White Paper to Identify Potential Pilot Projects Utilizing Tunnel Conveyance

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HARRIS COUNTY FLOOD CONTROL DISTRICT

White Paper to Identify Potential Pilot Projects Utilizing Tunnel Conveyance

The purpose of this white paper is to outline options for a potential tunnel conveyance pilot project that would provide drainage improvements and serve as a trial of tunnel conveyance systems before implementation of full-scale concepts. The pilot project would identify potential challenges, test procurement and construction methods, and refine implementation concepts. It should be focused on solving unmet flood risk reduction needs across a wide variety of conditions and facilitating future implementation of full-scale tunnel conveyance systems.

Why consider a Pilot Study?

- Potential to generate institutional knowledge at all levels of Harris County (HCFCD, Purchasing, Engineering, Construction, etc.) HCFCD has not designed or constructed underground conveyance systems on the depth or scale proposed before.
- Could allow for the implementation and refinement of alternate delivery methods on a smaller, more manageable scale prior to full scale implementation. HCFCD has historically not utilized alternative delivery methods.
- Could allow for quicker realization of interim flood risk reduction benefits than full-scale implementation.
- Has the potential to provide documented proof of concept and benefits that will facilitate federal and state investments in full-scale implementation.

This white paper is based on prior information developed for the Phase 1 and Phase 2 Tunnel Studies, with very limited additional engineering analysis. Importantly, prior studies were focused primarily on larger diameter tunnels and offered less detailed information on smaller diameter tunnels. Conclusions related to alternatives for different scales of pilot projects are conceptual and would need to be verified through further detailed analysis.

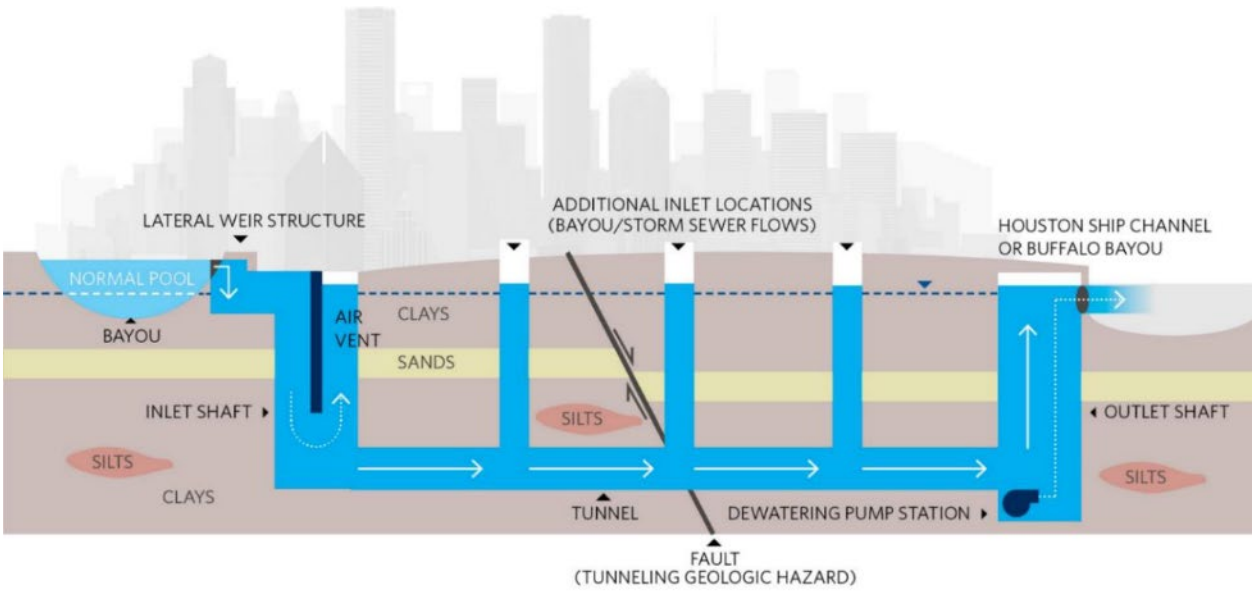
Conceptual Overview: Tunnel Conveyance

A tunnel conveyance system or tunnel conveyance pilot would likely be designed to operate as an inverted siphon, as illustrated in **Figure 1**. Stormwater would fill the tunnel and would flow under pressure through the tunnel. The system would function entirely by gravity. Intakes would convey flood waters efficiently and safely towards the tunnel and would likely include control structures such as weirs, gates, trash racks, and a drop structure down to the tunnel. Gates will be used to actively manage diversion of flows into the tunnel.

The outfall system would likely consist of a shaft and a series of control and energy dissipating structures that would provide a safe discharge of the diverted flood waters into the receiving water body. The outfall system would include an outlet structure that would be designed to disperse the flow to prevent high flow concentrations and scouring velocities. The tunnel outlet would be placed above normal downstream water levels to prevent backflow into the tunnel. To further manage backflow, it is anticipated the outfall system would include gates to minimize the potential for backflow. Trash racks would be used to prevent debris from entering the tunnel conveyance system in case of backflow. The outfall system would likely include dewatering pumps and grit removal pumps. Dewatering the tunnel after it is used would likely be needed to prevent sediment accumulation and formation of anoxic conditions due to stagnant water in the tunnel.

Figure 1 presents a conceptual rendering of how the Buffalo Bayou tunnel system, as proposed in the Phase 2 Tunnel Study, would work.

Figure 1: Typical Tunnel Conveyance System (Buffalo Bayou)



Potential tunnel sizes range between 10 ft in diameter to 40 ft in diameter, based on currently available technology. Tunnel depth would likely range from 50 to 100 feet below grade. Tunnel capacity is primarily driven by tunnel diameter, tunnel length, and the elevation differential between the intake and the outfall. As shown in **Table 1**, based on conceptual sizing information previously developed for the Phase 2 Tunnel Study, tunnel capacity is estimated to range between several hundred cubic feet per second (cfs) on the lower end and over 10,000 cfs on the upper end.

Based on conceptual information previously developed for the Phase 2 Tunnel Study, approximate tunnel cost was estimated for different lengths and sizes of tunnel. Tunnel cost includes costs for outfalls, intakes, and working shafts and length-variable costs for tunnel boring. Other costs include, but are not limited to, engineering, environmental mitigation, and right-of-way acquisition. Smaller / shorter tunnels are expected to cost approximately several hundred million dollars while longer / larger tunnels could cost several billion dollars. Cost was estimated on a five-point range, from low ($) to high ($$$$$), with low representing several hundred million dollars and high representing several billion dollars.

Table 1: Approximate Tunnel Capacity / Cost

		Approximate Tunnel Costs						
		10 ft	15 ft	20 ft	25 ft	30 ft	35 ft	40 ft
Approx. Capacity		~500 cfs	~1,250 cfs	~2,500 cfs	~4,000 cfs	~6,500 cfs	~9,000 cfs	~13,000 cfs
Tunnel Length	1 mi	$	$	$	$	$$	$$	$$
	5 mi	$	$	$$	$$	$$$	$$$	$$$
	10 mi	$$	$$	$$$	$$$	$$$$	$$$$	$$$$
	15 mi	$$$	$$$	$$$$	$$$$	$$$$$	$$$$$	$$$$$
	20 mi	$$$	$$$	$$$$	$$$$$	$$$$$	$$$$$	$$$$$

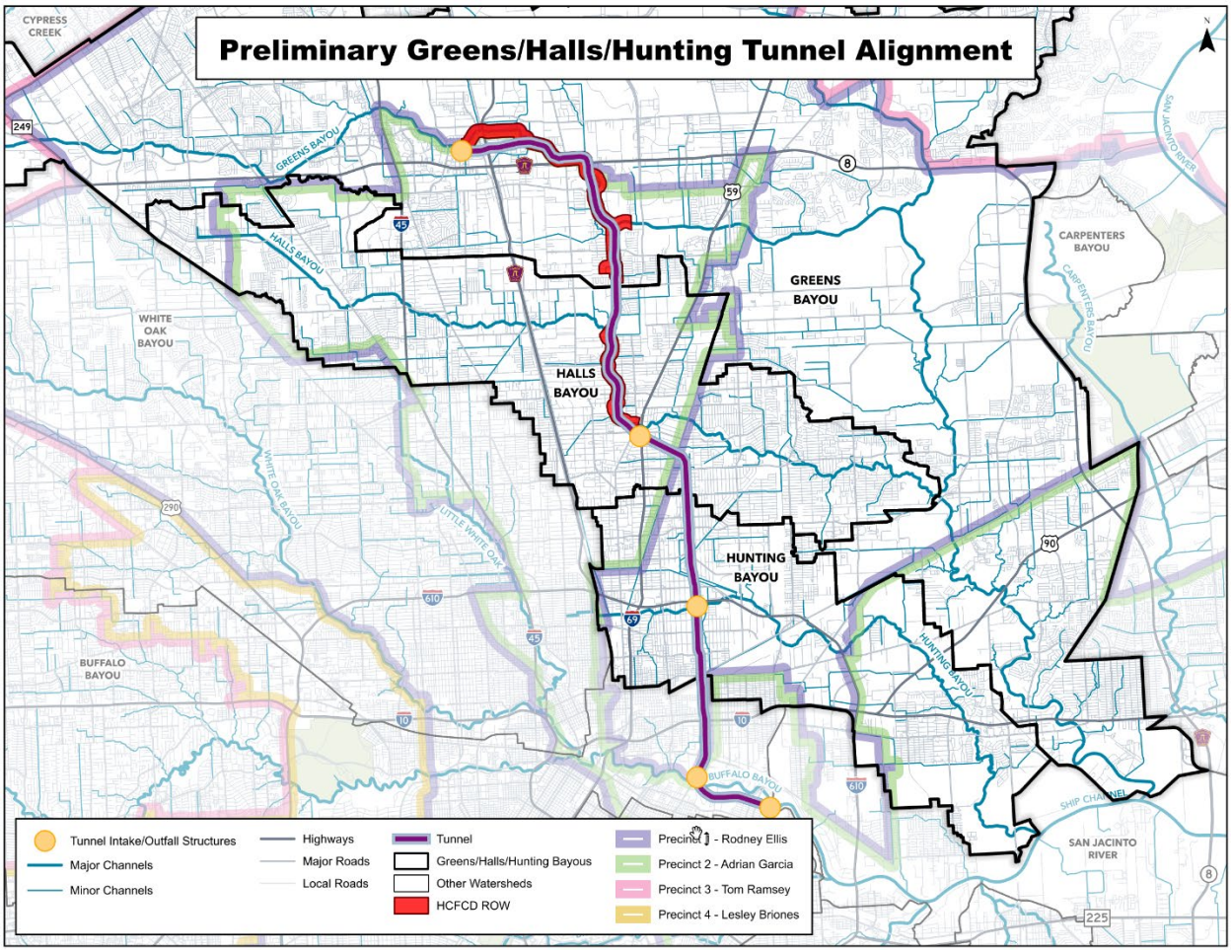
Greens / Halls / Hunting and Buffalo Bayou Potential Pilot Projects

Several conceptual tunnel alignments for large diameter, deep stormwater conveyance tunnels were identified during the development of the "Feasibility Study of Stormwater Conveyance Tunnels – Phase 2" report, completed in 2022 (Phase 2 Tunnel Study). These tunnel alignments were identified based on their ability to reduce flooding in areas with high flood risk and to minimize right-of-way requirements and environmental and social impacts associated with construction. Furthermore, these tunnel alignments represent the foundational elements of a potential Harris County tunnel system. More information on the Phase 2 Tunnel Study can be found here: https://www.hcfcd.org/Z-08.

Harris County Commissioners Court has expressed interest in pursuing a tunnel conveyance pilot project along the alignments previously identified for the Greens, Halls, and Hunting Bayou watersheds and the Buffalo Bayou watershed.

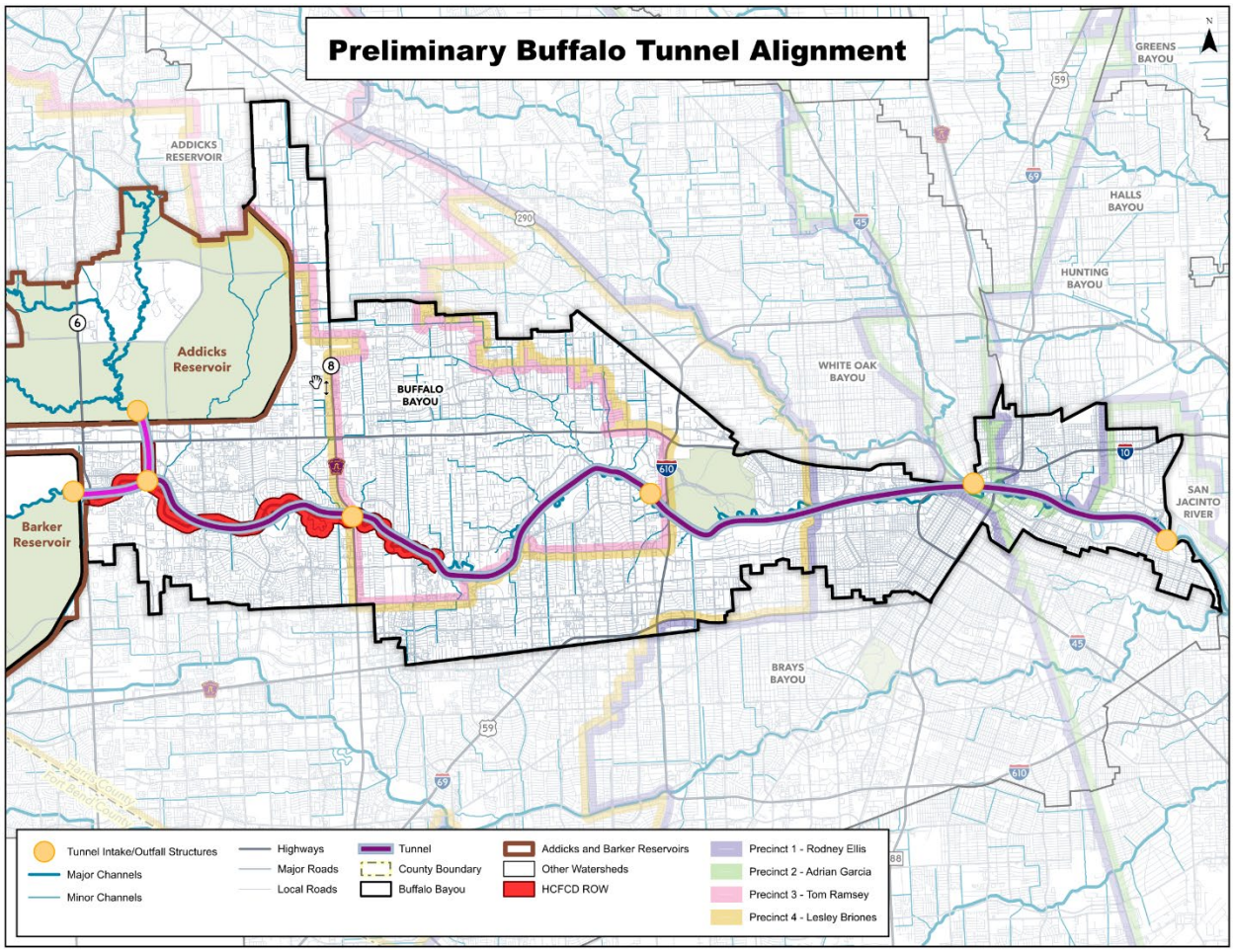
The conceptual alignment for the Greens / Halls / Hunting tunnel is shown in **Figure 2**. The proposed outfall for this tunnel alignment is the Houston Ship Channel, near the turning basin. Along the 18+ mile conceptual alignment identified in the Phase 2 Tunnel Study, preliminarily sized at a 35' diameter, bayou intakes are proposed at the tunnel's intersection with Hunting Bayou, Halls Bayou, and Greens Bayou.

Figure 2: Preliminary Greens / Halls / Hunting Tunnel Alignment



The conceptual alignment for the Buffalo Bayou tunnel is shown in **Figure 3**. The proposed outfall for this tunnel alignment is the Houston Ship Channel, near the turning basin. Along the 20+ mile conceptual alignment identified in the Phase 2 Tunnel Study, preliminarily sized at a 40’ diameter, bayou intakes are proposed at the confluence with White Oak Bayou, at IH-610, at BW-8, and at N. Eldridge Parkway. In addition, intakes are proposed within the Addicks and Barker reservoirs.

Figure 3: Preliminary Buffalo Bayou Tunnel Alignment



Both the Greens / Halls / Hunting and the Buffalo Bayou tunnel alignments are each currently estimated to cost $5 billion dollars or more. As such, due to scale and cost, full completion of either of these alignments as an initial pilot project is likely not feasible. Within each of the two conceptual tunnel alignments, several options exist for extracting a potential smaller pilot project. Likely options for an initial, smaller-scale, pilot project range from:

- Constructing the ultimate outfall (on the Houston Ship Channel)
- Constructing the ultimate outfall and an initial segment of tunnel (up to a working shaft)
- Constructing the ultimate outfall and an initial segment of tunnel (up to a bayou intake)

Completing such a pilot project would establish the critical downstream facilities needed to continue to build out the proposed tunnel system over future phases. However, the ability of any initial pilot project to provide immediate benefits would be dependent on its ability to reach a bayou intake. Regardless, initiating construction of the system would support accelerated future expansion in later phases.

Construction of a large-diameter diameter outfall structure is currently estimated to cost approximately $200 million. An extension to either the White Oak Bayou intake (on the Buffalo

Bayou tunnel) or the Hunting Bayou intake (on the Greens / Halls / Hunting tunnel) would increase cost to over $1 billion for each system.

Alternative Alignments for Potential Pilot Projects

While the initial direction from Harris County Commissioners Court was to evaluate pilot projects along the Buffalo Bayou and Greens / Halls / Hunting alignments identified in the Phase 2 Tunnel Study, other locations within the County could also serve as tunnel conveyance pilot projects. Pilot tunnels that run along a main stem bayou or serve a tributary or specific neighborhood, would be constructed to outfall to a receiving waterbody such that the increased conveyance would not cause adverse impacts.

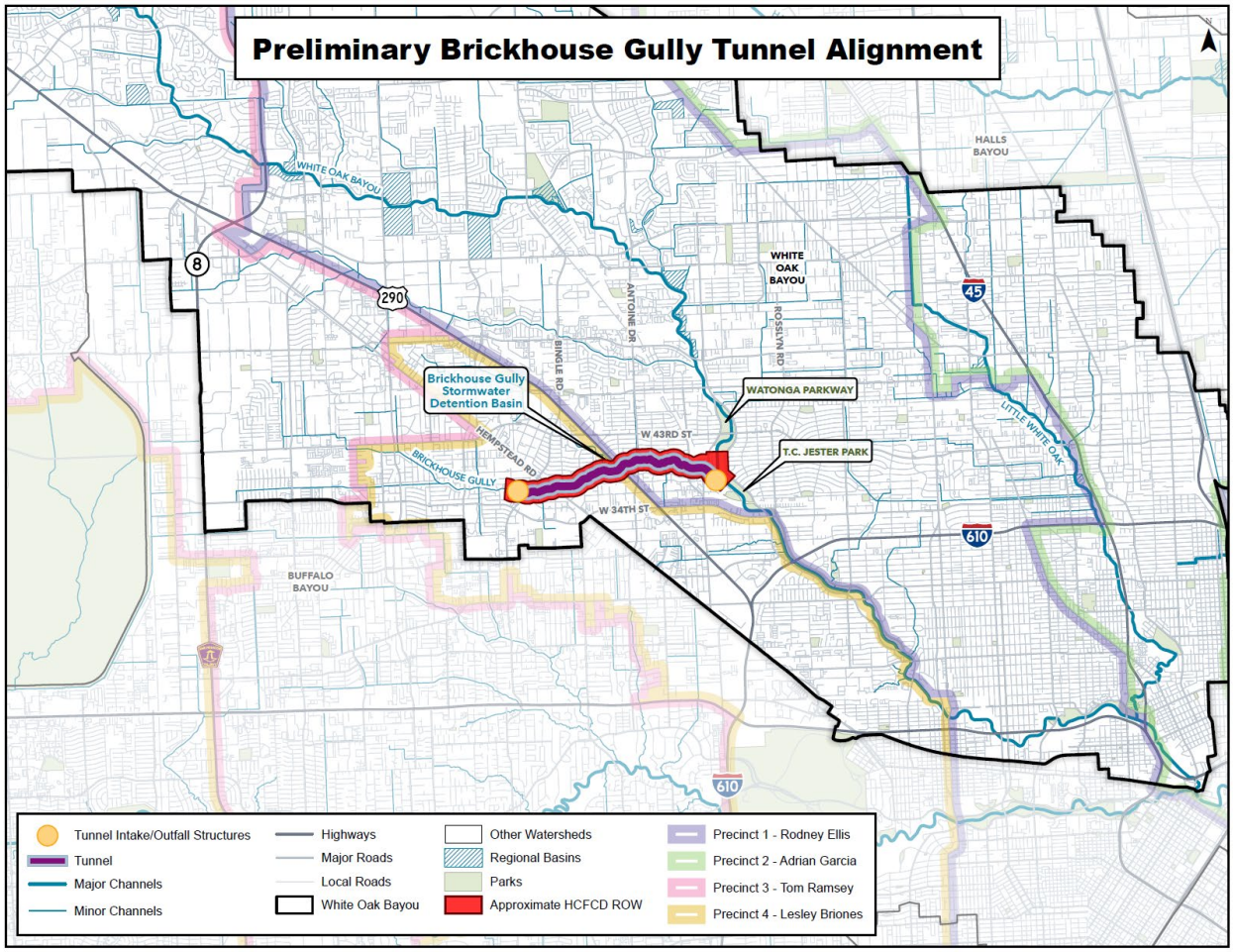
Such pilot tunnel alternative alignments could be shorter (e.g. less than 5 miles), smaller (10 to 20 ft), and less costly, as they would likely only need to serve smaller drainage areas within a watershed. However, any outfall to a main stem bayou would likely require impact mitigation (e.g. stormwater detention) in order to comply with Harris County's no adverse impact policies. Main-stem bayou tunnels could be considered in areas where surplus detention capacity has already been constructed, but associated conveyance improvements have not yet been developed.

Potential Pilot Project Alignments:

Based on prior analyses, several potential pilot project locations were identified. This list is not comprehensive nor all-inclusive but instead represents instead an initial geographic distribution of potentially valuable pilot projects that have been discussed previously or explored conceptually. These include:

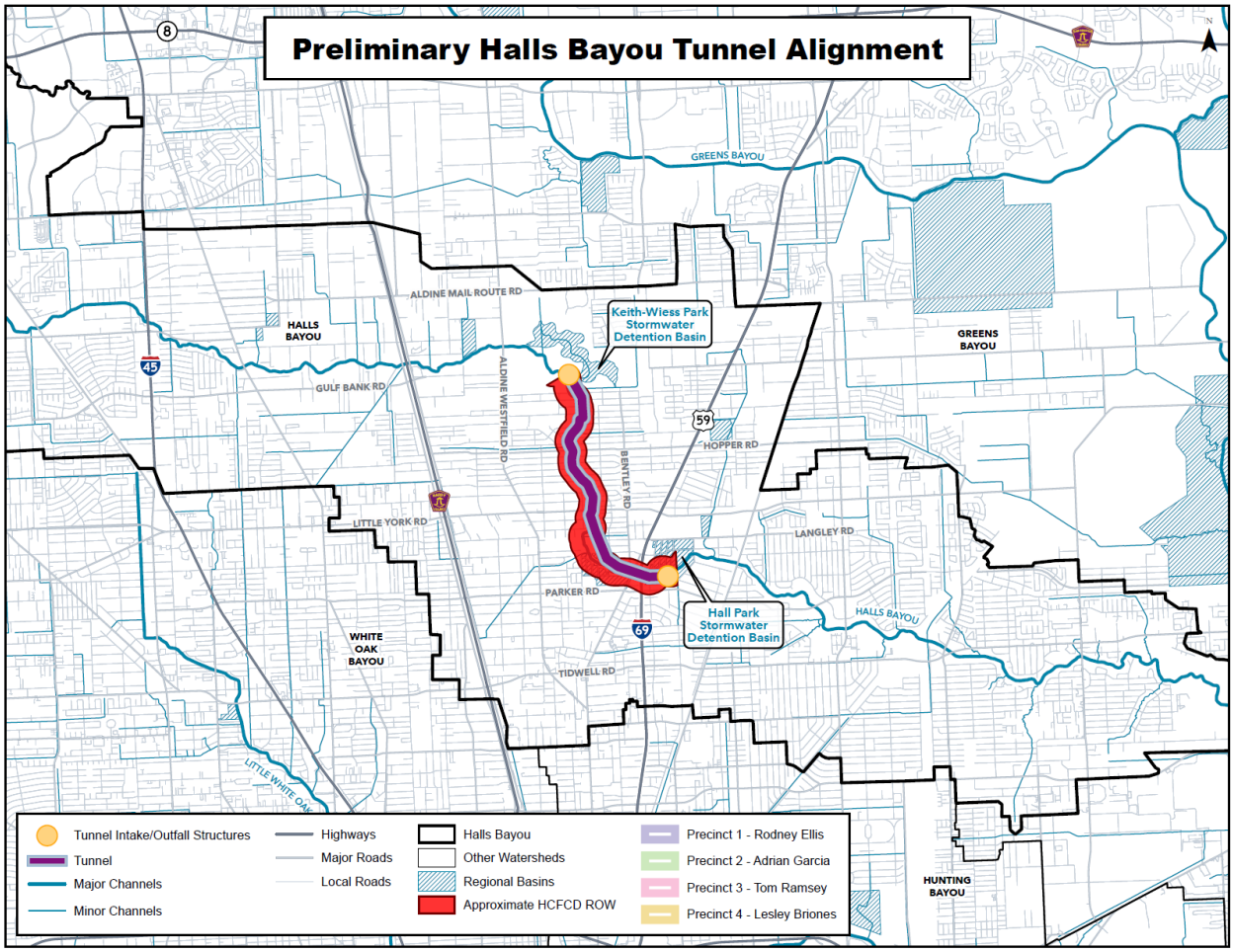
- **Brickhouse Gully:** Located in within the White Oak Bayou watershed, this pilot tunnel alignment would comprise a medium diameter tunnel spanning approximately 3.5 miles from where Brickhouse Gully crosses Bingle Road at the upstream intake to TC Jester Park near the confluence of Brickhouse Gully and White Oak Bayou at the outfall. Severely limited right-of-way and existing conveyance restrictions in this area make this an ideal location for a tunnel conveyance alternative. Given a relatively low flow in the channel, a smaller tunnel may still be sufficient to provide impactful benefits to the area. Exact intake and outfall locations and tunnel route would need to be confirmed through further study. Within the area that could potentially be served by the pilot tunnel alignment, several hundred homes are at risk of frequent flooding and could potentially benefit from the proposed pilot project. Mitigation would likely be required. Actual mitigation requirements and location would need to be determined through further study. This alignment is independent from an ultimate tunnel alignment identified in the Phase 2 study but could be connected to a tunnel along the White Oak Bayou mainstem in the future.

Figure 4: Potential Conceptual Brickhouse Gully Tunnel Pilot



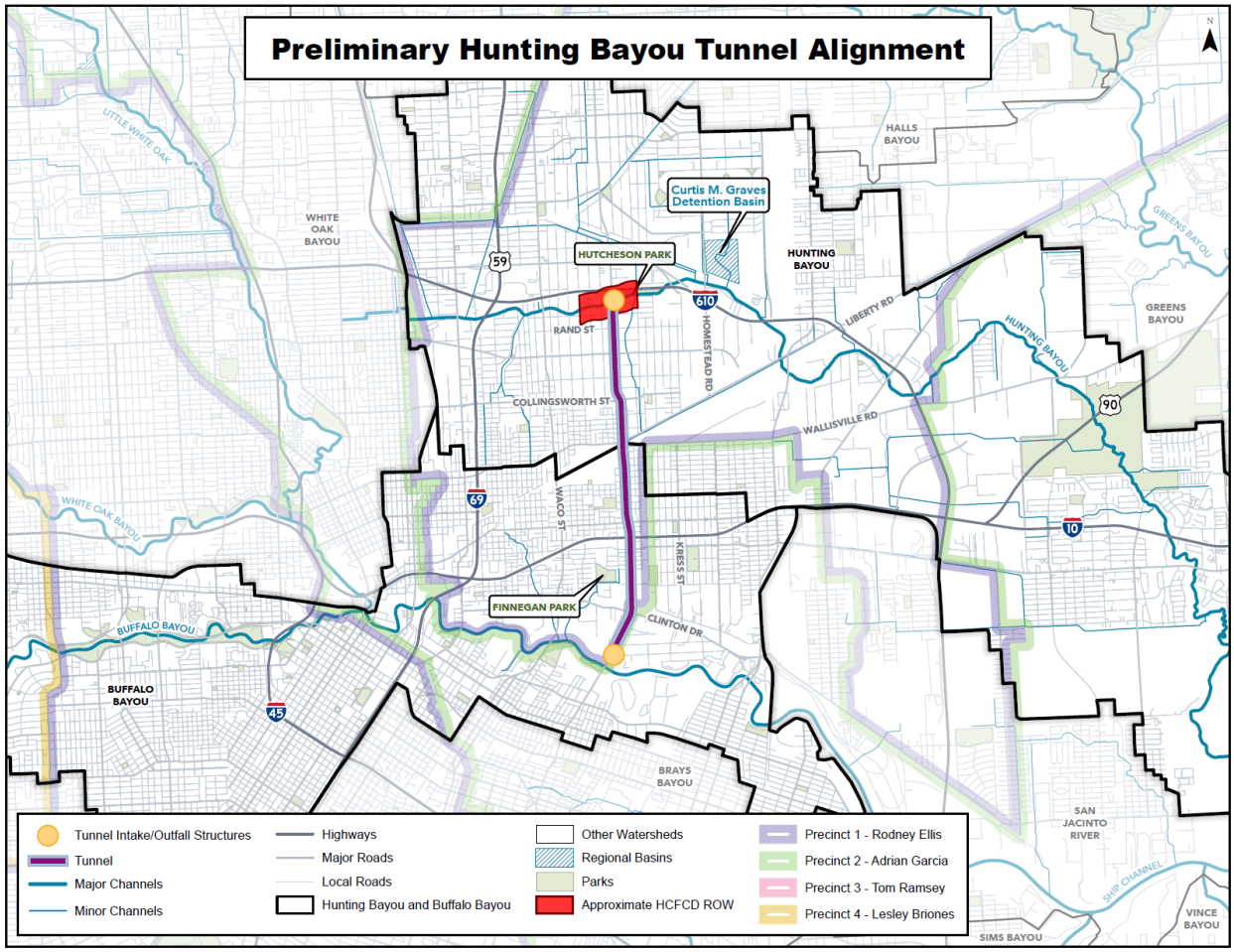
- **Halls Bayou:** Located within the Halls Bayou watershed, this pilot tunnel alignment would comprise a large diameter tunnel spanning approximately 3.5 miles from Keith Weiss Park at the upstream intake to the east side of Hwy 69 in a proposed area of detention at the outfall. Severely limited right-of-way, existing conveyance restrictions, and concentrated flood risk in this area make this an ideal location for a tunnel conveyance alternative. Given a moderate amount of flow in the channel, a medium diameter tunnel may still be sufficient to provide impactful benefits to the area. Exact intake and outfall locations and tunnel route would need to be confirmed through further study. Within the area that could potentially be served by the pilot tunnel alignment, several thousand homes are at risk of frequent flooding and could potentially benefit from the proposed pilot project. Mitigation would likely be required. Actual mitigation requirements and location would need to be determined through further study. This alignment is overlapping with an ultimate tunnel alignment identified in the Phase 2 study.

Figure 5: Potential Conceptual Halls Bayou Tunnel Pilot



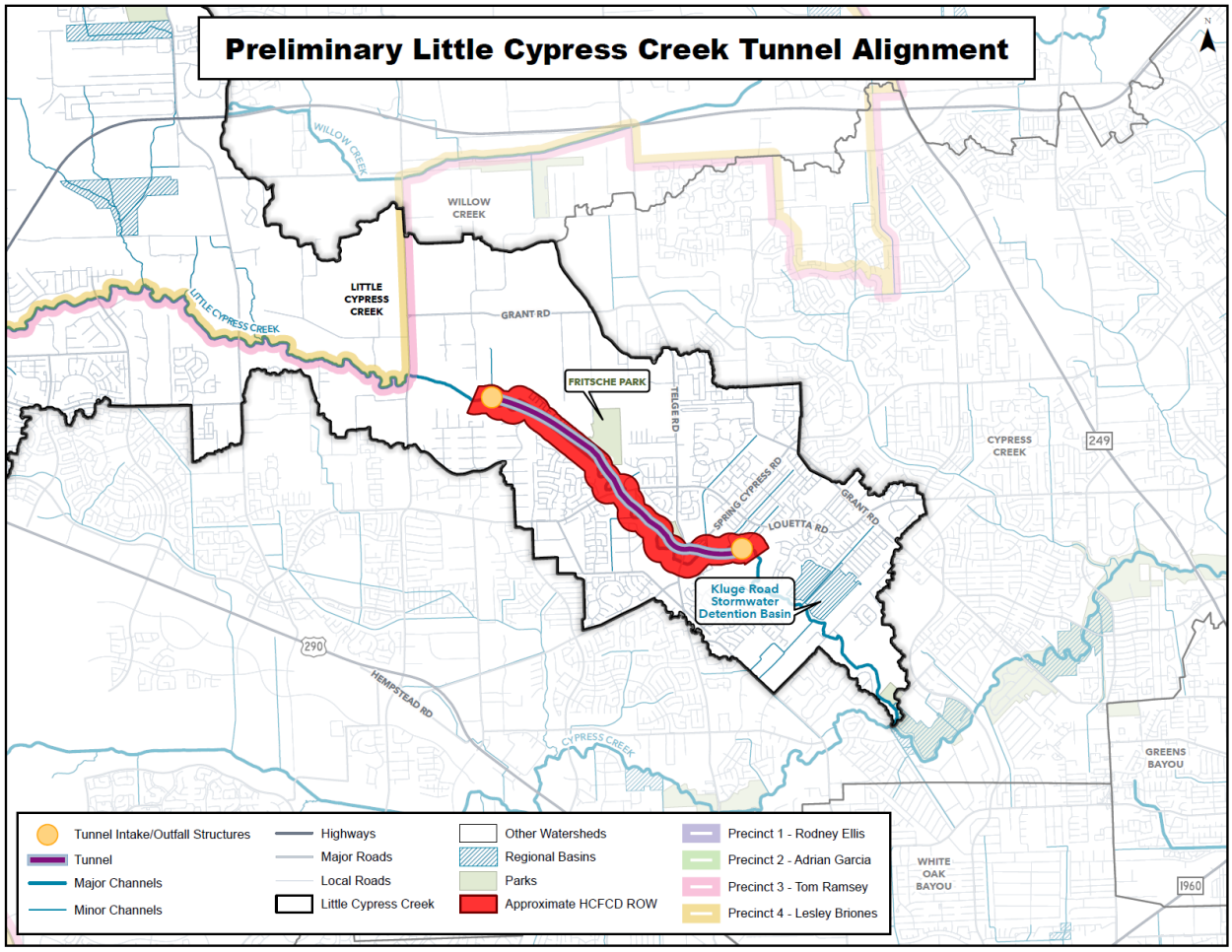
- **Hunting Bayou:** Located in within the Hunting Bayou watershed, this pilot tunnel would consist of a small to medium diameter tunnel spanning approximately 4 miles from Hunting Bayou at Lockwood Drive, down Lockwood Drive, to an outfall on Buffalo Bayou. Constraints along Hunting Bayou, such as railyards, make this an ideal location for a tunnel conveyance alternative. Exact intake and outfall locations and tunnel route would need to be confirmed through further study. Within the area that could potentially be served by the pilot tunnel alignment, several thousand homes are at risk of flooding and could potentially benefit from the proposed pilot project. Mitigation could potentially be required, depending on the outfall location. Actual mitigation requirements and location would need to be determined through further study. Note – this is the same alignment as is proposed for the ultimate Greens / Halls / Hunting tunnel system. As such, consideration must be given to having this pilot project function as a smaller single-purpose project (serving only Hunting Bayou), or as the starting phase of a large multi-purpose project (serving Hunting, Halls, and Greens bayous).

Figure 6: Potential Conceptual Hunting Bayou Tunnel Pilot



- **Little Cypress Creek:** Located within the Little Cypress Creek watershed, this pilot tunnel alignment would comprise a small to medium diameter tunnel spanning approximately 3 miles from just downstream of Cypress Rose Hill Road to the Gulf Club at Longwood. Restricted right-of-way along Little Cypress Creek makes this an ideal location for a tunnel conveyance alternative. Exact intake and outfall locations and tunnel route would need to be confirmed through further study. Within the area that could potentially be served by the pilot tunnel alignment, several hundred homes are at risk of flooding and could potentially benefit from the proposed pilot project. Mitigation would likely be required. Actual mitigation requirements and location would need to be determined through further study. This alignment is independent of the ultimate tunnel alignment identified in the Phase 2 study for Cypress Creek.

Figure 7: Potential Conceptual Little Cypress Creek Tunnel Pilot



Importantly, all four potential smaller-scale tunnel pilot projects identified above are entirely conceptual in nature and will require further study to evaluate feasibility, benefit, cost, and other considerations. Preliminary estimates of project cost for these alignments range from tens of millions of dollars to hundreds of millions of dollars, depending on tunnel size, tunnel length, and mitigation requirements. Further study would be required for all alignments, as no project specific hydraulic analysis nor engineering has been performed yet for these alignments.

Pilot Project Schedule Considerations

Schedule for any infrastructure project can be broken into two components, “pre-construction” and “construction”. Depending on the delivery method employed, the pre-construction phase typically includes procurement, preliminary engineering, agency coordination, final design, environmental permitting, and right-of-way acquisition.

Critically, for linear projects of this nature, it is typically necessary to complete preliminary engineering activities, including up-front survey and geotechnical activities, prior to initiating environmental permitting activities. And given right-of-way for such projects may not be owned by the Flood Control District, right-of-way acquisition activities are not typically initiated until approximately a 60% design level or later, once the project footprint is fully defined.

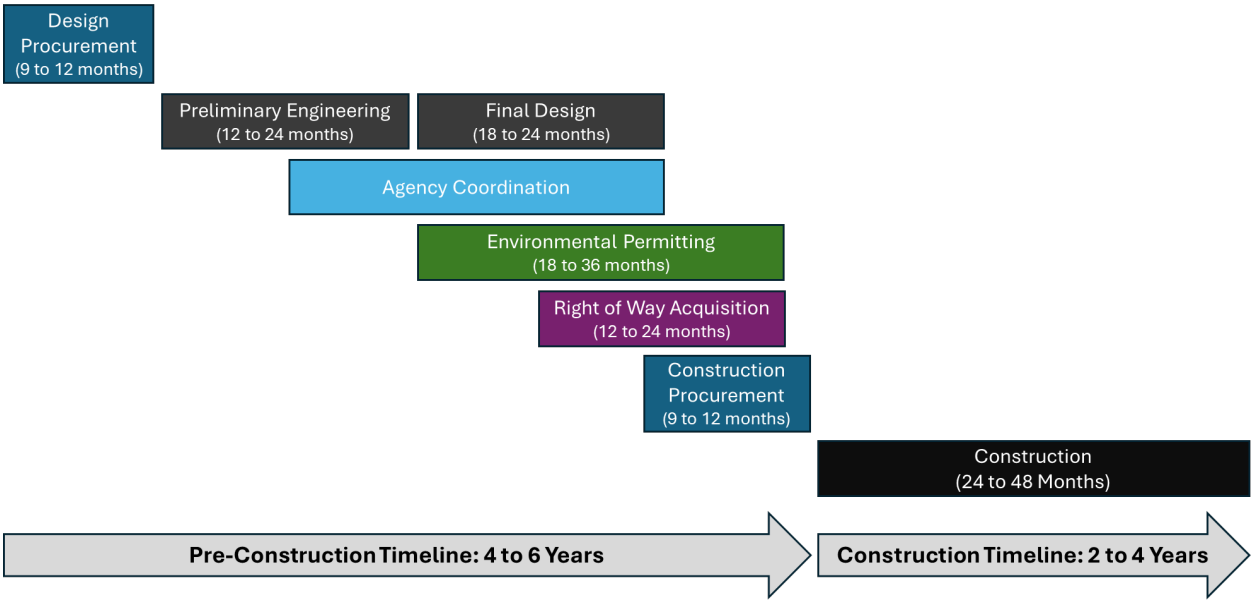
Estimated durations of pre-construction activities, for a project of this potential scale, are shown in **Figure 8**. As is shown, pre-construction activities for a project of this type and scale are anticipated to range from 4 to 6 years.

Utilizing a design-build delivery approach may provide some schedule efficiency, however given that environmental permitting and right-of-way acquisition are likely to define the critical path towards construction, schedule savings may be limited.

The construction phase of any pilot project would likely include procurement, mobilization, construction, and close-out. Construction duration, for bored tunnels, is heavily dependent on length. For any given tunnel size, there is a different "production rate", or feet of boring which can be completed by the tunnel boring machine in any given day. For a smaller diameter / smaller length pilot project, such as is being discussed for the alternative pilot project section, construction duration is estimated to range from 2 to 4 years (assuming a single boring machine is utilized), as shown in **Figure 8**. Construction schedule estimates were cross-checked with recent completed tunnel projects in the Houston area. This includes the 10 ft diameter, 4+ mile, West Harris County Regional Water Authority water supply tunnel which took approximately three years to construct.

In total, combining pre-construction and construction durations, a pilot project of this nature is anticipated to take between 6 to 10 years to complete, depending on length, size, and complexity of the pilot project ultimately selected.

Figure 8: Estimated Pilot Project Timeline



Other Considerations

Environmental Permitting:

Construction of any pilot tunnel is anticipated to require environmental permitting. If Federal funding is involved, additional environmental reviews and requirements would also be triggered. Regardless of funding source, impacts to wetlands and waters of the United States associated

with intake and outfall structures would likely trigger Section 404 permitting with the U.S. Army Corps of Engineers. While it is possible Nationwide Permits could be utilized to expedite the process, given the potential scale and significance of such a project, it is likely that an Individual Permit would be required. The permitting process would typically include the preparation of either an Environmental Assessment or an Environmental Impact Statement. And mitigation, likely in the form of purchasing mitigation bank credits, would likely be required to address impacts to streams and wetlands. Other mitigation may also be required if the project were to impact habitat associated with threatened or endangered species. Typically, environmental permitting efforts would begin at the 30% +/- design level. Given Federal requirements, the schedule for completing environmental coordination efforts and receiving regulatory approval for the project would typically be 18 to 36 months (as illustrated in **Figure 8**).

A positive of a tunnel construction, relative to traditional Flood Control District flood reduction approaches, are these tunnel projects have a much smaller footprint area (inlet and outlet only) due to the fact that the majority of this flood reduction system is underground. Accordingly, the environmental and community impact of tunnel construction is anticipated to be significantly less than for traditional measures.

Right-of-Way Acquisition:

Construction of any pilot tunnel is anticipated to require right-of-way acquisition. This includes both acquisition of lands for any intakes, working shafts, and outfalls as well as subterranean easements for the tunnel itself. Completion of right-of-way acquisition would typically be required prior to the award of a construction contract and initiation of construction activities. Acquisition of right-of-way would follow standard HCFCD procedures. Typically, right-of-way acquisition efforts would begin at the 60% design level. Given State law and local policies, the schedule for completing real estate acquisition efforts would typically be 12 to 24 months (as illustrated in **Figure 8**).

In addition to acquiring rights-of-way, it may also be necessary to relocate utilities in advance of construction. Such relocations may be required at intake or outfall locations, if locations without utility conflicts are not available. It is assumed, due to proposed tunnel depth, that relocations along the tunnel alignment could be avoided. If required, utility relocations would increase project cost and could increase project schedule.

Outfall Considerations:

Any tunnel must be designed to result in acceptable conditions at the outfall. First and foremost, this includes complying with Harris County's no adverse impact requirements, which prevent transferring flood risk from one area to another. Other important considerations include not adversely impacting the operation of the Houston Ship Channel and the Port of Houston, were the outfall to occur on the ship channel. Considerations would include potential impacts and mitigation actions as necessary to address water surface elevation increases and changes to channel velocities, sediment transport and deposition, scour, and water quality. Direct coordination and collaboration with the Port of Houston would be required for any outfall to the Houston Ship Channel.

Pilot Project Delivery and Funding Methods

Historically, tunnel projects in the United States have been split evenly between design-bid-build (DBB) or design-build (DB) type delivery methods. Either method could potentially be employed for a pilot tunnel conveyance project. The DBB method involves three sequential project phases: the design phase, which requires the services of a designer who will be the "designer of record" for the project; the bid phase, when a contractor is selected; and a build or construction phase, when the project is built by the selected (typically low bid) contractor. This sequence usually leads to a sealed bid, fixed-price contract. The DB method involves only one entity (design-builder) and a single contract with the owner to provide both engineering design services and construction. This integrated process overlaps design and construction which allows the project to potentially be fast tracked. In addition, cost efficiencies can potentially be achieved since the contractor and designer are working together throughout the entire process.

Funding options for a pilot project include, but are not limited to, selling bonds and/or obtaining grant funding. Grants could come from one of multiple programs such as FEMA, TWDB, State Allocations, Federal Community Project Funding, U.S. Economic Development Administration (EDA), or EPA. However, not all grant programs would be well-suited for a tunnel conveyance project or a project of the envisioned size and complexity. The U.S. Army Corps of Engineers is also a potential project funding partner, especially for the full-scale implementation of a larger Harris County tunnel system. Accordingly, the Flood Control District is advancing both the Buffalo Bayou and Tributaries Resilience Study and the SAFER Section 203 Feasibility Study to pursue this large-scale option. However, for a pilot project of smaller scale, the Federal timeline (potentially 10+ years until construction) makes this option a poor fit for a pilot project.

Another integrated delivery / funding option includes public private partnerships (P3). P3s vary and can encompass a broad range of approaches that involve a contractual relationship between the public owner and one or more private sector entities. P3 is a project delivery model that involves an agreement between a public owner and a private sector partner for the design, construction, financing, and often long-term operations and potentially maintenance of an infrastructure asset by the private sector partner over a specified term.

Pilot Project Prioritization Framework Scoring

This White Paper used information from reports already completed by the Flood Control District to determine the project prioritization framework scoring for the ultimate tunnel project on Buffalo Bayou and Greens / Halls / Hunting. Information to complete prioritization scores for alternative pilot project alignments are not currently available. For these alternative alignments, benefit information and refined operations and maintenance costs are not defined to the level necessary to accurately calculate benefits. These factors compose 50% of the scoring. If the Flood Control District is requested to complete detailed analysis for the alternative alignments, prioritization framework scoring can be completed as the additional information is developed. The scoring for the Greens / Halls / Hunting alignment and the Buffalo Bayou alignment, based upon the Phase 2 Tunnel Study results, is shown in **Table 2**.

Table 2: Project Prioritization Score

Ultimate Tunnel Alignment	Prioritization Framework Score
Greens / Halls / Hunting	4.45
Buffalo Bayou	3.05