances of the project's amenities. The project GIS was used to identify the existing populations with 0.5-, 1.0, and 1.5-mile buffers around the project footprint. Increases in these values over the existing facilities could then be quantified for comparative purposes. The project's potential impact as more of a destination park to draw users from a broader area and potential for creating increased density within these distances may also be significant but are beyond the scope of this report.

6.4 ECONOMIC DEVELOPMENT

Economic development for potential project alternatives relate to the economic benefits that may result from the development of the project. These benefits may result from increases in economic value and related tax revenue of adjacent and nearby property, the population within proximity, recreational opportunities, or the acreage of features that may be attributable to other ecosystem services. Studies that provide clear guidance for assessing economic development impacts have not been found. This report adopts a conservative approach based on the work of Crompton (2012). Observed impacts of an analogous project in Houston, Buffalo Bayou Park, indicate that economic impacts could be significantly greater and, thus, merit more market-based or academic study that is beyond the scope of this report.

An initial measure of the number of users served is the population within proximity is related directly to the population within a buffered radius of project features. As in the urban design approach, the project GIS was used along with 0.5-, 1.0-, and 1.5-mile buffers to identify populations within those distances of the project footprint. As noted above, these measures are limited in that they do not take into account potential impact on future development or service area expansion; these impacts, while they may merit additional study, are beyond the scope of this report.

6.4.1 Proximity Benefits to Property Values

Proximity benefits to property values were assessed for each alternative on the certified 2016 appraised land value as provided by HCAD. A 600-ft buffer was drawn around the project footprints with accessible green space for each alternative. For Alternatives 1 and 2, this included property north of the channel centerline but excluded restored space to the south, as this area was not made accessible. Alternative 3 included area to both the north and south of the channel.

The land values for residential parcels and commercial parcels dedicated to multi-family residential were summarized within this buffered region for each alternative. Other commercial properties, such as office space, were omitted from this study due to other factors beyond accessibility to green space that may influence these values. A one-time increase in land value of five percent was calculated for these areas in accordance with the previous work by Crompton (2012). This analysis represents a conservative application of one methodology for assessing beneficial impacts to land value and should not be considered the definitive assessment of project benefits. Although White Oak Bayou already benefits from the trail benefits identified in Crompton's study, a similar benefit is assumed for enhancement of the stream corridor. Actual benefits may be significantly greater than this analysis demonstrates and is subject to the particular approach to restoration and other influencing factors within the community, overall.

6.4.2 Acreage Contributing to Increased Economic Benefits

The acreage contributing to increased environmental benefits reflects the acres of habitat specified in each alternative concept. As previously discussed, this is regarded as the acreage of the restored channel as well as the total area of water quality wetlands provided. Additionally, it should be reiterated that these values do not represent the entirety of the total habitat that may be developed as a function of this

project. Specific environmental features will be further explored in subsequent phases of study once project stakeholders and additional goals are identified.

6.4.3 Recreation Benefits

Recreation benefits are subject to a number of factors including the quality of the recreational experience and the number of users-days anticipated for a particular amenity. The National Economic Development (NED) benefit evaluation contained in ER 1105-2-100, produced by USACE (2000) includes a variety of means for evaluating recreational value, including the Unit Day Value (UDV) method. This approach focuses on these two factors by assigning a dollar value to recreation based on a point system assigned to a facility multiplied by the number of user-days. Although identifying the number of user-days requires extensive survey and data collection that are outside the scope of this study, the assignment of points based on recreational features and the correlation to dollar values can be accomplished with relative ease. The analysis in this study focuses on assigning point values and relating these to dollar values. When compared against the baseline value for each type of recreation, a percent increase in unit recreational value can be identified. Additional information related to guidelines for assigning UDV's and corresponding dollar values assigned to the identified points can be found in the updated USACE reference for the 2017 fiscal year (USACE, 2016).

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7.0 RESULTS OF PROJECT METRIC EVALUATION AND COMPARISON OF IDENTIFIED ALTERNATIVES

Metrics were developed according to the methodology described in *Section 6.0* for all three alternatives considered. Where appropriate, this also included the development of corresponding values for the baseline scenarios with the existing concrete lining, specifically for the consideration of project development or replacement costs.

7.1 NATURAL CHANNEL DESIGN AND ENVIRONMENT

The results of the analysis related to natural channel design and environment are contained in *Table 4*, below. Alternatives 2 and 3 provided for approximately twice the area of geomorphic floodplain as Alternative 1 due to the larger project footprints, although the areas for both 2 and 3 were similar. In addition, both Alternatives 2 and 3 were able to accommodate the specified area of water quality features to provide adequate treatment for the identified outfalls. Overall acreage of habitat incorporated into Alternatives 2 and 3 were also found to be similar to one another, but were much greater than that found in Alternative 1 due to the overall footprint of the projects. It should be noted that all of these values are subject to final design and the resulting benefits may vary significantly once other components, such as native plantings and specific development of upland habitats are considered. In this case, Alternative 2 and, to an even greater degree, Alternative 3 will excel due to the larger areas that may be restored and improved.

Table 4: Natural Channel Design and Environment Metrics for All Alternatives

Metric		Unit	Alternative		
			1 (Limited Scale)	2 (North)	3 (North/South)
Acres of geomorphic floodplain provided		Acres	16.2	32.1	34.1
Acreage of stormwater quality features added	Deep Pool	Acres	0.0	1.6	1.6
	Wet Shelf		0.0	4.5	4.5
	Dry Shelf		0.0	7.3	7.3
	Total		0.0	13.4	13.4
Enhanced habitat features added ¹	Channel Bottom	Acres	8.3	13.9	13.9
	Water Quality Wetlands		0.0	13.4	13.4
	Total		8.3	27.3	27.3

¹Based on water quality features and channel features. Significant additional habitat may be developed within the newly developed project corridor beyond the features already identified here

7.2 ENGINEERING AND H&H

The metrics described for engineering and H&H characteristics were evaluated and the results are shown below in *Table 5*. First and foremost, it should be noted that the three alternatives evaluated were devised in such a way to prevent adverse impacts to flooding risk; impacts were modeled during the development of each option to verify that proposed configurations did not increase flood conditions. All metrics shown here describe an improved condition in respect to existing flood risk.

Table 5: Engineering and H&H Metrics for All Alternatives

Metric		Unit	Alternative		
			1 (Limited Scale)	2 (North)	3 (North/South)
Acre-feet increased channel capacity		Acre-feet	119.1	315.0	495.2
Average reduction in one percent water surface elevation within each major reach	Hogan to Taylor	Feet	0.06	0.12	0.10
	Taylor to Studemont		0.16	0.36	0.39
	Studemont to S. Heights		0.14	0.31	0.34
	S. Heights to E. Shepherd		0.07	0.13	0.14
	E. Shepherd to TC Jester		0.06	0.09	0.10
	TC Jester to W. 18th		0.03	0.04	0.05
	W. 18th to Loop 610		0.00	0.00	0.01
Number of structures with reduction to likelihood of flooding ²	Likely to Possibly ³		~100	~100	~100
	Possibly to None ⁴		~140	~140	~140
Population with reduction to likelihood of flooding ²	Likely to Possibly	Count	~125	~125	~125
	Possibly to None		~600	~600	~600
Specific infrastructure protected and access routes ¹	Institutions	Count	0	0	0
	Intersections		~12	~12	~12

¹An acre-foot of water represents an acre of land inundated by one foot of water or approximately 325,851 gallons.

²Uncertainty in modeling due to local conditions and level of precision render study results of all alternatives to within a similar magnitude.

³Of a total 1,859 structures considered "likely inundated" in base condition.

⁴Of a total 1,159 structures considered "possibly inundated" in base condition.

The increase in channel volume provided represents a very tangible benefit resulting from implementation of these alternatives, as this volume could potentially be used for detention associated with projects being developed within the watershed, such as those indicated above in *Table 3*. Alternative

3 provided far greater linear detention capacity than other options due to the scale of this concept and the amount of material that would be removed in order to produce its geomorphic floodplain and intermediate benches. However, both Alternatives 1 and 2 also produce sizable benefits to linear detention that may provide value to the overall project. Specific benefits will have to be considered and analyzed further in conjunction with identified projects. This scale of detention project is comparable to other projects by HCFCF and represent a substantial opportunity for developing detention within the study area. *Figure 4* illustrates the magnitude of comparably sized basins that have recently been completed within Harris County. It should be noted that, although these projects include both environmental and recreational features, they magnitude of these features do not compare to the level of benefits incorporated into the proposed project alternatives. The White Oak options include extensive trails and water quality wetlands in various concepts and also provide for the return of the channel to an earthen channel rather than a concrete-lined structure.

	H500-01-00 Phase 2	E500-11-00	E515-01-00
Photo			
Location	Homestead Road near IH-610	Jones Road near West Road	US 290 near Antoine Drive
Capacity	~575 ac-ft	~300 ac-ft	~100 ac-ft
Cost	\$19,700,000	\$7,600,000	\$5,100,000

Figure 4: Representative Detention Projects Completed by HCFCF

All alternatives also demonstrated reductions in water surface elevations for the one percent annual exceedance probability (100-year) event, extending as far upstream as the I-610 loop in the case of Alternative 3, which also demonstrated the greatest reductions in water surface. However, the scales of these improvements are small compared to the current extent of flooding, indicating that none of the alternatives provide significant benefit to flooding in the project area. This is also supported by the number of structures from which the one percent floodplain has been removed, the corresponding population, and the benefits to roadway crossings. All of these values were considered “too close to call” with similar benefits resulting from all three alternatives. An evaluation of this analysis is summarized in more detail in *Appendix B*.

Although not considered project metrics for weighting the benefits of each alternative, project costs and development timelines were also evaluated for the three alternatives as well as two baselines representing the ongoing maintenance and replacement of the concrete lining as well as the complete replacement of the current structure. This analysis is described in detail in *Appendix C* and the results are shown below in *Table 6*.

Table 6: Project Development Metrics for All Alternatives

Project Development Metric		Unit	Alternative		
			1 (Limited Scale)	2 (North)	3 (North/South)
Construction Cost ¹	Earthwork	\$	\$10,920,000	\$22,165,000	\$33,995,000
	Erosion Protection ²		\$12,480,000	\$13,390,000	\$17,745,000
	Outfalls		\$403,650	\$527,930	\$600,470
	Demolition, General Civil, Other		\$5,732,220	\$6,739,980	\$7,953,530
	Total		\$29,535,870	\$42,822,910	\$60,294,000
Annual Project O&M Cost	Armoring	\$	\$120,809	\$168,363	\$205,335
	Vegetation		\$52,771	\$73,417	\$95,115
	Total		\$173,580	\$241,780	\$300,450
Development Timeline	PER and Coordination	Months	18	18	24
	Survey/Field		6	6	6
	Design		12	14	16
	Permitting		12	12	12
	Construction		18	24	36
	Total		66	74	94

¹All construction costs include a 30 percent contingency.

²Erosion protection for all alternatives is significantly influenced by the conservative assumption of the need for soft armoring throughout the length of the channel. Continued evaluation may demonstrate a significant reduction in this cost if soil conditions permit.

Construction costs for the proposed alternatives ranged from approximately \$29.5-million up to over \$60-million for Alternatives 1 and 3, respectively. The most significant reason for this range is the scale of the projects and the volume of excavation required to develop each project footprint. Excavation and offsite disposal of material ranges from 270,000 cubic yards for Alternative 1 to as much as 862,500 cubic yards for Alternative 3 or 27,000 and 86,250 truckloads of material, respectively. These costs also reflect a significant cost for soft armoring of the channel equal to approximately 30 percent of the total construction cost. Further analysis of geotechnical conditions at the site may warrant significant reductions in these costs which may make all of the options more attractive, financially. These costs compare to present value costs of \$15.6-million and \$17.6-million for the ongoing maintenance of the existing channel lining or the one-time complete replacement of the concrete lining within the same reach, respectively.

Annual O&M costs for the three alternatives ranged from approximately \$173,600 to \$300,500 for Alternatives 1 and 3, respectively. Much of this cost is related to the ongoing maintenance of the soft channel armoring that expands considerably as project footprint increases requiring more extensive slope protection. As it is assumed that the construction costs include any necessary replacement of the concrete lining currently in place and no routine maintenance is provided for the existing concrete lining, no additional costs of maintaining the armoring will be incurred for the baseline scenarios. Both of these options have an estimated annual O&M cost of approximately \$45,300. Another sizable cost for all alternatives is the cost of vegetation management which increases considerably for Alternatives 2 and 3, which encompass a large footprint of green space. However, the maintenance of the acreage may fall under the responsibility of various project partners in addition to HCFCF. Therefore, these costs should be considered comprehensive until a specific cost-share is arranged.

Project development timelines also varied with project magnitude and complexity. Project preliminary engineering and coordination periods were assumed to be longer for Alternative 3 which also required time for coordination regarding the TxDOT tract to the south of the channel. Although survey and permitting for all options was assumed to be similar, design and construction estimates escalated from Alternatives 1 through 3. Total project timelines for Alternatives 1, 2, and three were estimated to be 48, 56, and 70 months, respectively. Replacement of the existing concrete lining was expected to require 38 months, in comparison.

7.3 URBAN DESIGN

Both urban design and economic development impacts are difficult to quantify and require expertise and study beyond the scope of this report. Nevertheless, the relative impacts of the alternatives are indicated by the metrics chosen. The urban design metrics that were reviewed demonstrated varying benefits related to all proposed alternatives, as shown in *Table 7*. While all alternatives resulted in the removal of the concrete lining throughout the study reach, with the exception of existing bridge crossings, each provided varying benefits to green space and accessibility. Although Alternative 1 retained existing trails infrastructure, Alternatives 2 and 3 provided almost 7,000 and just over 24,000 linear feet of additional trails, respectively. The additional trails added to Alternative 3 made accessible an additional 36 acres of green space due to realignment of the channel and access to the south side of the bayou. The change in green space, in both location and quantity, generated increases to the population within proximity within distances of 0.5-, 1.0-, and 1.5-miles.

The identified benefits to green space for all identified alternatives are of particular significance due to the location of the project area. Due to the high land values within the vicinity, the development and enhancement of green space at this scale is of significant value. The ability to expand trail sections to the lower portions of the channel section further enhance this benefit by providing a more immersive natural experience for users.

Table 7: Urban Design Metrics for All Alternatives

Metric		Unit	Alternative		
			1 (Limited Scale)	2 (North)	3 (North/South)
Acres of concrete replaced with green space		Acres	10.1	10.1	10.1
Linear feet of connected trails added		Feet	0	6,810	24,313
Acres of additional green space made accessible	North of Channel	Acres	0.0	0.0	2.5
	South of Channel		0.0	0.0	33.6
	Total		0.0	0.0	36.1
Increased population within proximity	0.5-mile	Count	25	0	219
	1.0-mile		255	375	1,171
	1.5-mile		500	1,530	2,320

7.4 ECONOMIC DEVELOPMENT

The results of the analysis related to natural channel design and environment are contained in *Table 8*, below. All alternatives produced a similar number of users within various distances from the facility, although Alternative 3 included additional population to the south due to the increased footprint associated with the incorporation of the TxDOT tract.

Benefits to land value within the immediate project area were found to be relatively similar based on the analysis adapted from Crompton (2012). This is due to the relatively similar footprints of the project and the lack of variability in applying land value benefits due to specific improvements to the corridor. It is very likely that the increased footprints and amenities provided by Alternatives 2 and 3 may increase land value in excess of that by Alternative 1. The additional, effective footprint of Alternative 3 to the south of the channel was also not found to significantly increase benefits due to the limited residential property within 600 feet of this green space. Further, more detailed and site-specific study may demonstrate much greater benefit to adjacent land values.

As recognized previously, the increase in area associated within environmental benefits was greatest in Alternatives 2 and 3, which included a more significant increase in channel bottom which could accommodate water quality wetlands.

Finally, recreation values for both general recreation and fishing increased similarly for all alternatives. This increase was the result of improvements to the carrying capacity provided by enhanced facilities for these uses and the significant improvement in environmental quality associated with channel restoration. This analysis did not take into account the potential increase in recreation days associated with increased usage. Therefore, these improvements can be considered a conservative estimate of potential recreational benefits of the project.

Table 8: Economic Development Metrics for All Alternatives

Metric		Unit	Alternative		
			1 (Limited Scale)	2 (North)	3 (North/South)
Number of users within proximity contributing to recreational use value, user health and transportation benefit	0.5-mile	Count	26,324	26,174	26,518
	1.0-mile		44,406	44,526	45,322
	1.5-mile		72,421	73,451	74,241
Proximity benefits contributing to increased property values		\$	\$5,527,655	\$5,392,515	\$5,624,144
Acreage contributing to increased environmental benefits		Acres	8.3	27.3	27.3
Increase in unit day value for recreation ¹	General	Percent	25%	25%	25%
	Fishing		10%	10%	10%

¹Increased recreational value based only on quality of recreational experience. This analysis does not account for the increased number of users anticipated.

8.0 POTENTIAL FOR RESTORATION UPSTREAM OF STUDY AREA

Evaluation of the channel restoration potential within the study area provides some information that can be used to translate the concept to upstream reaches of White Oak Bayou. While the segment downstream of Taylor Street provides some unique benefits due to the adjacent park space and facilities, many upstream reaches also exhibit some of these similar characteristics that may provide a suitable location for channel restoration. Information gathered as part of this study was adapted to examine the potential for upstream implementation.

Review of the cross-sections of Alternative 1 indicate the minimum extents required for development of a restoration project based on the channel configuration, limitations on channel slope, and requirements for adjacent maintenance buffers. The narrowest of these cross-sections measures approximately 200-ft wide. Cross-sections with approximately 250-ft width could support stable slopes as well as floodplain width in the channel bottom or intermediate slopes. Optimal geomorphic channel configuration could be accomplished in sections of approximately 350-ft of width or more. These compare favorably with the typical HCFCF ROW width of approximately 300-ft through most of this reach.

The extent of the main stem of White Oak Bayou from the upstream terminus of the study area to the I-610 was studied to identify available width for construction of restored sections. This included identification of adjacent green space available through the corridor, which was located in a manner similar to the way in which the maximum potential footprint was identified in the study reach. Several representative cross-sections from the White Oak Bayou hydraulic model were clipped to the available green space to determine the effective length that could allow for incorporation of the restored channel section. These dimensions were compared against the value in *Table 9* and assigned a potential for restoration based on the results.

Table 9: Assumed Width Requirements for Restoration of Upstream Cross-Sections

Potential for Restoration	Width Through Cross-Section
Favorable	≥ 350
Likely	≥ 250 and < 350
Possible	≥ 200 and < 250
Not Possible	< 200

All the examined cross-sections in the analysis were found to have extents allowing for at least some level of restoration. Available widths were found to exceed the 250-foot threshold throughout the extent of

the main stem with several sections exceeding 350 feet, meaning that a substantial restoration including geomorphic floodplain and water quality features could be incorporated. The distribution of these representative sections is shown in *Exhibit 10*.

It should be noted, however, that this is a high-level assessment that will require substantial additional study to determine if restoration of these upstream reaches is possible within the available footprint. This analysis assumes the following:

- Stream response to changes to channel configuration are similar to the study reach and further modeling does not demonstrate negative impacts to flood elevations,
- Upstream cross-sections can be excavated to a similar degree as the study reach,
- Upstream green space can be repurposed and be brought into the project, potentially changing its use due to different elevation relative to the local floodplain, and
- Stakeholders can be identified to make additional ROW available for project development.

9.0 RECOMMENDATIONS AND PATH FORWARD

This study presents a wide range of options that can successfully allow for the replacement of much of the concrete lining currently in place downstream of Taylor Street. Although all three are feasible, each option provides differing degree of utility and require varying levels of stakeholder commitment in order to develop. *Table 10* summarizes the strengths of each alternative. For this analysis, project cost and development have been illustrated separately and are represented as detracting factors for development due to the added cost and schedule.

Table 10: Overview of Features for Studied Alternatives

Focus Area	Alternative		
	1 (Limited Scale)	2 (North)	3 (North/South)
Natural Channel Design and Environment	●	● ● ●	● ● ●
Engineering and H&H	●	● ●	● ● ●
Urban Design	●	● ●	● ● ●
Economic Development	● ●	● ● ●	● ● ●
Project Cost and Development	△ △	△ △ △	△ △ △ △

● – Identified benefits from restoration

△ – Identified obstacles to restoration

The results of the comprehensive analysis demonstrate varying degree of benefit that increase proportional to project cost and magnitude. However, it should be noted that Alternative 2 generates many of the benefits of Alternative 3 but with a reduced project cost and timeline. The significant benefits of Alternative 3 results from the incorporation of the TxDOT tract to the south of the current channel. Although Alternative 3 makes this area accessible through development of trails, the full potential is not fully captured in the distance-based quantitative analysis due to the separation of this green space from development across the I-10 corridor. Exploration of means of providing access to the new space to residents south of the bayou may, therefore, be merited. Further analysis may focus on the limited incorporation of this property through the addition of trails which would provide additional green space and connectivity to Alternatives 1 or 2 without incurring the significant costs of excavation and channel development included in Alternative 3. Such a concept would provide benefits in the urban design focus area for Alternative 2 that would be comparable to those estimated for Alternative 3 at minimal

incremental cost. However, this approach would not provide the significant benefit of nearly 200 acre-feet of additional detention that can be realized through the implementation of Alternative 3.

Ultimately, the final design elements will dictate the costs and benefits of each alternative. This analysis demonstrates a range of options that can initiate the in-depth discussions required to finalize the ultimate restoration design. Actual elements such as recreational amenities and habitat provisions can be decided once stakeholders are identified and have an opportunity to revisit the constraints, opportunities, benefits, and metrics discussed in *Section 4.0*.

A work plan to continue this effort may consist of the following steps, which would require time in addition to the timelines presented in *Table 6*:

1. **Identify Stakeholders to Participate in Development of the Project:** This includes the current stakeholder group (MHRA, HCFCD, and COH), plus others who may wish to contribute to the process in order to generate mutual community benefit from the initiative. The inclusion of interested parties upstream may also be beneficial to expand the comprehensive benefit of the project outside of the immediate study area.
2. **Revisit Objectives and Metrics Based on This Study and Stakeholder Group:** This step would include the reevaluation of the objectives and metrics identified in this report to provide for further study and preliminary design of the project concept. Based on review of this study, stakeholders may identify certain objectives to focus on above others that might be considered. In addition, more specific objectives such as means of providing enhanced upland habitat within the project footprint may also be targeted at this time.
3. **Identify the Realistic Footprint of the Project:** This study provides three specific project footprints based on the three, identified alternatives; each of these options provides specific benefits and have an associated cost. The reimagined stakeholder group may utilize the updated list of objectives to select the alternative that best accomplishes these goals for a reasonable cost. It should be kept in mind that many of the benefits to green space and accessibility can be accomplished outside of the excavated footprint of the channel and can still benefit from the enhanced habitat following removal of the concrete lining.

4. Conduct Preliminary Engineering and Planning: This step would further the analysis presented here to answer specific questions identified within this study to provide a more complete understanding of the project concept. Specifically, this step should aim to determine:
 - What are the geotechnical conditions present throughout the study area and how can this understanding be used to reduce the conservative costs provided for armoring and stabilization of the channel? This is a significant factor, as removing this item from the construction OPCC for Alternative 1 would reduce the cost of this alternative to match the baseline cost estimated for the one-time replacement of the current channel lining and significantly reduce the cost of maintenance over the long-term.
 - What options can be considered for the TxDOT tract to the south of White Oak Bayou? If inclusion as part of the project excavated area is not possible, are there other ways to make this green space available without precluding any long-term use required by TxDOT?
 - What is the interest of other stakeholders in the vicinity of the project for utilizing linear detention in the project as regional detention for identified projects?
5. Project Design, Permitting, and Execution: Finally, the project may proceed to subsequent phases based on a united stakeholder group and a comprehensive vision based on further study and a reasonable design concept. More specifics for these later phases will be examined through the course of preliminary engineering and planning.

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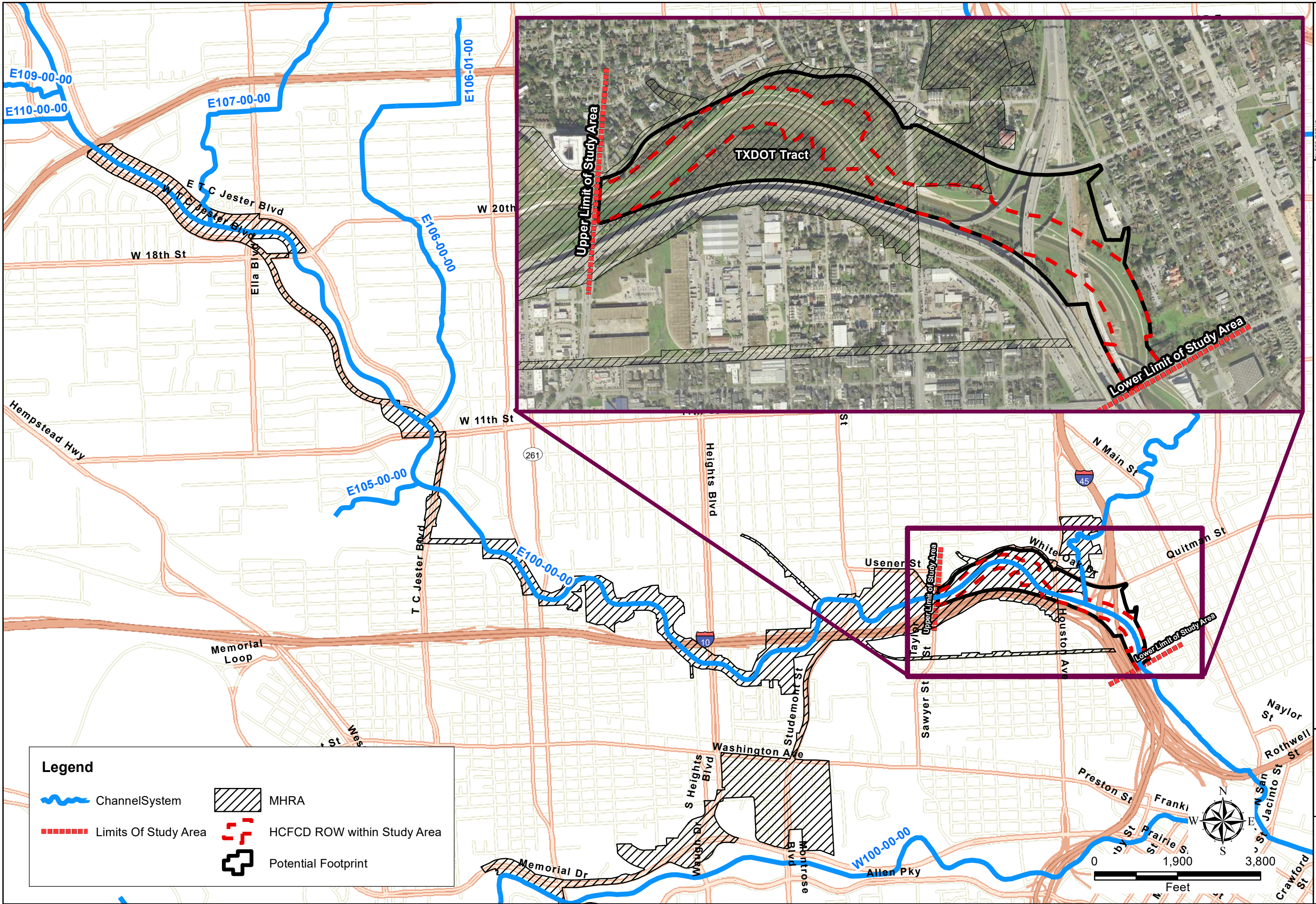
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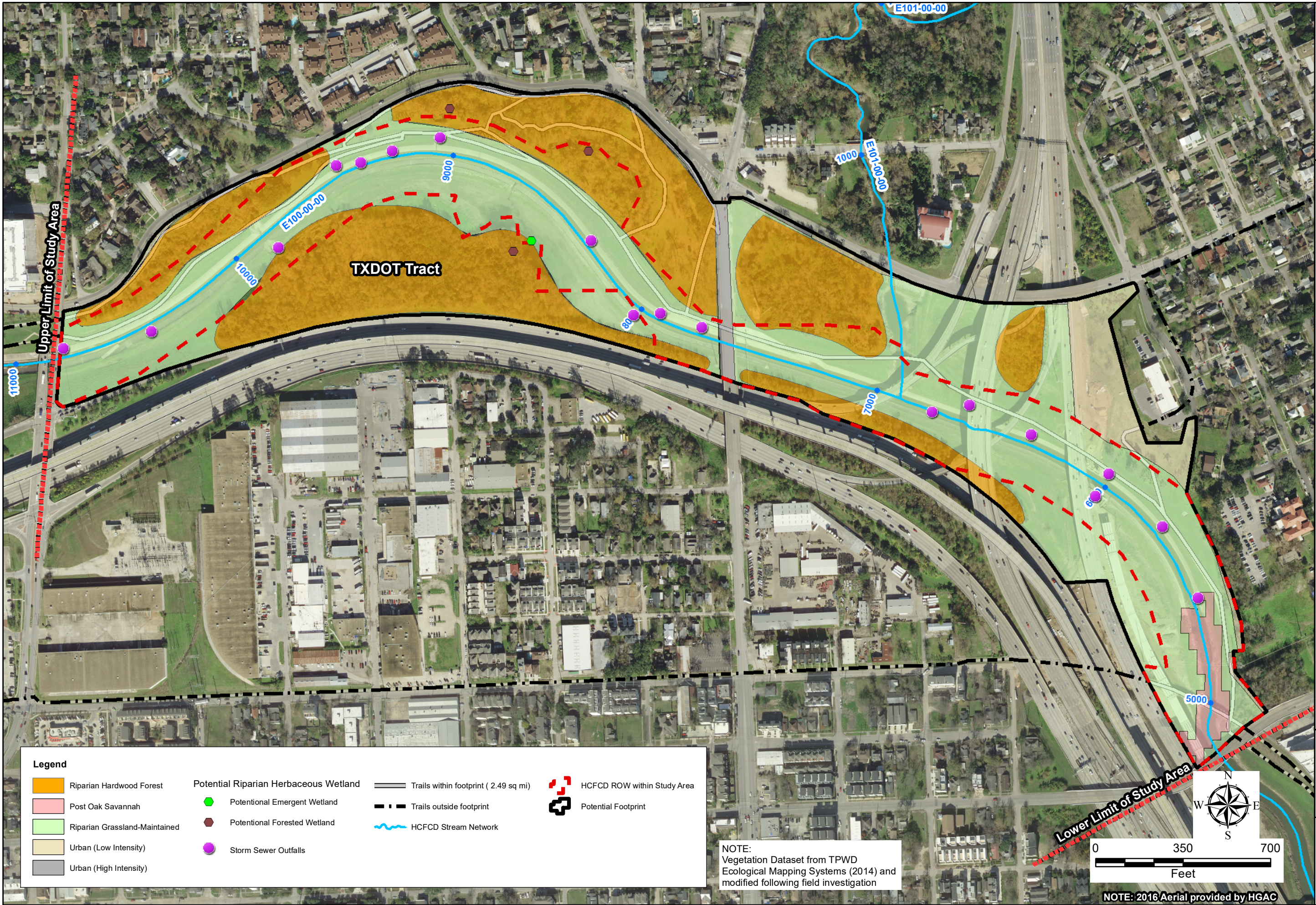
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NOTE:
Vegetation Dataset from TPWD
Ecological Mapping Systems (2014) and
modified following field investigation

NOTE: 2016 Aerial provided by HGAC

Legend

Riparian Hardwood Forest

Post Oak Savannah

Riparian Grassland-Maintained

Urban (Low Intensity)

Urban (High Intensity)

Potential Riparian Herbaceous Wetland

Potential Emergent Wetland

Potential Forested Wetland

Storm Sewer Outfalls

Trails within footprint (2.49 sq mi)

Trails outside footprint

HCFC Stream Network

HCFC ROW within Study Area

Potential Footprint

PROJECT NO.
HCF10026

DATE CREATED
10/12/2017

DATUM & COORDINATE SYSTEM
NAD83 State Plane (feet) Texas South Central

FILE NAME
Exhibit2_FieldInvestigation

PREPARED BY
DML

HARRIS COUNTY FLOOD CONTROL DISTRICT

Lower White Oak Bayou Channel Restoration Study

Field Investigation

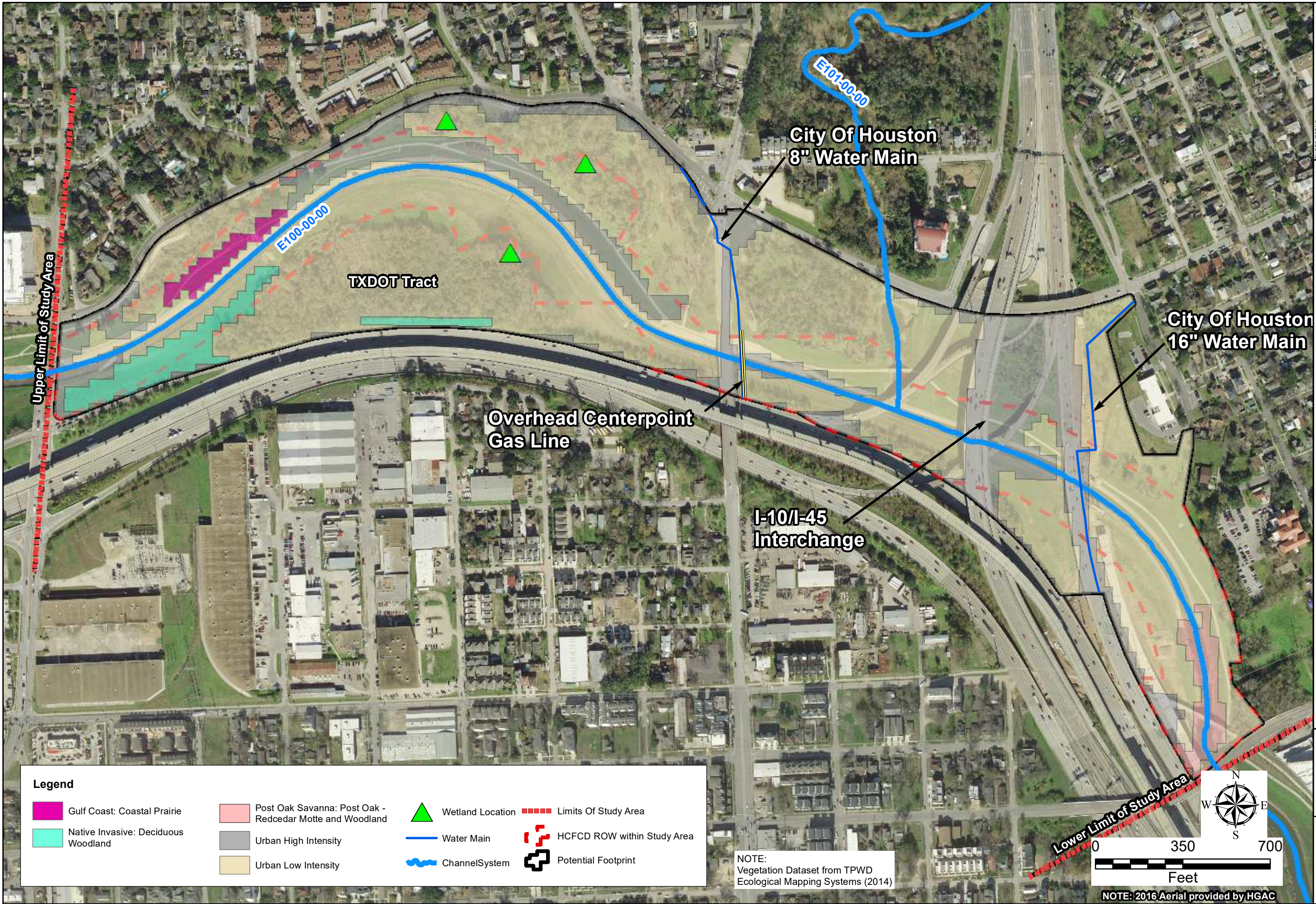
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NOTE:
Vegetation Dataset from TPWD
Ecological Mapping Systems (2014)

NOTE: 2016 Aerial provided by HGAC

HARRIS COUNTY FLOOD CONTROL DISTRICT		PROJECT NO. HCF10226
Lower White Oak Bayou Channel Restoration Study		DATE CREATED 7/6/2017
Constraints Map		DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central
EXHIBIT		FILE NAME Exhibit3_ConstraintsMap
3		PREPARED BY DML

Legend

Gulf Coast: Coastal Prairie

Native Invasive: Deciduous Woodland

Post Oak Savanna: Post Oak - Redcedar Motte and Woodland

Urban High Intensity

Urban Low Intensity

Wetland Location

Water Main

ChannelSystem

Limits Of Study Area

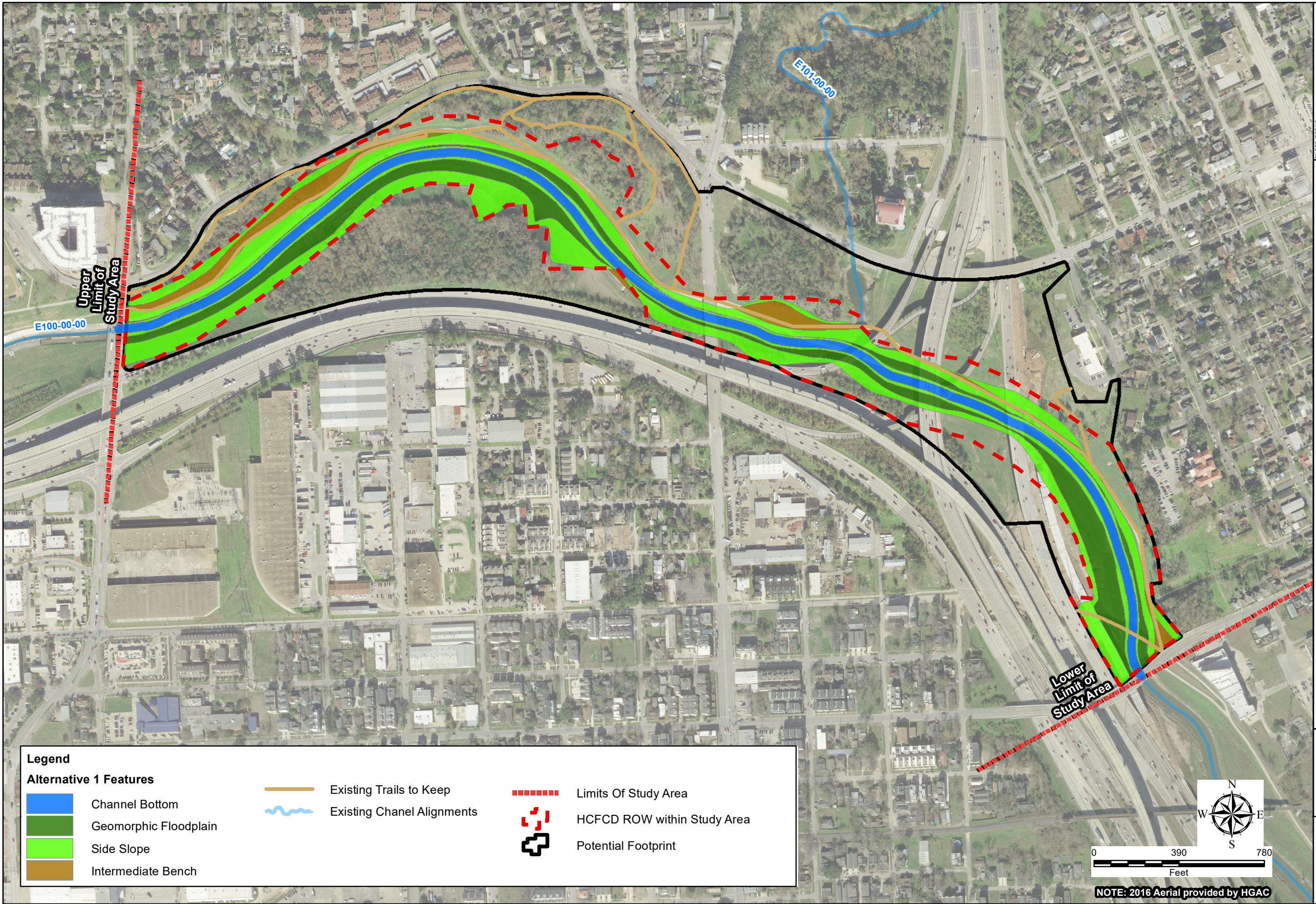
HCFCF ROW within Study Area

Potential Footprint

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Legend
Alternative 1 Features

Channel Bottom
 Geomorphic Floodplain
 Side Slope
 Intermediate Bench

Existing Trails to Keep
 Existing Chanel Alignments

Limits Of Study Area
 HCFCF ROW within Study Area
 Potential Footprint

PROJECT NO.

HCF10026

DATE CREATED

10/10/2017

DATUM & COORDINATE SYSTEM

NAD83 State Plane (feet) Texas South Central

FILE NAME

Exhibit4_Alternative_1

PREPARED BY

DML

Lower White Oak Bayou Channel Restoration Study

Channel Alternative Alignment #1 Plan View

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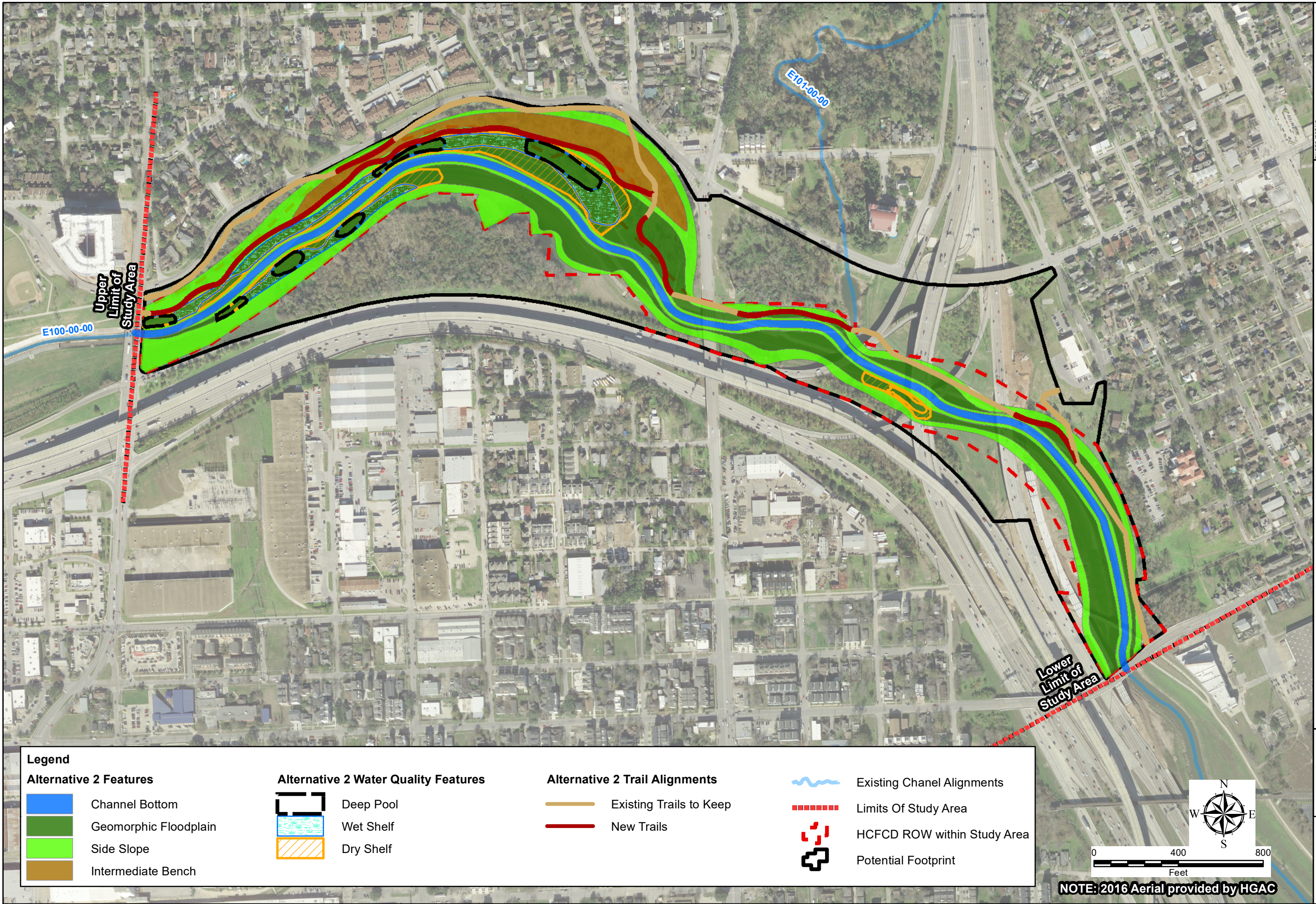
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Exhibit 5 - Channel Alternative Alignment #1



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Legend

Alternative 2 Features

- Channel Bottom
- Geomorphic Floodplain
- Side Slope
- Intermediate Bench

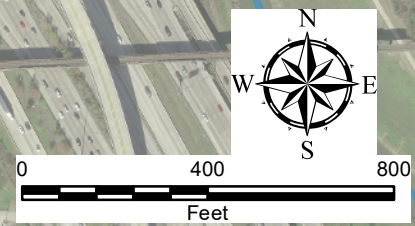
Alternative 2 Water Quality Features

- Deep Pool
- Wet Shelf
- Dry Shelf

Alternative 2 Trail Alignments

- Existing Trails to Keep
- New Trails

- Existing Chancel Alignments
- Limits Of Study Area
- HCFCF ROW within Study Area
- Potential Footprint



NOTE: 2016 Aerial provided by HGAC

HARRIS COUNTY FLOOD CONTROL DISTRICT		PROJECT NO. HCF10026
Lower White Oak Bayou Channel Restoration Study		DATE CREATED 10/10/2017
Channel Alternative Alignment #2 Plan View		DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central
		FILE NAME Exhibit6_Alternative_2
		PREPARED BY DML

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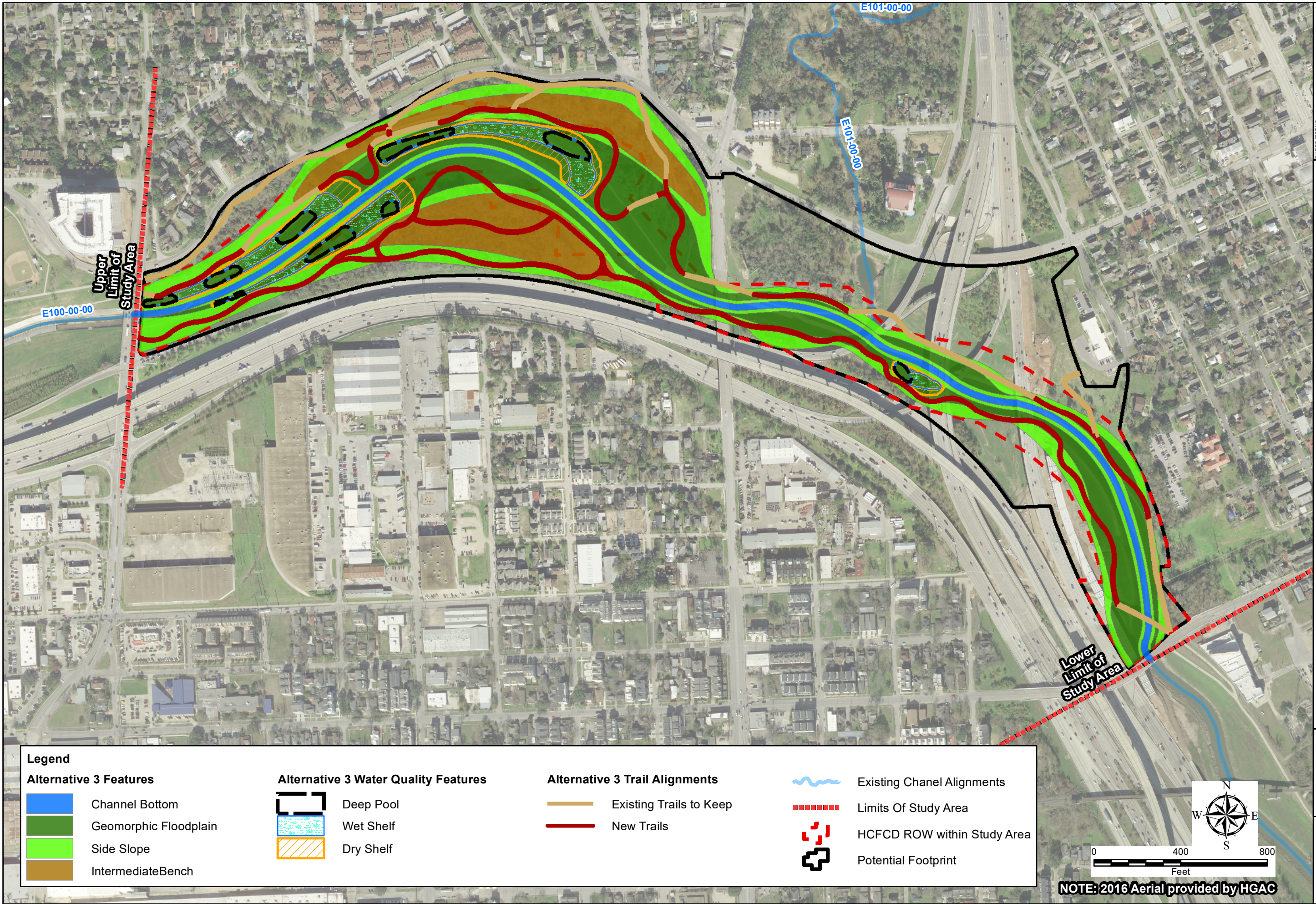
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Exhibit 6 - Channel Alternative Alignment #2



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Legend

Alternative 3 Features

- Channel Bottom
- Geomorphic Floodplain
- Side Slope
- IntermediateBench

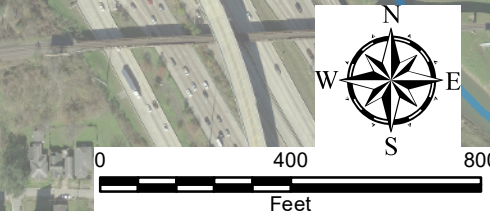
Alternative 3 Water Quality Features

- Deep Pool
- Wet Shelf
- Dry Shelf

Alternative 3 Trail Alignments

- Existing Trails to Keep
- New Trails

- Existing Chanel Alignments
- Limits Of Study Area
- HCFCF ROW within Study Area
- Potential Footprint



NOTE: 2016 Aerial provided by HGAC

HARRIS COUNTY FLOOD CONTROL DISTRICT		PROJECT NO. HCF10026
Lower White Oak Bayou Channel Restoration Study		DATE CREATED 10/10/2017
Channel Alternative Alignment #3 Plan View		DATUM & COORDINATE SYSTEM NAD83 State Plane (feet) Texas South Central
		FILE NAME Exhibit8_Alternative_3
		PREPARED BY DML

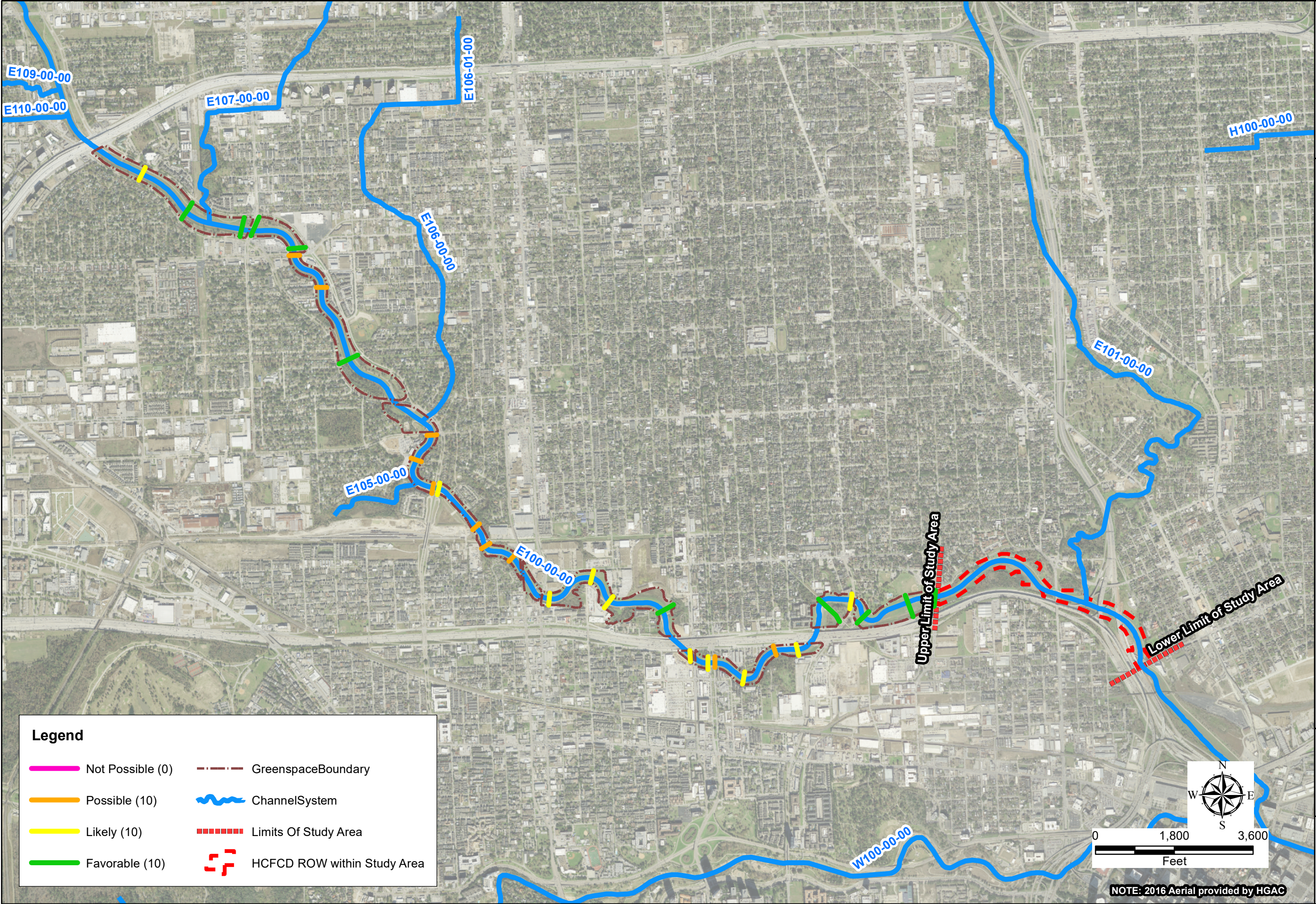
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Exhibit 7 - Channel Alternative Alignment #3



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Legend

Not Possible (0)

Possible (10)

Likely (10)

Favorable (10)

GreenspaceBoundary

ChannelSystem

Limits Of Study Area

HCFCF ROW within Study Area

HARRIS COUNTY FLOOD CONTROL DISTRICT		FN PROJECT NO	FBH10072
Lower White Oak Bayou Channel Restoration Study		DATE CREATED	10/10/2017
Upstream Implementation Potential		DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
		FILE NAME	Exhibit 10_ UpstreamImpPotential
		PREPARED BY	DML
FRESE NICHOLS		EXHIBIT	
FRESE AND NICHOLS, INC. 10497 TOWN AND COUNTRY WAY, SUITE 600 HOUSTON, TEXAS 77024 P: (713) 600-6800 F: (713) 600-6801		10	

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NOTE: 2016 Aerial provided by HGAC

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APPENDIX A

CONCEPTUAL LEVEL STABILITY ANALYSIS

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PROJECT MEMORANDUM



Innovative approaches
Practical results
Outstanding service

TO: Jason Afinowicz, P.E.
CC: Cory Stull, P.E.
FROM: Marc Miller, P.E.
SUBJECT: Conceptual-Level Slope Stability Analysis Summary
DATE: June 6, 2017
PROJECT: HCF16526, Lower White Oak Bayou Channel Restoration



FREESE AND NICHOLS, INC.
TEXAS REGISTERED ENGINEERING
FIRM F- 2144

Background

This project memorandum summarizes the slope stability analysis efforts for the LWOB project. The project is at the planning level and an alternatives analysis for reconstruction of the existing channel is currently underway. Our analysis is based on the following data and assumptions:

- The existing slopes are generally 3H:1V and concrete lined. The concrete lining is deteriorated, but no slippage or slope failures have occurred. A site visit conducted by FNI on February 12, 2017 did not identify evidence of large or significant global stability failures.
- Channel geometry will be modified, but the modifications will vary by channel station. In general, the channel section will be widened. The channel will generally be deepened across its width to the base of the existing pilot channel. If feasible, channel slopes will remain at 3H:1V.

Review of Existing Data

HCFCFCD provided existing (legacy) geotechnical data collected by TxDOT in the general vicinity of the channel. A summary of the reviewed data is as follows:

- TxDOT Boring 45-8 for IH-45 at WOB; data include laboratory test results
- TxDOT Borings ST-3, ST-4, RW-32 and RW-33 for IH-10 W. of Washington to E. of Taylor; data include laboratory test results
- TxDOT Borings 3-1 through 3-8 for IH-10 Detention Ponds; data include laboratory test results

HCFCFCD also provided a NRCS Custom Soil Resource Report of the project area generated using the Web Soil Survey on January 18, 2017. The analysis included a review of the legacy data and assess the data's suitability for use with this planning level analysis. The data is generally suitable, but boring coverage is primarily located on the western half of the project, with only one boring on the eastern half (Borehole 45-8). A review of the existing borings suggests that the stratigraphy is somewhat consistent, and can reasonably be extrapolated across the project reach. We recommend performing a full geotechnical study with additional borings during the conceptual or early

design stages of the project. Advanced shear strength testing (such as direct shear, triaxial shear, etc.) should be performed as part of that study.

Stratigraphy and Parameter Selection

The legacy boreholes were visually located using the boring location maps and Google Earth Pro. The resulting boring locations within and close to the project limits are shown on Figure 1. Subsurface stratigraphy was studied by using the existing boring data to create a generalized subsurface (fence) diagram along a west-to-east line along the approximate center of the project. The fence diagram is shown on Figure 2.

The data indicates general consistency within the channel borings, but varies for those borings outside the channel, and at higher surface elevations. This is expected due to the erosional and depositional processes associated with creek/channel alignments. Within the channel borings (see Boreholes 3-1 to 3-8), the data indicate that the stratigraphy can be generalized as presented in Table 1.

Table 1. Generalized Stratigraphy Descriptions in Channel Borings

Stratum	Thickness	Classification and Color	Description
I	3 to 13 ft	Lean-to-fat Clay, generally lean (CL) within channel limits, with sand and occasionally sandy, tan and gray	Generally soft LL=24 to 52, Avg.=34, S.D.=8.1 P200=55 to 92, Avg.=76.3, S.D.=20.4
II	3 to 15 ft	Silty Sand (SM) to Clayey Sand (SC), tan and gray	Generally loose to very loose LL= 26 to 27 (3 tests) P200=15.2 to 41.4, Avg.=27.4, S.D.=10.6
III	13 to 34 ft	Lean-to-fat Clay, generally fat (CH), reddish gray and tan	Generally soft to stiff LL=40 to 80, Avg.=64.0, S.D.=11.1 No P200 data provided
Note: Stratum II is described as "sand" on TxDOT borings, but the classification used above is based on USCS and laboratory data.			

In general, the groundwater in the channel borings varies from Elev. 7 to 9 feet, while the borings outside the channel had groundwater levels about 5 to 10 feet higher. It is assumed that groundwater is drawing down toward the channel, and that water is likely at or somewhat below the base along the channel alignment.

For the purposes of this preliminary study, the generalized stratigraphy shown in attached Figure 3 is assumed. To conservatively account for natural variation of the material, the presence of the clayey sand/silty sand stratum was ignored for some cases, and the thickness of the fat clay stratum was increased.

The legacy data does not reference existing Mohr-Coulomb strength parameters or shear strength testing that would have been performed to determine these parameters. Preliminary peak strength parameters for clays were selected using soil classification and published empirical correlations by Duncan et al (2014), while parameters for the sand materials were determined based on TCP blow count correlations in the TxDOT Geotechnical Manual (2012). The selected peak strength parameters are presented in Table 2, and refer to Figure 4 and Figure 5 for the relationships used to select these parameters.

Table 2. Selected Peak Material Parameters

Stratum	USCS	Moist Unit Weight	Consolidated-Drained		Consolidated-Undrained	
			ϕ' (deg)	c' (psf)	ϕ (deg)	c (psf)
I	CL	125	26	100	17	250
II	SC/SM	125	30	25	30	25
III	CH	125	22	100	15	300

Although peak strength will govern slope stability for deeper failures, softening from weathering of clays on the slope and crest could result in the development of fully softened shear strength (FSS). Given that the modified slopes will be exposed to the elements, softening is a significant concern for this project. Preliminary FSS strength parameters for both lean and fat clays were selected using soil classification the empirical correlation by Castellanos et al (2016). Refer to attached Figure 6 for the calculations for lean clays, and Figure 7 for the calculations for fat clays. To aid with interpretation, these figures include a best-fit straight line envelope up to a normal stress of 2,000 psf. The selected FSS parameters are presented in Table 3.

Table 3. Selected FSS Material Parameters

Stratum	USCS	Non-dimensional Power Function Parameter		Dimensional Power Function Parameter	
		"a"	"b"	"a"	"b"
I	CL (LL=42)	0.558	0.853	1.726	0.853
III	CH (LL=75)	0.427	0.771	2.469	0.771

Slope Stability Analysis

The slope stability analysis was performed on a two-dimensional model created with the SLOPE/W module of GeoStudio 2016, Ver. 8.16.1 (August 2016), as published by GEO-SLOPE International. The model utilizes limit equilibrium methods to determine the factor of safety against a rotational failure. The calculated safety factors for this preliminary analysis are considered accurate to about one decimal place and are presented as such. The Spencer computational method was selected, as it provides for moment equilibrium of each slice. The entry/exit routine was used to develop circular failure surfaces, and the optimization routine was also used in all models to study non-circular failure geometry. The default optimization settings for entry and exit angles were used in all cases. Tension cracks were not considered for this preliminary analysis.

The analysis was performed for an idealized channel cross section with a 3H:1V slope ratio with a slope crest at Elev. 18 and the toe of the slope at Elev. 0. One group of calculations considers the stratigraphy presented as Case A in Figure 3, and the second group (Case B in Figure 3) considers the absence of the sandy stratum and a thicker fat clay stratum. The analyses were performed for the following loading conditions:

- Long-term/steady-state conditions with groundwater at Elev. 8 and at Elev. 0 (base of channel).
- Rapid drawdown from the slope crest; conservatively assumes an instantaneous drawdown from the crest to the channel base. This results in a temporary and undrained loading, and was analyzed using both drained and undrained shear strengths (with the limiting value is selected).
- Shallow slides with fully softened shear strength and rainfall saturation. Pore pressures were modeled by applying an R_u coefficient equal to 0.35 (based on guidance by Castellanos et al, 2014) to approximate partial saturation of the weathered slope (10-ft thick shell) following rainfalls.

The results of the analysis for the various conditions are summarized in Table 4, and the failure geometry and sections are attached as Figure 8 through Figure 10.

Table 4. Preliminary Slope Stability Analysis Results

Stratigraphy	Groundwater	Description	Strength Case	Safety Factor	HCFCF Criteria
Case 3A	@ Elev. 8	Sunny day, global slide	Peak strength	2.0	1.5
Case 3A	@ Elev. 0	Sunny day, global slide	Peak strength	1.9	1.5
Case 3A	@ Elev. 8	Sunny day shallow slide	Clays fully softened	1.8	1.5
Case 3B	@ Elev. 8	Sunny day shallow slide	Clays fully softened	1.8	1.5
Case 3A	@ Elev. 0	Sunny day shallow slide	Clays fully softened	1.9	1.5
Case 3B	@ Elev. 0	Sunny day shallow slide	Clays fully softened	1.9	1.5
Case 3A	Elev. 18 to 0	Rapid drawdown	Limiting Case	1.8	1.25
Case 3B	Elev. 18 to 0	Rapid drawdown	Limiting Case	1.6	1.25
Case 3A	Ru=0.30	Rain-filled shallow slide	Fully softened shell	1.4	N/A
Case 3B	Ru=0.30	Rain-filled shallow slide	Fully softened shell	1.3	N/A

The FS slope stability criteria requirement in the *Harris County Flood Control District Policy Criteria and Procedure Manual for Approval and Acceptance of Infrastructure* (2010) is listed as 1.5 for long-term conditions, and 1.25 for rapid drawdown conditions. HCFCF does not specifically address criteria for shallow slides resulting from rain-filled, softened clays, but it is difficult to obtain a factor of safety of 1.5 for these conditions. The industry is generally trending toward safety factors greater than 1.1 to 1.3 for these cases (refer to Castellanos et al 2014 for a discussion).

Based on these criteria the proposed 3H:1V slope appears to be a feasible alternative, but this conclusion has the following caveats:

- The analysis assumes that there are no preexisting failures along the channel reach. If present, existing failures will significantly reduce stability of proposed modifications.
- The analysis does not consider backslopes or terraced topography, which could reduce stability. These factors could increase the potential for deeper failure geometry.
- Stratigraphy was extrapolated from limited boring data, and actual stratigraphy could vary. Future studies should include more boreholes to reduce this uncertainty.
- The analysis is based on estimated shear strength envelopes. Future studies should include advanced shear testing to define shear strength of the various strata.
- Shallow slope stability appears acceptable, but it should be expected that additional studies may reveal lower safety factors, which may increase associated maintenance costs for the channel. If desired, the slope could be flattened to lessen these potential costs.

Technical References

- Castellanos, B.A. and Brandon, T.L. "Use and Measurement of Fully Softened Shear Strength (CGPR #80)," Virginia Tech Department of Engineering, (November 2014)
- Castellanos, B.A. and Brandon, T.L. "Correlations for Fully Softened Shear Strength Parameters," ASTM Geotechnical Testing Journal Volume 39, Issue 4 (July 2016)
- Duncan, J. M., Wright, S. G., Brandon, T. "Soil Strength and Slope Stability, 2nd Edition," John Wiley & Sons (2014)
- Texas Department of Transportation, "Geotechnical Manual," Austin, Texas. 2012.



Figure 1. Aerial Map of Approximate Legacy Boring Locations

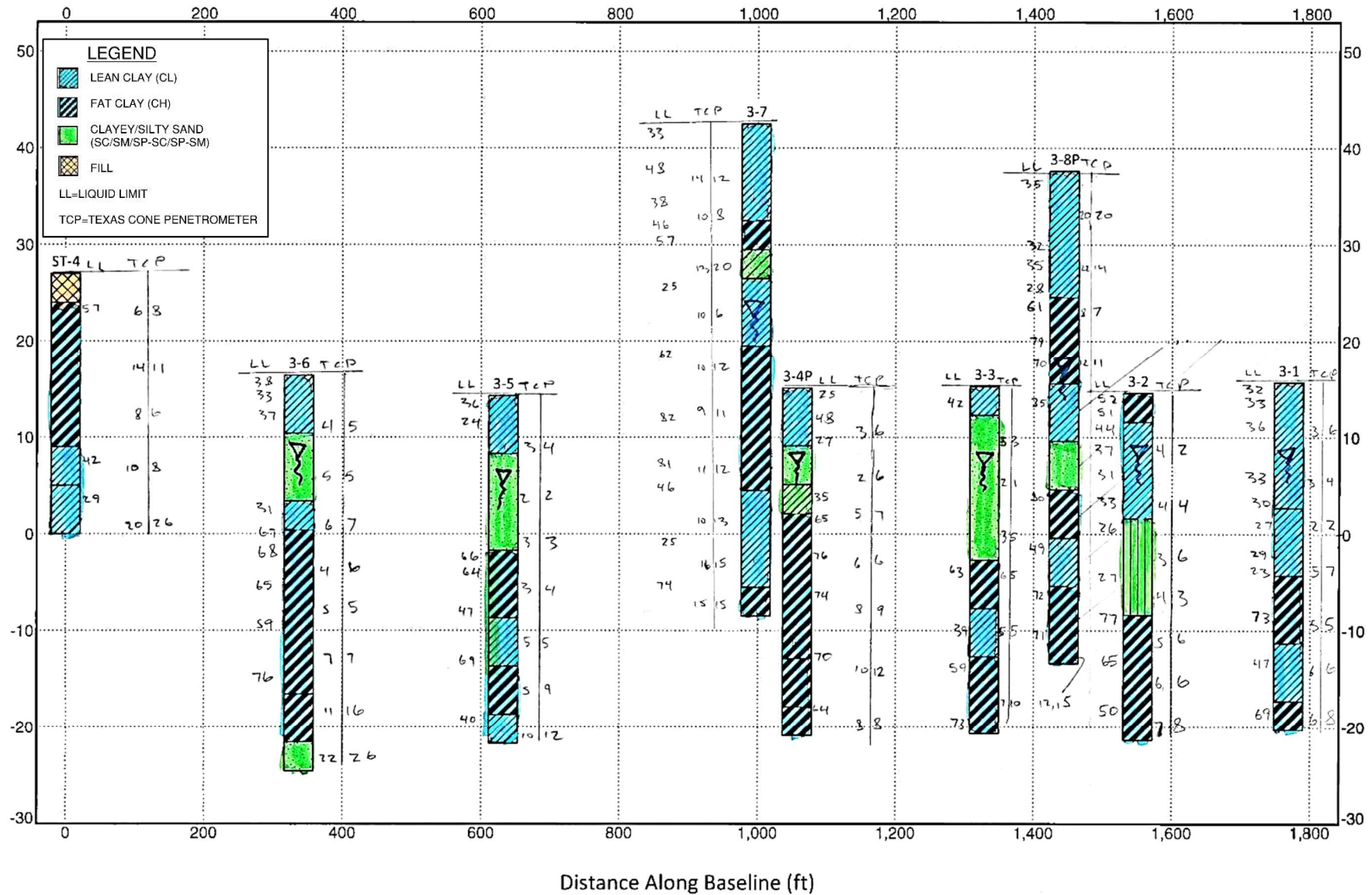


Figure 2. Fence Diagram of Legacy Borings

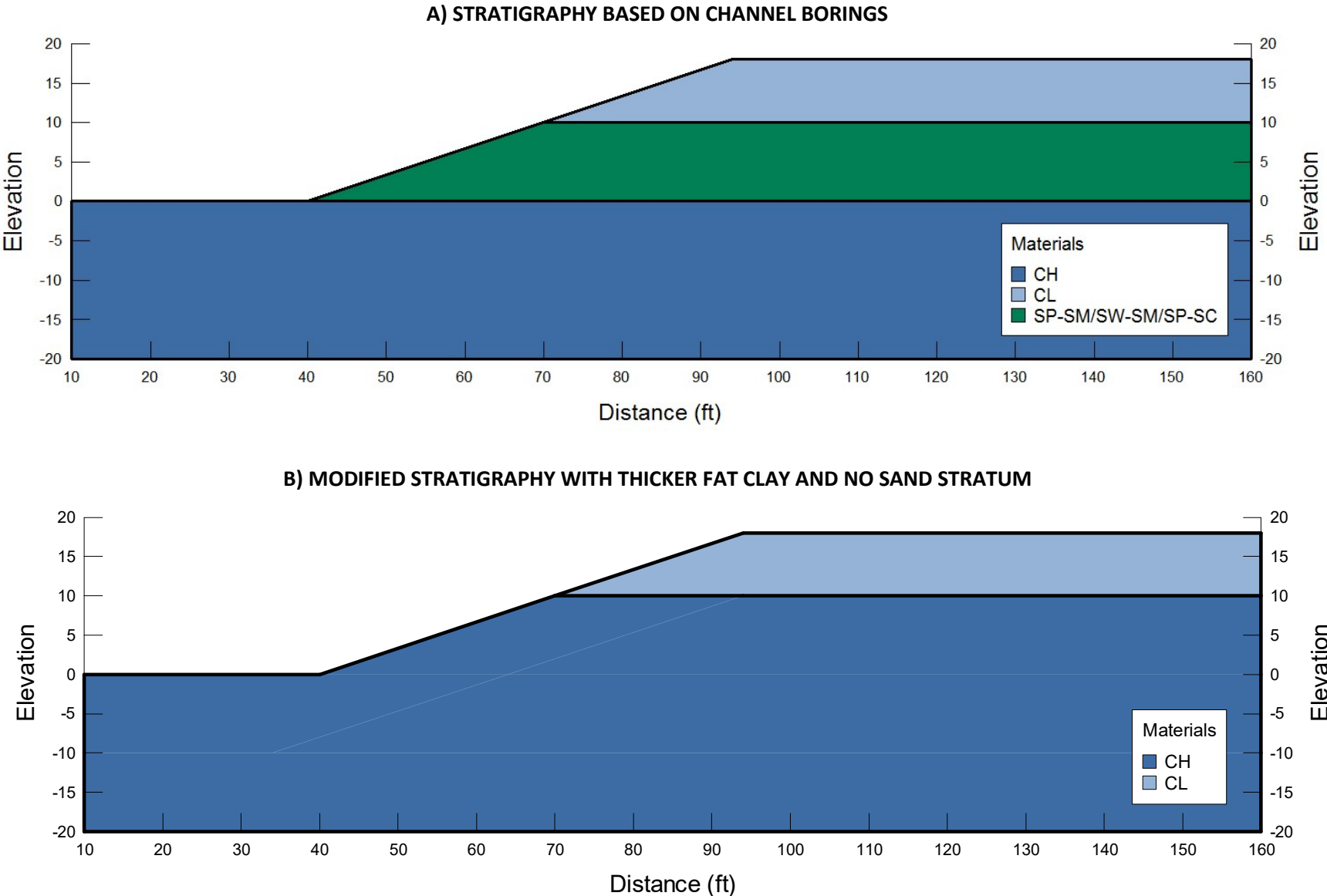


Figure 3. Generalized Channel Stratigraphy Section

Typical Values of Peak Friction Angle (ϕ') for Normally Consolidated Clays ^a		Typical Peak Drained Strengths for Compacted Cohesive Soils			
Plasticity Index	ϕ' (deg)	Unified Classification Symbol	Relative compaction, RC ^a (%)	Effective Stress Cohesion, c' (lb/ft ²)	Effective Stress Friction Angle, ϕ' (deg)
10	33 ± 5	SM-SC	100	300	33
20	31 ± 5	SC	100	250	31
30	29 ± 5	ML	100	200	32
40	27 ± 5	CL-ML	100	450	32
60	24 ± 5	CL	100	300	28
80	22 ± 5	MH	100	450	23
		CH	100	250	19

^a $c' = 0$ for these materials.
Source: Data from Bjerrum and Simons (1960).

^a RC, relative compaction by USBR standard method, same energy as the standard Proctor (ASTM D698) compaction test.
Source: After U.S. Department of the Interior (1973).

Figure 4: Typical Drained Strengths for Cohesive Soils (Duncan et al, 2014)

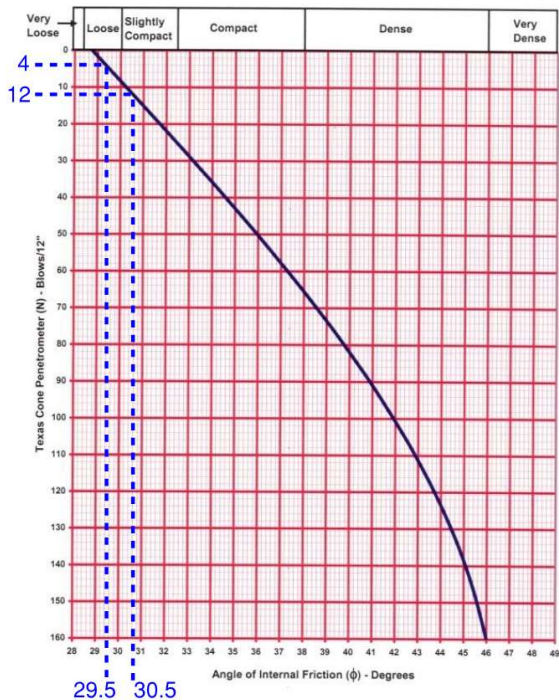


Figure 5. TCP vs. Internal Friction Angle for Cohesionless Soil

SHEAR STRENGTH OF CLAYEY MATERIAL BY CORRELATION

Project Name: White Oak Bayou

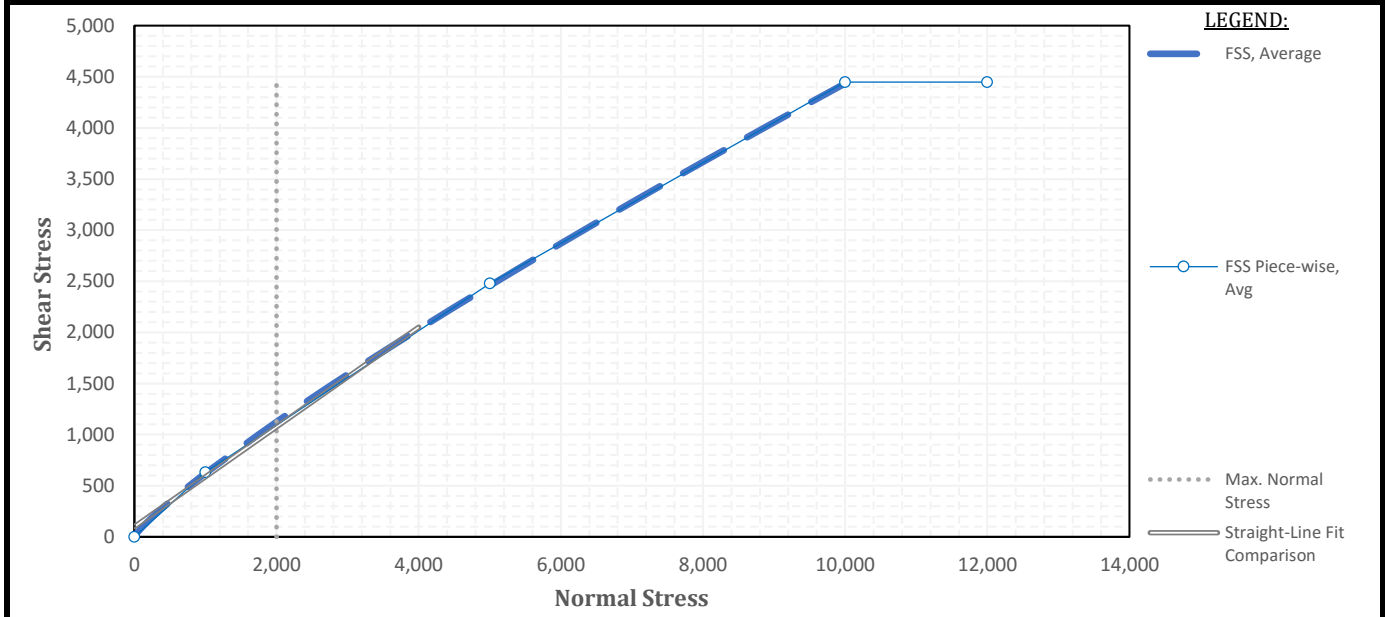
Project Number: HCF16526

Calc. By:

FS/MTM

1/30/2017

Dimensional Shear Strength Envelopes



All Stress Units: PSF

All Angle Units: DEGREES

Summary of Input Data and Index Property Parameter Calculations

Material Description:	Lean Clay (CL)	Predicted CF	29 %
Material Use/Loc.:	Stratum I	Selected CF:	50.0 %
Liquid Limit:	42	Cohesion Index (CI):	15.3
% Passing No. 200:	76	Clay Fraction (%CF):	N/T
		CF*PI:	1000

Correlation Function Parameters

Fully Softened POWER Parameters (Castellanos, 2016)		Residual Strength POLYNOMIAL Parameters (Stark & Hossain, 2013)	
	Average		
Non-dimensional "a"	0.558	Avg. Dimensional "a"	
Non-dimensional "b"	0.853	Avg. Dimensional "b"	
Dimensional "a"	1.726	Avg. Dimensional "c"	
Dimensional "b"	0.853		

Piece-Wise Function M-C Values

Description:		FSS, Average	
Normal Stress Range		ϕ'	c'
0	1,000	32.3	0.0
1,000	5,000	24.6	192.9
5,000	10,000	21.6	492.6
10,000	12,000	0.0	4447.9

Straight-Line Fit Line Mohr-Coulomb Parameters

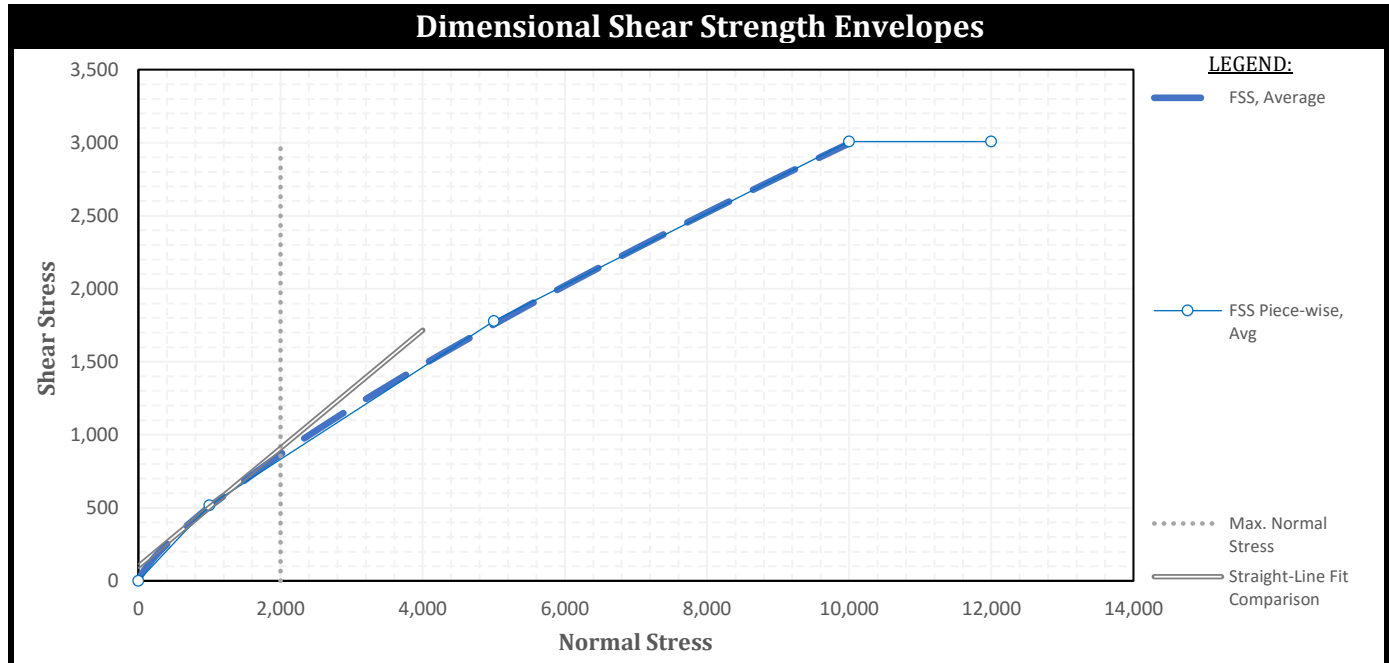
Normal Stress Range Maximum:	2000	Friction ϕ':	26.0	Effect. Cohesion:	100.0
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FIGURE 6

SHEAR STRENGTH OF CLAYEY MATERIAL BY CORRELATION

Project Name: White Oak Bayou
Project Number: HCF16526 **Calc. By:** FS/MTM **1/30/2017**



All Stress Units: PSF **All Angle Units:** DEGREES

Summary of Input Data and Index Property Parameter Calculations

Material Description:	CH	Predicted CF	54 %
Material Use/Loc.:	Stratum III	Selected CF:	60.0 %
Liquid Limit:	75	Cohesion Index (CI):	42.8
% Passing No. 200:	95	Clay Fraction (%CF):	N/T
		CF*PI:	2700

Correlation Function Parameters

Fully Softened POWER Parameters (Castellanos, 2016)		Residual Strength POLYNOMIAL Parameters (Stark & Hossain, 2013)	
	Average		
Non-dimensional "a"	0.427	Avg. Dimensional "a"	
Non-dimensional "b"	0.771	Avg. Dimensional "b"	
Dimensional "a"	2.469	Avg. Dimensional "c"	
Dimensional "b"	0.771		

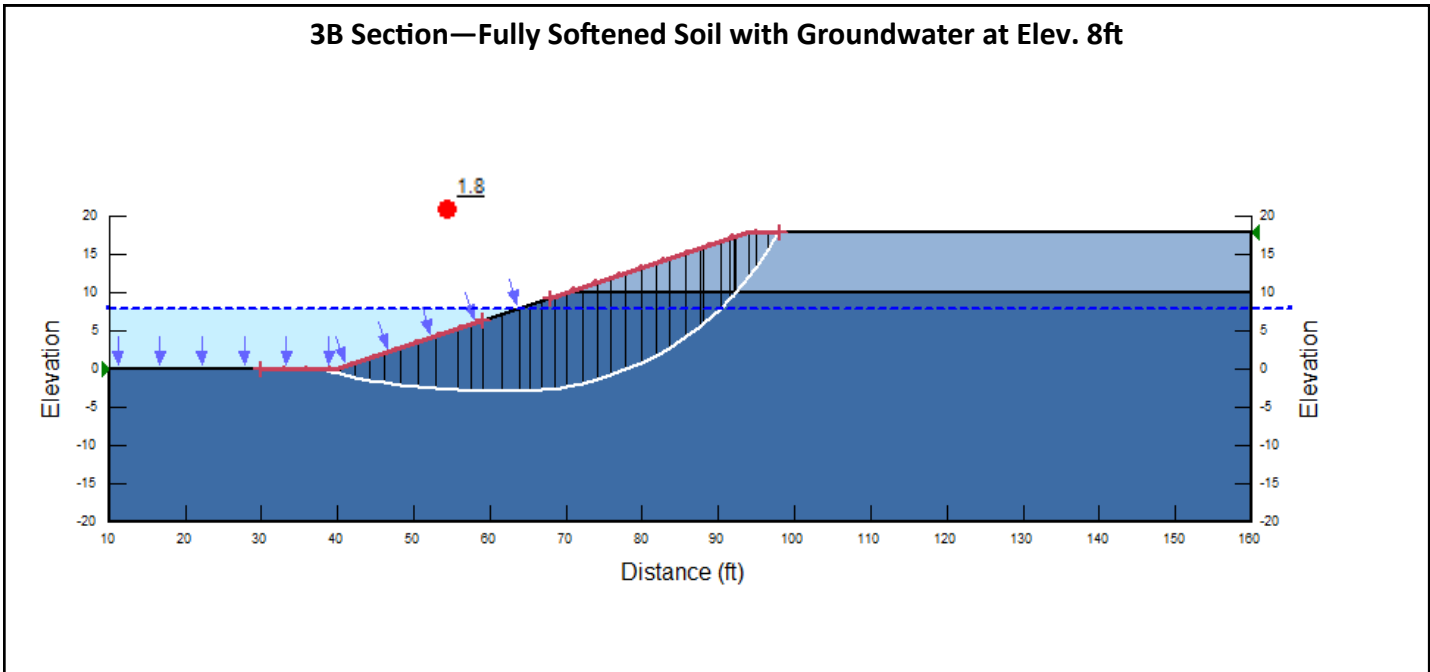
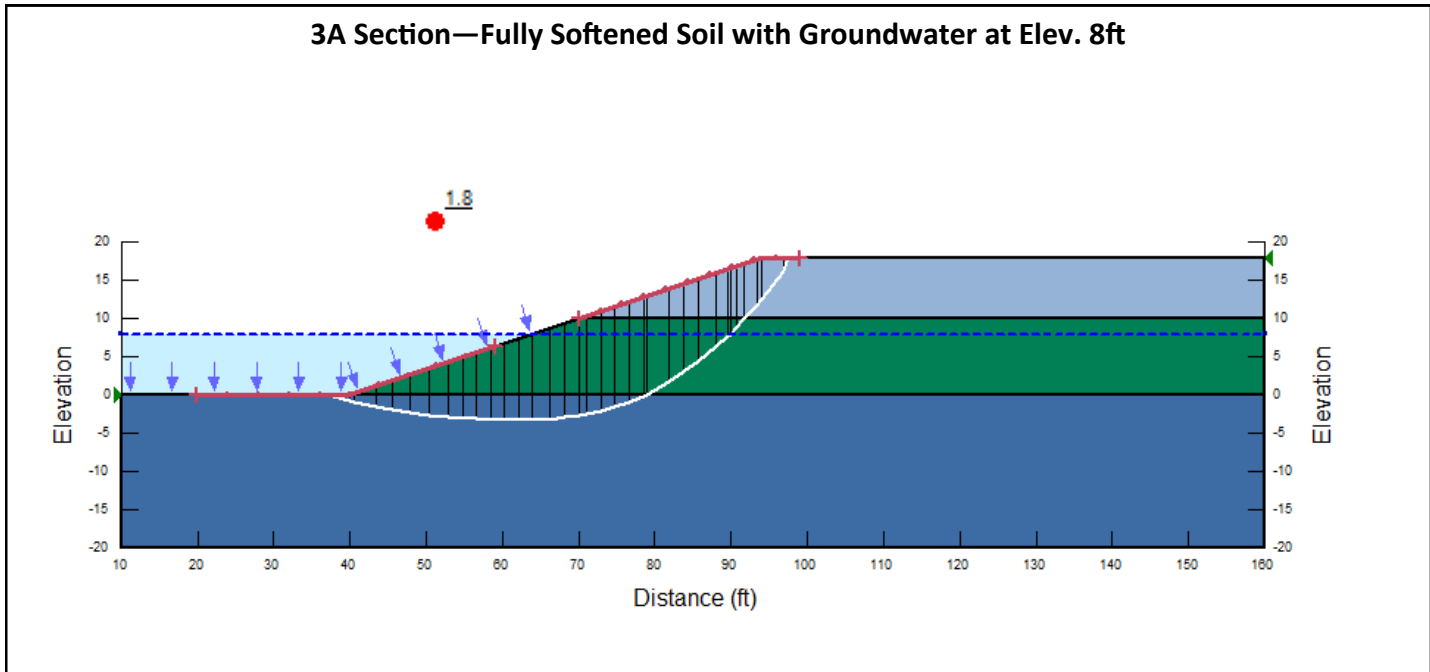
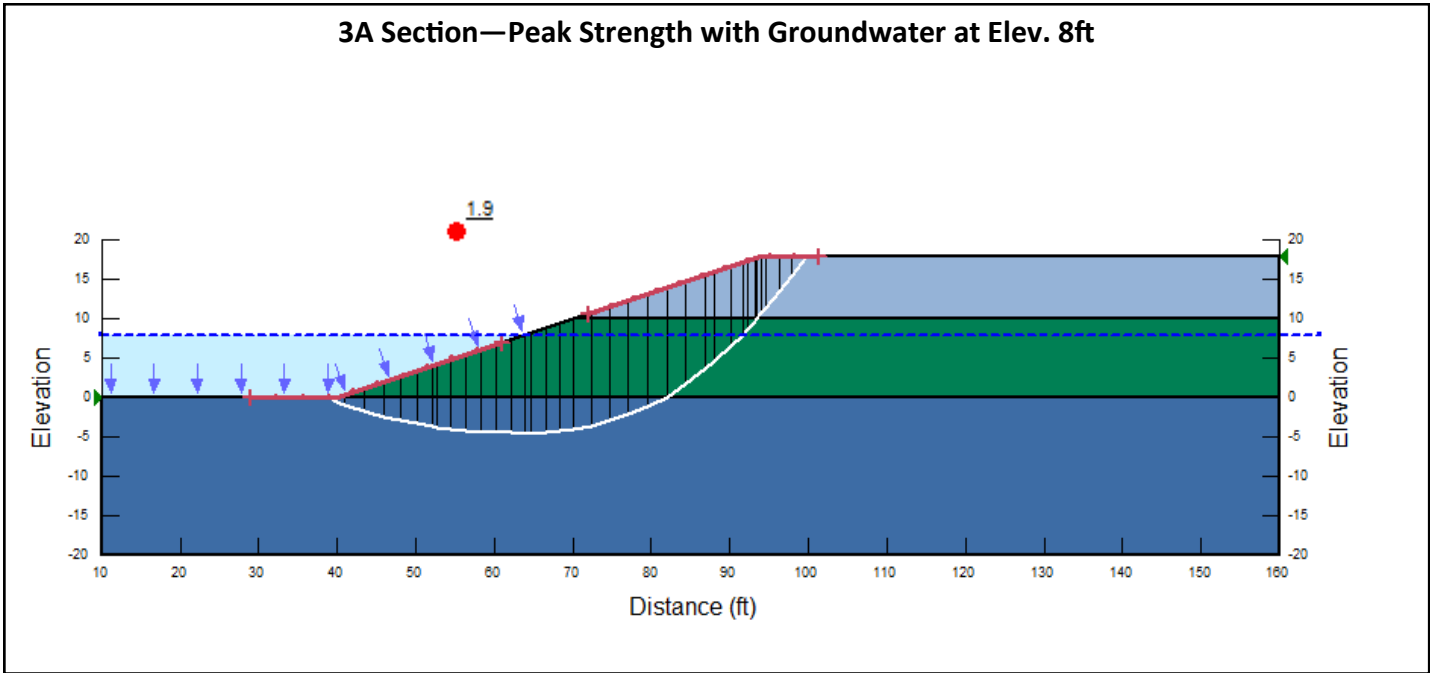
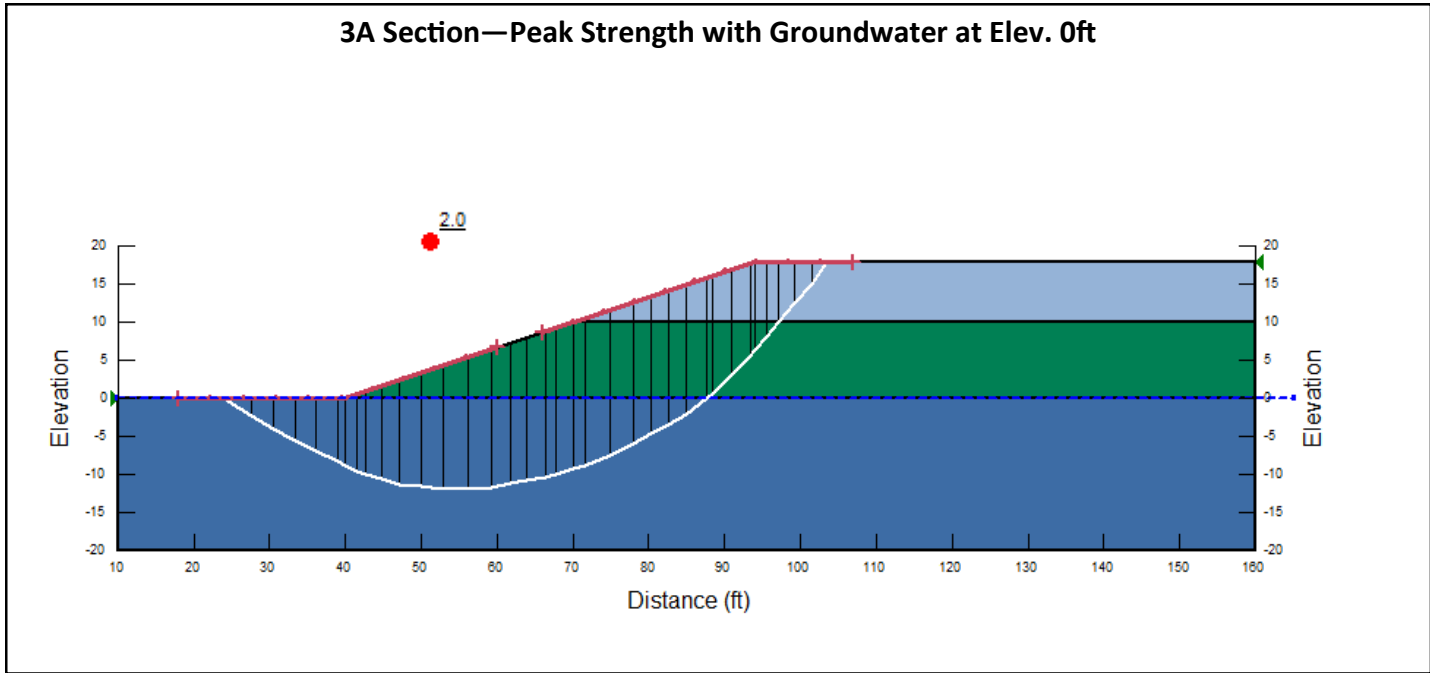
Piece-Wise Function M-C Values

Description:		FSS, Average	
Normal Stress Range		ϕ'	c'
0	1,000	27.4	0.0
1,000	5,000	17.3	225.9
5,000	10,000	13.9	530.2
10,000	12,000	0.0	3007.5

Straight-Line Fit Line Mohr-Coulomb Parameters

Normal Stress Range Maximum:	2000	Friction ϕ':	22.0	Effect. Cohesion:	100.0
-------------------------------------	------	-------------------------------------	------	--------------------------	-------

FIGURE 7



Material Type	Moist Unit Weight	Drained Conditions		Drained Conditions (FSS)	
	y, pcf	ϕ' (degrees)	c' (psf)	ϕ' (degrees)	c' (psf)
Clay (CL)*	125	26	100	20	100
SP-SM/SW-SM/SP-SC	125	30	25	30	25
Fat Clay (CH)*	125	22	100	20	100

* When used, fully softened shear strength denoted by "FSS"

Legend	
---	Phreatic Surface
+	Slip Surface Entry and Exit
●	Calculated Factor of Safety
↓↓↓↓↓	Surcharge Load (if used)

General Notes:

1. All elevations are in NAVD88 feet mean sea level (feet-msl).
2. Internal embankment features/zones and foundation stratigraphy are approximate and presented for illustrative purposes only.
3. Foundation stratigraphy estimated from FNI borings (2014) in conjunction with historical borings (1948).
4. Phreatic surfaces estimated from seepage analysis results and piezometric logs where applicable.

FNI PROJECT: HCF16526

FILE: T:\GEO\Slope Stability

DATE: February 2017

PREPARED BY: FS

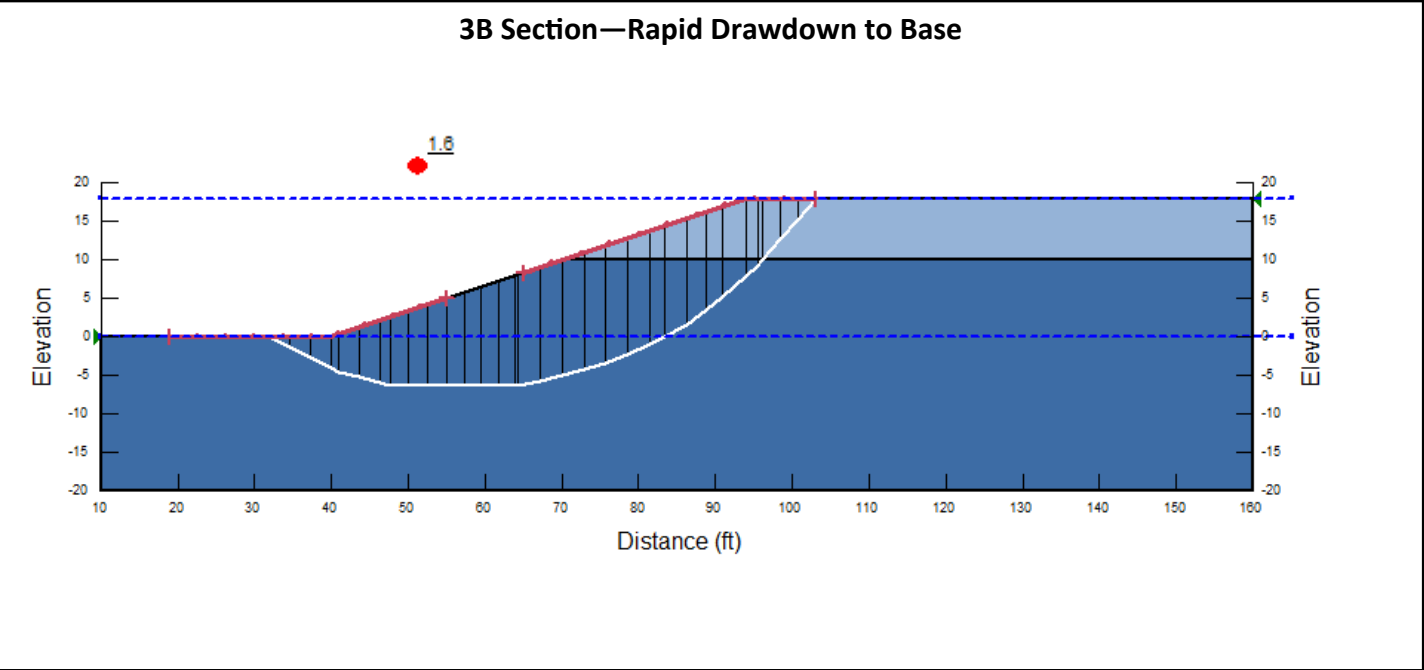
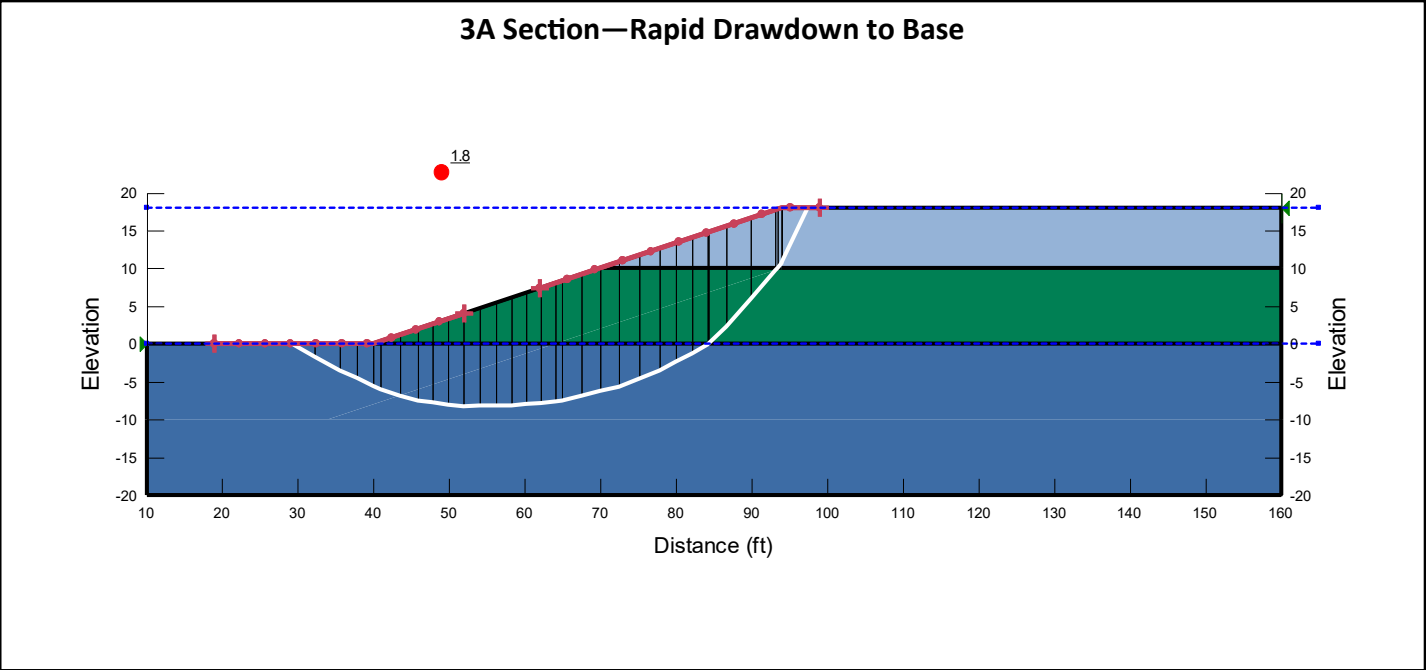
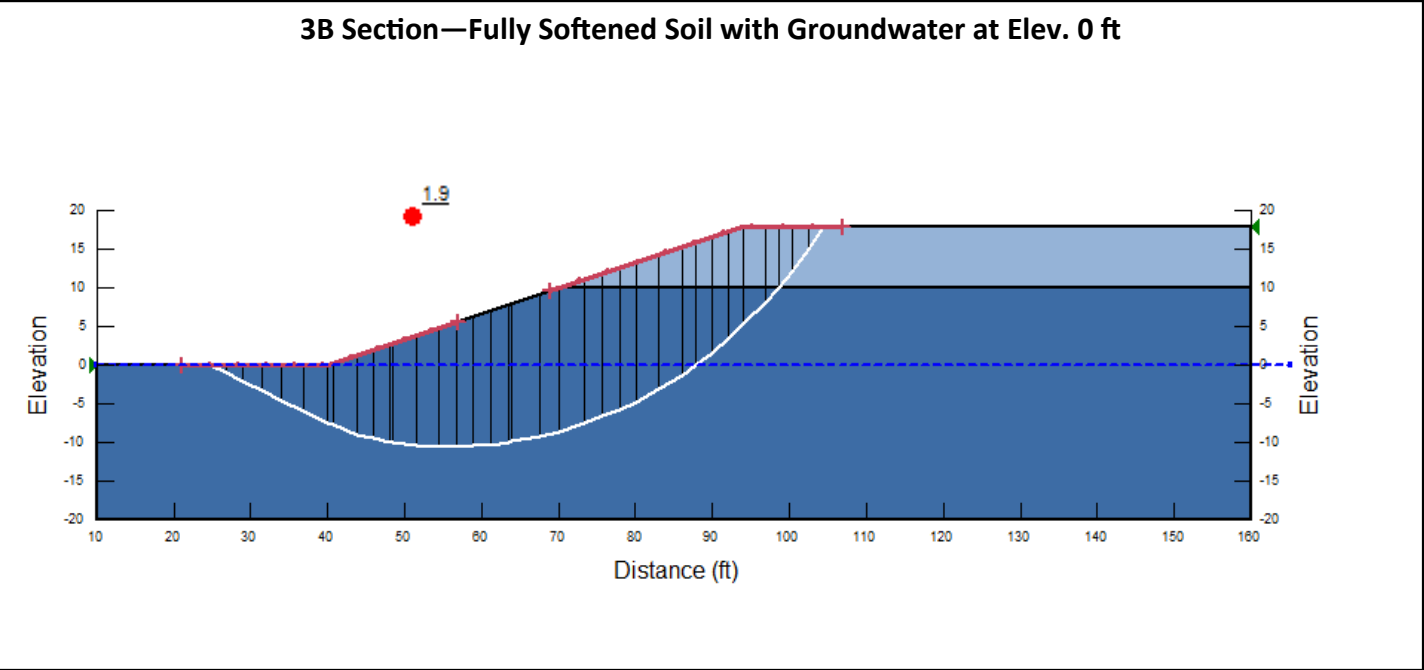
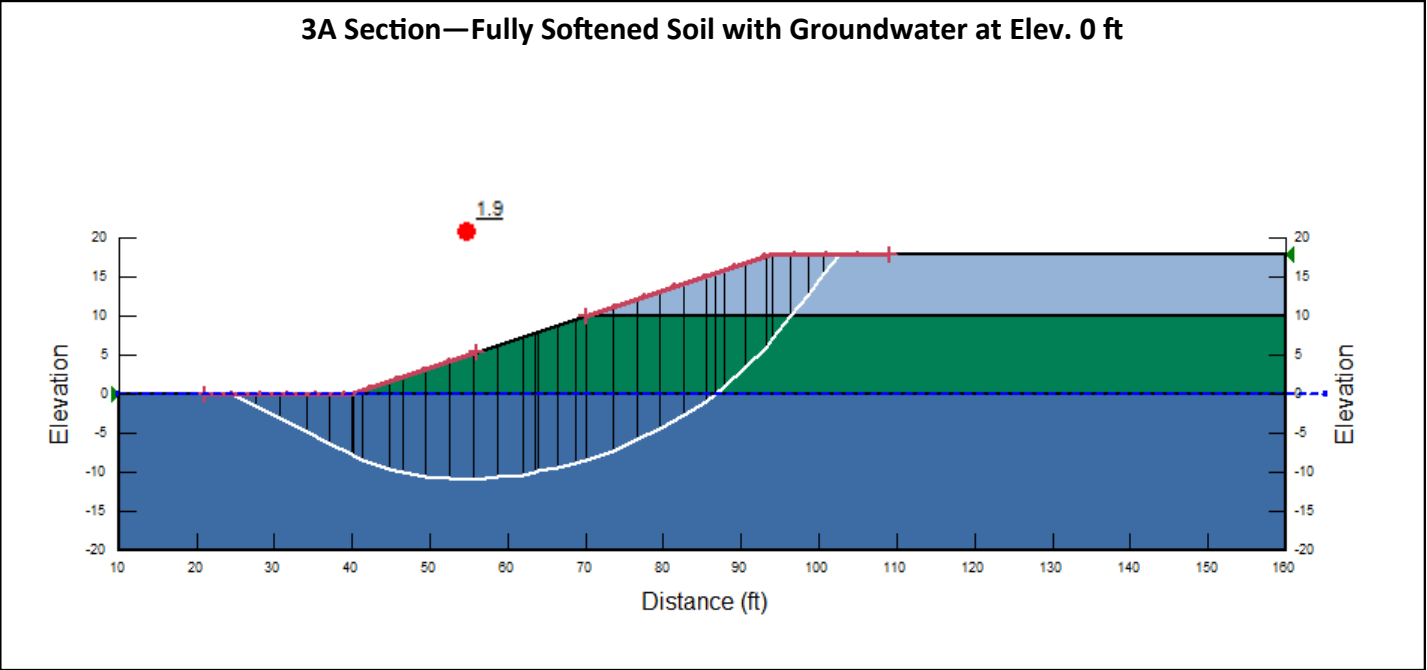
HARRIS COUNTY FLOOD CONTROL DISTRICT
WHITE OAK BAYOU

SLOPE STABILITY ANALYSIS
TYPICAL SECTION

FIGURE

8

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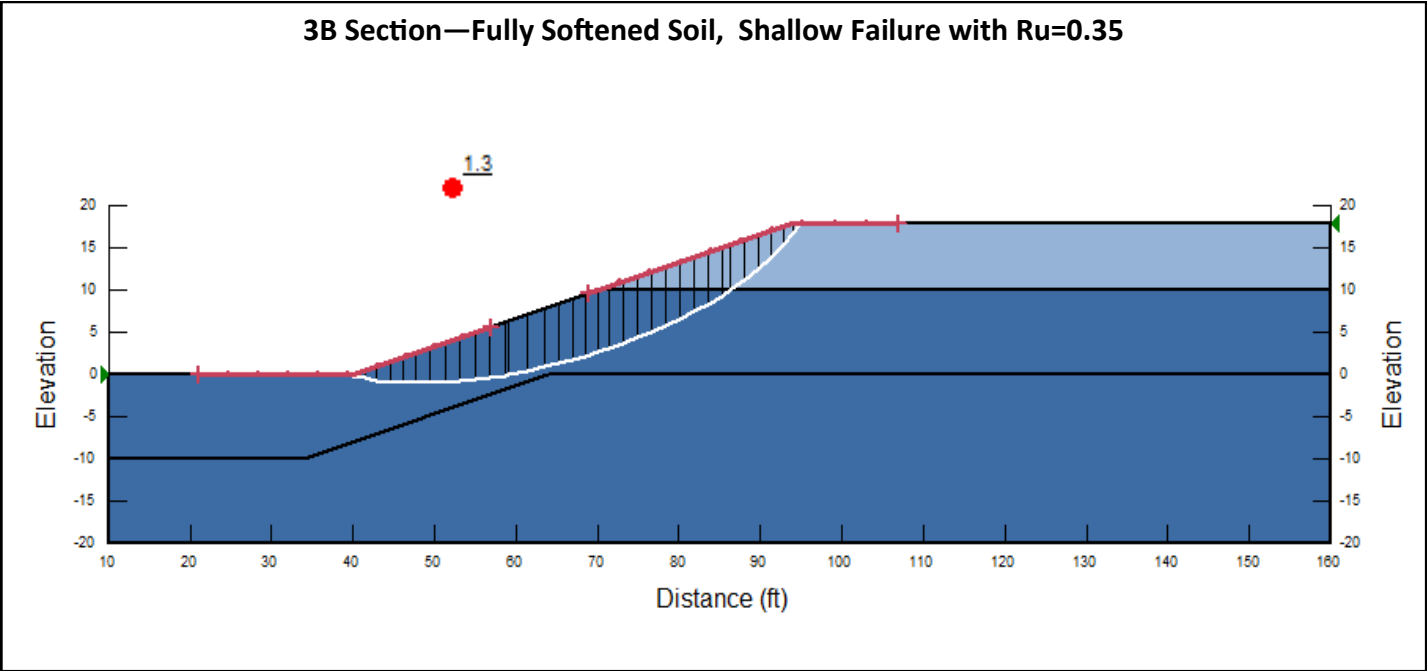
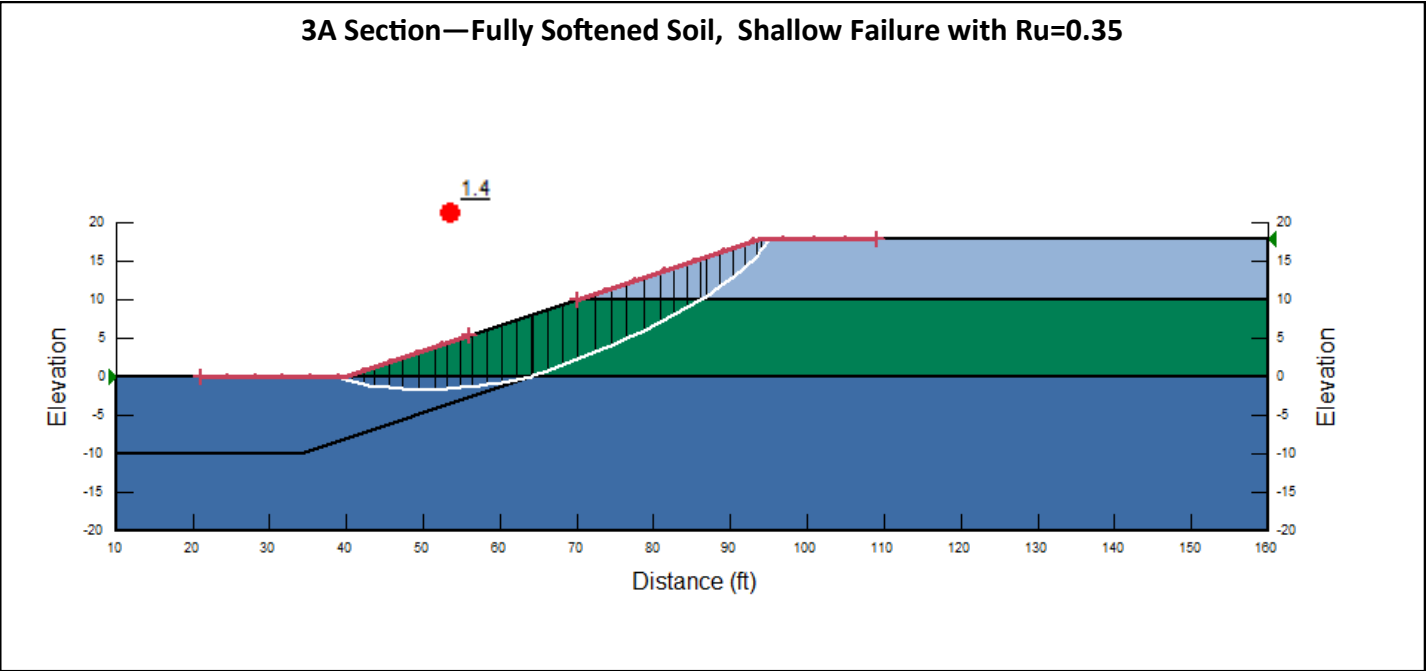
Material Type	Moist Unit Weight	Drained Conditions		Drained Conditions (FSS)	
	y, pcf	ϕ' (degrees)	c' (psf)	ϕ' (degrees)	c' (psf)
Clay (CL)*	125	26	100	20	100
SP-SM/SW-SM/SP-SC	125	30	25	30	25
Fat Clay (CH)*	125	22	100	20	100

Legend	
	Phreatic Surface
	Slip Surface Entry and Exit
	Calculated Factor of Safety
	Surcharge Load (if used)

* When used, fully softened shear strength denoted by “FSS”

- General Notes:**
- All elevations are in NAVD88 feet mean sea level (feet-msl).
 - Internal embankment features/zones and foundation stratigraphy are approximate and presented for illustrative purposes only.
 - Foundation stratigraphy estimated from FNI borings (2014) in conjunction with historical borings (1948).
 - Phreatic surfaces estimated from seepage analysis results and piezometric logs where applicable.

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Material Type	Moist Unit Weight	Drained Conditions		Drained Conditions (FSS)	
	y, pcf	ϕ' (degrees)	c' (psf)	ϕ' (degrees)	c' (psf)
Clay (CL)*	125	26	100	20	100
SP-SM/SW-SM/SP-SC	125	30	25	30	25
Fat Clay (CH)*	125	22	100	20	100

* When used, fully softened shear strength denoted by “FSS”

Legend	
	Phreatic Surface
	Slip Surface Entry and Exit
	Calculated Factor of Safety
	Surcharge Load (if used)

General Notes:

- All elevations are in NAVD88 feet mean sea level (feet-msl).
- Internal embankment features/zones and foundation stratigraphy are approximate and presented for illustrative purposes only.
- Foundation stratigraphy estimated from FNI borings (2014) in conjunction with historical borings (1948).
- Phreatic surfaces estimated from seepage analysis results and piezometric logs where applicable.

FNI PROJECT: HCF16526
FILE: T:\GEO\Slope Stability
DATE: February 2017
PREPARED BY: FS

**FRESE
NICHOLS**
4055 International
Plaza Suite 200
Fort Worth, TX 76109

HARRIS COUNTY FLOOD CONTROL DISTRICT
WHITE OAK BAYOU
SLOPE STABILITY ANALYSIS
TYPICAL SECTION

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APPENDIX B

FLOOD RISK MANAGEMENT ANALYSIS

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MEMORANDUM



Innovative approaches
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TO: Harris County Flood Control District (HCFCD)
FROM: Blaine Laechelin, P.E.
SUBJECT: Flood Risk Management Analysis
DATE: June 5, 2017
PROJECT: White Oak Bayou Channel Restoration



As part of the White Oak Bayou Channel Restoration Project, FNI was requested by HCFCD to perform an analysis of flood risk impacts related to the possible restoration of the reach of White Oak Bayou downstream of Taylor Street and upstream of Hogan Street in order to remove the concrete lining that is currently in place to stabilize the channel and provide enhanced flow conveyance during storm events. Primarily, it was necessary to demonstrate that any proposed alternative channel configurations would not negatively impact flood risk in the immediate study area or in upstream reaches of White Oak Bayou. These proposed alternatives for channel restoration are as follows:

- Alternative 1 – Low Impact Alternative: Channel modification is limited to existing HCFCD right-of-way (ROW) and is designed to retain existing trail features in their current locations.
- Alternative 2 – Expansion North of Channel: Channel modifications are expanded to the north of the channel into existing green space in order to provide for additional geomorphic floodplain, intermediate benches in channel slope, and linear detention.
- Alternative 3 – Expansion North and South of Channel: Channel modifications are expanded to existing green space to the north and south of the channel to further enhance floodplain, benching, and linear detention.

Each alternative was developed within the White Oak Bayou hydraulic model and evaluated for the 1-, 2-, and 10-percent flood conditions. Modifications included reshaping of channel cross-sections to accommodate adjusted channel geometry and the adjustment of channel roughness coefficients to account for the removal of concrete from the bottom of the channel. After verifying no negative impact as a result of the proposed channel restoration approaches, an evaluation of beneficial impacts to water surface elevations and inundation of areas adjacent to the channel was conducted. The depths of inundation of parcels within the floodplain were used to estimate the likelihood of structural flooding and the population present within inundated areas. The revised floodplain mappings were also used to identify critical infrastructure, institutions, and intersections that may benefit from reduced extents of inundation associated with each alternative. No revisions were made to the hydrology found in the existing White Oak Bayou model.

Development of Alternative Cross-Sections

The Draft Risk MAP model for E100-00-00 was used as a starting point for analysis, as directed by the White Oak Bayou Channel Restoration study team. Modifications were made to channel cross-sections in the reach downstream of Taylor Street and upstream of Hogan Street. This area and the studied sections are shown in

Exhibit 1 of this memorandum. Topographic data was also obtained from HCFCD in the form of LIDAR data in GIS to verify existing terrain within the HEC-RAS model. The locations of the existing cross-sections in the model provided by the HCFCD were utilized according to the channel reach lengths and distances through our study reach. No new sections were added to the model to represent the alternatives.

The model from HCFCD for White Oak Bayou was in HEC-RAS 4.00, therefore, alternatives were also developed in this same version. In this analysis, three alternatives were developed to revise the channel through our study reach.

Alternative 1 includes the removal of existing concrete channel bottom, the development of a new geomorphic channel with 3H:1V side slopes, a 40-ft bottom width, and incorporation of a 5-ft high bench areas to add flood storage capacity. This option does not require the realignment of trail facilities that are currently in place. Adjustments were limited to existing HCFCD ROW and existing bridge sections were retained as they currently are in the model, as it was assumed that modifications to these sections would be cost-prohibitive to project development. Channel inverts were set to match the existing cross section's lowest elevation. These modifications were applied to cross sections 4961 through 10643 to create the Alternative 1 proposed geometry.

Alternative 2 expands the channel geometry of Alternative 1 gaining additional flood storage and, in some cases, allows for a double bench in select areas. As in Alternative 1, existing bridge cross-sections were retained. Water quality features will be located in the bench areas and are not reflected within the proposed alternatives since the features will likely be depressed ponds and will be at capacity during significant rainfall events.

Alternative 3 modifies the concept of Alternative 2 by expanding the channel section north of Houston Avenue to include the tract of land owned by the Texas Department of Transportation (TXDOT) to the south of White Oak Bayou. Sections below Houston Avenue were generally identical to those in Alternative 2.

Attachment A summarizes the modified cross-sections through the study reach for Alternatives 1, 2, and 3.

In each alternative, the Manning's n values were adjusted based on the modifications to the channel. The values for each alternative were changed from 0.015 to 0.04 within the channel bottom to reflect removal of the concrete channel and replacement with an earthen lining. The Manning's n values were also revised to 0.04 in the overbanks where excavation was proposed to increase the capacity.

Model Results for Modified Cross Sections

The existing hydrology in the E100-00-00 model was used to evaluate the performance of the proposed alternative cross-sections. It was found that Alternatives 1, 2, and 3 demonstrated progressively greater benefit to the reduction in water surfaces under each of the 1-, 2-, and 10-percent flood conditions. *Figures 1, 2, and 3* illustrate the change in water surface elevation for the 1-, 2-, and 10-percent floods for Alternative 1 and compare results against the base model. *Figures 4, 5, and 6* show similar data for Alternative 2. Finally, *Figures 7, 8, and 9* illustrate the results of the three conditions for Alternative 3. These results demonstrate no significant reduction in flood levels but do not indicate any adverse impacts related to channel restoration.

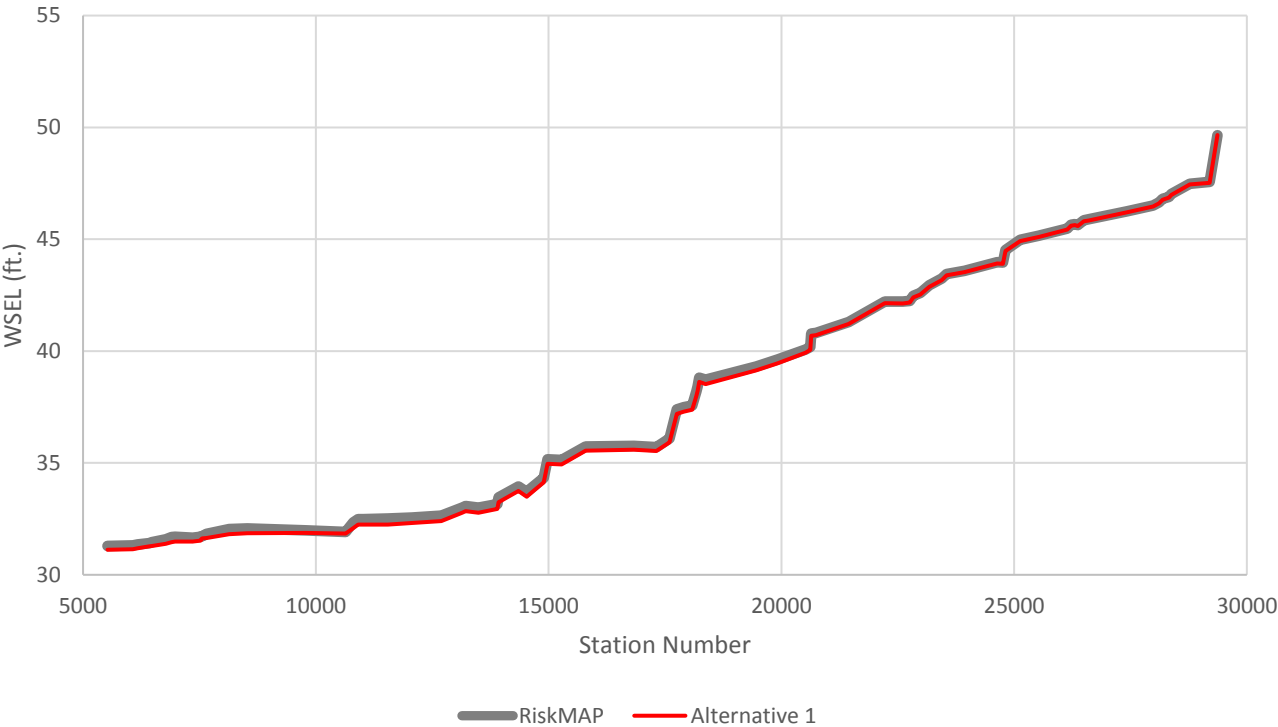


Figure 1: 10-Percent Water Surface Elevation Comparison for Alternative 1

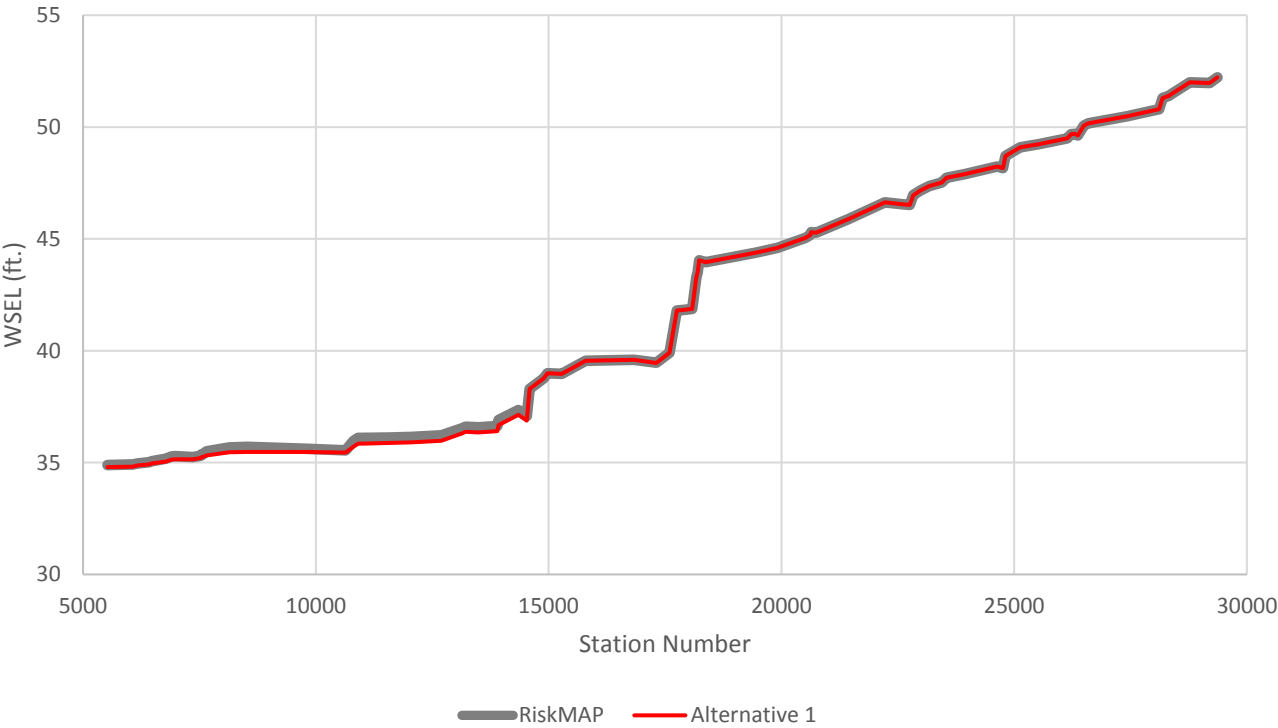


Figure 2: 2-Percent Water Surface Elevation Comparison for Alternative 1

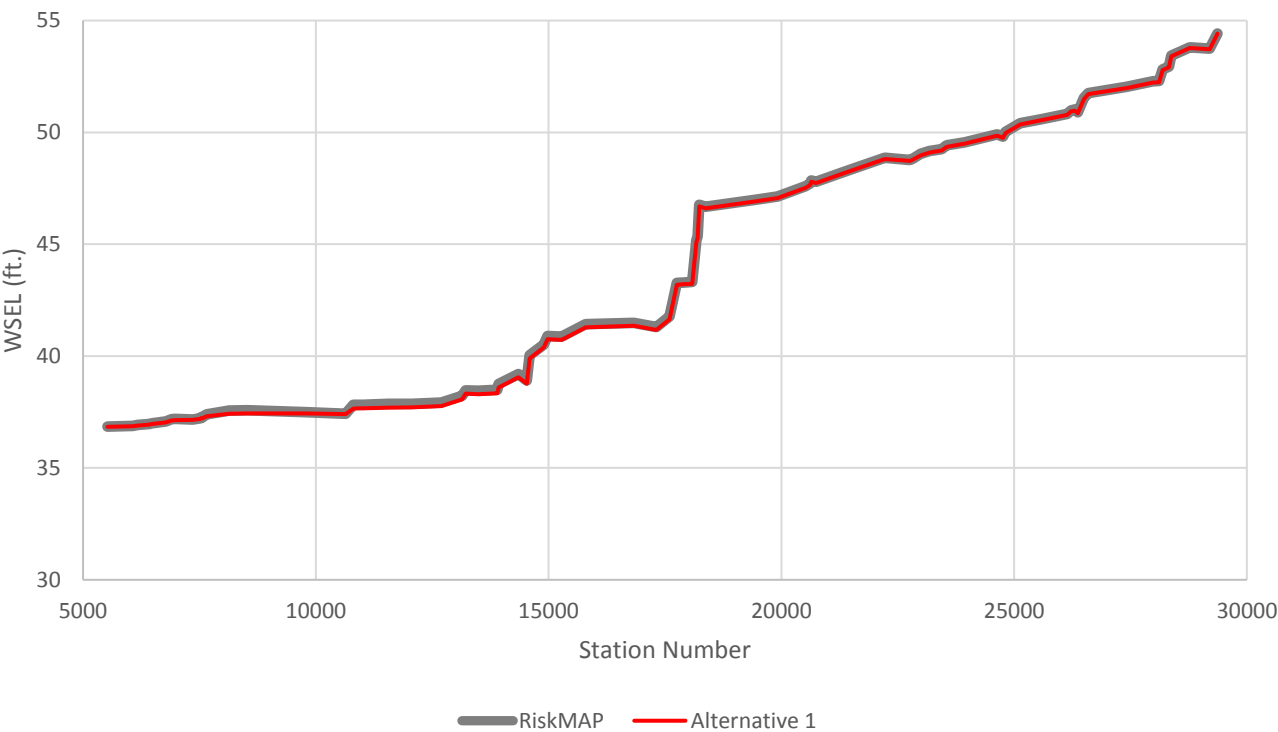


Figure 3: 1-Percent Water Surface Elevation Comparison for Alternative 1

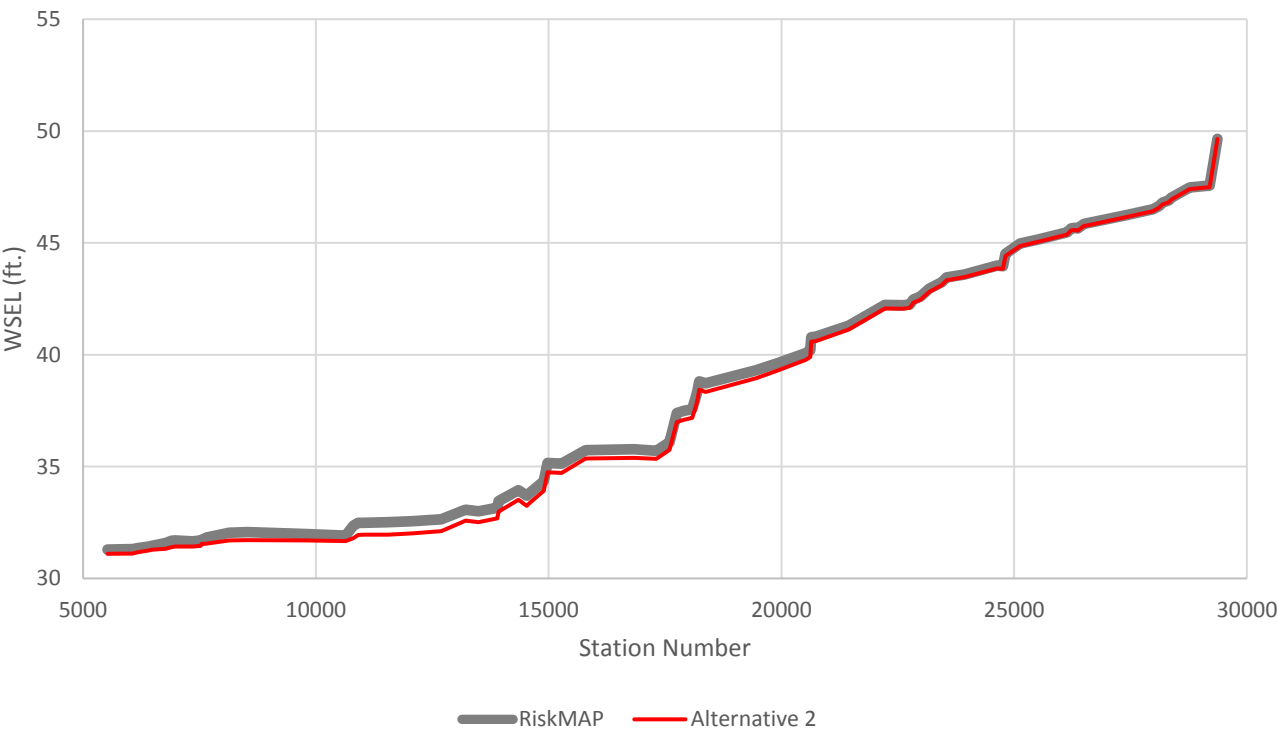


Figure 4: 10-Percent Water Surface Elevation Comparison for Alternative 2

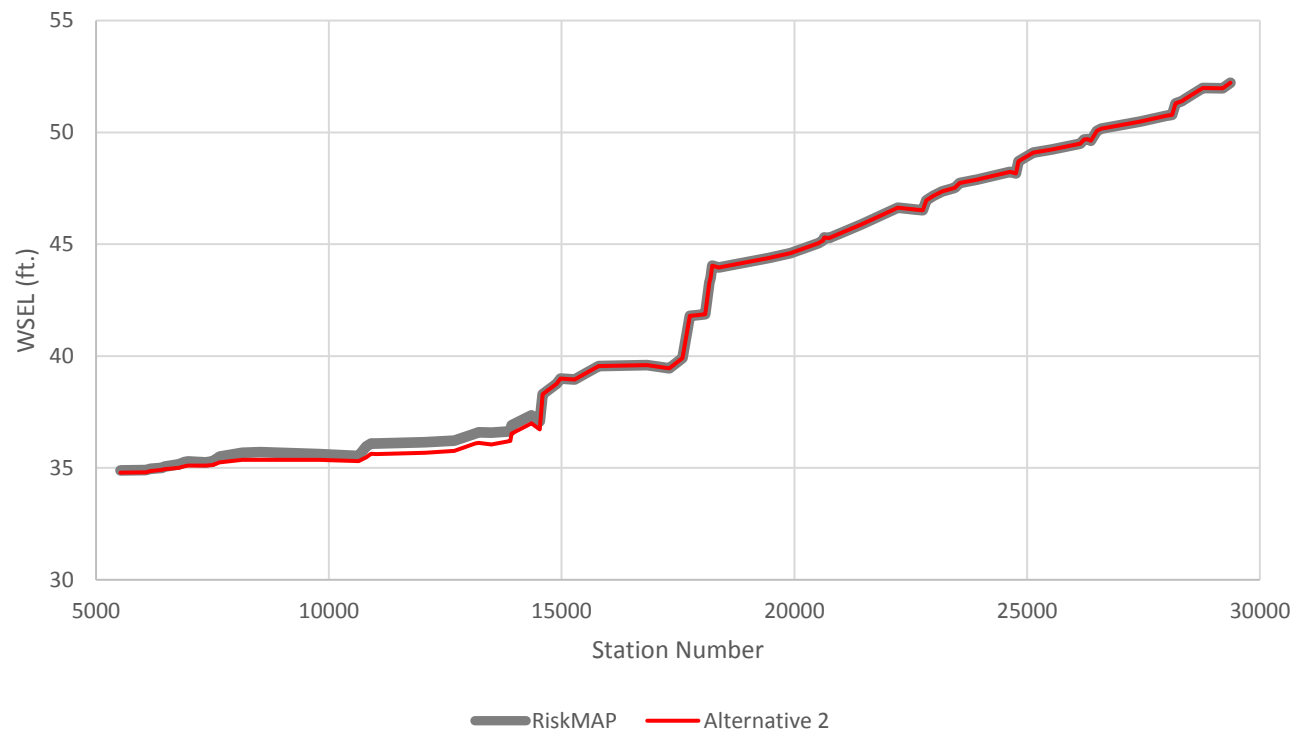


Figure 5: 2-Percent Water Surface Elevation Comparison for Alternative 2

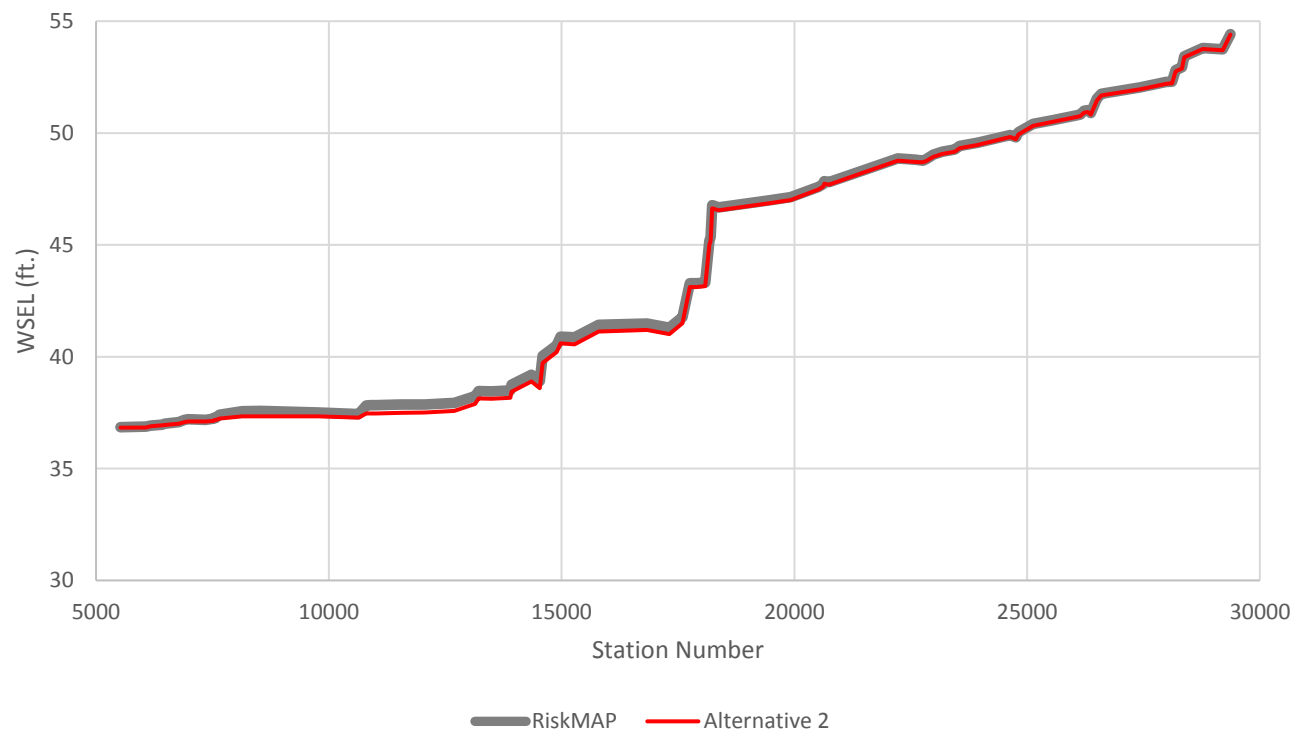


Figure 6: 1-Percent Water Surface Elevation Comparison for Alternative 2

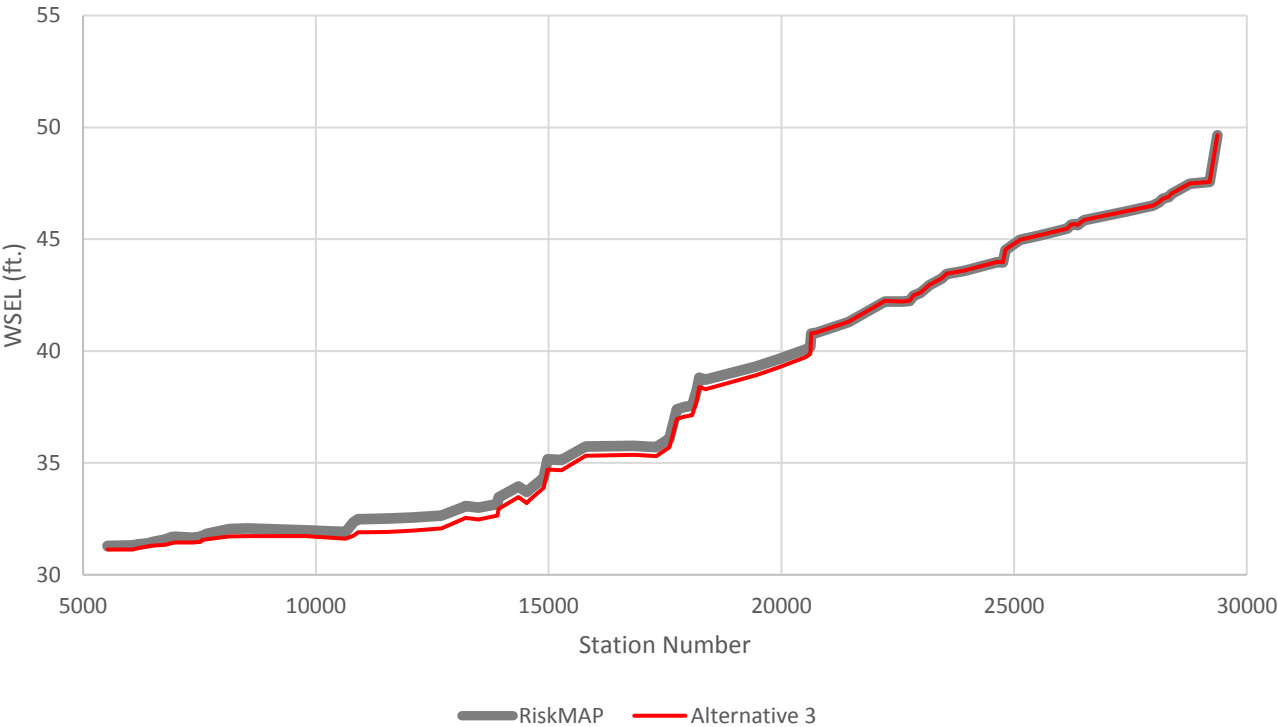


Figure 7: 1-Percent Water Surface Elevation Comparison for Alternative 3

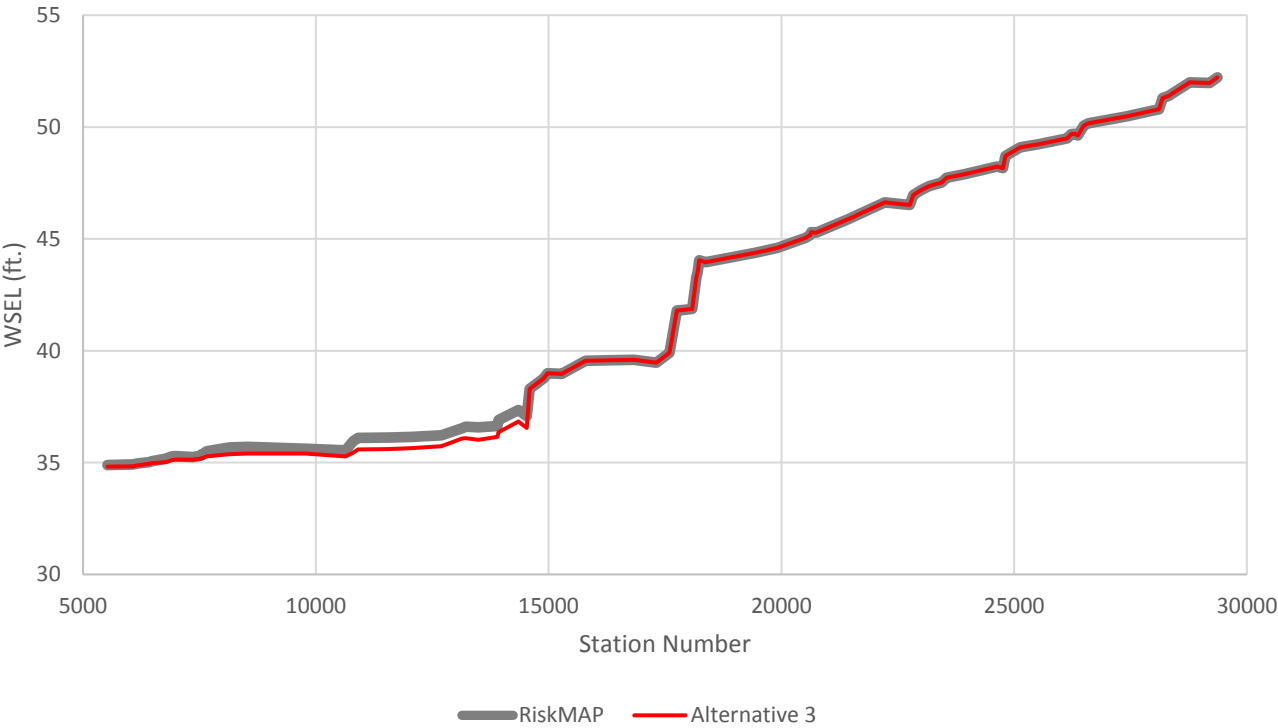


Figure 8: 2-Percent Water Surface Elevation Comparison for Alternative 3

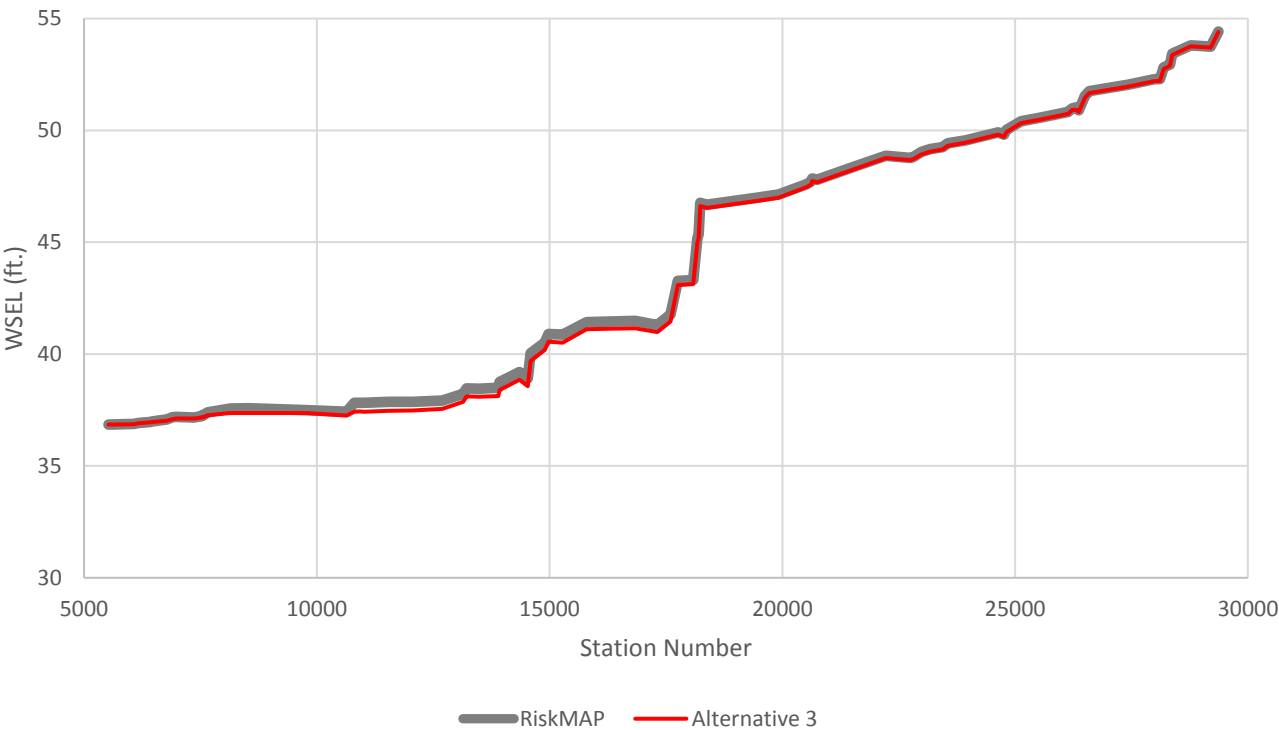


Figure 9: 1-Percent Water Surface Elevation Comparison for Alternative 3

Increase in Linear Detention through Study Reach

Linear detention is related to the volume of storage contained within the model for a given reach at a given flood elevation. This storage within the system may potentially be utilized by projects within the immediate vicinity and upstream of the project area to account for additional runoff that may occur as a result of the development or those projects. For the sake of this study, it was important to characterize this benefit so that the potential for incorporation of other ongoing programs can be considered in conjunction to a potential stream restoration project along White Oak Bayou.

For this analysis, a 1-percent flood condition was assumed for the purpose of comparison. A baseline level of channel storage was determined by comparing the 1-percent flood water surface to the existing ground surface as described by the LiDAR surface for the project area. Volumes were then calculated for the modeled flood level for each alternative and the corresponding modified land surface. All analyses were conducted in Civil3D alongside the development of the baseline and alternative land surfaces.

The differences in flood volume between the various alternatives and the baseline was used to represent the potential linear detention provided by each alternative. This represents a planning level estimation of benefit that could be further refined through additional hydraulic modeling in the future once specific, potential projects are identified. These increases in linear detention are shown below in *Table 1*.

Table 1: Increase in Linear Detention for Each Considered Alternative

Alternative	Increased Linear Detention (Acre-Feet)
1	119.1
2	315.0
3	495.2

Flood Risk Assessment

An analysis of flood risk conducted to identify potential beneficial impacts resulting from each proposed alternative. This includes an evaluation of:

- Number of structures from which the one-percent floodplain has been removed,
- Population from which the one-percent floodplain has been removed, and
- Approximate number of critical facilities and access routes protected.

Floodplains for the 1-percent event were exported for the baseline and each alternative project configuration using HEC-GeoRAS and the current LiDAR layer. These layers were clipped to the current effective floodplain and trimmed to remove model artifacts.

Elevation data for all parcels in the vicinity of White Oak Bayou was studies to assign the mean parcel elevation to each and every parcel in the dataset. These parcel polygons were converted to a point feature located at the centroid of each parcel and assigned an elevation value equal to this mean parcel elevation plus 18-inches (1.5-feet) to represent an assumed finished floor elevation. Parcel points that were located within the current and alternative floodplains were mapped and their elevations compared against the hydraulic model output. These values were used to categorize each parcel in the floodplain into one of three flood status categories described in *Table 2*.

Table 2: Flood Status Criteria Descriptions

Flood Status	Water Surface Elevation at Parcel Centroid
Likely	> Parcel Elevation + 1.5 ft.
Possible	Water Surface > Parcel Elevation but < Parcel Elevation + 1.5 ft.
None	< Parcel Elevation

The change in flood status for each parcel was compared between the baseline and each alternative to provide an estimate of potential benefits related to each proposed restoration alternative. The results of this analysis demonstrate relatively similar benefits related to each alternative, to the point that general values are reported in this study. The resulting numbers of structures which had a reduction in their flood status are shown below in *Table 3*. In addition, U.S. Census data was applied on a block-level basis to estimate the population of residential structures within the identified floodplains. This data provided an estimate of the population for which the flood status has been reduced, as shown in *Table 4*. The location of the parcels benefitting from each alternative are generally shown in *Exhibit 2*.

Table 3: Estimated Change in Flood Status by Parcel Type

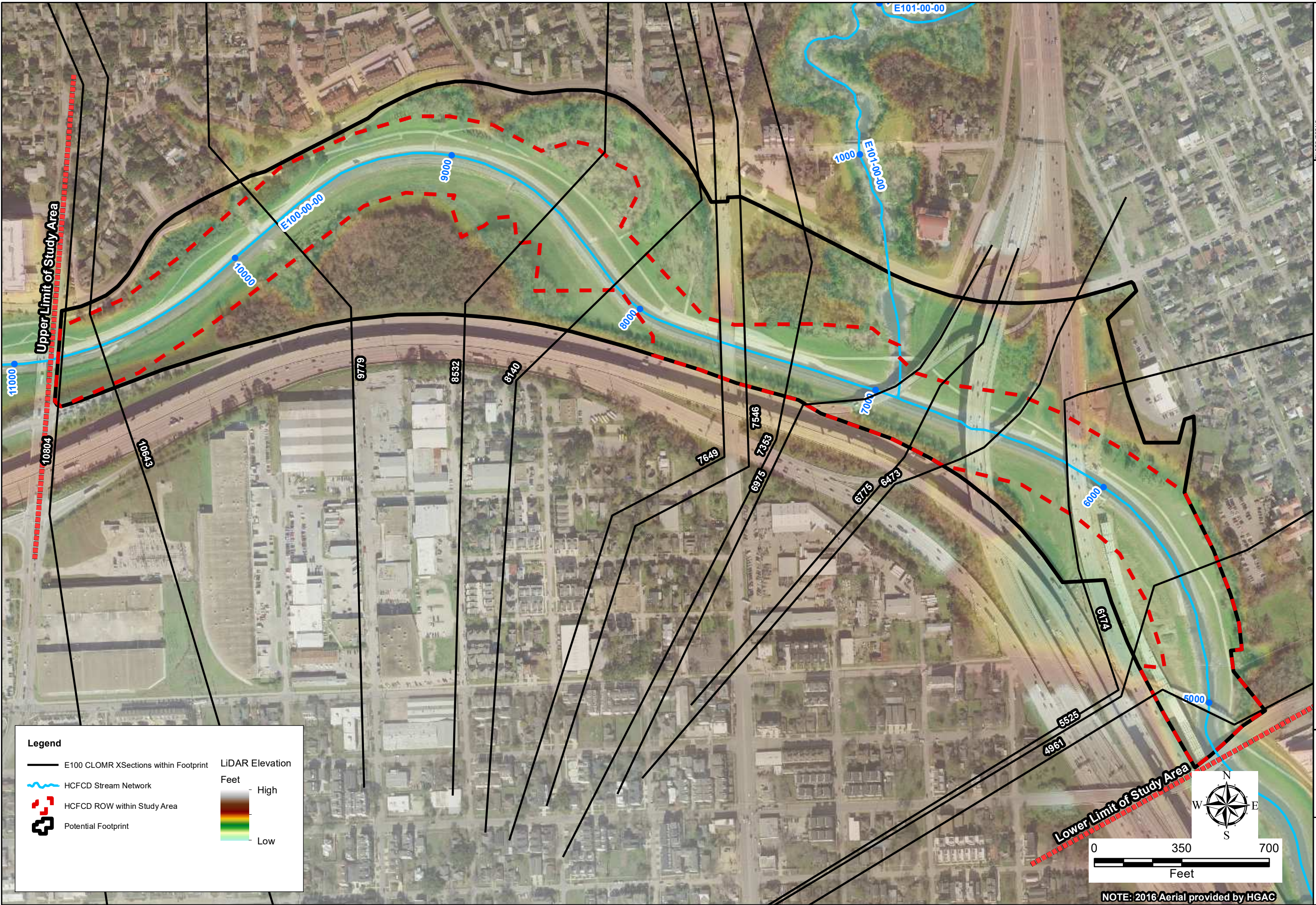
Parcel Type	Change in Status	Proposed Alternative		
		1 (Low Impact)	2 (North)	3 (South)
Non-Residential	Likely to Possibly	~35	~35	~35
	Possibly to None	~20	~20	~20
Residential	Likely to Possibly	~65	~65	~65
	Possibly to None	~120	~120	~120
Total	Likely to Possibly	~100	~100	~100
	Possibly to None	~140	~140	~140

Table 4: Estimated Population Change in Flood Status

Change in Status	Proposed Alternative		
	1 (Low Impact)	2 (North)	3 (South)
Likely to Possibly	~125	~125	~125
Possibly to None	~600	~600	~600

An analysis of available GIS information identified educational institutions, government offices, and medical facilities within the project area as well as roadway intersections. The location of these features relative to the floodplain was used as a basis of estimating flood risk benefit resulting from each proposed alternative. No critical facilities were found to benefit from the proposed channel projects. However, approximately 12 intersections were found to have the one-percent floodplain removed based on the analysis. The relative location of these intersections is shown in *Exhibit 3*.

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Legend

- E100 CLOMR XSections within Footprint
- HCFC Stream Network
- HCFC ROW within Study Area
- Potential Footprint

LiDAR Elevation

Feet

High

Low

Freese and Nichols, Inc.

10497 TOWN AND COUNTRY WAY, SUITE 600
HOUSTON, TEXAS 77024
P: (713) 600-6800
F: (713) 600-6801

EXHIBIT

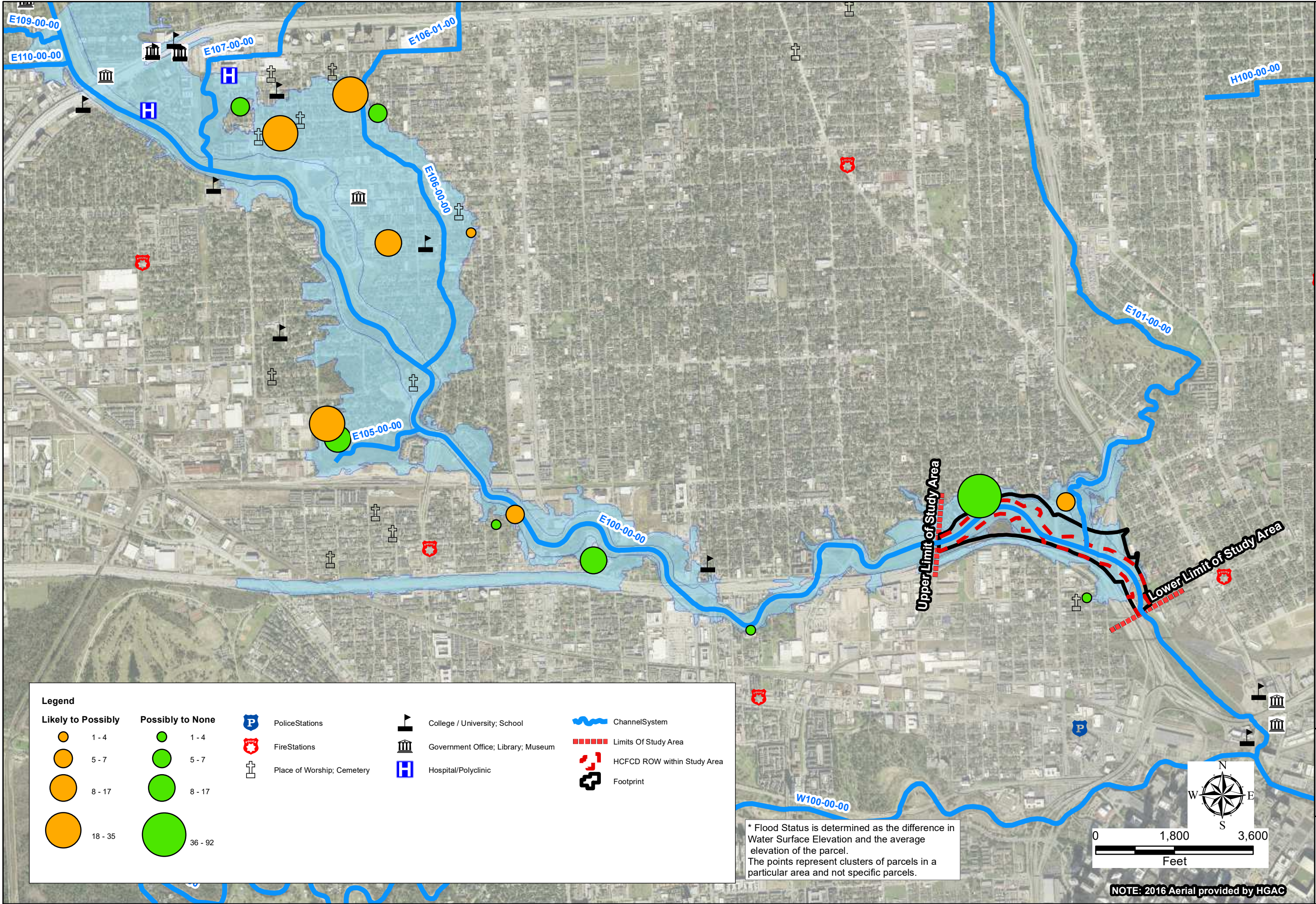
1

HARRIS COUNTY FLOOD CONTROL DISTRICT

Lower White Oak Bayou Channel Restoration Study

Cross Section Map

PROJECT NO.	HCF10026
DATE CREATED	6/7/2017
DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
FILE NAME	Ex1_WhiteOakBayouChannel_XSections
PREPARED BY	DML



Legend

Likely to Possibly

●

1 - 4

●

5 - 7

●

8 - 17

●

18 - 35

Possibly to None

●

1 - 4

●

5 - 7

●

8 - 17

●

36 - 92

P

Police Stations

Fire Stations

Place of Worship; Cemetery

College / University; School

Government Office; Library; Museum

Hospital/Polyclinic

Channel System

Limits Of Study Area

HCFCF ROW within Study Area

Footprint

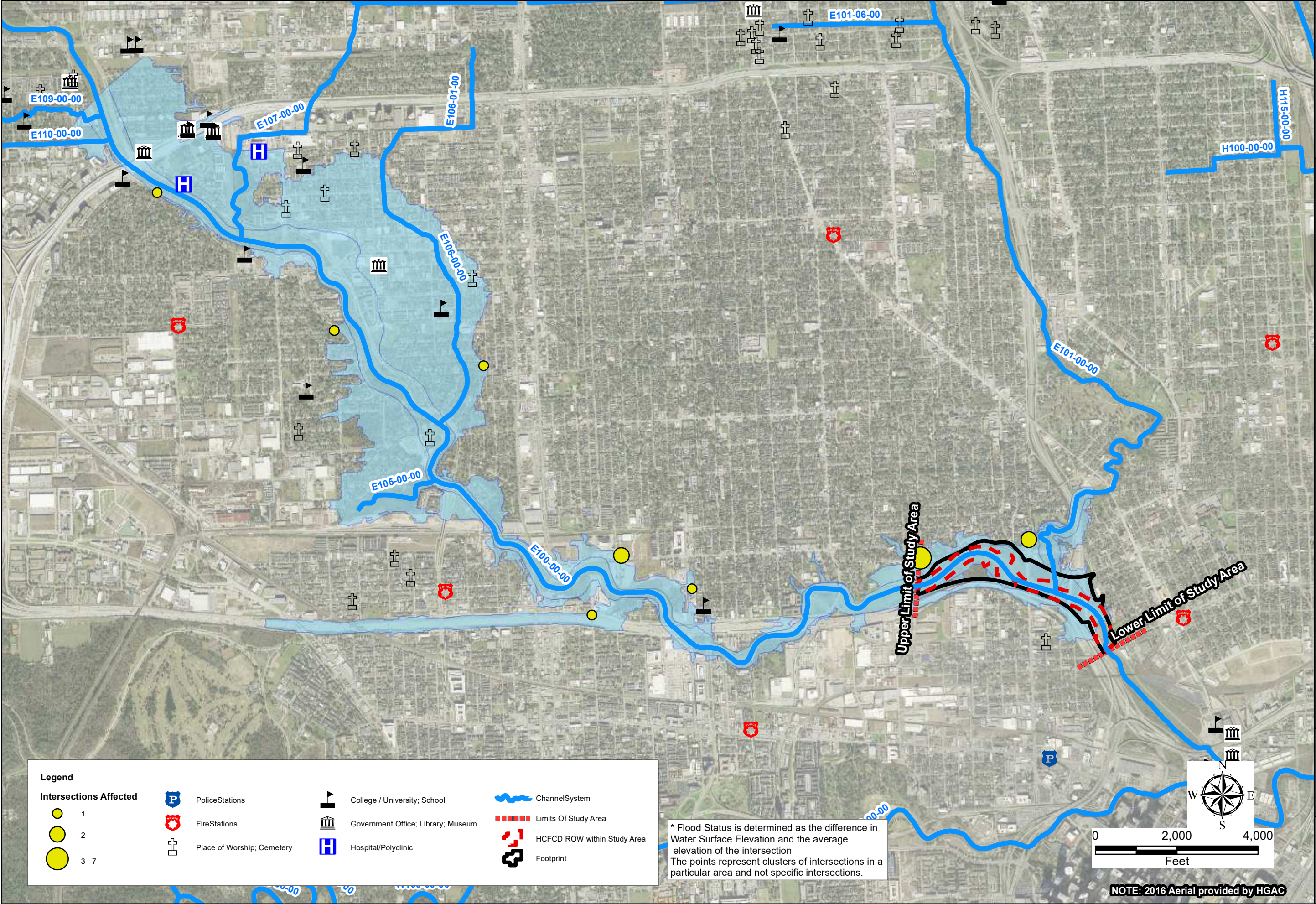
* Flood Status is determined as the difference in Water Surface Elevation and the average elevation of the parcel. The points represent clusters of parcels in a particular area and not specific parcels.

HARRIS COUNTY FLOOD CONTROL DISTRICT		FN PROJECT NO	FBH10032
Lower White Oak Bayou Channel Restoration Study		DATE CREATED	6/7/2017
Estimated Change in Flood Status of Parcels		DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Texas South Central
		FILE NAME	E02_ChangeInFloodStatusParcels
		PREPARED BY	DML
FRESE AND NICHOLS, INC.		EXHIBIT	
10497 TOWN AND COUNTRY WAY, SUITE 600 HOUSTON, TEXAS 77024 P: (713) 600-6800 F: (713) 600-6801		2	

Date Saved: 6/7/2017 4:24:06 PM

Path: H:\WR_PLANNING\Working\Flood Risk Management Memo\Ex2_ChangeInFloodStatusParcels.mxd

NOTE: 2016 Aerial provided by HGAC



Legend

Intersections Affected

● 1

● 2

● 3 - 7

Police Stations

Fire Stations

Place of Worship; Cemetery

College / University; School

Government Office; Library; Museum

Hospital/Polyclinic

Channel System

Limits Of Study Area

HCFCF ROW within Study Area

Footprint

* Flood Status is determined as the difference in Water Surface Elevation and the average elevation of the intersection
The points represent clusters of intersections in a particular area and not specific intersections.

PROJECT NO

DATE CREATED

DATUM & COORDINATE SYSTEM

FILE NAME

PREPARED BY

FBH10072

6/7/2017

NAD83 State Plane (feet) Texas South Central

Ex3_WhiteOakBayouChannel_AffectedIntersections

DML

HARRIS COUNTY FLOOD CONTROL DISTRICT

Lower White Oak Bayou Channel Restoration Study

Estimated Change in Flood Status of Intersections

FREESE AND NICHOLS, INC.

10497 TOWN AND COUNTRY WAY, SUITE 600
HOUSTON, TEXAS 77024
P: (713) 600-6800
F: (713) 600-6801

EXHIBIT

3

Date Saved: 6/7/2017 4:24:43 PM

Path: H:\WR_PLANNING\Working\Flood Risk Management Memo\Ex3_WhiteOakBayouChannel_AffectedIntersections.mxd

Attachment A
Modified Cross-Sections

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Attachment A – Modified Cross-Sections

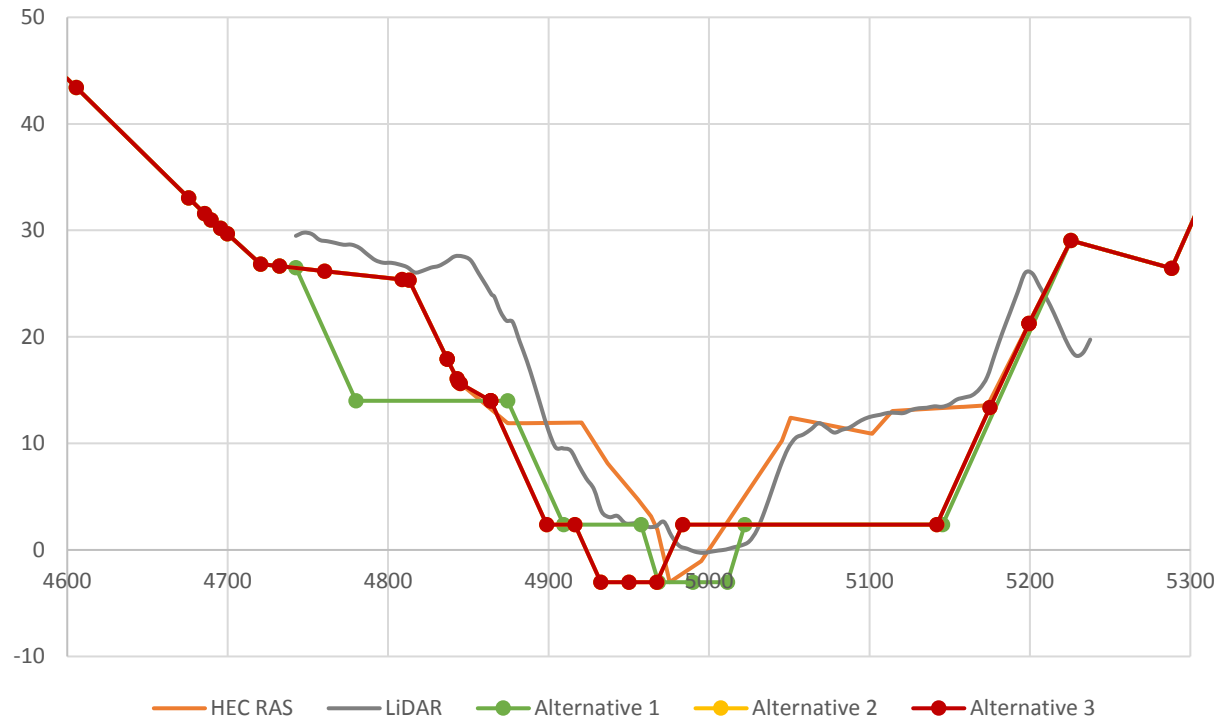


Figure 1: Modified Cross-Section 4961

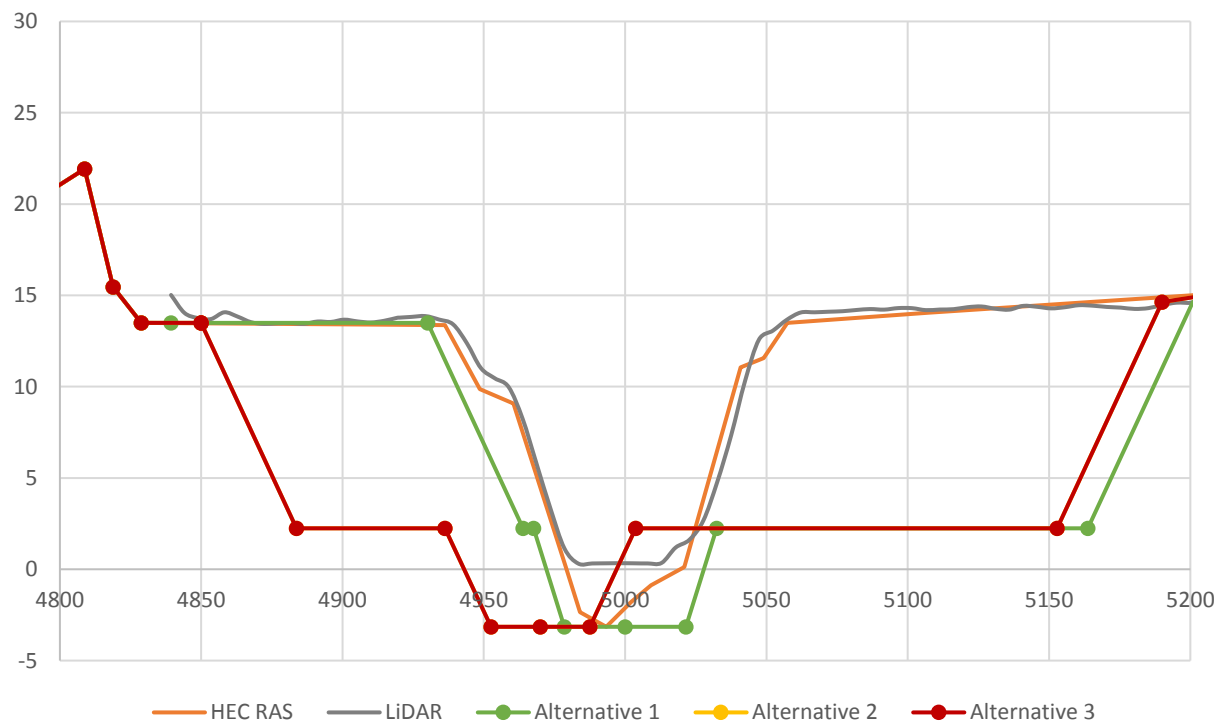


Figure 2: Modified Cross-Section 5525

Attachment A – Modified Cross-Sections

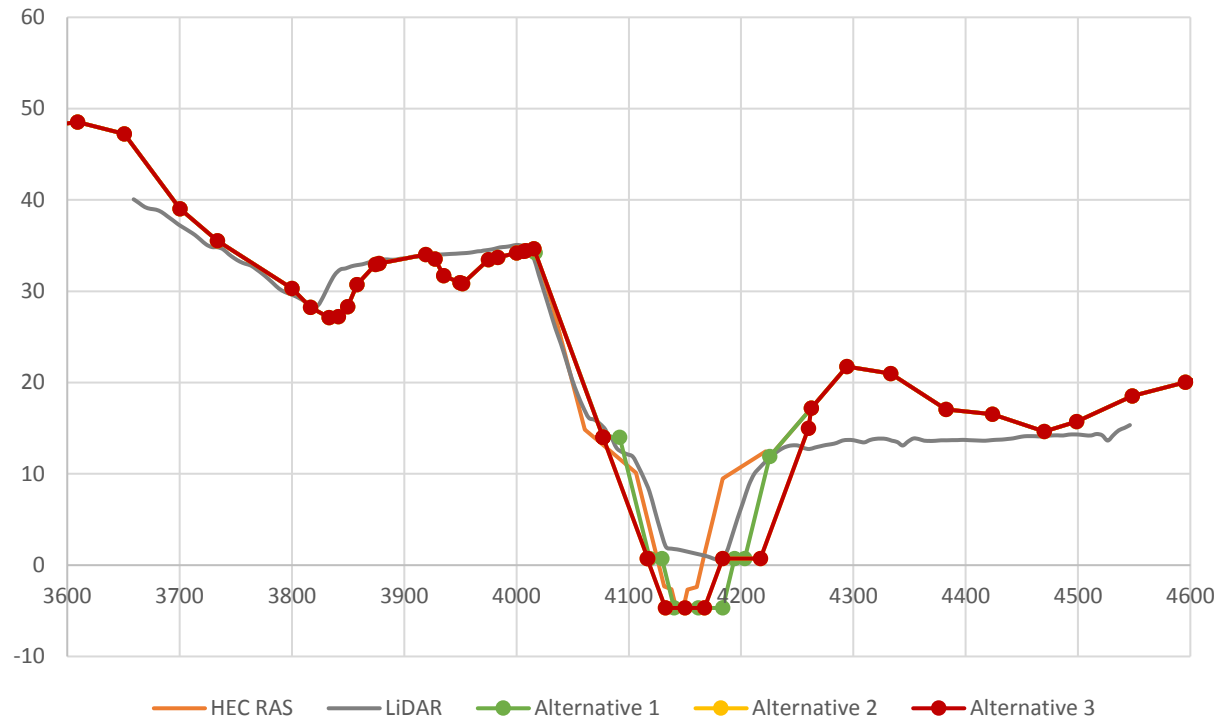


Figure 3: Modified Cross-Section 6174

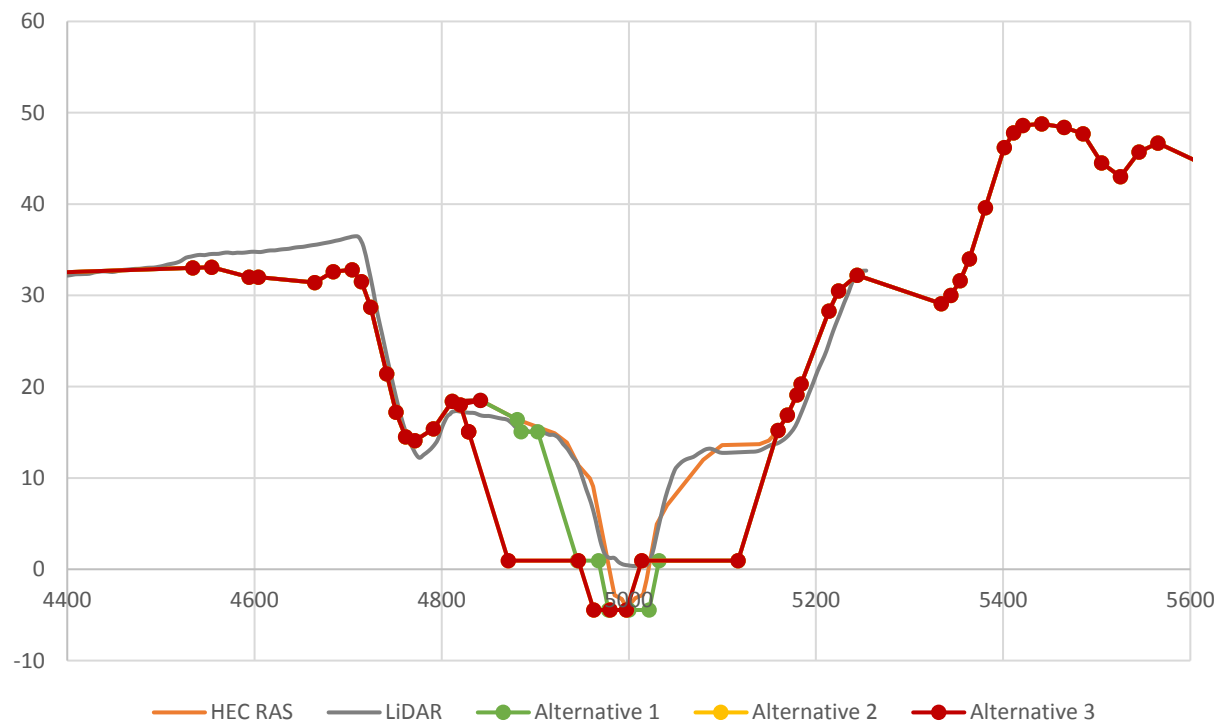


Figure 4: Modified Cross-Section 6473

Attachment A – Modified Cross-Sections

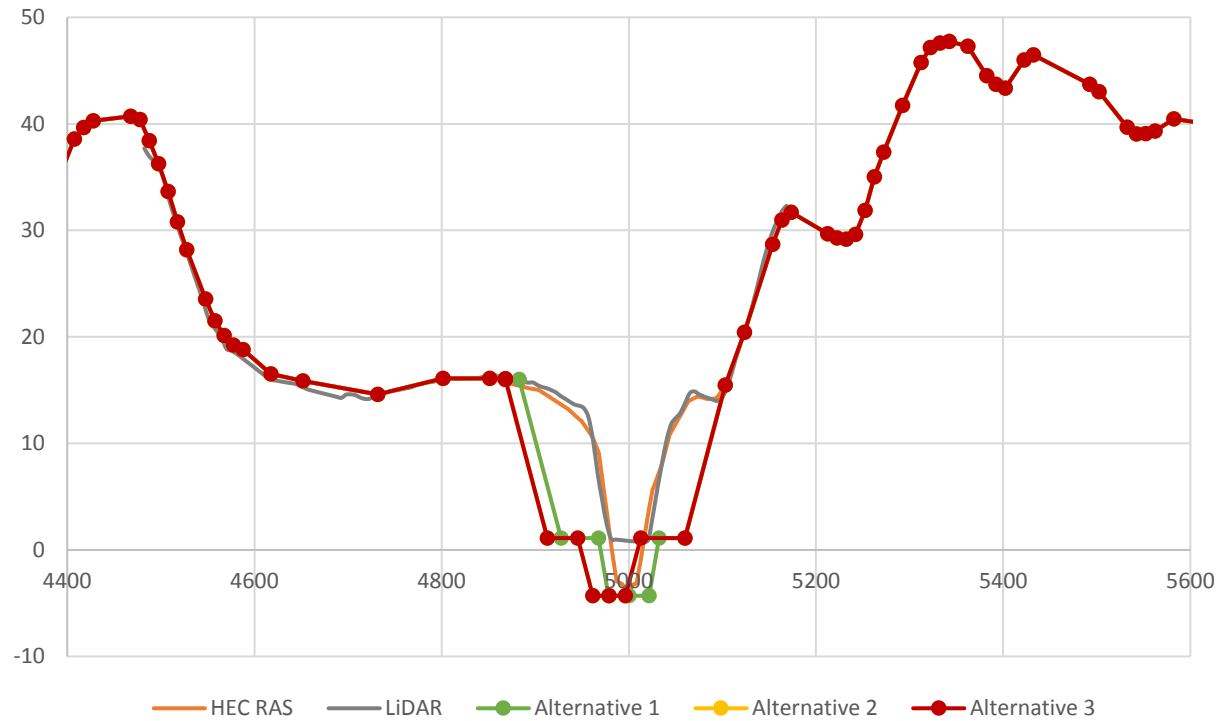


Figure 5: Modified Cross-Section 6775

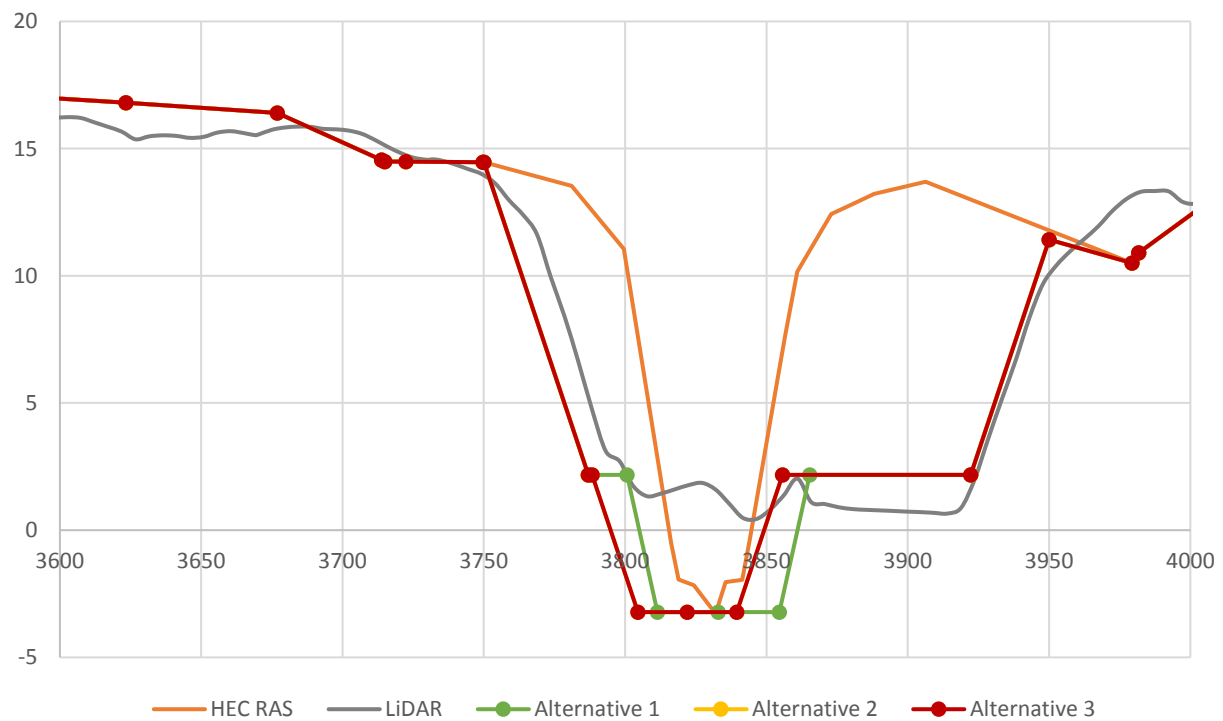


Figure 6: Modified Cross-Section 6975

Attachment A – Modified Cross-Sections

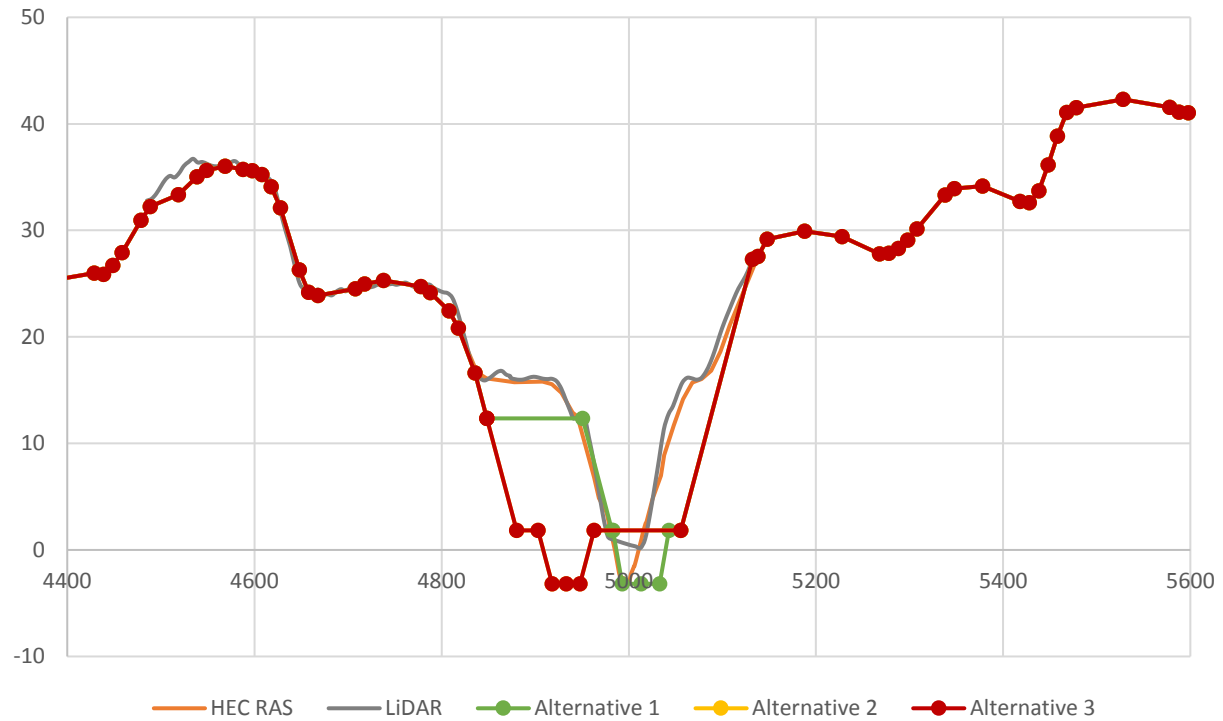


Figure 7: Modified Cross-Section 7353

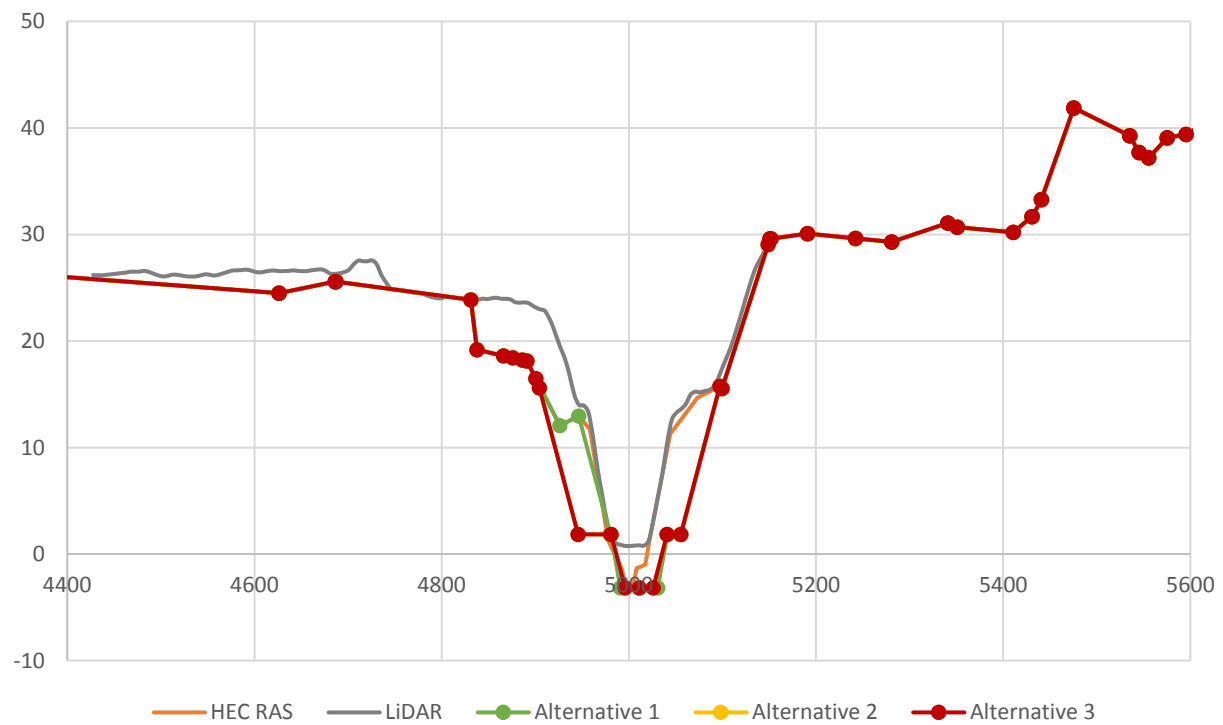


Figure 8: Modified Cross-Section 7546

Attachment A – Modified Cross-Sections

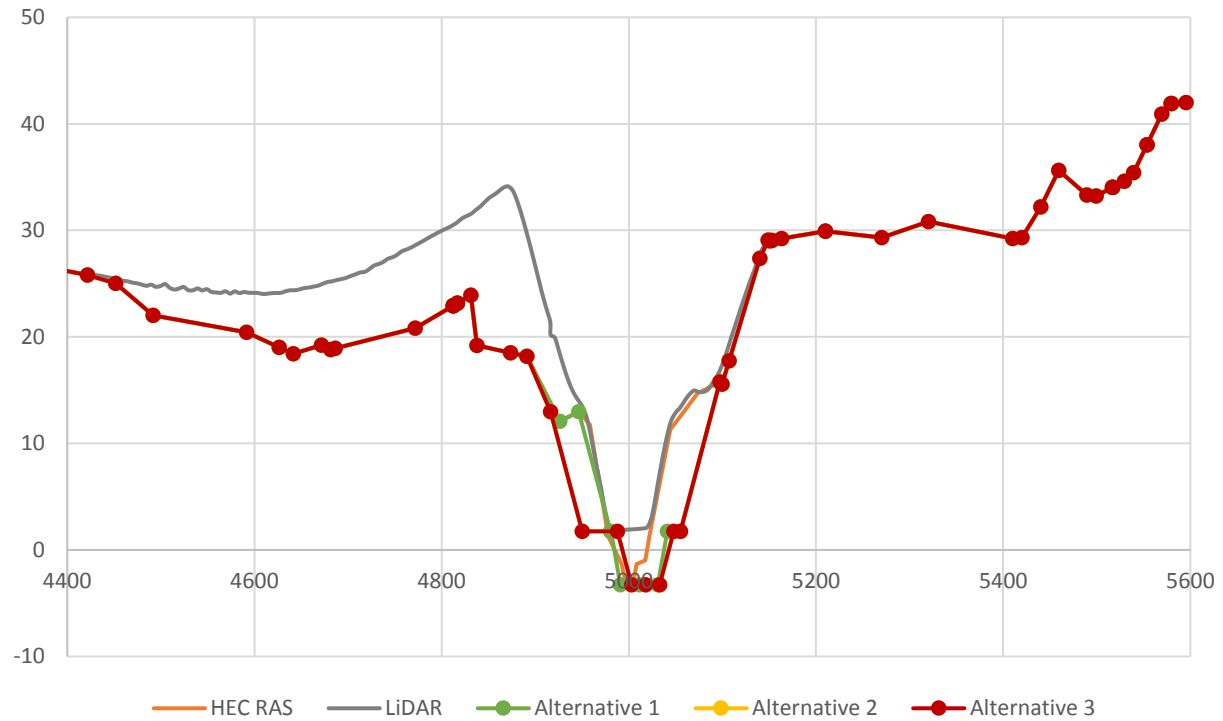


Figure 9: Modified Cross-Section 7649

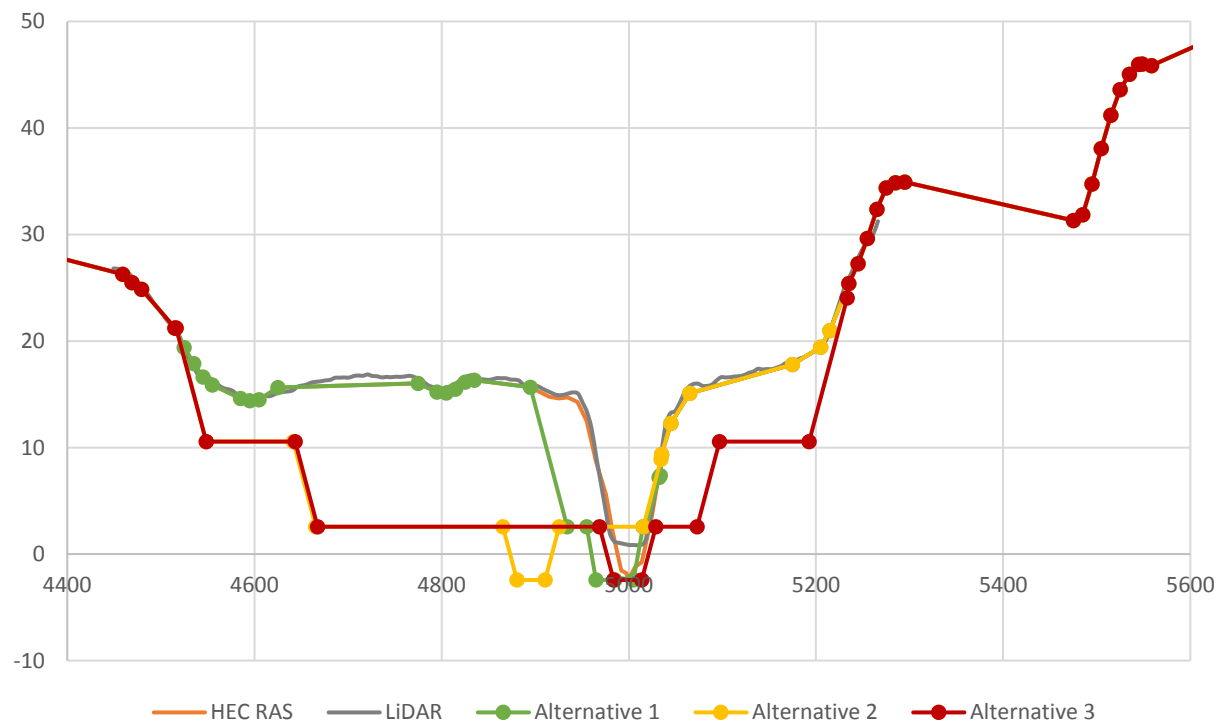


Figure 10: Modified Cross-Section 8140

Attachment A – Modified Cross-Sections

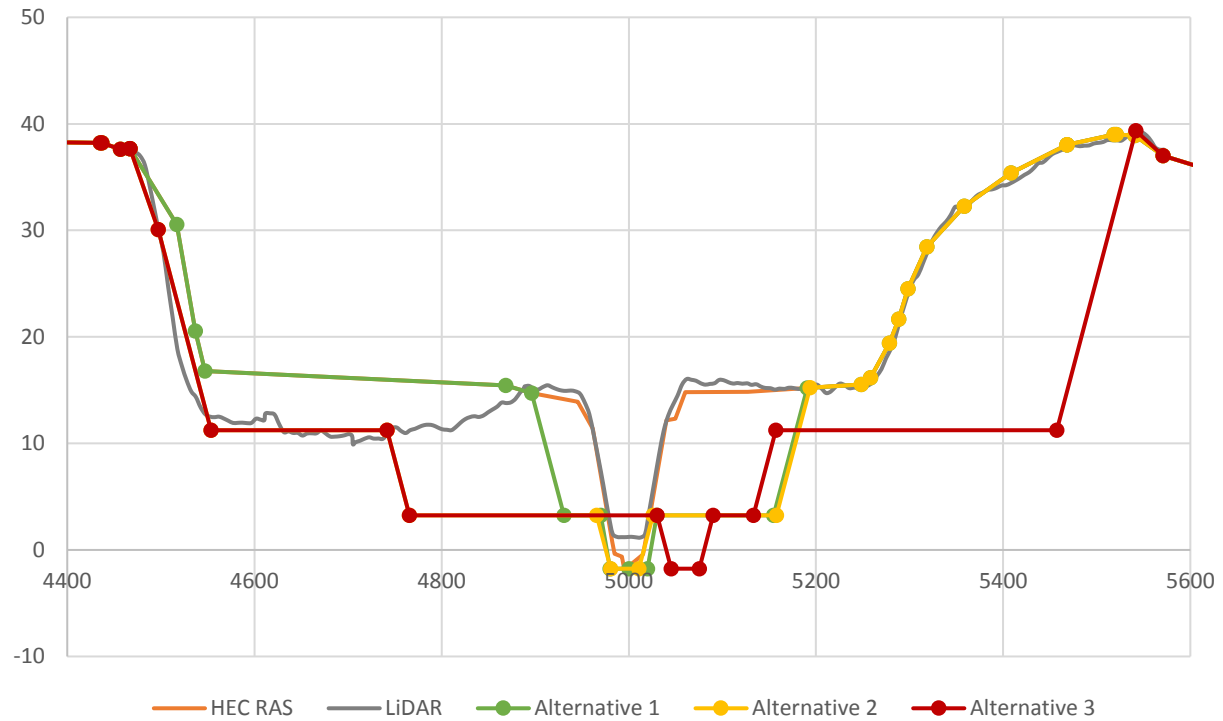


Figure 11: Modified Cross-Section 8532

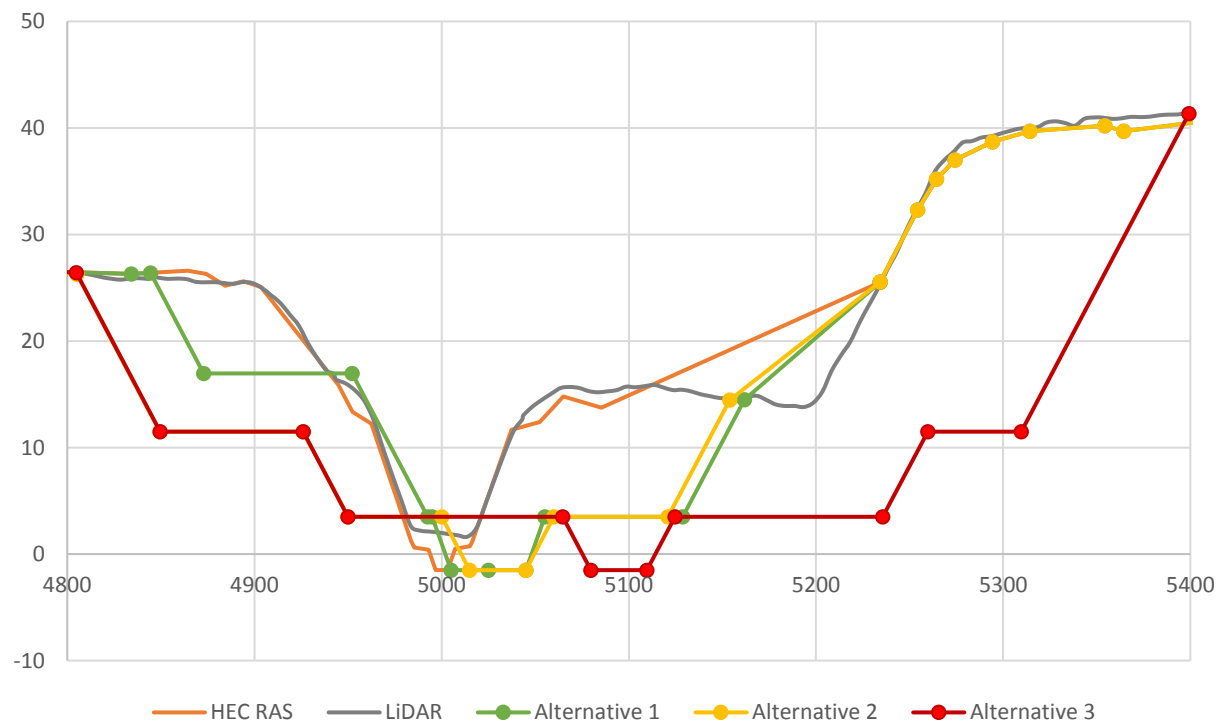


Figure 12: Modified Cross-Section 9779

Attachment A – Modified Cross-Sections

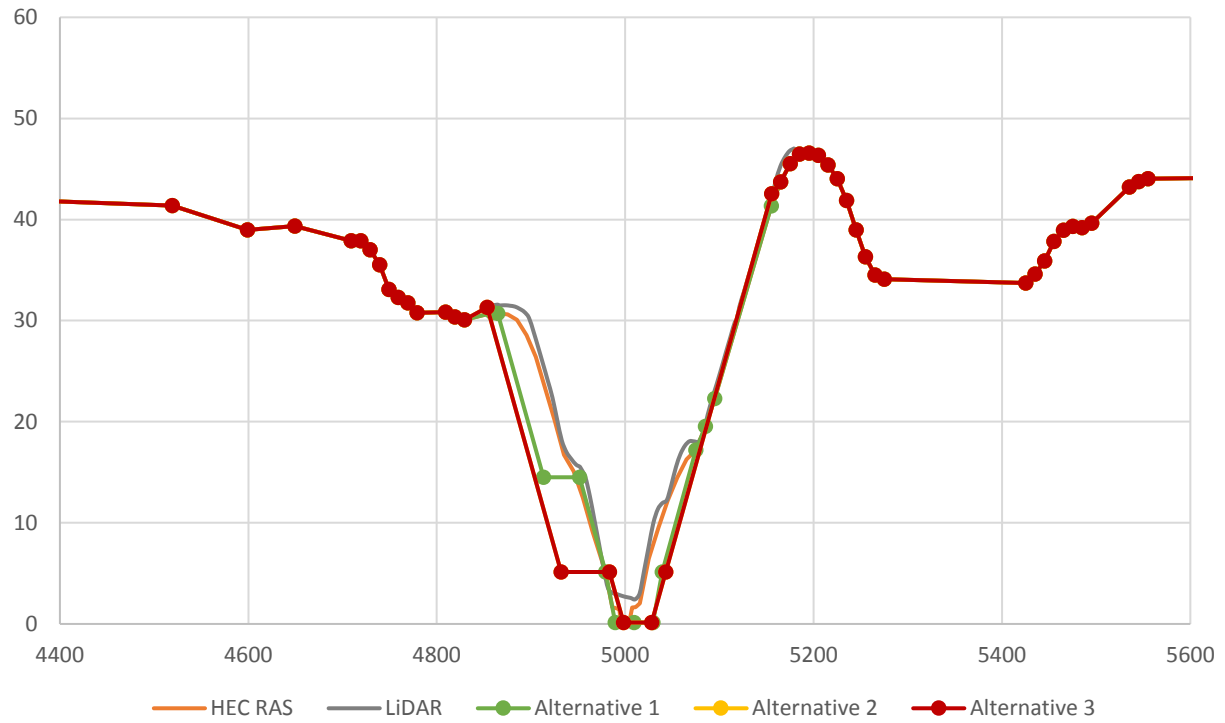


Figure 13: Modified Cross-Section 10643

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APPENDIX C

COST ESTIMATION AND PROJECT IMPLEMENTATION

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MEMORANDUM



Innovative approaches
Practical results
Outstanding service

10497 Town and Country Way, Suite 600 • Houston, Texas 77024 • 713-600-6800 • fax 713-600-6801 www.freese.com

TO: Harris County Flood Control District (HCFCD)
FROM: Kevin Kiniry (FNI)
SUBJECT: Cost Estimation and Project Implementation
DATE: October 6, 2017
PROJECT: White Oak Bayou Channel Restoration



As part of the White Oak Bayou Channel Restoration Project, FNI was requested by HCFCD to perform the following cost estimation and project implementation exercises specific to the project study area:

- Develop Opinions of Probable Construction Costs (OPCCs) for:
 - An in-kind replacement of the existing channel; and
 - Three design alternatives
- Perform a Present-Future value analysis for the existing channel over a 50-year period;
- Quantify anticipated operations and maintenance (O&M) costs for three design alternatives; and
- Prepare Project Implementation Schedules for three design alternatives.

Each of these efforts are further described in the following sections.

Development of OPCCs

A variety of data sources were consulted in support of developing the OPCCs, which are generally described as follows:

- Construction drawings for White Oak Bayou improvements prepared by the United States Army Corps of Engineers (USACE) were used to determine the quantity of reinforced concrete slope pavement armoring the existing channel;
- The channel cross-section geometry within the Current Effective hydraulic model of White Oak Bayou, as well as Light Detection and Ranging (LiDAR) data, were used to develop an existing conditions land surface in AutoCAD Civil 3D. Proposed surfaces representing the three design alternatives were also developed in AutoCAD Civil 3D as a function of this data;
- An assortment of Geographic Information Systems (GIS) shapefiles provided by HCFCD were used to define the overall project footprint and quantify the various channel components and ancillary features requiring removal and/or replacement. The GIS shapefiles were overlain on top of available aerial imagery;
- The City of Houston GIMS web applet was used to preliminarily identify storm drain infrastructure within the overall limits of the project. Data from GIMS was further verified based on observations from a series of field inspections performed by FNI;
- HCFCD bid tabulation data from recent years was used as a baseline for the development of unit prices. Select unit prices were adjusted based on FNI's experience with similar projects; and

- Observations made during a series of field investigations performed by FNI.

The following general assumptions were made in support of developing the OPCCs:

- For the general civil items:
 - Mobilization costs would not exceed 5% of the total contract amount;
 - Stormwater pollution prevention plan (SWPPP) costs were developed to account for items such as reinforced filter fabric fencing, inlet protection barriers, and filter dams;
 - Care of water costs were developed based on FNI's experience with similar projects;
 - Provisions for traffic control would be required for the channel crossings located at: Taylor Street, Houston Avenue, and Hogan Street;
 - Stabilized construction access points were calculated separate from SWPPP costs given the provisions necessary to facilitate ingress/egress routes around pedestrian trails and other greenbelt amenities;
 - Clearing and grubbing would minimally be required within the limits of earthwork operations. Additional clearing and grubbing would also be necessary in support of the contractor's ingress/egress routes;
 - Final grading, hydromulch, and cleanup costs were developed to account for the efforts to restore the disturbed areas when de-mobilizing the site; and
 - Utility coordination costs were developed to account for precautionary measures and location verification efforts likely needed for the proposed work within the vicinity of the aerial pipeline crossings within the project reach (inclusive of a gas pipeline as well as a water main).
- For the channel rehabilitation items:
 - All quantities generally correspond to the sources of data previously mentioned as well as the configurations of each alternative described within the main report;
 - Where required, a sufficient amount of suitable material would be available for on-site re-use for implementation of any of the design alternatives;
 - The following armoring systems were conservatively assumed to be necessary:
 - A rock riprap (or similar) system for the full cross-section of the channel to transition from the reinforced concrete slope pavement upstream of the project study area to a distance 300 feet downstream;
 - Reinforced concrete slope pavement for the full cross-section of the geomorphic channel at the 8 bridge crossing locations (inclusive of roads and pedestrian bridges); and
 - A buried rock riprap (or similar) system for the full channel cross-section for the remainder of the project study area not covered by the armoring systems described above.
 - The existing storm drain pipes would be removed and replaced in-kind with erosion protection added for 36-inch diameter pipes (and larger).
- Acquisition of right-of-way (ROW) necessary to implement any given alternative would be a function of the stakeholder agreements associated with the project, and therefore not be a cost incurred by HCFCD; and
- The overall contingency was set at 30%.

A summary of FNI'S OPCCs is presented in Table 1. Detailed OPCCs are included in Exhibit 1. It should be noted that these OPCCs do not include the costs associated with the additional engineering, survey, geotechnical exploration, and environmental permitting that would be performed as part of final design.

Table 1 – Summary of OPCCs

Description	OPCC
In-Kind Replacement	\$17,565,813
Alternative 1	\$29,535,870
Alternative 2	\$42,822,910
Alternative 3	\$60,294,000

Present-Future Analysis Exercise

Based on a review of data presented in HCFCD’s January 29, 2016 memorandum entitled, “Concrete Channel Lining Maintenance Costs”, FNI understands that the approximate annual cost of repairing concrete damages between the Studemont crossing and the downstream limit of the existing slope pavement is \$787,500. The associated reach length with this portion of White Oak Bayou is approximately 350 feet, which translates to an approximate concrete repair per linear foot unit cost (for one side of the channel) equal to \$2,250.00. Applying this approximate unit cost to the project study area, the anticipated cost of annual concrete repairs is approximately \$495,000. Taking into account an inflation rate of 2%, and applying this annual maintenance repair cost over a 50-year period, the approximate present and future values of the concrete channel lining within the project study area were determined to be \$15,600,000 and \$41,900,000 respectively.

Development of O&M Costs for Baseline and Alternatives 1, 2, and 3

To assist in quantifying the annual costs of standard O&M activities within the project study area (i.e., activities not associated with concrete channel lining repairs), FNI reviewed historical data documenting the vegetative management activities performed along White Oak Bayou from 2011 to 2015. Based upon this data, FNI understands that the vegetative management cost for the entirety of White Oak Bayou varies from approximately \$100,000 to \$200,000. The O&M activities attributed to this cost generally include:

- Turf establishment for areas of sparse grass coverage;
- Mowing operations;
- Application of herbicide to control vegetative overgrowth;
- Planting; and, on rare occasion,
- Selective clearing.

The project study area encompasses over a mile of channel length, which comes out to approximately 10% of the entire length of White Oak Bayou. It is important to note, however, that directly attributing 10% of the overall vegetative management cost to the project study area may underestimate the true cost given the varying overbank configurations that currently exist along White Oak Bayou. Therefore, FNI instead developed baseline and alternative-specific O&M costs for the project study area assuming that implementation of any of the design alternatives would presumably necessitate the following O&M activities:

- Turf establishment for areas of sparse grass coverage
- Mowing operations
 - Based on FNI’s correspondence with a Houston-based mowing contractor, the following unit prices were assumed applicable for the project study area:
 - With regards to the configuration of the existing channel:
 - All grass-covered areas = \$200/acre per occurrence

- With regards to the proposed configuration of the design alternatives:
 - Mildly sloped grass-covered areas = \$100/acre per occurrence
 - Grass-covered channel side slopes = \$300/acre per occurrence
 - It was assumed that mowing operations would occur on a quarterly basis and be performed for all grass-covered areas within the full extent of the existing ROW. Therefore, to determine the annual cost for mowing operations, the above-mentioned unit prices were multiplied by four.
- Inspection and maintenance of the various channel armoring features (for design alternatives only)
 - The unit cost (per linear foot) assumed applicable for these efforts was calculated as a function of:
 - The ratio of the typical unit cost for rock riprap erosion protection versus the typical unit cost for reinforced concrete channel lining;
 - The unit cost (per linear foot) for annual maintenance of the existing concrete channel lining; and
 - The length of the project study area.

It is important to note that, given the nature of the proposed design alternatives conceived by the collective project team, there is a great deal more amount of vegetative management required for implementing any of the alternatives as compared to that of the existing channel. A summary of FNI'S O&M cost estimates is presented in Table 2. Detailed O&M cost estimates are included in Exhibit 2.

Table 2 – Summary of O&M Cost Estimates

Description	OPCC
Existing Channel	\$45,292
Alternative 1	\$173,580
Alternative 2	\$241,780
Alternative 3	\$300,450

Project Implementation Schedules for Alternatives 1, 2, and 3

As an additional metric of comparison between moving forward with an in-kind replacement, Alternative 1, Alternative 2, or Alternative 3, generalized project implementation schedules were prepared. The primary project components incorporated in this exercise included:

- Miscellaneous field work to be completed by subconsultants to establish existing conditions, such as: topographic and property ownership surveying, as well as a geotechnical investigation;
- Engineering design activities necessary to develop construction drawings and project specifications;
- Applying for and securing a Section 408 Permit from USACE specific to implementing the preferred design alternative, specifically assuming that:
 - A permit would not be sought after until all project stakeholders unanimously approve the final construction drawings and project specifications; and
 - A permit could successfully be obtained by coordination with USACE Galveston District (i.e., routing the application through USACE headquarters or other out-of-state district would not be necessary).
- Construction of the preferred design concept, specifically assuming that:

- o Coordination with the project stakeholders would proceed favorably as a function of preliminary coordination efforts being performed during (and shortly following) final design. These efforts could conceivably occur concurrent to the 408 permitting process;
- o Construction duration variations between alternatives would generally be proportional to the overall project footprints. Additionally, design alternatives that include SWQ features (and other special vegetative features) necessitate additional work crews and thereby increase the duration of construction.

A summary of FNI'S project implementation schedules is presented in Table 3.

Table 3 – Summary of Project Implementation Schedules

Metric	Project Component	Baseline	Alternatives		
		Replace Lining	1 (Low Impact)	2 (North)	3 (North/South)
Project Implementation Schedule (months)	Subconsultant Field Work	6			
	Design	8	12	14	16
	408 Permitting	12			
	Construction	12	18	24	36
	Total	38	48	56	70

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EXHIBIT 1 - OPINIONS OF PROBABLE
CONSTRUCTION COSTS FOR DESIGN
ALTERNATIVES

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OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR	CHECKED BY	ACCOUNT NO
SB	KRK	HCF16526

Alternative 1

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
GENERAL CIVIL					
1	MOBILIZATION (NTE 5% OF TOTAL CONTRACT AMOUNT)	1	LS	\$1,082,000.00	\$1,082,000.00
2	STORMWATER POLLUTION PREVENTION PLAN (SWPPP)	1	LS	\$60,000.00	\$60,000.00
3	CARE OF WATER	1	LS	\$500,000.00	\$500,000.00
4	TRAFFIC CONTROL	1	LS	\$150,000.00	\$150,000.00
5	STABILIZED CONSTRUCTION ACCESS POINTS	1	LS	\$50,000.00	\$50,000.00
6	CLEARING AND GRUBBING	1	LS	\$25,000.00	\$25,000.00
7	FINAL GRADING, HYDROMULCH, CLEAN UP	1	LS	\$175,000.00	\$175,000.00
8	UTILITY COORDINATION	1	LS	\$40,000.00	\$40,000.00
				SUB =	\$2,082,000.00

CHANNEL REHABILITATION

DEMOLITION					
1	REMOVAL AND DISPOSAL OF EXISTING REINFORCED CONCRETE SLOPE PAVEMENT	1	LS	\$2,200,000.00	\$2,200,000.00
2	REMOVAL AND DISPOSAL OF EXISTING 18-INCH CMP	40	LF	\$40.00	\$1,600.00
3	REMOVAL AND DISPOSAL OF EXISTING 24-INCH RCP	260	LF	\$40.00	\$10,400.00
4	REMOVAL AND DISPOSAL OF EXISTING 24-INCH CMP	360	LF	\$40.00	\$14,400.00
5	REMOVAL AND DISPOSAL OF EXISTING 36-INCH RCP	300	LF	\$40.00	\$12,000.00
6	REMOVAL AND DISPOSAL OF EXISTING 42-INCH CMP	160	LF	\$40.00	\$6,400.00
7	REMOVAL AND DISPOSAL OF EXISTING 48-INCH RCP	40	LF	\$40.00	\$1,600.00
8	REMOVAL AND DISPOSAL OF EXISTING 60-INCH CMP	120	LF	\$40.00	\$4,800.00
9	REMOVAL AND DISPOSAL OF EXISTING 5-FOOT BY 10-FOOT RCB	30	LF	\$40.00	\$1,200.00
10	REMOVAL AND DISPOSAL OF EXISTING PEDESTRIAN TRAILS	3,750	LF	\$10.00	\$37,500.00

NEW CONSTRUCTION

11	NEW 18-INCH CMP	40	LF	\$50.00	\$2,000.00
12	NEW 24-INCH RCP	260	LF	\$200.00	\$52,000.00
13	NEW 24-INCH CMP	360	LF	\$55.00	\$19,800.00
14	NEW 36-INCH RCP	300	LF	\$275.00	\$82,500.00
15	NEW 42-INCH CMP	160	LF	\$150.00	\$24,000.00
16	NEW 48-INCH RCP	40	LF	\$350.00	\$14,000.00
17	NEW 60-INCH CMP	120	LF	\$200.00	\$24,000.00
18	NEW 5-FOOT BY 10-FOOT RCB	60	LF	\$675.00	\$40,500.00
19	18-INCH TO 36 INCH CONCRETE COLLARS - FOR CMP OUTFALLS	6	EA	\$1,100.00	\$6,600.00
20	42-INCH TO 60-INCH CONCRETE COLLARS - FOR CMP OUTFALLS	3	EA	\$1,700.00	\$5,100.00
21	EROSION PROTECTION FOR OUTFALLS 36-INCHES AND LARGER	8	EA	\$5,000.00	\$40,000.00
22	NEW PEDESTRIAN TRAILS	3,750	LF	\$10.00	\$37,500.00
23	EARTHWORK (EXCAVATION & ONSITE FILL)	30,000	CY	\$10.00	\$300,000.00
24	EARTHWORK (EXCAVATION & OFFSITE DISPOSAL)	270,000	CY	\$30.00	\$8,100,000.00
25	EROSION PROTECTION ALONG UPSTREAM REACH OF PROJECT	1	LS	\$1,500,000.00	\$1,500,000.00
26	EROSION PROTECTION FOR BRIDGE CROSSINGS	1	LS	\$500,000.00	\$500,000.00
27	EROSION PROTECTION FOR REMAINDER OF PROJECT REACH	1	LS	\$7,600,000.00	\$7,600,000.00
				SUB =	\$20,637,900.00

SUBTOTAL:	\$22,719,900
CONTINGENCY 30%	\$6,815,970

PROJECT TOTAL \$29,535,870

NOTES:

1. ROW ACQUISITION COSTS HAVE NOT BEEN INCLUDED



OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR	CHECKED BY	ACCOUNT NO
SB	KRK	HCF16526

Alternative 2

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
GENERAL CIVIL					
1	MOBILIZATION (NTE 5% OF TOTAL CONTRACT AMOUNT)	1	LS	\$1,569,000.00	\$1,569,000.00
2	STORMWATER POLLUTION PREVENTION PLAN (SWPPP)	1	LS	\$60,000.00	\$60,000.00
3	CARE OF WATER	1	LS	\$500,000.00	\$500,000.00
4	TRAFFIC CONTROL	1	LS	\$150,000.00	\$150,000.00
5	STABILIZED CONSTRUCTION ACCESS POINTS	1	LS	\$50,000.00	\$50,000.00
6	CLEARING AND GRUBBING	1	LS	\$80,000.00	\$80,000.00
7	FINAL GRADING, HYDROMULCH, CLEAN UP	1	LS	\$305,000.00	\$305,000.00
8	UTILITY COORDINATION	1	LS	\$40,000.00	\$40,000.00
				SUB =	\$2,754,000.00
CHANNEL REHABILITATION					
DEMOLITION					
1	REMOVAL AND DISPOSAL OF EXISTING REINFORCED CONCRETE SLOPE PAVEMENT	1	LS	\$2,200,000.00	\$2,200,000.00
2	REMOVAL AND DISPOSAL OF EXISTING 18-INCH CMP	100	LF	\$40.00	\$4,000.00
3	REMOVAL AND DISPOSAL OF EXISTING 24-INCH RCP	220	LF	\$40.00	\$8,800.00
4	REMOVAL AND DISPOSAL OF EXISTING 24-INCH CMP	380	LF	\$40.00	\$15,200.00
5	REMOVAL AND DISPOSAL OF EXISTING 36-INCH RCP	320	LF	\$40.00	\$12,800.00
6	REMOVAL AND DISPOSAL OF EXISTING 42-INCH CMP	240	LF	\$40.00	\$9,600.00
7	REMOVAL AND DISPOSAL OF EXISTING 48-INCH RCP	120	LF	\$40.00	\$4,800.00
8	REMOVAL AND DISPOSAL OF EXISTING 60-INCH CMP	120	LF	\$40.00	\$4,800.00
9	REMOVAL AND DISPOSAL OF EXISTING 5-FOOT BY 10-FOOT RCB	140	LF	\$40.00	\$5,600.00
10	REMOVAL AND DISPOSAL OF EXISTING PEDESTRIAN TRAILS	9,250	LF	\$10.00	\$92,500.00
NEW CONSTRUCTION					
11	NEW 18-INCH CMP	100	LF	\$50.00	\$5,000.00
12	NEW 24-INCH RCP	220	LF	\$200.00	\$44,000.00
13	NEW 24-INCH CMP	380	LF	\$55.00	\$20,900.00
14	NEW 36-INCH RCP	320	LF	\$275.00	\$88,000.00
15	NEW 42-INCH CMP	240	LF	\$150.00	\$36,000.00
16	NEW 48-INCH RCP	120	LF	\$350.00	\$42,000.00
17	NEW 60-INCH CMP	120	LF	\$200.00	\$24,000.00
18	NEW 5-FOOT BY 10-FOOT RCB	140	LF	\$675.00	\$94,500.00
19	18-INCH TO 36 INCH CONCRETE COLLARS - FOR CMP OUTFALLS	6	EA	\$1,100.00	\$6,600.00
20	42-INCH TO 60-INCH CONCRETE COLLARS - FOR CMP OUTFALLS	3	EA	\$1,700.00	\$5,100.00
21	EROSION PROTECTION FOR OUTFALLS 36-INCHES AND LARGER	8	EA	\$5,000.00	\$40,000.00
22	NEW PEDESTRIAN TRAILS	7,250	LF	\$10.00	\$72,500.00
23	EARTHWORK (EXCAVATION & ONSITE FILL)	17,500	CY	\$10.00	\$175,000.00
24	EARTHWORK (EXCAVATION & OFFSITE DISPOSAL)	562,500	CY	\$30.00	\$16,875,000.00
25	EROSION PROTECTION ALONG UPSTREAM REACH OF PROJECT	1	LS	\$1,500,000.00	\$1,500,000.00
26	EROSION PROTECTION FOR BRIDGE CROSSINGS	1	LS	\$500,000.00	\$500,000.00
27	EROSION PROTECTION FOR REMAINDER OF PROJECT REACH	1	LS	\$8,300,000.00	\$8,300,000.00
				SUB =	\$30,186,700.00
				SUBTOTAL:	\$32,940,700
				CONTINGENCY 30%	\$9,882,210

PROJECT TOTAL

\$42,822,910

NOTES:

1. ROW ACQUISITION COSTS HAVE NOT BEEN INCLUDED



OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR	CHECKED BY	ACCOUNT NO
SB	KRK	HCF16526

Alternative 3

ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
GENERAL CIVIL					
1	MOBILIZATION (NTE 5% OF TOTAL CONTRACT AMOUNT)	1	LS	\$2,209,000.00	\$2,209,000.00
2	STORMWATER POLLUTION PREVENTION PLAN (SWPPP)	1	LS	\$60,000.00	\$60,000.00
3	CARE OF WATER	1	LS	\$500,000.00	\$500,000.00
4	TRAFFIC CONTROL	1	LS	\$150,000.00	\$150,000.00
5	STABILIZED CONSTRUCTION ACCESS POINTS	1	LS	\$50,000.00	\$50,000.00
6	CLEARING AND GRUBBING	1	LS	\$150,000.00	\$150,000.00
7	FINAL GRADING, HYDROMULCH, CLEAN UP	1	LS	\$415,000.00	\$415,000.00
8	UTILITY COORDINATION	1	LS	\$40,000.00	\$40,000.00
				SUB =	\$3,574,000.00
CHANNEL REHABILITATION					
DEMOLITION					
1	REMOVAL AND DISPOSAL OF EXISTING REINFORCED CONCRETE SLOPE PAVEMENT	1	LS	\$2,200,000.00	\$2,200,000.00
2	REMOVAL AND DISPOSAL OF EXISTING 18-INCH CMP	160	LF	\$40.00	\$6,400.00
3	REMOVAL AND DISPOSAL OF EXISTING 24-INCH RCP	260	LF	\$40.00	\$10,400.00
4	REMOVAL AND DISPOSAL OF EXISTING 24-INCH CMP	540	LF	\$40.00	\$21,600.00
5	REMOVAL AND DISPOSAL OF EXISTING 36-INCH RCP	360	LF	\$40.00	\$14,400.00
6	REMOVAL AND DISPOSAL OF EXISTING 42-INCH CMP	240	LF	\$40.00	\$9,600.00
7	REMOVAL AND DISPOSAL OF EXISTING 48-INCH RCP	120	LF	\$40.00	\$4,800.00
8	REMOVAL AND DISPOSAL OF EXISTING 54-INCH RCP	100	LF	\$40.00	\$4,000.00
9	REMOVAL AND DISPOSAL OF EXISTING 60-INCH CMP	120	LF	\$40.00	\$4,800.00
10	REMOVAL AND DISPOSAL OF EXISTING 5-FOOT BY 10-FOOT RCB	140	LF	\$40.00	\$5,600.00
11	REMOVAL AND DISPOSAL OF EXISTING PEDESTRIAN TRAILS	10,500	LF	\$10.00	\$105,000.00
NEW CONSTRUCTION					
12	NEW 18-INCH CMP	160	LF	\$50.00	\$8,000.00
13	NEW 24-INCH RCP	260	LF	\$200.00	\$52,000.00
14	NEW 24-INCH CMP	540	LF	\$55.00	\$29,700.00
15	NEW 36-INCH RCP	360	LF	\$275.00	\$99,000.00
16	NEW 42-INCH CMP	240	LF	\$150.00	\$36,000.00
17	NEW 48-INCH RCP	120	LF	\$350.00	\$42,000.00
18	NEW 54-INCH RCP	100	LF	\$200.00	\$20,000.00
19	NEW 60-INCH CMP	120	LF	\$200.00	\$24,000.00
20	NEW 5-FOOT BY 10-FOOT RCB	140	LF	\$675.00	\$94,500.00
21	18-INCH TO 36 INCH CONCRETE COLLARS - FOR CMP OUTFALLS	6	EA	\$1,100.00	\$6,600.00
22	42-INCH TO 60-INCH CONCRETE COLLARS - FOR CMP OUTFALLS	3	EA	\$1,700.00	\$5,100.00
23	EROSION PROTECTION FOR OUTFALLS 36-INCHES AND LARGER	9	EA	\$5,000.00	\$45,000.00
24	NEW PEDESTRIAN TRAILS	15,750	LF	\$10.00	\$157,500.00
25	EARTHWORK (EXCAVATION & ONSITE FILL)	27,500	CY	\$10.00	\$275,000.00
26	EARTHWORK (EXCAVATION & OFFSITE DISPOSAL)	862,500	CY	\$30.00	\$25,875,000.00
27	EROSION PROTECTION ALONG UPSTREAM REACH OF PROJECT	1	LS	\$1,500,000.00	\$1,500,000.00
28	EROSION PROTECTION FOR BRIDGE CROSSINGS	1	LS	\$500,000.00	\$500,000.00
29	EROSION PROTECTION FOR REMAINDER OF PROJECT REACH	1	LS	\$11,650,000.00	\$11,650,000.00
				SUB =	\$42,806,000.00
				SUBTOTAL:	\$46,380,000
				CONTINGENCY	30% \$13,914,000

PROJECT TOTAL \$60,294,000

NOTES:

1. ROW ACQUISITION COSTS HAVE NOT BEEN INCLUDED

- Coordination with the project stakeholders would proceed favorably as a function of preliminary coordination efforts being performed during (and shortly following) final design. These efforts could conceivably occur concurrent to the 408 permitting process;
- Construction duration variations between alternatives would generally be proportional to the overall project footprints. Additionally, design alternatives that include SWQ features (and other special vegetative features) necessitate additional work crews and thereby increase the duration of construction.

A summary of FNI'S project implementation schedules is presented in Table 3.

Table 3 – Summary of Project Implementation Schedules

Metric	Project Component	Baseline	Alternatives		
		Replace Lining	1 (Low Impact)	2 (North)	3 (North/South)
Project Implementation Schedule (months)	Subconsultant Field Work	6			
	Design	8	12	14	16
	408 Permitting	12			
	Construction	12	18	24	36
	Total	38	48	56	70

EXHIBIT 2 - COST ESTIMATES FOR
ANTICIPATED OPERATIONS AND
MAINTENANCE ACTIVITIES

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OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR		CHECKED BY		ACCOUNT NO	
SB		KRK		HCF16526	
Anticipated Annual Operations and Maintenance Costs - Existing Channel					
ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
ALL MAINTENANCE OPERATIONS					
	TURF ESTABLISHMENT	3	AC	\$600.00	\$1,980.00
	MOWING OPERATIONS - COMBINATION OF FLAT GROUND AND SLOPES	33	AC	\$800.00	\$26,270.00
	HERBICIDE	11	AC	\$600.00	\$6,590.00
				SUB =	\$34,840.00
		CONTINGENCY		30%	\$10,452.00
TOTAL MAINTENANCE COST					\$45,292.00

NOTES:

1. LIMITS OF MOWING OPERATIONS INCLUDE THE CHANNEL SIDE SLOPES, BENCHES IN SIDE SLOPES, MAINTENANCE BERMS, AND THE PARKS/RECREATION AREAS.



OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR		CHECKED BY		ACCOUNT NO	
SB		KRK		HCF16526	
Anticipated Annual Operations and Maintenance Costs - Alternative 1					
ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
ALL MAINTENANCE OPERATIONS					
	TURF ESTABLISHMENT	16	AC	\$600.00	\$9,880.00
	MOWING OPERATIONS - FLAT GROUND	11	AC	\$400.00	\$4,410.00
	MOWING OPERATIONS - SLOPES AND STORMWATER QUALITY FEATURES	22	AC	\$1,200.00	\$26,300.00
	MAINTENANCE OF CHANNEL ARMORING FEATURES	5,850	LF	\$15.88	\$92,930.00
				SUB =	\$133,520.00
				CONTINGENCY	30%
				TOTAL MAINTENANCE COST	\$173,580.00

NOTES:

1. LIMITS OF MOWING OPERATIONS INCLUDE THE GEOMORPHIC CHANNEL, CHANNEL SIDE SLOPES, BENCHES IN SIDE SLOPES, STORM WATER QUALITY FEATURES, MAINTENANCE BERMS, AND THE PARKS/RECREATION AREAS.



OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR		CHECKED BY		ACCOUNT NO	
SB		KRK		HCF16526	
Anticipated Annual Operations and Maintenance Costs - Alternative 2					
ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
ALL MAINTENANCE OPERATIONS					
	TURF ESTABLISHMENT	23	AC	\$600.00	\$13,770.00
	MOWING OPERATIONS - FLAT GROUND	15	AC	\$400.00	\$6,190.00
	MOWING OPERATIONS - SLOPES AND STORMWATER QUALITY FEATURES	30	AC	\$1,200.00	\$36,510.00
	MAINTENANCE OF CHANNEL ARMORING FEATURES	5,850	LF	\$22.14	\$129,510.00
				SUB =	\$185,980.00
				CONTINGENCY	30%
				TOTAL MAINTENANCE COST	\$241,780.00

NOTES:

1. LIMITS OF MOWING OPERATIONS INCLUDE THE GEOMORPHIC CHANNEL, CHANNEL SIDE SLOPES, BENCHES IN SIDE SLOPES, STORM WATER QUALITY FEATURES, MAINTENANCE BERMS, AND THE PARKS/RECREATION AREAS.



OPINION OF PROBABLE CONSTRUCTION COST

MAY 20, 2017

ESTIMATOR		CHECKED BY		ACCOUNT NO	
SB		KRK		HCF16526	
Anticipated Annual Operations and Maintenance Costs - Alternative 3					
ITEM	DESCRIPTION	QUANTITY	UNIT	UNIT PRICE	TOTAL
ALL MAINTENANCE OPERATIONS					
	TURF ESTABLISHMENT	28	AC	\$600.00	\$16,800.00
	MOWING OPERATIONS - FLAT GROUND	14	AC	\$400.00	\$5,410.00
	MOWING OPERATIONS - SLOPES AND STORMWATER QUALITY FEATURES	42	AC	\$1,200.00	\$50,950.00
	MAINTENANCE OF CHANNEL ARMORING FEATURES	5,850	LF	\$27.00	\$157,950.00
				SUB =	\$231,110.00
				CONTINGENCY	30%
				TOTAL MAINTENANCE COST	\$300,450.00

NOTES:

1. LIMITS OF MOWING OPERATIONS INCLUDE THE GEOMORPHIC CHANNEL, CHANNEL SIDE SLOPES, BENCHES IN SIDE SLOPES, STORM WATER QUALITY FEATURES, MAINTENANCE BERMS, AND THE PARKS/RECREATION AREAS.