Buffalo Bayou and Tributaries Resiliency Study, Texas

Review of Completed Projects

Report of Findings

May 2025

Photograph: Record breaking rainfall from Hurricane Harvey in 2017 caused catastrophic flooding in Houston. The above photograph shows completely submerged Memorial Drive and Allen Parkway adjacent to Buffalo Bayou in Houston, Texas on August 26th, 2017.

US Army Corps of Engineers®
Galveston District

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DEPARTMENT OF THE ARMY
GALVESTON DISTRICT, CORPS OF ENGINEERS
P. O. BOX 1229
GALVESTON, TEXAS 77553-1229

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EXECUTIVE SUMMARY

ES1 - Introduction

The U.S. Army Corps of Engineers, Galveston District (USACE) and Harris County Flood Control District (HCFCD) have prepared this Report of Findings to document the results of the Buffalo Bayou and Tributaries Resilience Study (BBTRS). This report is a response to Section 1221 of the Water Resources Development Act of 2024 (WRDA 2024) which directed expedited completion of BBTRS and submittal of a Chief's Report by December 31, 2025.

The purpose of BBTRS is to identify, evaluate, and recommend actions to promote community and infrastructure resilience by reducing harmful flood risks to people, property, and critical infrastructure in the Buffalo Bayou watershed. Three 500-year storms have hit Houston in the last 10 years. These storms are known colloquially as the Memorial Day flood in 2015, the Tax Day flood in 2016, and Hurricane Harvey in 2017. Each storm was bigger than the prior year, culminating with Harvey which made landfall on August 25, 2017, near Rockport, TX as a Category 4 hurricane that stalled over east Texas producing record rainfall and disastrous impacts.

In Harris County alone, Harvey is estimated to have flooded 154,000 structures and 600,000 vehicles, while causing 37,000 people to relocate to shelters, and requiring thousands of emergency rescue calls. This report will focus on the impacts of the increasing frequency and intensity of storms like Harvey within the Addicks, Barker, and Buffalo Bayou watersheds, because of the critical importance of two dams, Addicks and Barker, which were constructed and placed into operations by USACE west of downtown Houston in the 1940's.

ES2 - Changed Conditions

Congress has authorized USACE to recommend modifications of existing USACE projects, when deemed necessary due to changed conditions. Important changes that impact the Buffalo Bayou system are summarized here:

Rainfall. Regional precipitation patterns have changed and have increased the frequency and intensity of rainfall events. NOAA published the most recent precipitation frequency atlas for Texas in 2018 (Atlas 14) that incorporates rainfall data from the 1940s through 2017. Atlas 14 shows a significant **25 to 50% increase** in future precipitation for each frequency from a 2-year return interval to a 1,000-year return interval.

Development. Growth and expansion of the greater Houston area has surrounded Addicks and Barker since construction of the projects in what was then a rural setting west of Houston. The government owned land (GOL) elevation upstream of the dams is below the elevation at the ends of the dams, resulting in inundated structures in the reservoirs before flows spill around the dams or over the spillways. **Approximately 8,000 structures were flooded in the reservoir pool during Harvey. Approximately 17,000 structures also flooded downstream from the combined effects of local rainfall and reservoir releases.**

Project Design. The Flood Protection Plan for Buffalo Bayou was developed in 1940. The plan included the construction of the Addicks and Barker Reservoirs, which were completed later that decade. The construction included 7.4 miles of channel rectification immediately downstream of the dams. However, other **major components of the project were never built**. The Cypress Creek Levee was a component above the reservoir that would have helped reduce inflows to Addicks, and the South Canal would have

routed reservoir discharges and downstream Buffalo Bayou flows around highly developed areas of downtown and the Port of Houston. Other features would have managed floods on White Oak Bayou, which joins Buffalo Bayou near downtown Houston.

The passage of the 1954 Flood Control Act (FCA54) added channel enlargement of the remaining 21.9 miles of Buffalo Bayou downstream to the Houston Ship Channel turning basin, while removing other plan features. However, the additional 21.9 miles of channel improvement along Buffalo Bayou was **not constructed after intense local environmental opposition in 1971**.

Summary. Constrained, unfinished, and facing increased stresses from more frequent and intense rainstorms, the Buffalo Bayou flood risk system has limited ability to adapt to changing economic, social, physical and meteorological conditions. The limitations of the existing system were revealed during Hurricane Harvey (2017) when the extreme flood caused devastating impacts upstream and downstream of the dams.

ES3 - Evaluation of Alternatives

The study team formulated a full range of alternatives to reduce upstream inflows, increase storage in the reservoirs, improve structural integrity of the dams, increase conveyance of releases downstream, and reduce the vulnerability of people and property in the adjacent floodplains Several iterations of evaluation narrowed the focus of the study to downstream conveyance alternatives, including channel enlargement, a subsurface tunnel, or a non-structural buy-out of properties up to a 15,000 cubic feet per second (CFS) flowline. The final iteration determined that the tunnel provided more benefits and is more cost-effective than the other alternatives, while causing fewer environmental and social impacts.

ES4 - Further Evaluation of the Tunnel Alternatives

HCFCD conducted additional analysis of the tunnel alternative under new guidelines for a Comprehensive Benefit Analysis (CBA). The analysis took advantage of newly available hydrologic and hydraulic (H&H) models to strengthen the multi-faceted benefit analysis of the Tunnel Alternative, considering and balancing economic, environmental, and social factors. The CBA introduced novel methods for measuring non-monetary benefits and helped fully illustrate the wide range of benefits to be derived from reduced flooding. Additional engineering refinement and optimization was also performed. Results of the CBA demonstrate that the tunnel would:

- Reduce the number of flooded structures along Buffalo Bayou by 46% in a 100-year event
- Significantly reduce the probability of the reservoir pool inundating upstream communities in events up to and including the 500-year storm event (this is distinct from frequency of upstream tributary flooding)
- Generate up to $137,000,000 of average annual equivalent flood damage reduction benefits and a 0.4 benefit-to-cost ratio (BCR) at a cost of $8.2B
- Reduces by 67% the total number of days residents are displaced from their homes (100-year event in the Buffalo Bayou watershed); reduces financial and mental health burdens associated with recovery.
- Significantly increases the resiliency of the reservoir system, increasing the maximum non-damaging discharge rate by up to a factor of seven (11,000 CFS in the tunnel and up to 4,000 CFS in the channel dependent on downstream flooding conditions), and reducing reservoir

draw-down time from 53 days to 7.5 days (following a 0.01 (100-yr) Annual Exceedance Probability (AEP) event), preparing the system for a sequential rain event.

- Prevent the permanent displacement of 63,000 residents and 34,000 jobs, and the loss of nearly $5,000,000,000 in gross regional product, following a 500-year flood event.
- Requires only 40 acres of surface disturbance, an estimated 95% reduction in direct and indirect impacts as compared to other structural solutions under consideration, while preserving existing habitats and natural resources, parkland, and recreational amenities which are of high value to the community.

A portion of these benefits would also apply to the channel alternative if it were evaluated with the same H&H model; however, the tunnel would continue to have higher benefits than the channel enlargement, because of the operational flexibility and additional risk reduction that is offered by locating the intakes inside the reservoirs. The tunnel is the best available structural alternative.

That said, there are limitations to the performance of the tunnel. The tunnel reduces average annual damages by $137,000,000, which is about 27% of the without project average annual damages in the Buffalo Bayou watershed (including Buffalo Bayou, upper Addicks, and upper Barker); meaning that $379,000,000 in average annual damages remain. Most of the damage reduction occurs on Buffalo Bayou downstream of the dams, where $114,000,000 of $285,000,000, or 40%, of damages are reduced. The residual health, safety, and infrastructure impacts are expected to correlate to these residual physical damage percentages.

ES5 - Findings and Recommendations

This Report of Findings summarizes the evaluation of alternative actions to reduce flood risks on the Buffalo Bayou system to support community and infrastructure resiliency. Applicable engineering, economic, social, environmental and legal criteria have been considered. Furthermore, Sec 1221 of WRDA 2024 states that the report "shall contain recommendations for projects that:

> *(1) align with community objectives;*
> *(2) avoid or minimize adverse effects on the environment and community; and*
> *(3) promote the resiliency of infrastructure."*

Accordingly, four critical findings and associated recommendations are submitted:

1. Increase Conveyance – The tunnel is the most effective of the structural alternatives considered. It is technically sound and has the least environmental and social impacts. It significantly improves emergency operations capabilities, allowing safe release of water from the dams up to 15,000 CFS while reducing the duration and extent of upstream reservoir-induced flooding. Therefore, I recommend that the USACE be authorized to complete a 35% design of the tunnel system and complete necessary environmental and coordination requirements, including public comment. This will provide a much higher fidelity estimate of the costs, benefits and environmental impacts to better inform a construction investment decision. The estimated cost of completing an EIS, 35% design, and related site investigations is $80,000,000 to $100,000,000. It may also be possible to update the cost estimate to Class III for around $30 million without completing 35% design requirements.
2. Dam Safety – Armoring the emergency spillways may be necessary to bring life safety risks within tolerable risk guidelines. Therefore, I recommend that the USACE complete the Dam Safety

Modification Study (DSMS) for the emergency spillways and implement the study's recommendations. The estimated cost to complete the DSMS is $1,500,000.

3. Water Control Manual – Normal operations in the Water Control Manual currently limit flows to 2,000 CFS at Piney Point (the downstream control point); however, flows up to 4,000 CFS at Piney Point do not cause damage to structures on Buffalo Bayou during normal operations. Furthermore, induced surcharge operations are not optimized for the dams as they exist today, potentially adding risk. Therefore, USACE Galveston District will immediately implement an interim update to the Water Control Manual to both increase the normal allowable discharge at Piney Point and to reanalyze the induced surcharge plan to optimize use of available storage upstream and downstream. This updated Water Control Manual will serve to reduce risk as much as possible until tunnel construction and/or implementation of DSMS recommendations are complete. Each of those elements will require specific Water Control Manual updates prior to the end of construction. Proposed Water Control Manual updates must undergo public reviews. The estimated cost of Water Control Manual updates is $1 million.

4. Upstream Acquisition – Government Owned Lands (GOL) do not satisfy current acquisition policies. The tunnel would reduce the frequency of flooding above GOL but does not meet current policies for reservoir land acquisition or prevent water beyond GOL. Therefore, I recommend that the USACE be authorized to acquire necessary real estate interests to 104 feet North American Vertical Datum 1988 (NAVD 88) in Barker Reservoir and 108 feet NAVD 88 in Addicks Reservoir. Costs are estimated to be $14,872,300,000.

ES6 – Legal and Policy Limitations

The USACE acknowledges these recommendations have not reached legal and policy requirements for a construction authorization. Additional site investigations, technical analyses, environmental assessments, and independent expert and public reviews are required prior to a USACE recommendation for a construction authorization. These policy and legal requirements could be addressed as described below, with approval and subsequent funding.

ES6.1 - Legal Limitation

- Environmental compliance is incomplete for all environmental laws, as documented in Section 4 of this report. The National Environmental Policy Act (NEPA) requires that USACE prepare an Environmental Impact Study (EIS) prior to project construction, and USACE policy, Engineering Regulation (ER) 200-2-2, ordinarily requires the EIS to be completed during the feasibility study phase. The Report of the Chief of Engineers cannot recommend a federal project for construction if the NEPA process hasn't been completed. It can, however, recommend additional analysis. ER 200-2-2 provides for Categorical Exclusions for NEPA, one of which is for "Planning and technical studies which do not contain recommendations for authorization or funding for construction but may recommend further study."
- An Independent External Peer Review (IEPR) has not been conducted. Section 2034 of WRDA 2007, as amended, requires that USACE decision documents undergo an IEPR to obtain expert assessments of economic, environmental, and engineering assumptions and technical analyses, including formulation of alternatives, model application, and methods for integrating risk and uncertainty. If the project is authorized to receive funding for further site investigations and design development, an IEPR will be completed on the resulting EIS and design documents.

ES6.2 - Policy Limitations

- USACE and Administration policies require that the Assistant Secretary of the Army for Civil Works (ASA(CW)) approve a recommended plan that is not the National Economic Development (NED) plan, the plan that maximizes net national economic benefits. The study applied current guidance and policies for a comprehensive benefits framework to measure economic, social and environmental benefits of the tunnel alternative. However, the new guidance still includes the requirement that the ASA(CW) approve recommendations for an alternative that is not the NED Plan. A NED exception request will be submitted for review and approval in parallel with the processing of this Report of Findings.
- USACE policy does not have a minimum performance requirement. Instead, multiple scales of alternatives are to be evaluated to find a cost-effective scale that maximizes net benefits. Early iterations of the study evaluated smaller increments of conveyance; however, the final two iterations focused on 15,000 CFS once it was determined that lower flows would not meaningfully improve performance of the system in larger events where USACE faces significant risk when operating the system. This focus on 15,000 CFS was implicitly approved in 2021 with the last approved study scope, schedule and budget. However, explicit approval is needed to resolve the policy concern. This request will be incorporated into the NED exception described in the first bullet above.
- USACE policy requires Agency Technical Review (ATR) of all technical analyses and supporting documentation of project recommendations. Documentation of the tunnel evaluation, like the engineering models, cost estimating, and comprehensive benefits analyses have been reviewed by a USACE ATR team; however, resolution of review concerns have not been fully backchecked to reach closure. The technical evaluations of other alternatives and this Report of Findings have not undergone ATR.
- USACE policy requires a Class III cost estimate in Chief's Reports that request Congressional authorizations. The current cost estimate for the tunnel is a Class IV. A Class III estimate requires an appropriate level of design maturity that cannot be achieved without the necessary level of funding to complete site investigations and approximately 35% design. Hence the request for authorization to receive funding for design rather than a construction authorization. If funded, the design documentation and resulting Class III cost estimate would be used as the basis for further recommendations to Congress in a final Chief's Report.

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1 STUDY INFORMATION

1.1 Introduction

The U.S. Army Corps of Engineers (USACE), in partnership with the Harris County Flood Control District (HCFCD), is conducting a feasibility study of the Buffalo Bayou and Tributaries flood risk management system.

The partnership between the USACE and the HCFCD began in the 1940s with the construction of the Addicks and Barker Dams. The dams create reservoirs controlling water flow into Buffalo Bayou, capturing and gradually releasing excess rainwater during and after heavy storms. The construction of the Addicks and Barker Dams proved vital in mitigating the impact of destructive flooding that had historically plagued the city of Houston.

However, in 2017, those dams were tested when Hurricane Harvey devastated the Houston region, dumping more than 50 inches of rain over a four-day period and incurring $125 billion in damages across the metropolitan area. The USACE owned and operated reservoirs contributed to flooding of thousands of structures upstream when pool levels exceeded the limits of government-owned land (GOL) and downstream along Buffalo Bayou as waters overflowed streambanks.

1.2 Study Purpose

The Bipartisan Budget Act of 2018 (BBA18) funded the Buffalo Bayou and Tributaries Resiliency Study (BBTRS) to reassess the Addicks and Barker Reservoirs system in light of changed physical and economic conditions in the region. The study aims to identify, evaluate, and recommend actions to promote community and infrastructure resilience by reducing harmful flood risks to people, property, and critical infrastructure in the Buffalo Bayou watershed and its tributaries.

The changed physical and economic conditions in the Houston region are clear. Over the last 80 years, the metropolitan area has seen significant population growth, with 4.7 million residents now calling Harris County home (2020 U.S Census). Furthermore, Houston's place as the Energy Capital of the World, home of the largest port by foreign tonnage, and the number one export metro and center of global trade makes the region a critical part of the national and global economies. The city is home to 26 Fortune 500 companies with another 47 companies on the Fortune 1000 list headquartered in the region.

USACE has owned and operated the dams since original construction in the 1940s. The watersheds and our understanding of rainfall have dramatically changed over that time. We have modified the dams many times over the years to reduce risk for the residents that live around the project. Unfortunately, the many changes in both the projects and climatology resulted in substantial residual flood risk for the residents and risk for USACE. During Hurricane Harvey, that risk was realized for the first time with thousands of homes and businesses flooding.

This report of findings documents analyses conducted by USACE and HCFCD. The report is a response to Section 1221 of the Water Resources Development Act of 2024 (WRDA 2024), which requires a final report of the Chief of Engineers by December 31, 2025.

> *SEC. 1221. BUFFALO BAYOU TRIBUTARIES AND RESILIENCY STUDY, TEXAS.*
> *(a) In General.--The Secretary shall expedite completion of the Buffalo Bayou Tributaries and Resiliency Study, Texas, carried out pursuant to title IV of the Bipartisan Budget Act of 2018 (132 Stat. 76).*
> *(b) Reports.--The final report of the Chief of Engineers for the study described in subsection (a) shall contain recommendations for projects that--*
> *(1) align with community objectives;*
> *(2) avoid or minimize adverse effects on the environment and community; and*
> *(3) promote the resiliency of infrastructure.*
> *(c) Deadline.--Not later than December 31, 2025, the Secretary shall submit to the Committee on Transportation and Infrastructure of the House of Representatives and the Committee on Environment and Public Works of the Senate the final report described in subsection (b).*

1.3 Study Location

Buffalo Bayou watershed is in the San Jacinto River Basin located in Harris, Fort Bend, and Waller counties in southeast Texas. Barker Dam sits above Buffalo Bayou, and Addicks Dam is on South Mayde Creek, a tributary of Buffalo Bayou. Both dams are on the northwestern boundaries of the city limits of Houston.

1.4 Study Scope

The Buffalo Bayou and Tributaries Resiliency Study evaluates six watersheds (Figure 1):

- Upper Cypress Creek (267 square miles),
- White Oak Bayou (111 square miles),
- Brays Bayou (127 square miles),
- Addicks Reservoir (138 square miles),
- Barker Reservoir (126 square miles); and,
- Buffalo Bayou (102 square miles).

The six watersheds are included in the modeling and technical analyses of flooding, but the primary scope of the study is to reduce flood risk for the Addicks, Barker, and Buffalo Bayou watersheds, with benefits also possible within the White Oak Bayou watershed. Alternative plans were formulated in the shaded portions of the study area, and the effects were measured by hydrologic and hydraulic (H&H) models over the area bounded in red.

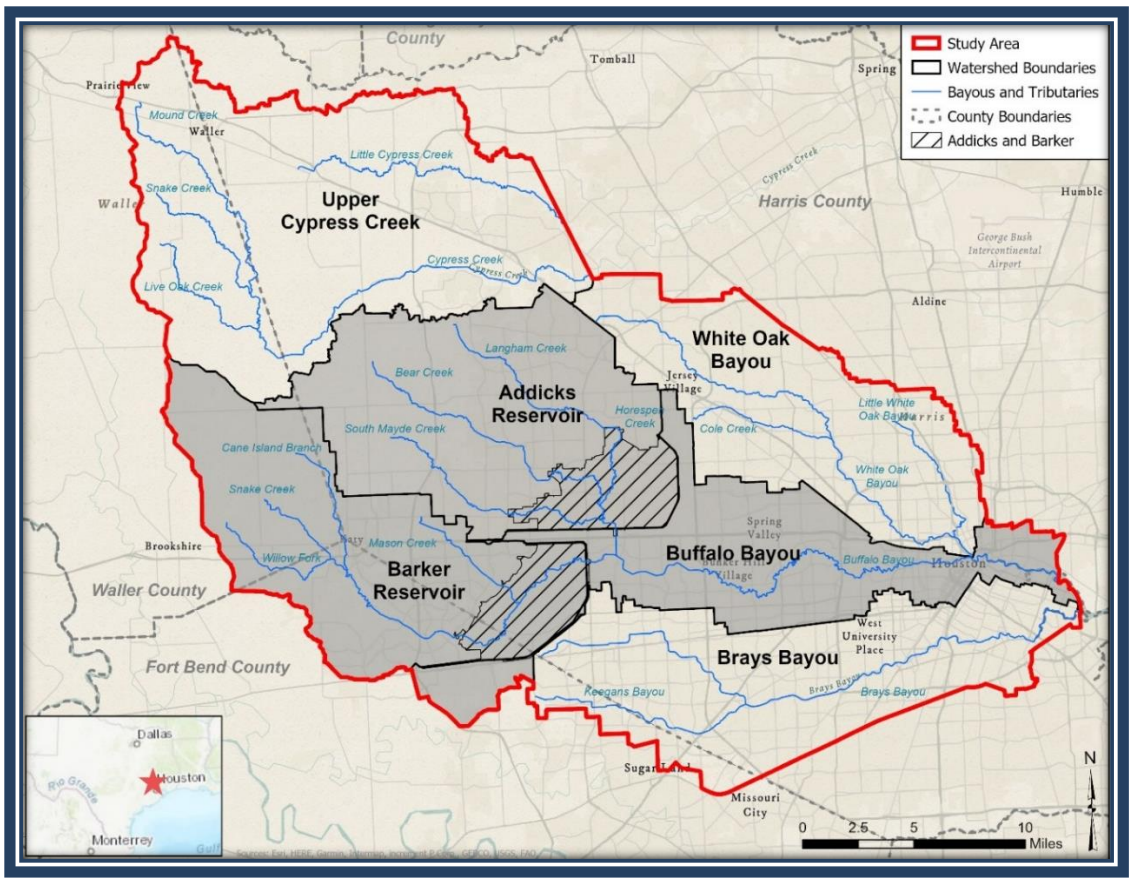

Figure 1. Addicks and Barker Reservoirs and Buffalo Bayou, Texas Study Area Map

1.5 History of the Buffalo Bayou and Tributaries System

USACE is the regulating agency for Addicks and Barker Reservoirs. The Addicks and Barker Reservoirs are part of the Buffalo Bayou and Tributaries, Texas flood risk-management system located on the west side of Houston, Texas. Addicks and Barker Dams were completed in the mid-1940s. These reservoirs provide flood risk-management benefits for the City of Houston, and for the Port of Houston and the Houston Ship Channel, which is formed from the lower end of Buffalo Bayou. Over four million people live and work in and transit through the Buffalo Bayou watershed.

Devastating floods in 1929 and 1935 prompted authorization of the Buffalo Bayou and Tributaries Project in the Rivers and Harbors Act of 1938. The Flood Protection Plan for Buffalo Bayou in Houston was developed in 1940, which included the construction of the Addicks and Barker Reservoirs, completed later that decade (Figure 2). However, other major components of the project, such as the White Oak Reservoir, a 25-mile-long North Canal, a 25-mile-long South Canal, the Cypress Creek Levee, and the 2-mile-long Brickhouse Gully Bypass Channel, were never built. These unconstructed features would have managed the Cypress Creek overflow and created bypass channels to route flood flows and reservoir discharges around highly developed areas of Downtown and the Port of Houston.

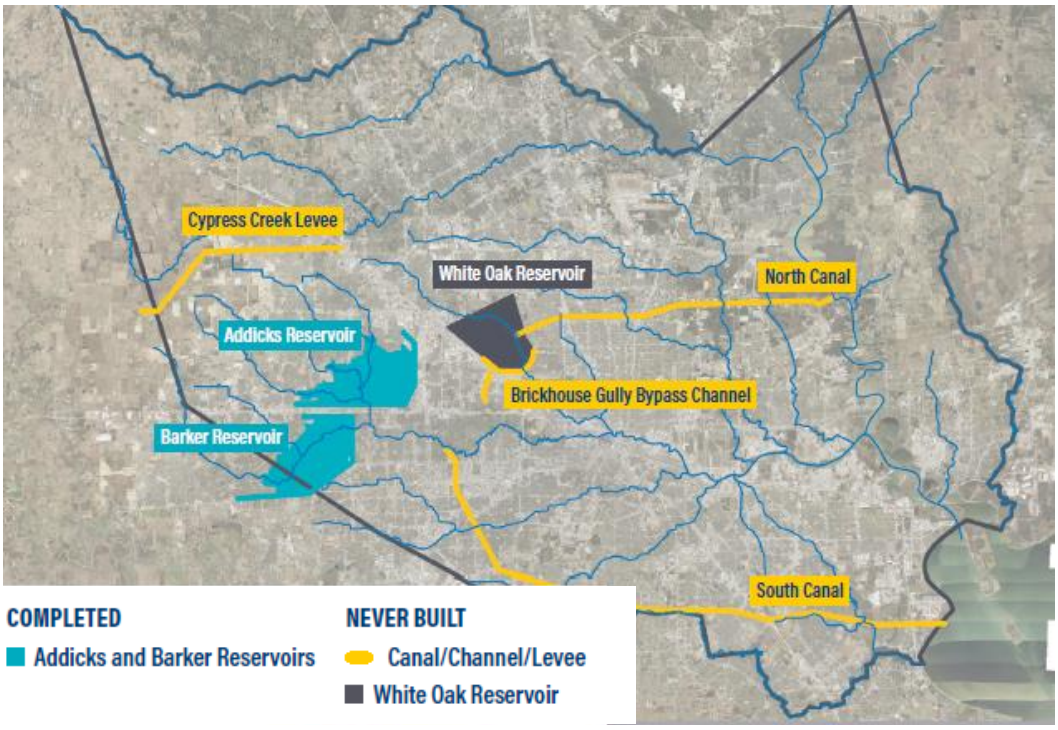

Figure 2. 1940 Proposed Flood Protection Plan.

The 1954 Flood Control Act modified the master flood control plan for Buffalo Bayou and Tributaries. The updated flood control plan included the already constructed Addicks and Barker Dams and 7.4 miles of channel rectification downstream. It also authorized channel enlargement of the remaining 21.9 miles of Buffalo Bayou downstream to the Houston Ship Channel turning basin, stream enlargement for 10.4 miles of White Oak Bayou and 25.4 miles of Brays Bayou. The additional 21.9 miles of channel enlargement along Buffalo Bayou was not constructed after intense local environmental opposition in 1971.

Addicks and Barker Reservoirs were originally designed and constructed to reduce the peaks of flood hydrographs by extending the duration of flow but were not fully gated. Outlet gates were added incrementally, and the reservoirs were fully gated by the 1960s. A new Water Control Manual was published in 1962 which included the induced surcharge operation schedule. By the 1970s, new prolonged pools resulting from the addition of gates caused seepage through and under the embankments. Emergency seepage control measures were planned in the late 1970s and constructed by 1982.

An updated hydrology report was published in 1977, leading to a new understanding of dangerous flood risk at the dams. To address this new risk, both dams were raised, and emergency spillways were added to the lower ends to prevent erosion during the probable maximum flood (PMF). Construction of new spillways and raising the main embankment was completed in 1989 on both dams. Additional real estate to operate the projects that could now withstand the probable maximum flood (the largest flood that could probably occur in the watersheds) was not acquired. The Water Control Manual was not updated following the new hydraulic analyses or dam construction. It was updated in 2012 to codify the 2,000 CFS discharge limit at Piney Point for normal operations but the induced surcharge curves were not functionally changed.

A dam safety screening in 2007 led to identification of new risk of failure at both the primary outlets and emergency spillways on both dams. The Dam Safety Action Classification (DSAC) was set at DSAC I in 2009 and funding for the primary outlets was prioritized. A series of interim risk reduction measures were implemented to help reduce immediate risk and construction of both new outlet works was completed by 2020, after which the DSAC rating was changed to DSAC II. Risk associated with the emergency spillways and high population at risk remains to be addressed in an upcoming Dam Safety Modification Study. The Water Control Manual was updated in 2019 to include operations of the new structures, but it did not functionally change the normal or induced surcharge operations plans.

1.6 Hurricane Harvey

The BBTRS was initiated in response to several recent flood events in the Houston metro area, including Hurricane Harvey that struck Texas with devastating effects in August 2017. Harvey made landfall on August 25th about 30 miles northeast of Corpus Christi near the communities of Rockport and Fulton. The Category 4 hurricane caused extensive damage as it moved north toward San Antonio and then veered sharply east towards Houston and Louisiana. Harvey's inland stall caused heavy rainfall across Harris and surrounding counties over a four-day period from 26 to 29 August with nearly 50 inches total in select locations. HCFCD estimates that nearly 70% of the county was covered with up to 1.5 feet of water, flooding nearly 154,000 structures.

A combination of development and higher rainfall volumes has led to increased runoff into the reservoirs. Table 1 shows that the two highest pool elevations over the projects' lives occurred in 2016 and 2017, with the 2017 Harvey flood producing the highest recorded floods in both reservoirs and on Buffalo Bayou.[1]

Table 1. Top 5 Historic Peak Stages in Addicks and Barker Reservoirs; High Water Marks on Buffalo Bayou near West Belt Rd.

Addicks		Barker		Buffalo Bayou	
Date	**Elevation**	**Date**	**Elevation**	Date	**Elevation**
Aug-17	109.1	Aug-17	101.6	Aug-17	71.6
Apr-16	102.65	Apr-16	95.24	Apr-09	65.4
Mar-92	97.46	Mar-92	93.6	Apr-16	65.3
Apr-09	96.90	Nov-02	93.24	Mar-92	64.5
Nov-02	96. 45	Nov-98	92.31	May-15	62.9

Addicks Reservoir peaked during Harvey at a record elevation of 109.10 feet on August 30th surpassing the previous record of 103 by 6.5 feet. At maximum pool, the reservoir was impounding 217,726 acre-feet of water and reached an elevation of 108.0 feet on August 29th resulting in uncontrolled flow around the

[1] All elevation data is in the North American Vertical Datum of 1988 (NAVD 88)..

end of the north spillway for the first time. These events are shown in relation to the GOL at elevation 103 feet which was exceeded by just over six feet (Figure 3).

Barker Reservoir reached a peak pool elevation of 101.6 feet on August 30th impounding 171,000 acre-feet. Barker Reservoir exceeded its previous record pool of 95 feet by 6.3 feet. Flows did not go around either of Barker's spillways. Additionally, these events are shown in Figure 3 in relation to the GOL at elevation 95 feet which was exceeded by almost seven feet.

As shown in Figure 3, rain began falling on August 25th. On August 28th, induced surcharge releases from the reservoirs were initiated (at approximately 8,000 CFS combined). Later that day, pool elevations moved past government owned land and approximately 8,000 structures were flooded upstream of the reservoirs. On August 29th, uncontrolled flow around the Addicks dam began, and induced surcharge releases were increased to approximately 13,000 CFS combined. Subsequently these flows combined with runoff from record rainfall in Buffalo Bayou. Approximately 17,000 structures were flooded to some extent downstream. On August 31st, the reservoirs reached their peak levels. Induced surcharge releases continued until September 20th, leaving areas along Buffalo Bayou flooded or inaccessible for weeks.

Figure 3 compares the stream flow rate downstream at Piney Point against an estimate of non-damaging flows along Buffalo Bayou downstream of the dams. As discussed above, downstream water level elevations and duration were influenced by induced surcharge releases during the extreme rainfall which necessitated releases to empty the Addicks and Barker Reservoirs following the Water Control Manual; the first time this has been required.

Hurricane Harvey resulted in flooding upstream and downstream of the Addicks and Barker Dams, driving unprecedented reservoir operations. Figure 3 shows the approximate duration of flooding upstream and downstream of the dams. Pool levels exceeded GOL above both dams for more than 10 days while flows in Buffalo Bayou exceeded 4,000 CFS at Piney Point for about 19 days. The record flooding that occurred upstream of the dams and along Buffalo Bayou during Harvey exceeded previous floods of record from Tax Day 2016, March 1992, and Tropical Storm Allison (2001). Water levels were generally above the 0.002 (500-yr) annual exceedance probabilities (AEP) from HWY 6 downstream to Farther Point and between the 0.01 (100-yr) and 0.002 AEP downstream of Farther Point to east of downtown Houston. Hurricane Harvey was ultimately one of the costliest tropical events in US history, with an estimated $125,000,000,000 in damages.

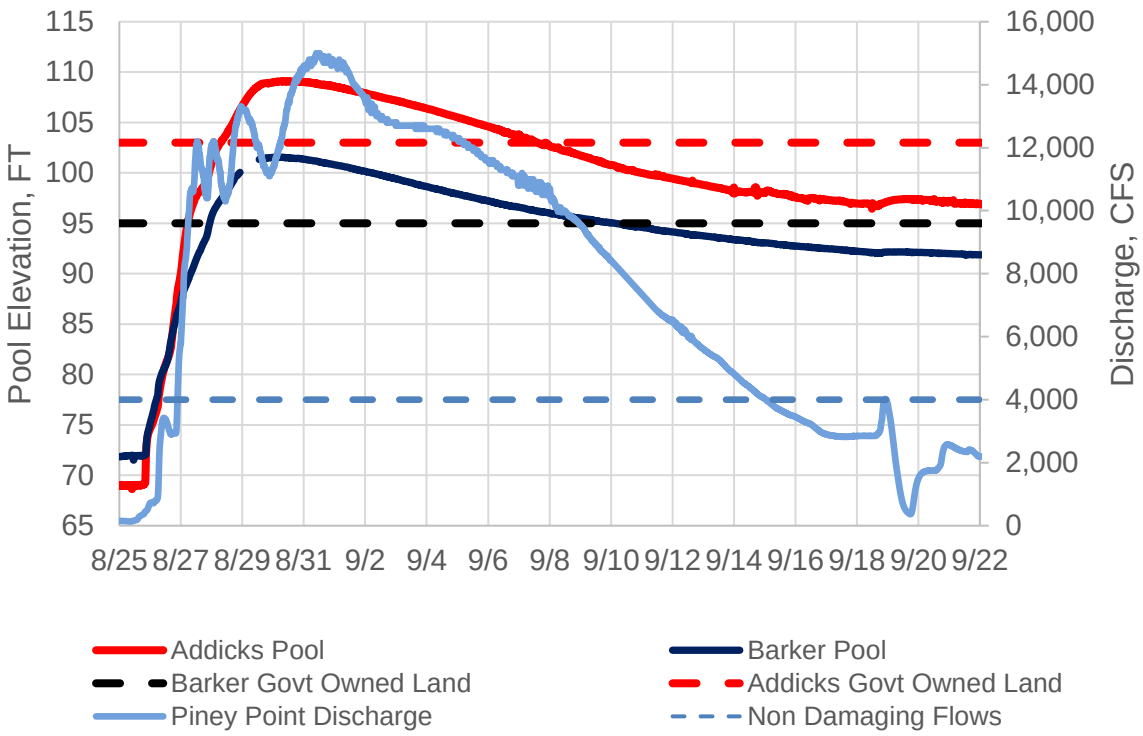

Figure 3. Pool elevations and downstream discharge at Piney Point during Hurricane Harvey.

1.7 Hydrologic Loading Curve Update

BBTRS required development of a hydrologic loading curve for both reservoirs using all available hydrologic data. This loading curve represents the best hydrologic data model currently available for the reservoirs. The loading curve was developed using an inflow volume-based approach, as outlined in Risk Management Center Technical Report 2018-03 (U.S. Army Corps of Engineers, 2018). The final loading curves for Addicks Dam and Barker Dam are shown in Figure Exe-3 and Figure Exe-4, respectively, and the pertinent elevations and AEP results are shown in Table Exe-1 and Table Exe-2, respectively. The new analysis shows that government owned land pool levels are at 1/110 and 1/40 ACE (the annual chance of exceedance in any year) at Addicks and Barker, respectively. The elevation at which induced surcharge can be triggered is now at 1/50 ACE for both reservoirs. These facts make it more likely than ever before that we will be faced with a similar problem of both upstream and downstream flooding around the reservoirs (over time the likely of reaching these pool elevations continues to increase).

The analysis included evaluation of the annual exceedance probability of reaching the induced surcharge elevations in both reservoirs. Induced surcharge refers to releases that will be made regardless of flooding conditions downstream of the dams. When the reservoir pool equals or exceeds 101 FT at Addicks and 95.7 FT at Barker, the induced surcharge regulation schedule for each dam is followed. Above these thresholds, the pool elevation and rate of rise dictate releases; the result could range from no releases up to the maximum releases (about 8,000 CFS from each dam).

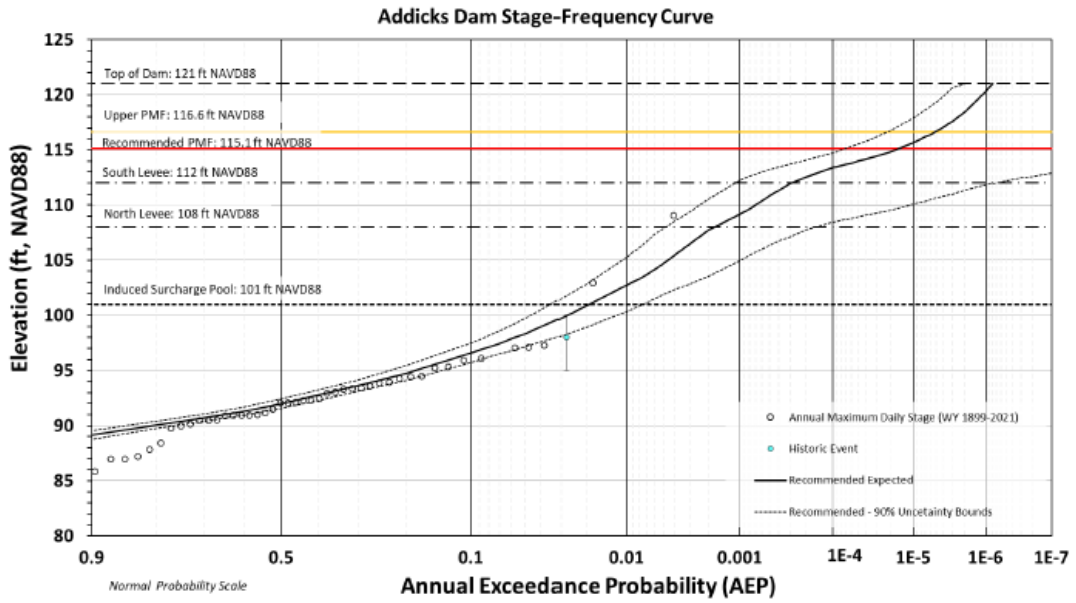

Figure Exe-3. Recommended stage frequency curve for Addicks Dam

Table Exe-1. Pertinent elevations and annual exceedance probabilities for Addicks Dam

Critical Reservoir Elevation	Elevation	AEP - Upper	AEP - Expected	AEP - Lower	Expected Return Period
Top of Dam	121.0	2.0E-06	7.9E-07	<1.00E-08	1,262,000
Upper PMF	116.6	2.3E-05	5.3E-06	<1.00E-08	189,000
PMF Recommended	115.1	7.3E-05	1.6E-05	<1.00E-08	62,500
South Spillway	112.0	1.1E-03	2.9E-04	7.0E-07	3,000
North Spillway	108.0	4.9E-03	1.7E-03	1.6E-04	570
Government Owned Land	103.0	1.9E-02	9.1E-03	2.8E-03	110
Induced Surcharge	101.0	3.5E-02	1.9E-02	7.5E-03	50

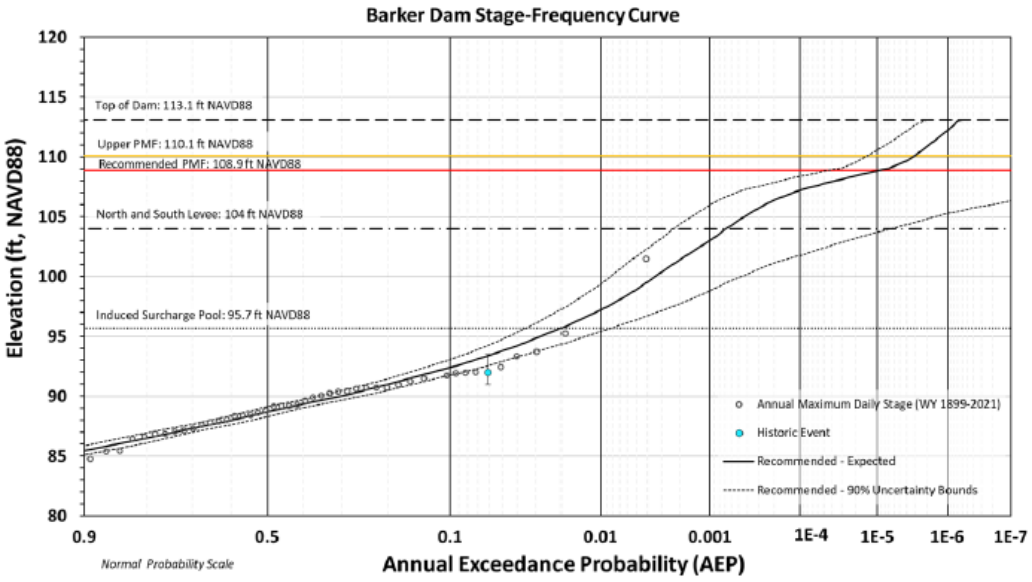

Figure Exe-4. Recommended stage frequency curve for Barker Dam

Table Exe-2. Pertinent elevations and annual exceedance probabilities for Barker Dam

Critical Reservoir Elevation	Elevation	AEP - Upper	AEP - Expected	AEP - Lower	Expected Return Period
Top of Dam	113.1	2.0E-06	6.0E-07	<1.0E-08	1,664,000
Upper PMF	110.1	1.4E-06	3.0E-06	<1.0E-08	331,000
PMF Recommended	108.9	4.3E-05	9.3E-06	<1.0E-08	107,000
Spillway	104.0	2.3E-03	6.8E-04	6.5E-06	1,000
Induced Surcharge	95.7	3.5E-02	2.0E-02	8.2E-03	50
Government Owned Land	95.0	4.6E-02	2.8E-02	1.3E-02	40

1.8 Public Coordination

Between April 30 and May 9, 2019, USACE and the HCFCD hosted five Public Scoping Meetings. Three meetings were held near Buffalo Bayou downstream of Addicks and Barker reservoirs, and two meetings were held upstream. The main themes identified during scoping include:

- General agreement and support for the intent of the study; however, commenters are discouraged by the length of the study and the amount of time that will pass before measures are fully functional and flood risk benefits are realized. Many suggested implementing interim projects that could be completed in the next couple of years to afford some protection during this process.
- Strong support for implementing Nature-Based Features (e.g. preserving the Katy Prairie through land acquisition, restoring native habitats and bayous, using green infrastructure, preserving natural features such as oxbows and meanders, etc.) to store water and mitigate flooding risks in lieu of or in concert with traditional engineered solutions. Comments also cite

a substantial cost-savings by implementing nature-based features, protection of existing green space from future development, and opportunity to provide additional outdoor recreation.

- Lack of support for the Brays Bayou Diversion Channel and the Cypress Creek Levee from residents in the Brays Bayou Watershed and in the Cypress Creek Watershed, respectively, who indicate implementing these measures, would increase the flooding risk within the already overtasked receiving waters.
- General concern for environmental and social impacts because of implementing any flood risk reduction measures. Most concerns surround how the measure would impact flooding downstream or in the receiving watershed and the associated cost or loss with a potential increase in flooding; significant resources such as riparian corridors, wetlands, and wildlife; and recreation and open space.
- Identification of new measures or alternatives to consider including those from existing independent reports/studies and the commenters own knowledge for where and/or how to conduct storage or conveyance of storm waters. Some of the ideas that were not presented to the public during scoping include: pumping floodwaters out of the watersheds; dredging the bayous, tributaries, canals, and reservoirs to increase capacity; removing trees from the reservoirs; constructing a series of detention ponds throughout the system; and preserving and restoring the Katy Prairie and other important wetland, grassland and forested habitat types.
- Identification of measures that regulate commercial and residential development in floodplains, drainage areas, and critical watersheds and changes in policy, regulations, and codes related to development.

1.9 Problem Statement and Planning Objectives

The project delivery team (PDT) developed brief problem statements and planning objectives used to guide the identification and evaluation of potential solutions. Hurricane Harvey presented an enormous challenge for the region and demonstrated a need to address changed conditions around the two dams and downstream on Buffalo Bayou. Harvey produced record rainfall amounts that accumulated in Addicks and Barker Reservoirs resulting in record pool elevations. Flood waters from Harvey flooded homes upstream and put extreme pressure on the two dams; and controlled releases contributed to downstream flows that exceeded the carrying capacity of Buffalo Bayou. Flooding during Harvey revealed several inherent risks in the system: 1) upstream risks when inflows exceed reservoir capacity, 2) dam safety risks if a dam component were to fail during a flood, and 3) downstream risks when flows exceed channel capacity or when induced surcharge releases are triggered. Figure **4** provides an operational overview of Addicks and Barker, showing critical elevations and related release rates when the pools reach those elevations. Problem statements, planning objectives, and constraints are summarized below.

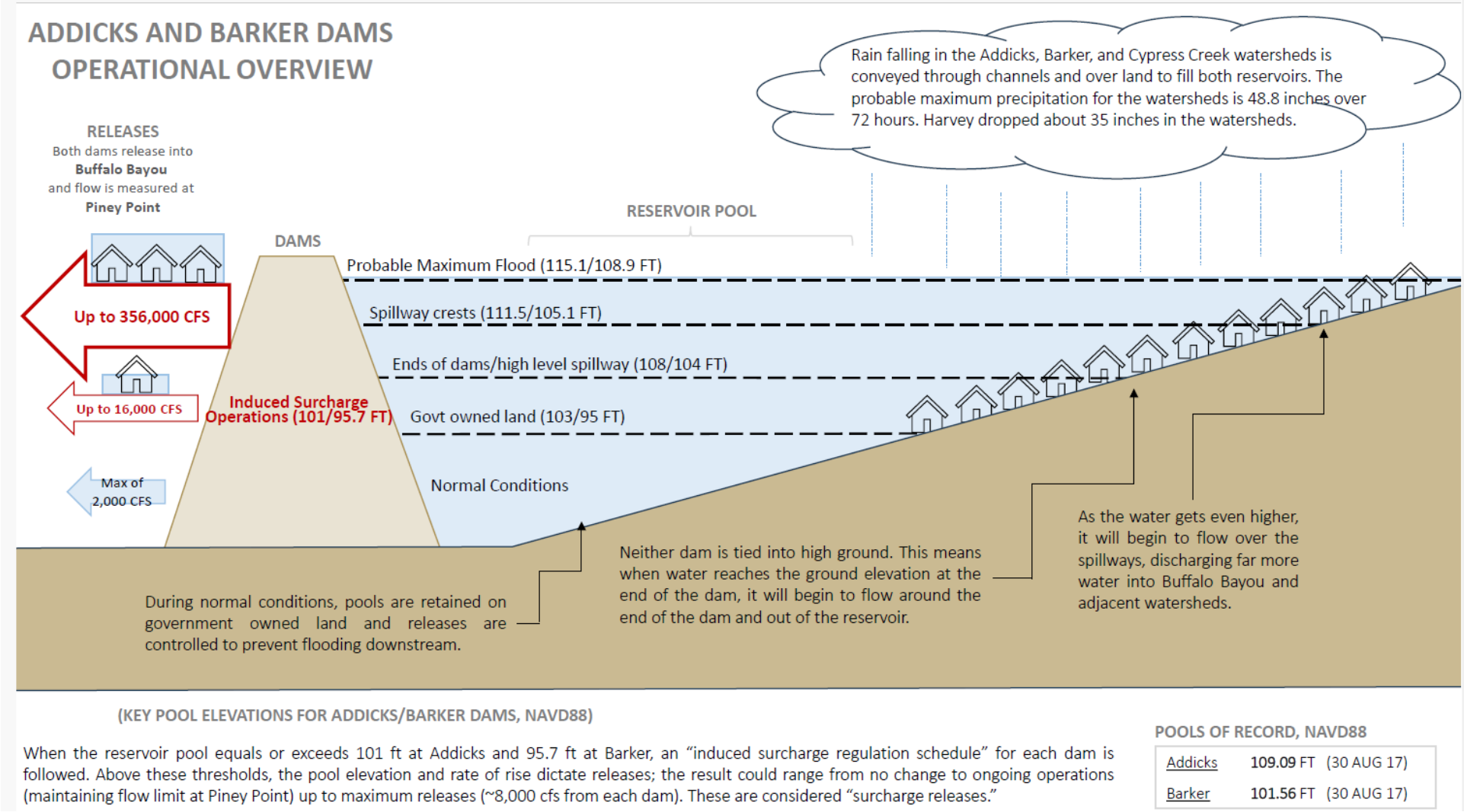

Figure 4. Operational Overview of Addicks and Barker Dams

1.10 Problems

1. Intense rainfall events cause flooding in the Buffalo Bayou watershed and significant inflows into the Addicks and Barker Reservoirs.
2. High water levels in Addicks and Barker reservoirs can extend beyond project lands and pose unacceptable risks to health and human safety, private property, and public infrastructure; Addicks and Barker floods off government owned land at the 110-year and 40-year return period, respectively. (Return period is the inverse of annual exceedance probability. It refers to the annual likelihood of occurrence.)
3. Pool releases from Addicks and Barker reservoirs combine with downstream inflows to pose risks to health and human safety, public infrastructure, and private property.
4. PMF water elevations for both Addicks and Barker dams have increased as well as the frequencies leading to increased loading on spillways;
5. Spillway protective concrete layers are more than 25 years old and have cracks, separations, and are eroded.
6. Land subsidence has lowered spillway elevations.

1.11 Objectives and Constraints

Objectives include:

1. Reducing life-safety risks consistent with USACE tolerable risk guidelines;
2. Reducing damages to homes, businesses, and infrastructure in the study area for the 50-year period of analysis (2036 through 2085); and,
3. Supporting community & infrastructure resilience and recovery.

The planning constraint is to avoid increasing flood risk or transferring flood risk to other areas. Transferred risk is defined as a result of an action taken in one region of a system to reduce risk, where that action shifts the risk burden to another region in the system. Any eventual recommendation will avoid increasing or transferring the risk to another area.

2 Iterative Planning Process

USACE uses an iterative planning process in which alternative plans are formulated and evaluated to determine how well they achieve the objectives. Within each iteration, plans that perform poorly against the study objectives are dropped from consideration, and the remaining plans are carried forward for more detailed evaluations. BBTRS has completed four iterations of evaluation:

- Iteration 1 - Initial Formulation & Screening – Full range of alternatives
- Iteration 2 - Evaluate Focused Array of Alternatives
- Iteration 3 - Evaluation Final Array of Alternatives
- Iteration 4 – Engineering Refinement and Comprehensive Benefit Evaluation – Tunnel Only

The following evaluation criteria were used throughout the iterations with increasing level of detail and refinements of the plan details:

- Reduction in Flood Damages
- Life Safety risks
- Community and Social Impacts
- Costs, including required mitigation
- Impacts to Critical Infrastructure
- Impacts to T&E species
- Cultural Impacts
- Reservoir Operations – Pool elevations, durations, and downstream releases
- Local Sponsor Support

2.1 Iteration 1

2.1.1 Iteration 1 - Initial Formulation and Screening

To address study objectives as it relates to flood risk management, the PDT identified a wide range of alternative plans that could address the problems. Generally, alternatives consider combinations of actions that would:

- Increase system storage via new reservoirs, detention storage, or excavation in Addicks and Barker reservoirs;
- Increase conveyance with new tunnels or by increasing capacity in existing channels;
- Divert water away from the reservoirs and Buffalo Bayou;
- Increase the structural reliability of the dams;
- Use nonstructural measures to reduce exposure or vulnerability of people, homes and other property in harm's way through measures including property acquisition, flood-proofing or elevating structures in place.

Table 2 summarizes alternatives and the initial screening-level evaluation. The first screening eliminated diversions and tunnels. Diversions were judged to not be effective during flood events that overload Addicks and Barker, because adjacent watersheds could also be at flood stage and their capacity to store flood water from Buffalo Bayou is limited. Diverting water beyond adjacent watersheds would also likely be prohibitively expensive and controversial. Tunnels were dropped because they were assumed to perform the same conveyance function as channels but were assumed to cost significantly more ($2.2 to $12 billion at July 2019 price levels). ***Note: Although they were dropped in this iteration, tunnels remained a consideration, because HCFCD was assessing technical feasibility and cost-effectiveness of tunnels in separate studies. This information would be brought to the BBTRS evaluation in a later iteration – Evaluation Iteration 2.***

Table 2. Initial Evaluation of Alternatives

Alternative Plans	Description	Added Measures	In Focused Array	Notes
Alt 1: No Action	No plan is implemented because of this study	None	**Yes**	This forms the baseline for costs, benefits, and impact comparison. It aids in understanding how each plan functions compared to the baseline
Alt 2: Cypress Creek Dam and Reservoir	Store water on Cypress Creek by constructing a new dam and reservoir	$2.1 to 2.9 billion	**Yes**	None
Alt 3: Addicks and Barker Reservoir Excavations	Increase storage capacity within each reservoir by deepening portions of the reservoirs	$1.3 to 1.8 billion	No	This plan provides only localized benefits
Alt 4: Tunnels	Convey up to 20,000 cubic feet per second (CFS) of floodwaters through underground tunnels that would capture water at the dams and empty water into the Houston Ship Channel/Galveston Bay	$6.5 to 12 billion	No	Tunnels provide comparable benefits as other alternatives but at a much higher cost in this iteration
Alt 5: Diversions	Divert water from the Buffalo Bayou Watershed to Brays and/or the Brazos River	$0.25 to 0.35 billion	No	Diversions present a high risk in long-term operation because Brays and or the Brazos River may already be flooded
Alt 6: Buffalo Bayou Channel Improvements	Widen and deepen Buffalo Bayou from just below Addicks and Barker Dams to convey 15,000 CFS	$1.0 to 1.25 billion	**Yes**	None
Alt 7: Downstream Nonstructural	Large-scale acquisition plan along Buffalo Bayou to convey 15,000 CFS	None	**Yes**	Mandatory to carry forward
Alt 8: Combined Plan (Alts 2 + 6)	Store water on Cypress Creek by constructing a new dam/reservoir AND widen and deepen Buffalo Bayou from just below Addicks and Barker Dams to convey 15,000 CFS (Alternatives 2 and 6)	$3.0 to 4.25 billion	**Yes**	None

2.2 Iteration 2

2.2.1 Iteration 2 - Evaluate Focused Array of Alternatives

The focused array of alternatives included the No Action Plan (baseline for comparison), three structural alternatives, and a nonstructural alternative. Structural alternatives include a new dam and reservoir on upper Cypress Creek, channel improvements on Buffalo Bayou, and a combination of these two. Ancillary measures were added to the anchor measure to broaden each plan's effectiveness.

Table 3 shows measures included for further evaluation of each alternative. Note that excavation in existing reservoirs does not create enough additional capacity to have a significant effect as a primary anchor measure; however, it was kept as an ancillary or complementary measure that could be used in combination with other alternatives. Similarly, diversions were kept as ancillary measures to optimize reservoir or channel improvement alternatives.

Table 3. Management Measures Comprising the Revised Array of Alternatives

Measures	Alternative Plans			
	Cypress Creek Dam and Reservoir	Buffalo Bayou Channel Enlargements	Downstream Nonstructural	Combined Plan
Anchor				
Cypress Creek Dam	X			X
Buffalo Bayou Channel Improvement		X		X
Ancillary				
Upper Buffalo Dam	X	X		X
Addicks Reservoir Excavation	X	X		X
Barker Reservoir Excavation	X	X		X
North Canal via Houston Diversion	X	X		X
Barker to Brays Diversion	X			
Cane Island Branch Channel Improvement	X	X		X
Downstream Relocation			X	
Downstream Acquisition			X	
Downstream Elevation			X	

2.2.1.1 Alternative Plan 2: Cypress Creek Dam and Reservoir

Alternative Plan 2, Cypress Creek Dam and Reservoir would construct a new 190,000-acre foot reservoir upstream of Addicks in the Cypress Creek watershed. Embankment crowns would be 190 feet with spillways at 187 feet.

An induced surcharge operation schedule similar to Addicks and Barker was developed. One overflow spillway discharges into the Cypress Creek watershed, while a second discharges into the Addicks Watershed. The primary control structure releases into Cypress Creek. A downstream control point with a maximum flow of 2,000 CFS would be just upstream of Tomball Parkway. First costs for the Cypress Creek Dam were estimated at $2.14 billion to $2.90 billion. With ancillary measures included, first costs were estimated to be between $4.5 to $6.1 billion.

2.2.1.2 Alternative Plan 6: Buffalo Bayou Channel Improvements

Alternative Plan 6, Buffalo Bayou Channel Improvements involves rehabilitating Buffalo Bayou to increase conveyance up to 15,000 CFS by excavating, widening, and re-grading the existing channel. The centerline of the channel improvement is assumed to be the same as the existing channel. The number and size of storm drains needed to lower the channel invert were roughly estimated as were impacts to existing bridges and may not be completely captured. Average cut depth was estimated at 11.6 feet with a channel bottom width of 70 feet and top of channel width of 230 feet. Channel side slopes would be one-foot vertical drop for every four feet in horizontal width (1V:4H) and the improved channel would be about 24 miles in length. First costs for the Buffalo Bayou Channel Improvement were estimated to be between $946 million to $1.23 billion. With ancillary measures included, first costs were estimated to be between $3.1 to $4.1 billion.

2.2.1.3 Alternative Plan 7: Downstream Nonstructural

Alternative Plan 7, Downstream Nonstructural would involve acquiring and relocating existing structures downstream of Addicks and Barker dams along Buffalo Bayou. Multiple scales were considered with costs ranging from $210 million to $9.7 billion.

2.2.1.4 Alternative Plan 8: Combination of Alternatives 2 and 6 (Cypress Creek Dam and Buffalo Bayou Improvements)

Alternative Plan 8, Combination Alternative would merge plans 2 and 6. Costs were estimated at $5.2 to $7.0 billion with ancillary measures included.

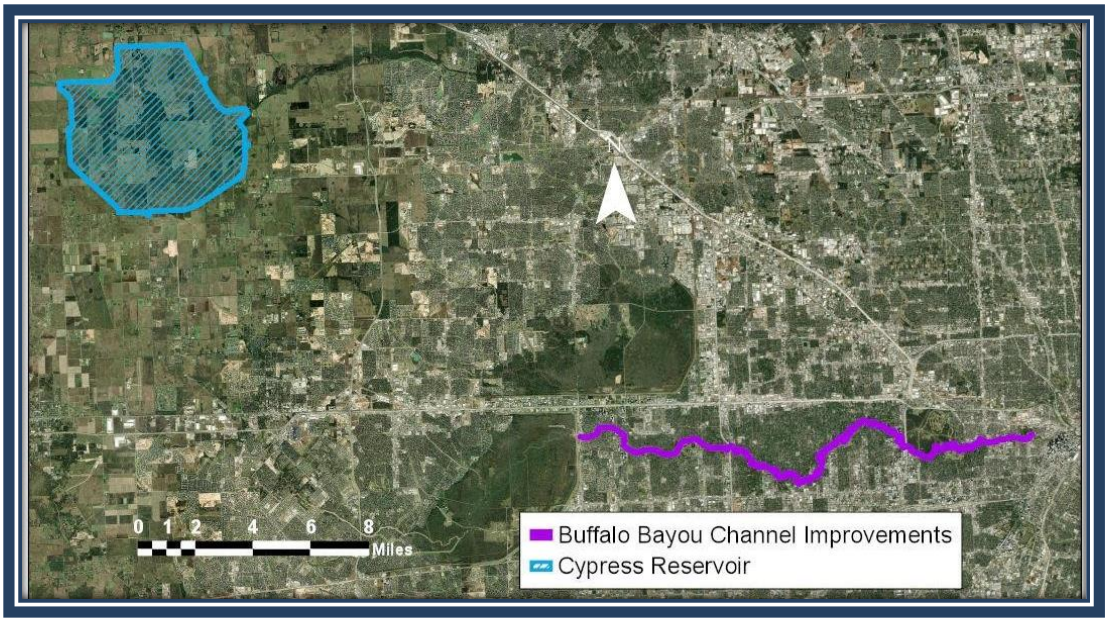

Figure 5. Alternative Plan 8 Combined Plan with Buffalo Bayou Channel Improvements (Alternative 6) and Cypress Reservoir (Alternative 2)

2.2.2 Iteration 2 - Structural Alternatives

Structural alternatives were evaluated to identify the most cost-effective alternative to address planning objectives, and an alternative's impact on life safety risks. As displayed in Table 4, no structural alternatives had a strong BCR. Alternative 6 (Buffalo Bayou Channel Enlargement) was estimated to have had the lowest cost and highest BCR at 0.3; however, BCRs do not reflect life-safety benefits. As a standalone option, the channel plan was estimated to reduce estimated fatalities from 223 to 82 in the daytime scenario. When combined with Alternative 2 (Cypress Creek Dam and Reservoir) to form Alternative 8 (Combination Plan), first costs were estimated to increase by an additional $2 to $3 billion, and would reduce life safety risks by an additional 35 lives at Addicks reservoir, but would have no change in safety risks at Barker.

Table 4. Cost Effective Analysis of Structural Alternatives, October 2019 Price Levels, Costs in $Billions

Alternative Plan	Project Costs (includes Ancillary Measures)	Benefit Cost Ratio*	Mitigation Acres	Life Safety Potential Life Loss	
				Addicks (Day)	Barker (Day)
1. No Action	**None**	None	None	99	124
2. Cypress Creek Dam & Reservoir	$4.5 to 6.1	0.1	7,523	22	25
6. Buffalo Bayou Channel Enlargement	$3.1 to 4.1	0.3	3,093	57	25
8. Combination (Alt. 2 and Alt. 6)	$5.2 to 7.0	0.2	7,593	22	25

***Based on the high costs**

Other considerations include the effectiveness of the alternatives at reducing the peak and duration of high pool elevations during large flood events and containing reservoir pools on GOL. Figure 6 and Figure 7 show pool elevations during a 0.002 AEP event at Addicks and Barker, respectively. These results reflect the changed precipitation conditions in the watershed. The horizontal solid black line marks the extent of GOL. None of the alternatives were estimated to meaningfully reduce the peak of the 0.002 AEP flood below the government boundary at either reservoir. The alternatives reduce flood duration above government land, which helps reduce recovery time but does not meaningfully reduce property damages and life safety risks.

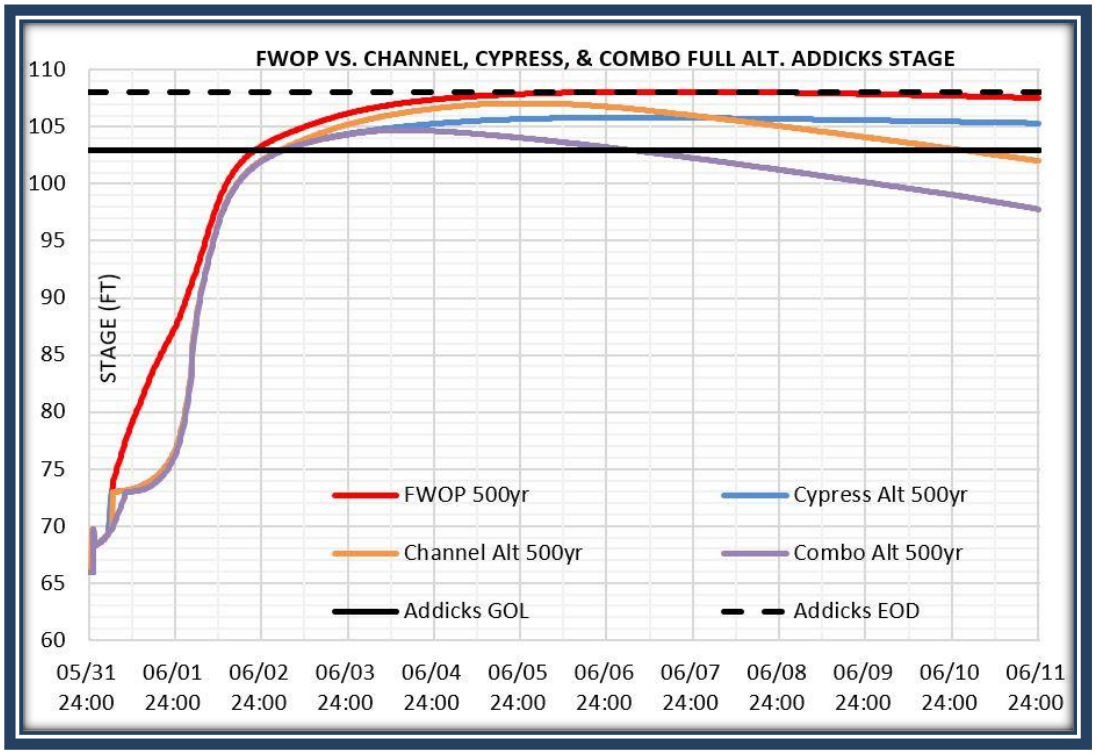

Figure 6. Addicks Reservoir FWOP 0.002 AEP vs Alternative Plans 2, 6, and 8

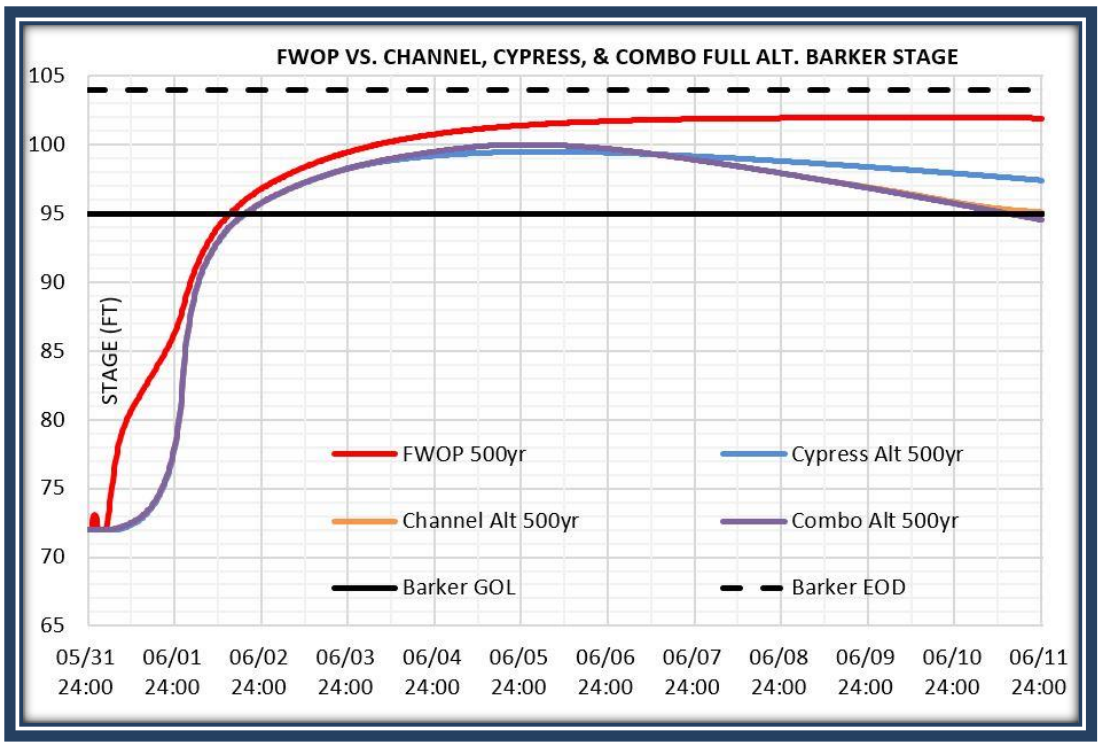

Figure 7. Barker Reservoir FWOP 0.002 AEP vs Alternative Plans 2, 6, and 8

Based on the evaluation, Alternative 6 (Buffalo Bayou Channel Improvement) was assessed to be the most cost-effective structural plan and was estimated to reduce 63% of the life safety risks, while incurring half the environmental impacts of the reservoir and one-third of the combined plan. Further evaluation showed that the ancillary measures were not cost-effective, and they were dropped from the costs. Based on information available at the time, the channel was believed to be the most cost-effective structural plan with an estimated BCR of 0.9 after the second iteration. However, that BCR would fall substantially in subsequent evaluations as costs increased and benefits were reduced by induced damages, as explained in Iteration 3.

2.2.3 Iteration 2 - Nonstructural Alternative

To assess the nonstructural alternative, the PDT looked at various scales of downstream acquisitions to allow increased releases from Addicks and Barker reservoirs up to 15,000 CFS (equivalent performance level of the channel improvement plan). Multiple scales were considered with costs ranging from $1.9 billion to 9.8 billion, at 2019 price levels. The amount of land required to convey 15,000 CFS was estimated to cost $2.3 billion in 2019. This alternative was carried forward for further comparison to the channel enlargement alternative in the next iteration of evaluation.

2.2.4 Iteration 2 - Dam Safety Modification

The third component of plan formulation addressed dam safety. USACE has recently completed a replacement of outlet structures at both dams. The study that recommended replacing the outlets also identified a need to further investigate subsidence and cracking of concrete spillways. BBTRS has evaluated

alternatives to replace the concrete armoring of the spillways. Further development of the armoring project will occur in a separate DSMS.

2.2.5 Iteration 2 - Upstream Real Estate Requirements for Systems Operations

A significant effect of the changed conditions in the surrounding watersheds is that GOL are more likely to be exceeded during large events than when the projects were originally constructed. Federal dams constructed in urban settings today are typically required to own lands at least to the standard project flood (SPF) elevation. At dams with a high-level spillway like Addicks and Barker, GOL should be equal to the spillway crest elevation. At Addicks and Barker, the SPF elevation is approximately seven feet higher than the current GOL elevation, and the spillway crests are two to three higher than the SPF. Table 5 shows pertinent elevations and Figure 8 maps key elevation boundaries. To address changed conditions and ensure continued safe operations of the dams, USACE may acquire properties to the end of dam elevation, 108 feet and 104 feet, and possibly up to the spillway crest elevation, 111.5 feet and 105 feet at Addicks and Barker respectively.

In the original design, the land acquisition flood was determined as the 1935 storm centered over each watershed. The original real estate acquisition plan called for an additional three feet of freeboard above the land acquisition flood. Three feet of freeboard applied to the current SPFs would produce elevations of 112.7 feet in Addicks and 105 feet in Barker.

Table 5. Elevation Details for Addicks and Barker Dam (elevations in feet, NAVD88)

	Addicks Dam	Barker Dam
Probable Maximum Flood	115.1	108.9
Approx. Spillway Crest	111.5	105.0
Harvey Peak Pool Level	109.1	101.6
Induced Surcharge Starts	101.0	95.7
Elevation at the end of dams/High Level Spillway	108.0	104.0
Standard Project Flood	109.7*	102.0*
First Home Flooded	103.4	97.1
Government Owned Land (GOL)	103.0	95.0
First Street Flooded outside of GOL	101.2	94.9

*These values remain draft.

The lands adjacent to the GOL are almost fully developed with neighborhoods of relatively high-density and high-value properties, infrastructure, and commercial business ventures. There are 16,000 structures on the adjacent lands that are at or below the end of dam elevation of 108 feet and 104 feet, at Addicks and Barker respectively. Most of the structures, approximately 14,500, are residential. The total acquisition cost is estimated to be approximately $14,872,300,000, as shown in Table 6.

Table 6. Upstream Real Estate Acquisition Costs - FY2025 Price Levels

Account	First Cost	Contingency	Total
01 Lands & Damages	$11,314,000,000	$3,443,900,000	$14,757,900,000
30 PED (FED Admin Fee)	$104,000,000	$10,400,000	$114,400,000
Total			$14,872,300,000

Assumptions:

Assumes 9600 Properties In Harris County And 6,400 In Fort Bend County - Total 16,000

Assumes Fee Simple Acquisition

Assumes Pl 91-646 Benefits Will Include (Per Property) $31k Relocation Payments, $10k Moving Expense And $31k Differential

Land Values Provided By Re Appraiser In Accordance With BBTRS Channel Buyouts Project Cost Estimate 4-29-25

Contingency For Land Values Is 35%

Contingency For Administrative And Other Costs Is 25%

This Is A Rough Order Magnitude Cost Estimate, Not In Compliance With Uspap Standards. This Information Is Subject To Change

Estimate Does Not Include Facility/Utility Relocations, Relocations Of Roads, Cemeteries Or Other Impacted Facilities

ASSUMES ACQUISITIONS WILL BE PERFORMED BY USACE (Previously Assumed In The 2020 Analysis)

Assumes Buyouts Will Be Acquired Through A Tiered Approach, Prioritizing Willing Sellers And Properties At The Lowest Elevations Within The Footprint (Avoid Overwhelming The Market)

Buyouts Within The Footprint Will Be Mandatory, Therefore Condemnations Are Expected

Re Anticipates Performing A Survey Of Available Housing As A Part Of The Study

In addition, such property acquisition would have significant impacts to the people, businesses, and neighborhoods in the area and to the local tax base. This includes potentially consequential impacts on the many municipal utility districts (MUDs) which provide water/sewer and other public services to residents and businesses in this area. A MUD is one of several types of special districts in Texas that function as independent, limited governments. Managed by an elected Board, MUDs utilize property tax revenues and user fees received from water and sewer services to cover operating costs and to repay bonded indebtedness. The proposed property acquisition will directly impact over 30 MUDs and indirectly impact many additional MUDs, as many MUDs are subsidiary to a "master" MUD. Removing any substantial tax base from a MUD threatens the ability of the MUD to service its debt and transfers additional costs to property owners outside the acquisition area. Accordingly, the impact of such property acquisition is not contained only to the area being acquired but also extends to large areas outside the flood pool. Proposed acquisition may also trigger other costs, such as assumption of debt incurred to support the development of the neighborhoods being acquired. Furthermore, similar impacts could occur to school districts and emergency services districts, which would be similarly harmed by such large-scale property acquisition. The reduction in the MUD tax base varies by MUD but ranges as high as 100% for the Baker Road MUD upstream of the Addicks reservoir and 90% for Harris County MUD 255 upstream of the Baker reservoir. In addition, approximately 15 of the impacted MUDs are located in neighboring Fort Bend County. Impacted MUDs are illustrated in Figure 9 (Addicks) and Figure 10 (Barker).

The USACE, Galveston District is recommending authorization to acquire necessary upstream real estate interests. Acquisition of this scale is complex and could take decades to complete (mandatory or voluntary) which would further increase cost. Second, no non-federal sponsor is prepared to support implementation, as required by law for any newly authorized project, raising issues as to the appropriate authority which would ultimately be required to complete the necessary acquisition. The recommendation was retained for

consideration, but it was not further evaluated in Iterations 3 and 4, with the caveat that current federal operational needs may require acquisition to the high level spillway functionally located at the end of the dams, and that the current judgment in the Court of Federal Claims (currently on appeal) has indicated that USACE has taken a permanent flowage easement at the level of flooding that occurred during Hurricane Harvey upstream (109.1 Addicks and 101.6 FT Barker).

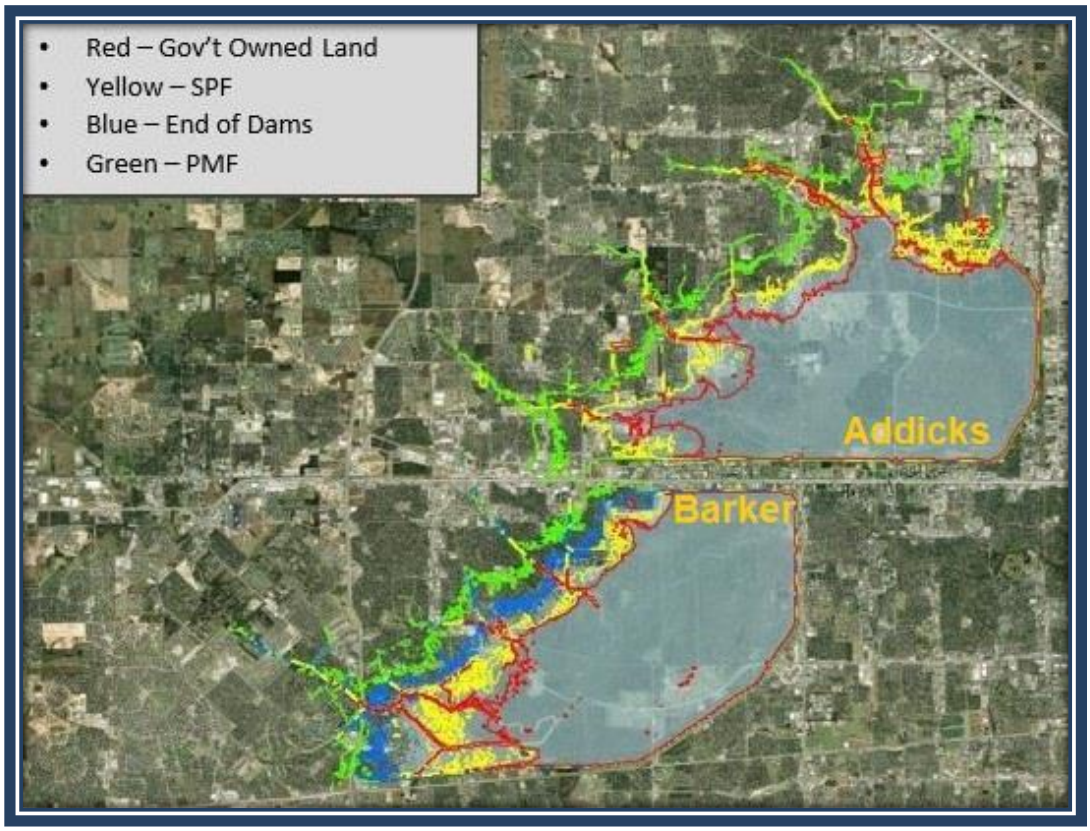

Figure 8. Map Showing Various Elevations at Addicks and Barker Reservoirs

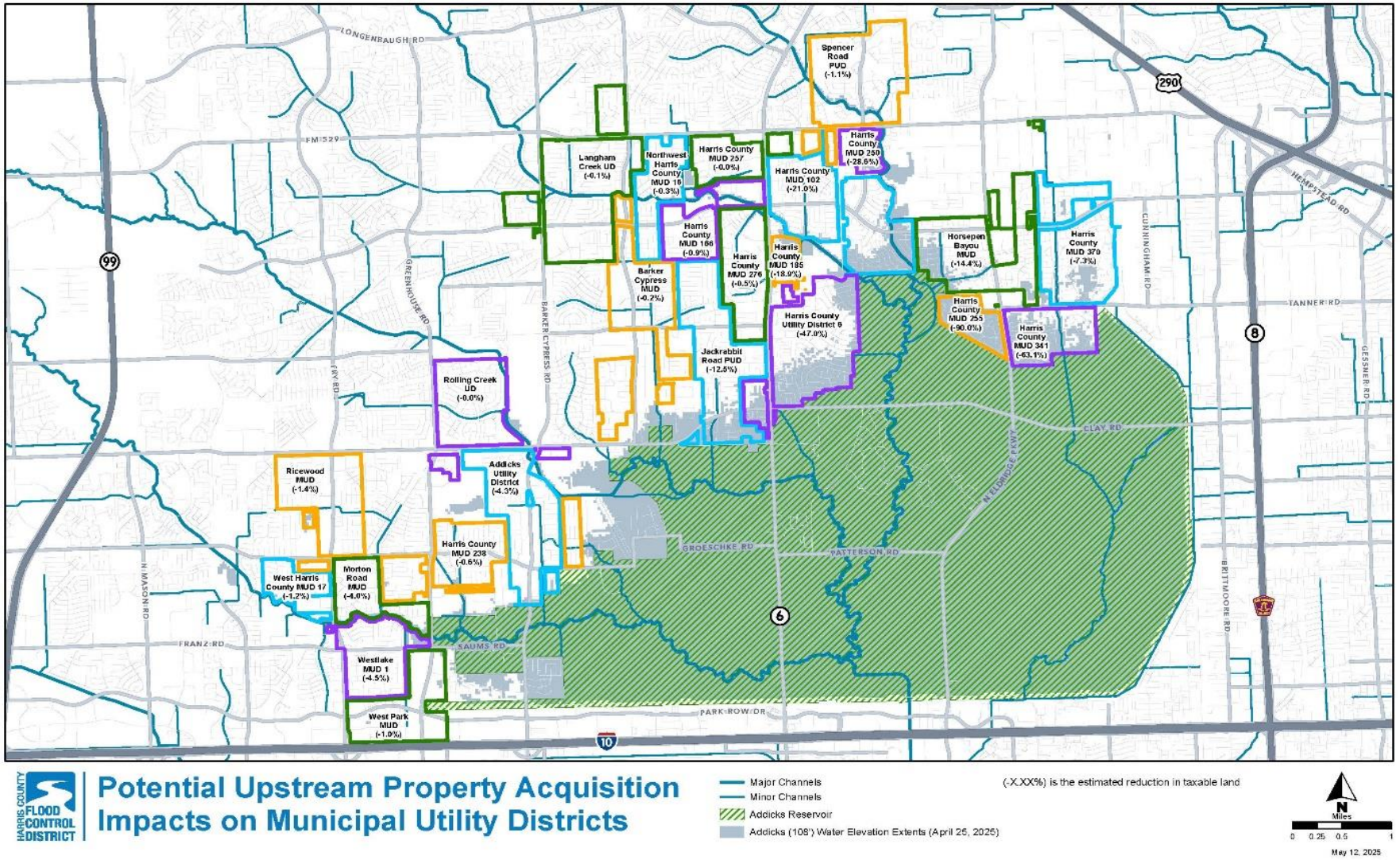

Figure 9. Impacts of Potential Land Acquisition on Municipal Utility Districts – Addicks

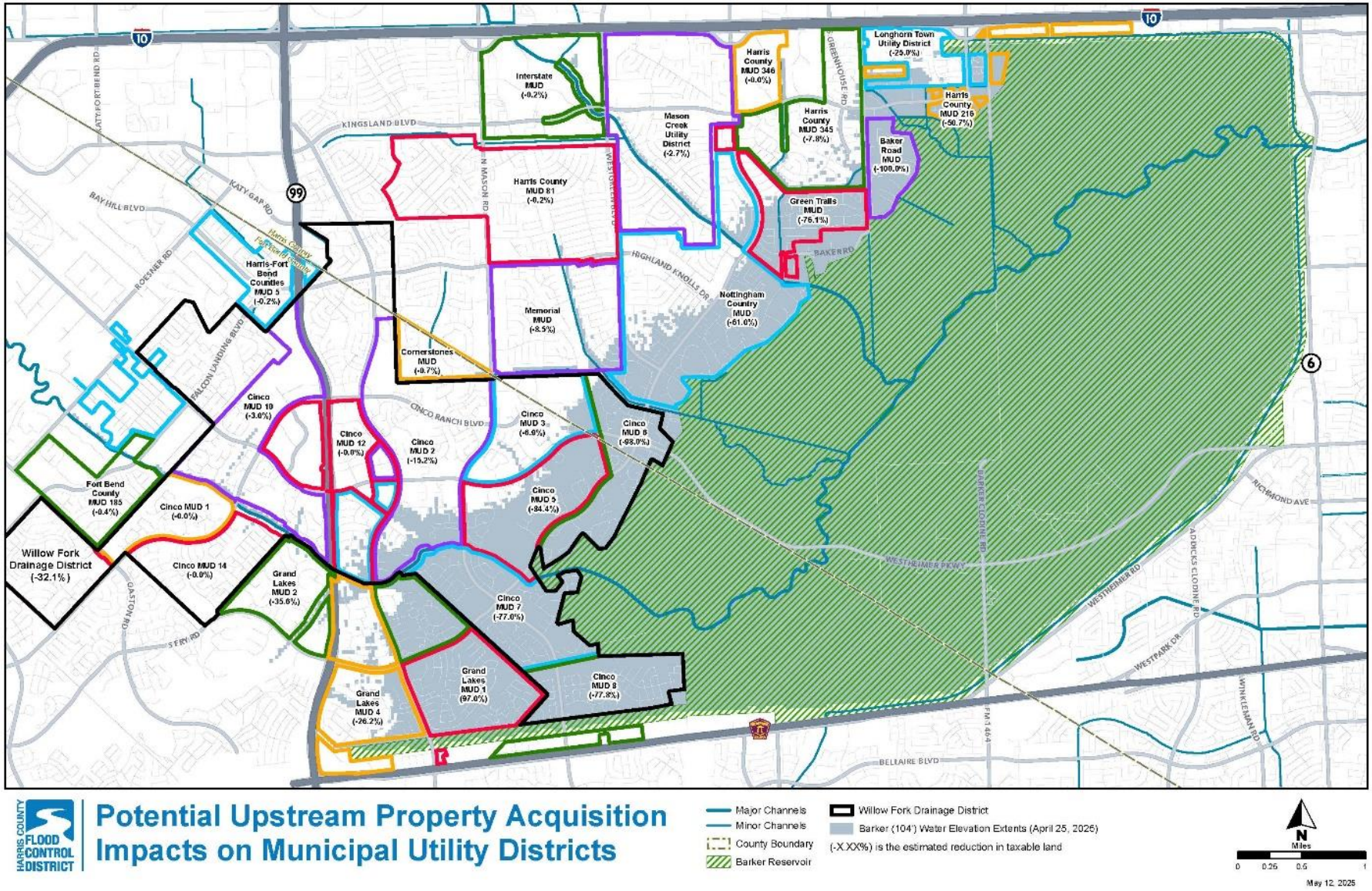

Figure 10. Impacts of Potential Land Acquisition on Municipal Utility Districts - Barker

2.2.6 Iteration 2 – Conclusions

Two alternatives were carried forward for further evaluation and comparison in the next iteration

- Buffalo Bayou Channel Improvements Alternative – Increasing conveyance through channel improvements was estimated to be the most-cost-effective structural alternative and was retained for further evaluation in the final array**.** Channel enlargement was the conveyance method evaluated in iteration 2; however, tunnels would be revisited in the next iteration with updated costs and benefits.
- Non-Structural Alternative - The non-structural alternative was identified as the NED plan ***in this iteration*** and was retained for further evaluation in the final array.

Two actions were identified for further consideration but are not part of the comparison to the above alternatives, because the requirements they address are not resolved by other alternatives. These actions will be considered for inclusion in the final recommendations.

- The spillways may warrant replacement of the concrete armoring, and further development of that project will be completed in a DSMS.
- Upstream real estate ideally should be acquired up to the elevation at the ends of the dams. This action does not have a non-federal sponsor and will not be included in the next evaluation iteration. It will however be retained for consideration by USACE leaders**.**

2.3 Iteration 3

2.3.1 Public Review of Interim Report of Findings

USACE released an Interim Report for public review and comment on October 2, 2020. The interim report presented the results of the first 2 iterations of evaluation, but it did not make specific recommendations for a preferred alternative. Four virtual public meetings were held in October 2020 to provide the public with an overview of the Interim Report and answer questions about the study and alternatives considered.

Over 2,400 comment submissions were received. Public comments objected to the environmental impacts that channel enlargement would have on Buffalo Bayou and expressed support for the tunnels as a less-damaging alternative. Furthermore, the acquisition of over 1,900 parcels of land along Buffalo Bayou, needed to accommodate the proposed channel modification, was also strongly opposed. Figure 11 displays a summary of the review comments categorized by the main comment themes and how many comments were received in each theme.

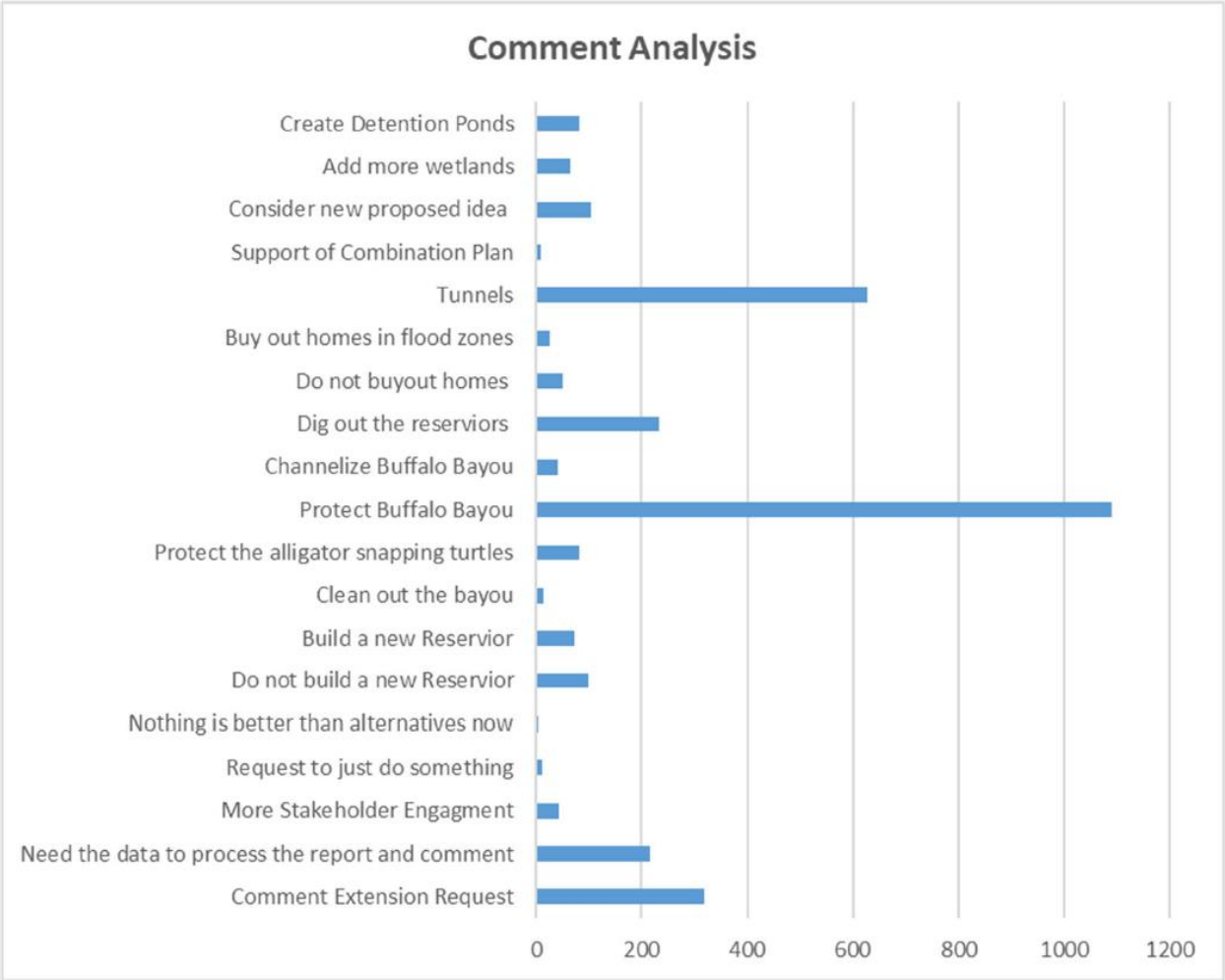

Figure 11. Summary of Interim Report Public Review Comments, by theme and count

HCFCD was completing the 2nd phase of their tunnel investigations in this timeframe, so new cost and performance information was available to evaluate a tunnel as a conveyance option. Accordingly, the tunnel alternative was re-introduced in the Final Array for further evaluation and comparison to channel enlargement and the non-structural plan.

2.3.2 Iteration 3 – Evaluation of Final Array of Alternatives

Final array of Alternatives:

- No Action
- Non-Structural Measures – Downstream Buyouts
- Channel Improvement on Buffalo Bayou
- Tunnel from Addicks and Barker to Houston Ship Channel

The alternatives were scaled to a performance capacity of 15,000 CFS flows on Buffalo Bayou for this third evaluation iteration. This scale was selected because peak discharge at Piney Point during Hurricane Harvey was 15,000 CFS (plotted in Figure 3), setting the standard for conveyance in this project. The BBTRS

evaluated other alternatives and found that smaller conveyance options did not provide acceptable benefits for this project. Key concerns driving the scale of the alternatives include:

- **Relieving USACE Risk:** Downstream conveyance less than 15,000 CFS does not meaningfully alter the scope or duration of large floods on the upstream property. At 15,000 CFS and greater, the duration of upstream inundation exceeding government owned land is reduced. Downstream damaging effects already occur between 4,000 CFS and 15,000 CFS so downstream acquisition is likely necessary given the current water control manual and necessary exceptions for operation. During large floods, surcharge will already require releases at 15,000 CFS, so scoping the downstream reach for less than this is not advisable in light of the current experience during Hurricane Harvey and the associated claims related to that event.
- Performance: Hydraulic and economic analyses show that the larger conveyance alternatives provide the greatest benefits. Simply put, the smaller scale conveyance alternatives are not worth constructing in Buffalo Bayou under this project. They do not have a comprehensive effect on the system.

USACE, Galveston processed a scope schedule and budget request to finalize the study with the evaluation of these alternatives at the 15,000 CFS scale. The request was approved, and the team continued the evaluations.

The existing Buffalo Bayou channel can convey 4,000 CFS at Piney Point without damaging structures, so the tunnel was sized to carry approximately 11,000 CFS to achieve a combined total of 15,000 CFS. However, during a massive flood like Harvey, even releasing the additional 4,000 CFS will contribute to flooding downstream.

The original channel alternative was initially undersized for the intended conveyance, so the dimensions of the channel alternative were widened and lengthened. These engineering modifications increased bottom width from 70 feet to 120 feet and increased estimated first cost from ~$1.2 billion to over $5 billion. This widening also requires acquisition of over 1,900 parcels and further impacts adjacent parks and natural spaces along the bayou. Lands Easements Rights-of-Way and Disposal Areas (LERRDs) for the channel are estimated to exceed 50% of total project cost. Induced damages also were present in the improved model at the confluence of Buffalo Bayou and White Oak Bayou. This was not fully resolved in the design, so the benefits were substantially lower because they were offset by the increased damages at the downstream end of the channel. As shown in Table 7, the revised BCR for the channel modification was estimated to be 0.04.

The non-structural alternative was also reformulated due to cost. This iteration assumed a buyout of 341 parcels damaged by the 0.04 AEP (25-yr) flood event for nearly $2 billion. As shown in Table 7, the revised BCR for the non-structural alternative was estimated to be 0.02.

The tunnel alternative reflected an initial tunnel design, consisting of a 40-foot diameter trunk line and 30-foot extensions into each reservoir. Project first cost was estimated at $6.6 billion (FY22 Price Level), with a resultant BCR of 0.13. Importantly, optimization of tunnel intakes had not yet been performed, meaning performance improvements were expected upon further engineering analysis and design refinement.

Table 7. Benefit and Cost Results for Iteration 3 (2022 price levels)

COST-BENEFIT ANALYSIS			
Alternatives	**Non-Structural**	**Channel**	**Tunnel**
First Cost	**$ 1,896,964,000**	**$ 5,264,827,000**	**$ 6,600,000,000**
Interest During Construction	$ -	$ 1,366,690,000	$ 461,132,000
Total Investment Cost	$ 1,896,964,000	$ 6,631,517,000	$ 7,061,132,000
Average Annual Cost	$ 63,583,000	$ 222,278,000	$ 236,677,000
Average Annual O&M Cost	$ -	$ 28,567,000	$ 7,692,000
Total Average Annual	$ 63,583,000	$ 250,845,000	$ 244,369,000
Benefits (Structures / Contents)	$ 1,114,000	$ 8,957,000	$ 32,109,000
Net Benefits	**$ (62,469,000)**	**$ (241,888,000)**	**$ (212,260,000)**
Benefit-Cost Ratio	0.02	0.04	0.13
Life Safety (EAALL)*	**1.28**	**1.21 (5.47%)**	**1.22 (4.69%)**	**1.11 (13.28%)**

EAALL=Expected Average Annual Life Loss

Table 8. Evaluation of Planning Criteria for Iteration 3

PLANNING CRITERIA				
	No Action	**Non-Structural**	**Channel**	**Tunnel**
Efficiency	**Y**	N	N	N
Effectiveness	N	**L**	**L**	**P**
Completeness	N//A	**Y**	**Y**	**Y**
Acceptability	P	**P**	**P**	**Y**

Y=Yes, N=No, L=Limited, P=Partial, N/A=Not Applicable

2.3.3 Iteration 3 – Conclusions

- None of the alternatives were deemed efficient when benefits were compared to costs.
- The non-structural plan and the channel plan had limited effectiveness, both in terms of damage reduction and in life safety risks.
- The tunnel alternative performed better on both metrics, with four times the damage reduction benefits and three times the life safety improvement.
- The Tunnel Alternative had the lowest environmental and social impacts and was deemed to meet the acceptability criteria. The Non-structural and Channel Alternatives could partially meet the criteria by satisfying mitigation requirements; however, they would face significant implementation challenges, due to the lack of support from the public and lack of a non-Federal sponsor.
- The tunnel is also far more adaptable to flooding conditions with the ability to optimize flood risk reduction based on actual water on the ground, allowing operators to prioritize flood reduction in

specific sub watersheds. The benefits of this operating flexibility will be further evaluated when funding is available to analyze more scenarios.

- The additional costs of upstream real estate are not included. These may be required either as a result of a takings determination or judicial ruling.

Prior to these results, policy staff believed the channel alternative could be the alternative that maximized net benefits, which would set the basis for Federal cost share. The sponsor could then request a Locally Preferred Plan (LPP), if they preferred the Tunnel alternative. However, the evaluation results demonstrate that there is no basis for Federal interest in the channel, due to the low cost-effectiveness and the high negative impacts. Similarly, the downstream non-structural plan is not cost effective. No plan is cost-effective if upstream real estate is included in the total project costs.

2.4 Iteration 4

2.4.1 Engineering Refinement & Comprehensive Benefit Analysis – Tunnel Alternative

Iteration 4 only considered the No Action alternative and the Tunnel Alternative. The Iteration 3 results and conclusions showed the Tunnel Alternative to be more effective than the Non-structural and Channel Alternatives, while also causing fewer negative impacts. However, costs continued to outweigh benefits. At the conclusion of Iteration 3, HCFCD requested an opportunity to further evaluate and advance the Tunnel Alternative using newly available (2022) MAAPnext hydrologic and hydraulic models and to strengthen the multi-faceted justification for Federal interest in the Tunnel Alternative, considering and balancing economic, environmental, and social factors (a Comprehensive Benefits Analysis or CBA). This included further engineering refinement and expansion of the CBA in line with newly issued policy.

This section presents a summary of the efforts performed during Iteration 4 and presents a comprehensive benefits decision-making framework and analysis to inform selection of a recommended plan. The analysis has been guided by evolving policy to determine Federal interest. Most importantly, in 2021, the Assistant Secretary of the Army for Civil Works (ASA(CW)) policy directive titled "Comprehensive Documentation of Benefits in Decision Document" directed USACE to start incorporating factors identified in the 2014 'Principles, Requirements, and Guidelines" into the USACE civil works planning process. Specifically, this directive:

- Requires that the "decision framework considers the total benefits of project alternatives, including equal consideration of economic, environmental and social categories".
- Requires the USACE to "collaborate with non-federal partners" and "consider state and local concerns and engage state and local interests in all aspects of planning" and "evaluate plans in full consideration of discussions with the public and stakeholders, and in collaboration with non-federal partners to ensure scoping decisions will enable an assessment of benefits in total and by type".
- Requires that USACE planning studies must "evaluate and provide complete accounting, consideration and documentation of the total benefits of alternative plans across all benefit categories", including both monetized/quantified and qualitative benefits, "across national and regional economic, environmental, and social benefit categories".
- Requires that reports explain the "rationale and basis for the recommended plan, including the full and equivalent considerations of benefits in total and by type" and will "outline the basis for selecting the plan based on monetary, quantitative, or qualitative outputs and federal, state, local, and international concerns".

Importantly, this policy directive:

- Does not negate the need to identify the NED Plan that meets the Federal objective as defined by the 1983 Principles and Guidelines.
- Does not negate the need to request an NED Exception from ASA(CW) should a plan other than the NED Plan be recommended.
- Does not explicitly dictate which plan should be considered as the "Federal Interest Plan" for the purpose of cost-share, requiring ASA(CW) to make this determination.

In submitting this report, the PDT understands that a definitive determination of Federal interest is likely not possible. And that under this new paradigm, and current laws and policies, there is a significant degree of subjectivity in the assessment of Federal interest. Accordingly, the PDT's goal is to provide sufficient information to allow the "Decision Maker" (e.g. Chief of Engineers, ASA(CW)) to weigh all factors and make the appropriate decision regarding merit and Federal interest / cost-share.

2.4.2 The Tunnel Alternative

Based on work completed by HCFCD as part of their Phase 1 and Phase 2 tunnel studies (completed separate from BBTRS), HCFCD proposed and developed a Tunnel Alternative to mirror the hydraulic performance of USACE's previously recommended BBTRS channel alternative (15,000 CFS conveyance channel). The current Tunnel Alternative alignment is illustrated in Figure 12. Project first cost is estimated at $8.2 billion (FY25 Price Level), including a 51% contingency developed by the Abbreviated Risk Analysis (ARA) method.

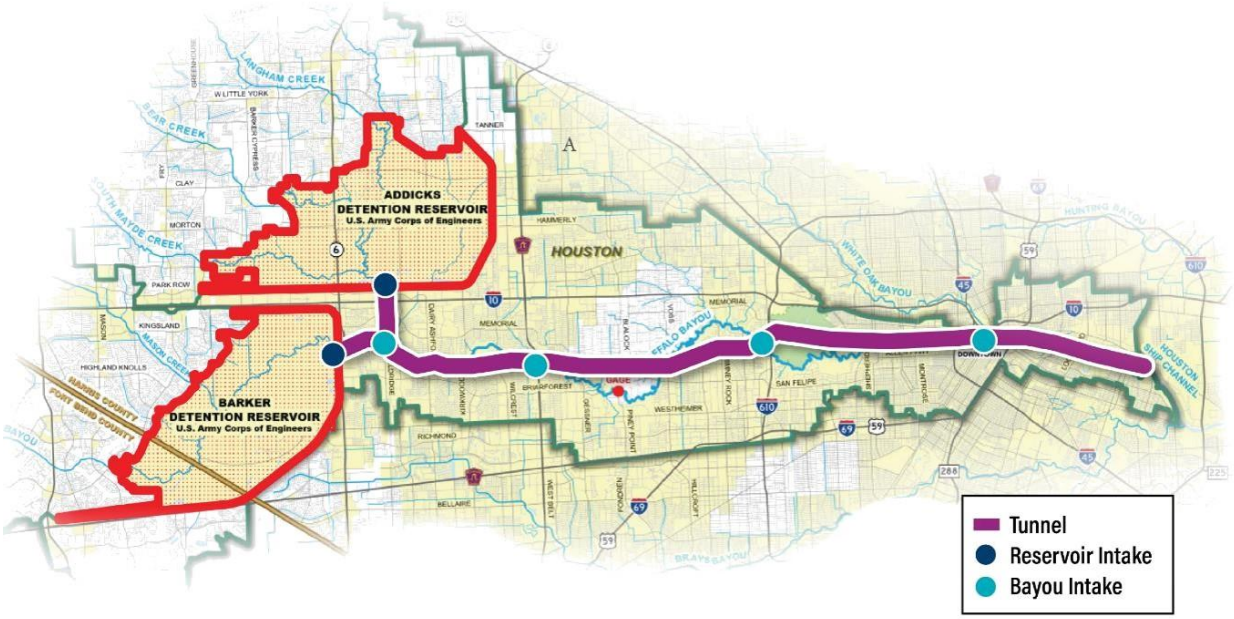

Figure 12. Proposed Tunnel Alignment

In summary, the proposed Tunnel Alternative consists of the following components:

- Reservoir intakes inside each of the reservoirs (Addicks and Barker)
- 30-foot diameter collector tunnels, connecting each reservoir intake to the main tunnel trunkline
- 40-foot diameter tunnel, set approximately 60 to 100 feet below grade, starting just downstream of the reservoirs and discharging to an outfall located on the Houston Ship Channel
- Four bayou intakes, regularly spaced along Buffalo Bayou / White Oak Bayou that allow for adaptive flood risk management throughout the watershed; and
- Three working shafts, necessary to facilitate construction of the tunnel.

The tunnel conveyance system will be designed to operate as an inverted siphon, as illustrated in Figure 13. As such, stormwater will completely fill the tunnel and will flow under pressure through the tunnel. The system is anticipated to function entirely by gravity. Intakes will convey flood waters efficiently and safely towards the tunnel. Intakes will likely include control structures such as weirs and gates, trash racks, and a conveyance channel or chute that would direct flow towards the drop structure. Gates will be used to actively manage diversion at the reservoir intakes and the bayou intakes. Gates are needed to allow for flexibility to achieve optimal flood reduction benefits under a wide range of storm events. Gates are also needed to prevent backflow from the tunnels to Buffalo Bayou when flow is diverted into the tunnel at the reservoir intakes.

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

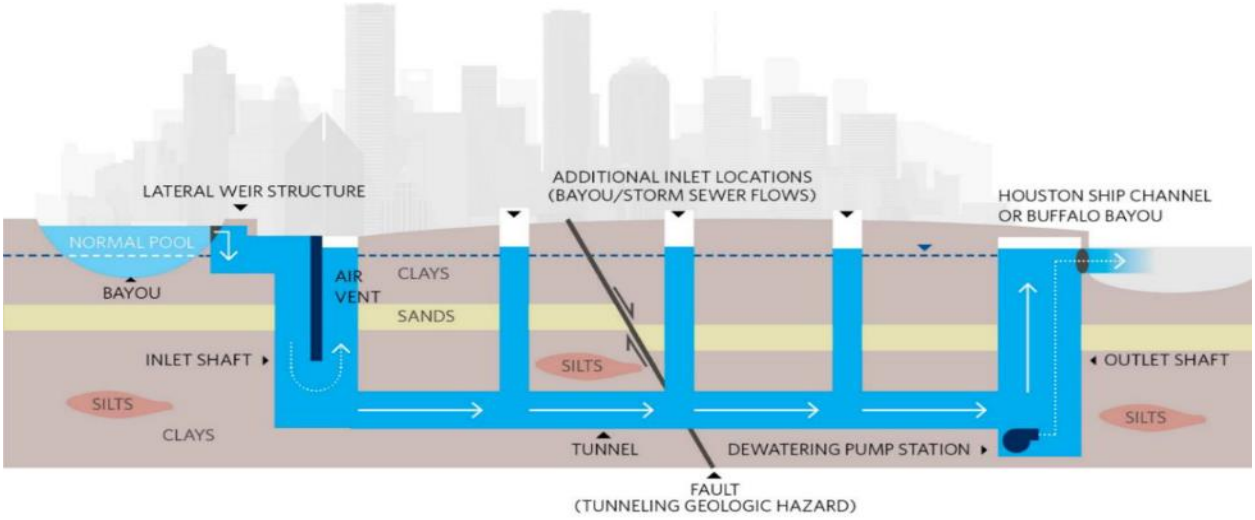

Figure 13. Typical Tunnel Conveyance System

Gated intakes within the reservoirs and along Buffalo Bayou allow water to be discharged into the tunnel, as desired. One objective of the tunnel is to provide a separate conveyance system that allows discharges to be made from the reservoirs to address flood risks or dam safety concerns, without impacting Buffalo Bayou and the communities along the bayou. A second objective is to provide flood risk reduction along Buffalo Bayou. Specifically, objectives for upstream and downstream areas are as follows:

- UPSTREAM: By increasing the non-damaging discharge capacity from the reservoirs, the tunnel system can better moderate / manage pool elevations within each reservoir. This provides flood risk reduction for properties located outside GOL that can be inundated by the reservoir pool in an extreme event. This is accomplished through the addition of a tunnel intake within each reservoir, which allows water from the reservoirs to exit the reservoirs and enter the tunnel. Importantly, the Tunnel Alternative proposes no changes to the existing control structures. These new intakes are in addition to the existing control structures and will be operated in concert with the existing control structures. The Water Control Manual will require update if a tunnel is added to the system.
- DOWNSTREAM: First, by providing an alternative conveyance system, the Tunnel Alternative may prevent the need for induced surcharge releases from the existing control structures into Buffalo Bayou, thus avoiding flood damages along Buffalo Bayou associated with such releases. Second, through four regularly spaced bayou intakes, the tunnel is able to pull floodwaters off Buffalo Bayou (or lower White Oak Bayou), thus reducing flow rates and water surface elevations along each bayou. This also benefits the numerous small and large tributaries to Buffalo Bayou, which are sensitive to elevated tailwater conditions.

Floodwater collected from the reservoirs, Buffalo Bayou, or lower White Oak Bayou is discharged into the Houston Ship Channel at an outlet structure located near the Turning Basin, as shown in Figure 14. Due to the wide cross section and significant conveyance capacity of the ship channel (along with the near infinite storage capacity provided by Galveston Bay and the tidally driven ship channel), discharges from the tunnel do not result in significant changes to water surface elevation along the Houston Ship Channel (meaning on the order of magnitude of several tenths of a foot or less). Importantly, all water in the Buffalo Bayou and Tributaries system already drains to this point. It should be noted that Galveston Bay and the Houston Ship Channel is used as the downstream boundary condition for all hydraulic modeling. Importantly, assumptions for relative sea level rise have been incorporated into the modeling.

The BBTRS presents many complexities, primarily because it includes a large study area (covering over 500 square miles) composed of multiple watersheds or zones with differing flood drivers and vulnerabilities. Each of these zones are illustrated in Figure 14. Specifically, this includes:

- Zone 1: Addicks and Barker Reservoirs / Watersheds
- Zone 2: Upper Buffalo Bayou
- Zone 3: Lower Buffalo Bayou and White Oak Bayou

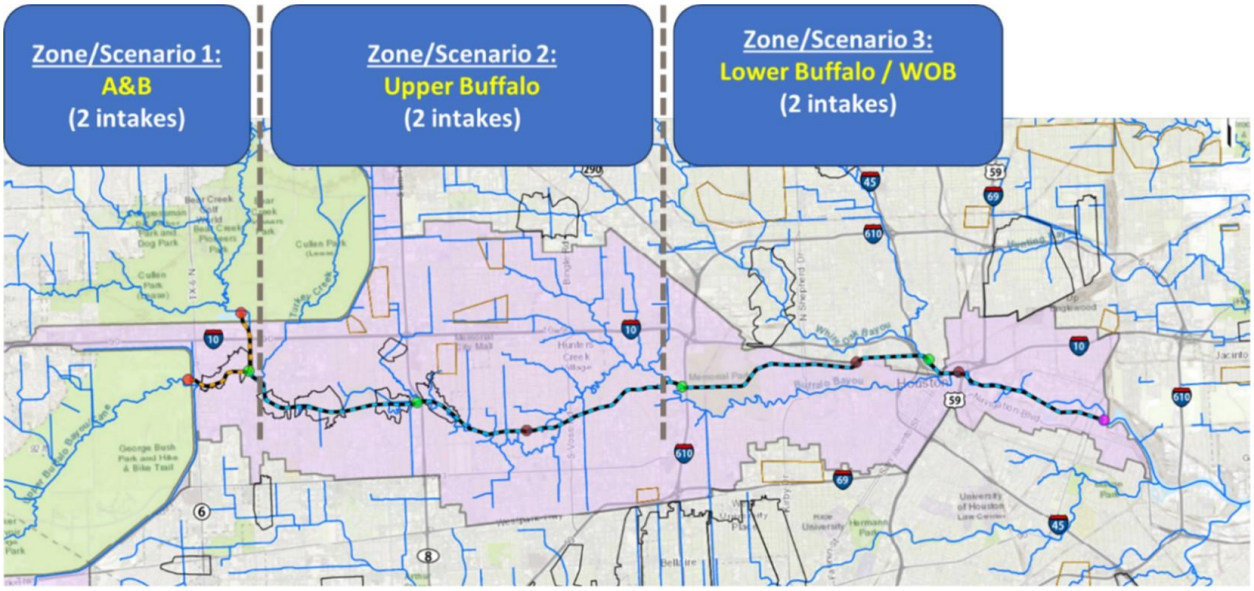

Figure 14. Tunnel Operational Zones/Watersheds

Zone 1 represents an area that has historically performed well during heavy rain events, as the reservoirs prevent reservoir pool driven flooding in events up to approximately the 0.01AEP (100-year) event. However, in less frequent events, when the reservoir pool exceeds GOL, catastrophic flooding can occur (as seen during Hurricane Harvey). It should be noted that the reservoir models (which are based on the established Water Control Manuals) prevent discharges from the reservoirs into Buffalo Bayou from exceeding 2,000 CFS for all storm events modeled (meaning the PDT is not modeling induced surcharge discharges). Importantly, conditions in the downstream zones generally do not impact or influence performance in Zone 1 or the operation of the Addicks and Barker Reservoirs control structures.

Zone 2 represents a highly populated area where significant structural flood damage occurs in events including or less frequent than the 0.02 AEP (50-year) event. However, for more frequent events, Buffalo Bayou provides a generally desirable level of service. This area was subject to extensive flooding during Hurricane Harvey, as a result of both local rainfall runoff and induced surcharge releases from the reservoirs (two peaks). Zone 2 also corresponds approximately to the limits of the previously evaluated Buffalo Bayou channel conveyance alternative. Importantly, as the reservoirs generally do not discharge into Buffalo Bayou during rain events, flooding along upper Buffalo Bayou is generally independent of conditions in Zone 1. Only in major floods (such as what occurred during Hurricane Harvey) would reservoir release be made into Buffalo Bayou while flooding continues. Additional flow will go around and over the spillways during even larger floods (refer to Figure 4).

Zone 3 represents a highly populated area where significant flood damages can occur at all frequency events, most specifically along White Oak Bayou and its tributaries. This area is also home to a greater proportion of significantly vulnerable communities. Similar to upper Buffalo Bayou, flooding along lower Buffalo Bayou and White Oak Bayou is generally independent of conditions in Zone 1. In addition, flooding in this area is also only partly influenced by conditions in Zone 2, as White Oak Bayou contributes significantly more flow at the confluence than is carried in Buffalo Bayou upstream of the confluence.

Importantly, the Tunnel Alternative has been designed to serve each of these zones. There are two intakes within each zone (as shown in Figure 14), and the power of the proposed system is the ability to apply the full tunnel capacity (~11,000 CFS) to whichever zone is experiencing the heaviest rainfall. In this manner, the tunnel system can provide high-impact, targeted, flood risk management, adapting to the needs of a specific rain event.

2.4.3 The Comprehensive Benefits Framework

The proposed comprehensive benefits framework is presented in Figure 15. Specific goals for the comprehensive benefits analysis include:

- Comply with all aspects of the January 2021 "Comprehensive Documentation of Benefits in Decision Document" policy directive.
- Align with new policy guidance (e.g. ER 1105-2-103)
- Provide a full and equivalent consideration and accounting of benefits in total and by type, including equal consideration (if warranted) of economic, environmental, and social categories.
- Explain the rationale and basis for the recommended plan based on monetary, quantitative, and/or qualitative outputs and Federal, state, and local concerns.
- 'Focus on the people' and enhance consideration of the impacts of infrastructure projects and flooding on the strength of our communities and the economy, considering social vulnerability.
- Employ a resiliency framework to better assess the impact of different alternatives on the ability of our infrastructure and communities to withstand, recover, and adapt to disturbances both now and into an uncertain future.
- Identify solutions that align with community and natural values and promote social and economic opportunity.

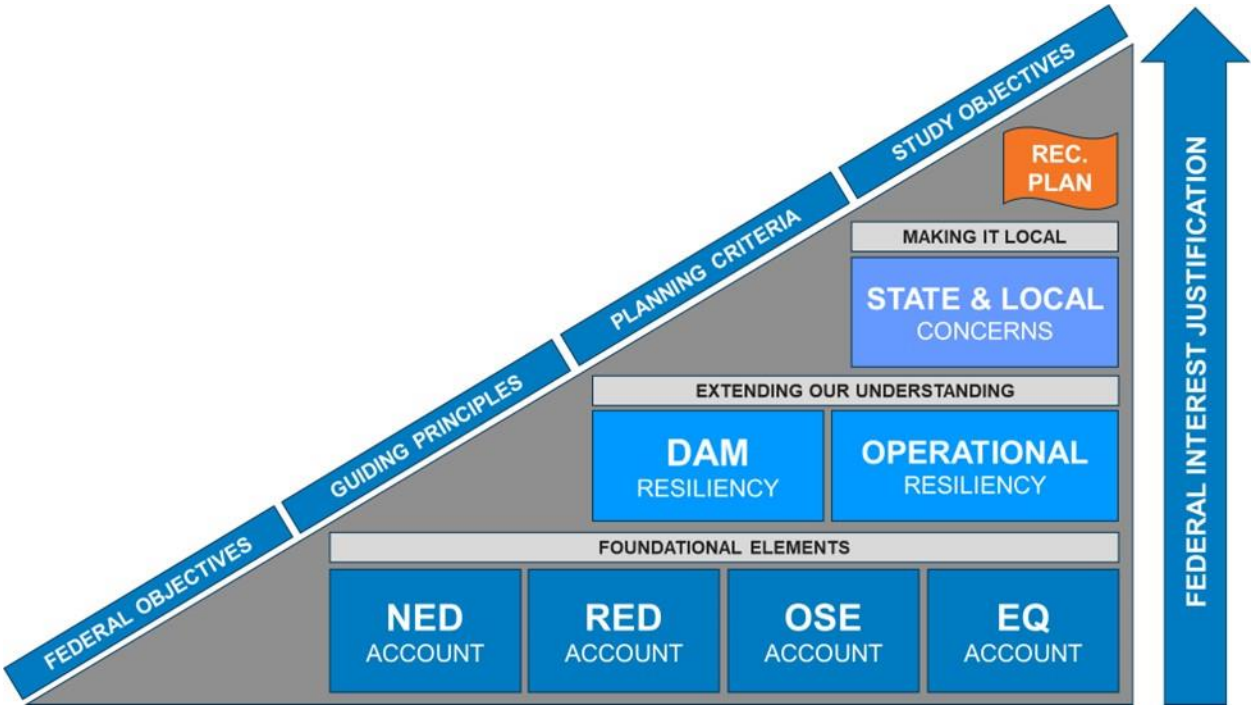

Figure 15. Comprehensive Benefits Framework

Critically, the proposed analysis is foundationally based on the full and equal consideration of benefits within the Four Accounts (NED, RED, OSE, and EQ). To extend understanding of complex issues and considerations, two sets of resiliency accounts (Dam Resiliency, Operational Resiliency) are utilized as a second layer of evaluation. And finally, to ensure consideration of local issues, a third layer of analysis is performed within a State & Local Concerns account. Each alternative is also measured against the planning criteria, considering efficiency, effectiveness, completeness, and acceptability.

Ultimately, the justification for Federal interest is built from the bottom of the pyramid up, with each additional layer of evaluation providing nuance to inform and shape the recommendation based on the accounting of benefits within the Four Accounts. Accordingly, the "total" benefits of each alternative are being measured. The criteria prescribed in Sec 1221 of WRDA 2024 are also reflected in these three layers. Sec 1221 states that recommendations shall:

- Avoid or minimize adverse effects on the environment and community. These effects are measured in the OSE and EQ accounts in the first layer
- Promote the resiliency of infrastructure. This is captured in the middle layer
- Align with community objectives. This is captured in the top layer and also in the beneficial effects in the first layer

2.4.4 Iteration 4 – Evaluation Results

The Tunnel Alternative was evaluated through more than 100 metrics to measure performance in economic, social, environmental, and resilience terms. The full matrix of results is not presented here. However, the critical findings are highlighted in the evaluation of each layer of the comprehensive benefits framework.

Table 9, Table 10, and Figure 16 summarize the overall effectiveness of the tunnel at reducing the number of structures flooded and physical damages in each zone.

Table 9. Structures Flooded Future Without Project (FWOP) and Benefitting Structures Future With Project (FWP) 0.01 AEP (100-year) event and 0.002 AEP (500-year) event.

WITHOUT FUTURE RAINFALL

Scenario	Reach	Flooded (#)	Removed (#)	Reduced (#)	Removed (%)	Reduced (%)	Benefitted (%)	Notes
0.2% AEP (500-yr)								
1	Addicks Flood Pool	1559	1474	85	**95%**	5%	100%	3.5' WSE Reduction
1	Barker Flood Pool	1259	1258	0	**100%**	0%	100%	3.8' WSE Reduction
2	Buffalo Bayou	8684	2925	3161	**34%**	36%	70%	
3	White Oak Bayou	10377	372	1612	4%	**16%**	19%	
1% AEP (100-yr)								
1	Addicks	3	3	0	**100%**	0%	100%	4.0' WSE Red. (Within GOL)
1	Barker	1	1	0	**100%**	0%	100%	3.3' WSE Red. (Within GOL)
2	Buffalo	2594	1118	316	**43%**	12%	55%	
3	White Oak Bayou	3910	216	1684	6%	**43%**	49%	

WITH FUTURE RAINFALL

Scenario	Reach	Flooded (#)	Removed (#)	Reduced (#)	Removed (%)	Reduced (%)	Benefitted (%)	Notes
0.2% AEP (500-yr)								
1	Addicks Flood Pool	3207	2331	876	**73%**	27%	100%	2.2' WSE Reduction
1	Barker Flood Pool	3663	3659	3	**100%**	0%	100%	3.6' WSE Reduction
2	Buffalo Bayou	11547	2671	4828	**23%**	42%	65%	
3	White Oak Bayou	12900	476	4968	4%	**39%**	42%	
1% AEP (100-yr)								
1	Addicks	38	38	0	**100%**	0%	100%	3.7' WSE Red. (Within GOL)
1	Barker	1	1	0	**100%**	0%	100%	3.5' WSE Red. (Within GOL)
2	Buffalo	4319	1981	617	**46%**	14%	60%	
3	White Oak Bayou	5366	250	2145	5%	**40%**	45%	

Table 10. Average Annual Physical Damages and Benefits, FY24 Price Levels

Watershed	Physical Damages Without Project	Physical Damages With Project	Benefits	Percent of Damages Reduced
Addicks	$ 124,223,230	$ 112,179,920	$ 12,043,310	9.7%
Barker	$ 107,383,970	$ 95,875,540	$ 11,508,430	10.7%
Buffalo	$ 285,241,580	$ 171,031,440	$ 114,210,140	40.0%
Total	$ 516,848,780	$ 379,086,900	$ 137,761,880	26.7%

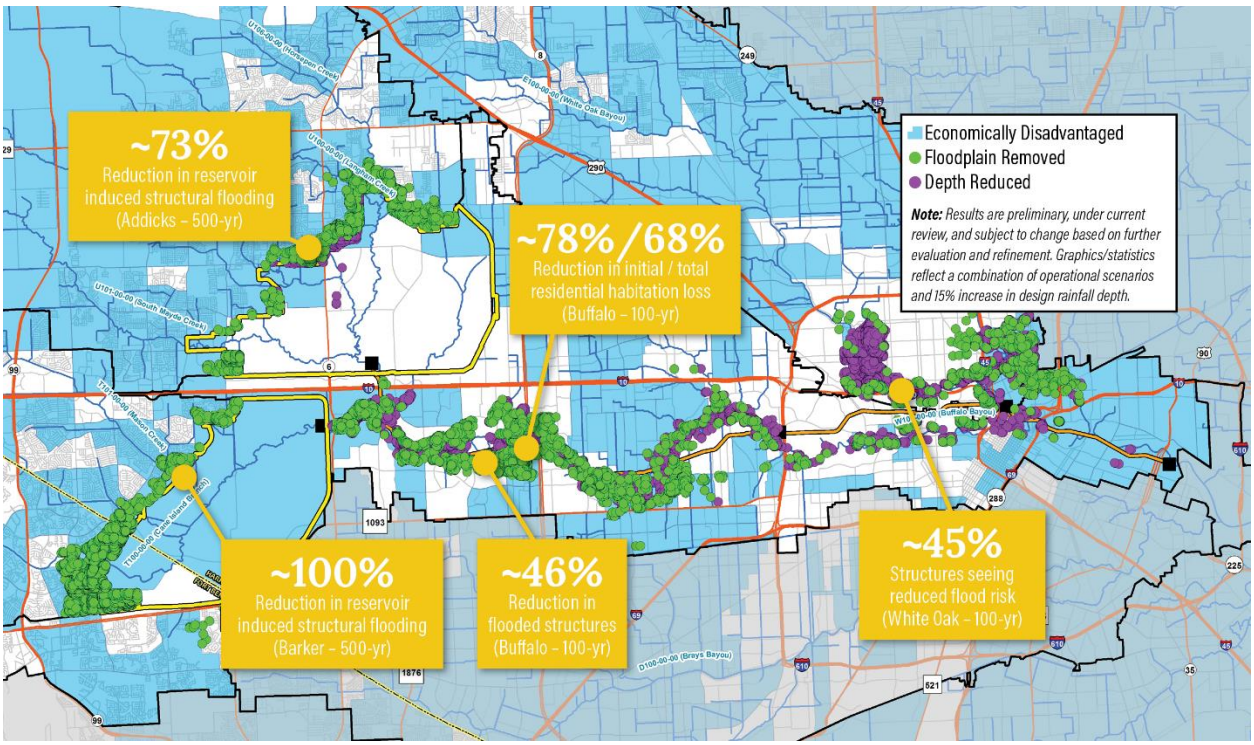

Figure 16. Project Performance - Percent of Structures Benefitting

2.4.4.1 First Layer of Evaluation

The first layer of evaluation includes the equal consideration of the Four Accounts (NED, RED, OSE, EQ). The following presents a summary of this evaluation:

- **NED Account:** The Tunnel Alternative is effective at reducing flood damages in the Addicks, Barker, Buffalo Bayou, and lower White Oak Bayou watersheds, generating over $137M of average annual benefits. However, given the generally infrequent nature of flooding and the high cost of construction, the Tunnel Alternative results in a benefit-to-cost ratio of 0.4. These results for the Tunnel Alternative represent an un-optimized solution whose performance may improve as intake configuration/operation is refined in further phases. Regardless, among other alternatives under consideration, the targeted flood risk management offered by the Tunnel

Alternative is anticipated to offer the greatest degree of flood risk reduction and therefore, by extension, NED benefits.

Table 11. Tunnel Alternative Costs, Benefits, and BCR

Account Code	Project First Cost $1,000's (FY2025)
01 - LANDS AND DAMAGES	683,900
02 - RELOCATIONS	47,000
15 - FLOODWAY CONTROL & DIVERSION STRUCTURES	6,019,000
30 - ENGINEERING & DESIGN	957,000
31 - CONSTRUCTION MANAGEMENT	494,000
TOTAL PROJECT FIRST COST (ROUNDED)	**8,200,900**
INTEREST DURING CONSTRUCTION	$980,100
TOTAL ECONOMIC COST	$9,181,000
ANNUAL COST	$356,824
ANNUAL BENEFITS	$137,000
NET BENEFITS	$(223,724)
BENEFIT-COST-RATIO	**0.4**

- **RED Account:** Compared conceptually to the other alternatives anticipated to be included in the final array, the Tunnel Alternative is anticipated to be the highest performing alternative within the RED Account. Specifically, the Tunnel Alternative minimizes negative RED impacts (e.g. removal of tax base) while maximizing positive RED benefits (e.g. losses avoided by improved flood risk management and investment spurred by reduced real or perceived flood risk). It prevents the loss/migration of 63,000 residents and 34,000 jobs, $4.4 Billion of gross regional product, $7.8 Billion of total output, and $3.8 Billion of personal income within Harris and Fort Bend counties (0.002AEP). In total, the targeted flood risk management offered by the Tunnel Alternative is anticipated to offer the greatest degree of flood risk reduction and therefore, by extension, avoidance of regional economic losses (jobs, income, output) in the aftermath of a flood event.
- **OSE Account:** Compared conceptually to the other alternatives anticipated to be included in the final array, the Tunnel Alternative is anticipated to be the highest performing alternative within the OSE Account. Specifically, the Tunnel Alternative minimizes negative OSE impacts (e.g., displacements, impacts to community character, connectivity, and cohesion) while maximizing positive OSE benefits (e.g., protecting life safety, protecting critical community and environmental resources, reducing residual risk). Of note, the Tunnel Alternative drives significant reduction in habitation impacts, which captures the immediate and persistent social consequences of flooding. Specifically, in the Buffalo Bayou watershed, in the 0.01 AEP event, initial habitation loss is reduced by 78%, total habitation loss is reduced by 68%, and habitation loss duration is reduced by 51%. In total, the targeted flood risk management offered by the tunnel alternative is anticipated to offer the greatest degree of flood risk reduction and therefore, by extension, reduction in the scale and duration of negative social impacts. Accordingly, the Tunnel Alternative supports an enhanced level of community resilience. This includes preserving or enhancing the vibrancy of existing communities, while preparing communities to better withstand and recover faster from both frequent and severe flood events.

- **EQ Account:** The Tunnel Alternative is anticipated to be the least environmentally damaging practicable alternative that meets the planning objectives, with no significant cumulative adverse environmental consequences. The Tunnel would cause 40 acres of total disturbance and impact four acres of threatened and endangered species habitat – a 95% reduction in impacted wetland, riparian, and upland habitat compared to the channel alternative. Considering the scale of the proposed action and its broader benefit to the community, the Tunnel Alternative's environmental impacts can be reasonably minimized and, therefore, the Tunnel Alternative is anticipated to be the highest performing action alternative within the EQ Account.

In total, across all four accounts, the Tunnel Alternative performs strongly and is anticipated to be the highest performing alternative among those ultimately considered. Importantly, the No Action Alternative does not contribute to any of the planning objectives (e.g. life safety, flood risk reduction, community resilience). The Nonstructural Alternative will likely be effective at reducing flood damages in specific locations but will not contribute to the broader infrastructure and community resilience objectives. Furthermore, large-scale buyouts (if identified as the nonstructural alternative) generate significant social consequences that would have to be weighed carefully against the geographically confined social and economic benefits derived. Buyouts without NFS participation are legally limited, without additional legislative authority, to property within a takings analysis for the current operational needs of the project and/or mandated judgements resulting from the litigation over Harvey. To produce similar total benefits as the Tunnel Alternative, other structural alternatives would have to demonstrate a similar degree of flood risk reduction, at a similar or lower cost, and without consequential social or environmental effects.

2.4.4.2 Second Layer of Evaluation

The second layer of evaluation encompasses aspects of critical infrastructure resiliency, in the face of changing conditions. The Tunnel Alternative:

- Reduces Peak Reservoir Pool Elevations for the 0.2% and 1% AEP floods by 2.2 feet and 3.7 feet in Addicks and 3.6 feet and 3.5 feet in Barker, respectively.
- Provides up to 7-fold increase in non-damaging releases and corresponding reduction in time to draw the pool down.
- Reduces the risk associated with sequential events.
- Reduces the frequency of exceeding government owned lands.

The following presents a summary of this evaluation:

- Dam Resiliency Account: Compared conceptually to the other alternatives included in the final array, the Tunnel Alternative is anticipated to be the highest performing alternative within the Dam Resiliency Account. The Tunnel Alternative increases the ability of USACE to better manage conditions at the reservoir to reduce dam safety risks, both now and into an uncertain future. The creation of a secondary conveyance system, with no restrictions on use, maximizes operational flexibility and simplifies reservoir operation. While not captured in probabilistic flood damages/benefits, reducing (even slightly) the possibility of an adverse dam safety outcome (such as what occurred during Hurricane Harvey) has significant flood risk management benefits and increases the resiliency of both critical infrastructure and the community at large.

- Operational Resiliency Account: Compared conceptually to the other alternatives in the final array, the Tunnel Alternative is anticipated to be the highest performing alternative within the Operational Resiliency Account. The Tunnel Alternative significantly increases the ability of the operator to better manage the combined system to maximize flood risk reduction performance under a wide range of conditions (including sequential rain events). While not fully captured in probabilistic flood damages/benefits, the ability to perform under variable conditions drives additional "real-world" economic and social benefits, in addition to supporting the resiliency of both critical infrastructure and the community at large.
- Acquiring upstream real estate to the ends of the dams makes operations more resilient by enabling safe operations of the dams up to that point, which is consistent with current USACE regulations. Updating the WCM immediately will further enhance operational resiliency by optimizing the available storage space until the tunnel is constructed and the real estate is acquired. WCM should also be revised as property is acquired to different elevations and upon completion of the tunnel.

In total, across these two resiliency accounts, the Tunnel Alternative performs strongly and is anticipated to be the highest performing alternative among those ultimately considered. The No Action Alternative does not contribute to any of the planning objectives (e.g. life safety, flood risk reduction, community resilience). The Nonstructural Alternative is anticipated to perform poorly within these accounts, as its benefits are anticipated to be isolated only to the properties bought out / floodproofed. As such, there is little to no opportunity to accommodate changing conditions or to contribute broader resiliency objectives. To produce similar total benefits as the Tunnel Alternative, other structural alternatives would have to demonstrate similar contributions to the resiliency and operational flexibility of the dams and the combined regional flood risk management system.

2.4.4.3 Third Layer of Evaluation

The third layer of evaluation provides an assessment of each alternative's ability to address priority state and local concerns. The following presents a summary of this evaluation:

- **State & Local Concerns**: Compared conceptually to the other alternatives, the Tunnel Alternative is anticipated to be the highest performing alternative within the State & Local Concerns. The Tunnel Alternative reduces the frequency and severity of adverse outcomes associated with the operation of the Addicks and Barker Reservoirs to a level commensurate with public expectations. Furthermore, the Tunnel Alternative achieves this desired level of flood risk reduction while minimizing community and environmental impacts. State and local concerns do not want the "cure" to be more detrimental than the "disease" and aim to prevent the inequitable distribution of negative project impacts to economically disadvantages populations. The Tunnel Alternative successfully addresses stated state and local concerns. As a result, the general public would strongly support the Tunnel Alternative instead of channelizing Buffalo Bayou.

The No Action Alternative does not contribute to any of the planning objectives (e.g. life safety, flood risk reduction, community resilience) and also represents substantial remaining federal costs which will be incurred as part of the necessary operation of the project, specifically, necessary fully federal acquisitions as a result of additional litigation and takings analyses. Furthermore, due to changing hydrology, inaction could lead to an increase in the frequency and severity of adverse outcomes associated with the Addicks and Barker Reservoirs. Accordingly, there would be no state or local support for a "No Action" recommendation.

Next, the performance of the Tunnel Alternative is assessed in comparison to the established study objectives, the overarching Federal objectives, the guiding principles, and the planning criteria. The following sections detail these summary conclusions. Note – these conclusions reflect an integration of all the various metrics and accounts discussed above.

2.4.5 Study Objectives

The initial phases of this feasibility study established three formal study objectives. In the sections below, the Tunnel alternative is summarily assessed against these objectives.

- **Flood Risk Reduction:** The Tunnel Alternative is effective at achieving flood risk reduction in all portions of the study area. This includes a 73% reduction in reservoir induced flooding in the Addicks Reservoir, 100% reduction in reservoir induced flooding in the Barker Reservoir [0.2% AEP, with future rainfall], and a 46% reduction in flood structures in the Buffalo Bayou watershed [1% AEP, with future rainfall]. Reductions of this scale in extreme event flood damages represent transformational risk reduction in these less frequent but highly impactful storm events.
- **Dam / Life Safety:** The Tunnel Alternative is effective at augmenting the ability of the reservoir system to safely manage a wide variety of extreme events. Furthermore, reducing the frequency of stressor events, emergency spillway usage, and control structure releases, in addition to general flood risk reduction, supports an overall reduction in life safety risk associated with non-breach flooding events. Within this objective, the PDT recognizes that dam safety risk is being assessed separately, as part of the companion DSMS.
- **Community Resilience:** The Tunnel Alternative is effective at augmenting community resiliency and reducing the impacts of recovery after a flood event. Both the scale/extent of flooding and the duration of flooding is reduced as a result of the proposed alternative, which has important social and economic benefits. In the Buffalo Bayou watershed, in the 0.01 AEP event , initial habitation loss is reduced by 78%, total habitation loss is reduced by 68%, and habitation loss duration is reduced by 51%. Furthermore, fewer businesses, rental housing, and associated community infrastructure are impacted, supporting accelerated recovery.

2.4.6 Federal Objectives

WRDA 2007 established the Federal Objectives for water resources investments. In the sections below, the Tunnel Alternative is summarily assessed against these objectives.

- **Maximize Economic Development:** The Tunnel Alternative results in an estimated BCR of 0.4, which is below unity (1.0). The BCR reflects the challenges (cost) of providing flood risk reduction in an ultra-urban environment, as well as skewed distribution of probabilistic damages in a study area which generally performs well in more frequent events, but sees significant damages is less frequent events. Compared to other alternatives which achieve a similar scale of flood risk reduction, the Tunnel Alternative is anticipated to have the strongest BCR.
- **Avoid Unwise Use of Floodplains and Flood Prone Areas:** The Tunnel Alternative reasonably minimizes adverse impacts and vulnerabilities of existing development located within floodplains and flood prone areas. The study area includes many flood-prone established

neighborhoods who have seen flood risk increase significantly due to increased regional rainfall. While large-scale buyout or managed retreat is not possible in this ultra-urban environment, the flood risk reduction provided by the Tunnel Alternative minimizes vulnerabilities and increases the resiliency of established communities.

- **Protect and Restore Natural Systems:** Due to its limited surface disturbance area, the Tunnel Alternative prevents significant impacts to existing natural systems. While ecosystem restoration is not an objective of this study, no other alternative achieves the same degree of flood risk reduction while minimizing impacts to existing riparian and aquatic habitats. This includes avoidance of sensitive habitats for threatened and endangered species as well as historic and cultural resources.

2.4.7 Guiding Principles

The 2014 'Principles, Requirements, and Guidelines" established several Guiding Principles for Federal investment in water resources now and into the foreseeable future. In the sections below, the Tunnel Alternative is summarily assessed against these principles.

- **Sustainable Economic Development:** As discussed above, the Tunnel Alternative achieves significant reductions in economic damages associated with flooding. Furthermore, when looking at regional economic impacts, the flood risk reduction provided prevents local / regional economic losses, including population and job loss in the aftermath of a flood event. In total, the proposed improvements increase the resiliency of the greater Houston area, which as a significant economic engine for the nation, contributes to the Nation's resiliency.
- **Floodplains:** As discussed above, the Tunnel Alternative reasonably minimizes adverse impacts and vulnerabilities of existing development located within floodplains and flood prone areas. The study area includes many flood-prone established neighborhoods who have seen flood risk increase due to climate change. While large-scale buyout or managed retreat is not possible in this ultra-urban environment, the flood risk reduction provided by the Tunnel Alternative minimizes vulnerabilities and increases the resiliency of established communities.
- **Public Safety:** As discussed above, the Tunnel Alternative is effective at augmenting the ability of the reservoir system to safely manage a wide variety of extreme events. Furthermore, reducing the frequency of stressor events, emergency spillway usage, and control structure releases, in addition to general flood risk reduction, supports an overall reduction in life safety risk associated with non-breach flooding events. Within this objective, the PDT recognizes that dam safety risk is being assessed separately, as part of the companion DSMS.
- **Healthy and Resilient Ecosystems:** As discussed above, due to its limited surface disturbance area, the Tunnel Alternative prevents significant impacts to existing natural systems. While ecosystem restoration is not an objective of this study, no other alternative achieves the same degree of flood risk reduction while minimizing impacts to existing riparian and aquatic habitats. This includes avoidance of sensitive habitats for threatened and endangered species as well as historic and cultural resources. Furthermore, preserving these existing ecosystems supports an enhanced quality of life for nearby residents.
- **Watershed Approach:** The Tunnel Alternative embodies a watershed approach which seeks identification of a comprehensive solution which can achieve multiple goals over the entire watershed. This includes provision of flood risk reduction benefits both upstream and

downstream of the reservoirs, and a holistic understanding of the integrity and identity of communities, and the interconnected economic, social, and environmental systems which comprise the study area.

2.4.8 Planning Criteria

The 1983 'Principles and Guidelines' established four criteria for evaluation of water resources projects: effectiveness, efficiency, completeness, and acceptability. Benefits, costs, and social and environmental impacts are used to judge the degree to which an alternative plan meets these criteria. In the sections below, the Tunnel Alternative is assessed against these criteria.

- **Effectiveness:** The Tunnel Alternative is partially effective at reducing life safety risks and flood damages while promoting community resilience. This is demonstrated by the scale of improvements (e.g. 73 / 100% reduction in reservoir induced flooding upstream of the Addicks / Barker Reservoirs [0.2% AEP, with future rainfall], 46% reduction in flood structures in the Buffalo Bayou watershed [1% AEP, with future rainfall]. This includes consideration of future hydrologic changes, providing increased resiliency into an uncertain future.
- **Efficiency:** The Tunnel Alternative, measured exclusively within the NED Account, has not yet been shown to be efficient / cost-effective, as reflected by a benefit-to-cost ratio below unity.
- **Completeness:** The Tunnel Alternative represents a complete solution, not requiring additional improvements to achieve the benefits projected. This includes consideration of future hydrologic change, supporting desired performance over the analysis period (50 years) and the anticipated project lifespan (100 years).
- **Acceptability:** The Tunnel Alternative can comply with applicable laws, regulations, and public policies. Specifically, this includes completion of an EIS and compliance with local floodplain management standards. In addition, the alternative represents what is anticipated to be the least environmentally damaging practicable alternative. Furthermore, the Tunnel Alternative has broad-based support from State and local concerns.

In total, the Tunnel Alternative performs well against the established planning criteria. As has been understood throughout the duration of the study, to meet the traditional threshold for efficiency or cost-effectiveness, the recommended alternative likely must account for the uncertainties associated with this complex system, changing conditions, and the monetary and non-monetary regional economic, social, and environmental benefits. Accordingly, the decision maker will be asked to weigh the information presented in this report to assess whether the total benefits generated rise to the level of Federal interest.

2.5 Iteration 4 – Conclusions

The Tunnel Alternative consistently shows strong performance across a wide variety of metrics and is anticipated to be the highest performing alternative within each of the Four Accounts and across all three layers of evaluation. The total benefits of the Tunnel Alternative are reflected in reduced flood damages, reduced life safety risks, reduction in adverse economic, social, and environmental impacts of the proposed action, and significant improvements to the resiliency of the regional flood risk management system in the face of changing conditions, the vitality of at-risk neighborhoods, and the ability of communities to better withstand and recover from severe flooding events. Furthermore, the flexible operation of the tunnel system allows for an operational strategy that can maximize performance in any given flood event and can be

tailored to offer flood risk reduction to those most vulnerable. No other alternative will produce the benefits of the flexible Tunnel Alternative while minimizing adverse impacts across the full spectrum of accounts.

Importantly, stepping back from the detailed evaluation framework, the proposed Tunnel Alternative:

- Provides a robust and adaptable solution providing targeted flood risk reduction upstream of Addicks and Barker Reservoirs, along Buffalo Bayou, and on the lower reaches of White Oak Bayou
- Improves the resiliency of the dams in the face of changing conditions
- Allows for targeted operation to benefit those most vulnerable
- Reduces residual risk associated with the existing Federal project

The Tunnel Alternative effectively addresses study objectives (flood risk reduction, life safety, and community resiliency) with minimal environmental and social impact, in accordance with state and local input. As such, benefitted communities are strengthened by the proposed Federal action, not impaired, which enhances the ability of at-risk communities to better withstand and recover from severe flood events. This also aligns with the objective of empowering resilient communities through innovative flood risk management programs.

Furthermore, by incorporating risk and uncertainty associated with changing hydrologic conditions into the planning process, the Tunnel Alternative is able to address not only the challenges of "today" but also the risks of "tomorrow". Critically, the region must prepare for more frequent and intense rain events. The Tunnel Alternative represents a robust adaptation strategy.

2.6 Iteration 4 - Risk and Uncertainty

In summary, there are multiple considerations that will impact both the assessment of total benefits and the traditional BCR for the Tunnel Alternative (or any alternative analyzed). It is incumbent on the reader to understand the constraints associated with the current framework of the study and the current status of the study effort. The following provides a list of important risks / uncertainties / considerations that may impact ultimate justification of Federal interest:

- **Cost Estimates:** the analysis utilizes a Class IV cost estimate for the tunnel that is subject to change (either up or down). Results include 51% contingency in the cost estimate. Also, USACE has not prepared a Real Estate Plan with a Gross Appraisal.
- **H&H Analysis:** the analysis utilizes preliminary hydrologic and hydraulic model outputs, which are subject to change. ATR review was conducted but not finalized. Changes may impact project performance.
- **Probabilistic Scenarios:** the analysis considers three different scenarios, to better capture the performance of the system across a wider range of events. Depending on allowed assumptions, project performance may improve or worsen based on how benefits are allowed to be aggregated across probabilistic scenarios. It should be noted that the vast majority of benefit analyses have been conducted only for Scenario 2. In addition, to date, this analysis considers only a 24-hour storm duration and only covers storms as infrequent as 0.002 AEP (500-year) event (Harvey and the PMF have not been analyzed). Performance is anticipated to improve for longer duration events, as the tunnel will have more time to discharge flows, thus allowing it to better moderate/manage reservoir pool levels.

- **Induced Surcharge Releases:** the analysis currently assumes no induced surcharge releases from the reservoirs. However, if assumed to occur in without project scenarios, and if avoided in with project scenarios, significantly more benefits could be achieved with the proposed action. Changing the operation of the induced surcharge curves based on construction of the tunnel will result in reduced damages downstream
- **Engineering Optimization:** the analysis reflects an in-progress optimization of the tunnel / gate operational scheme. Further refinement of the control / operational schemes to be employed is anticipated to improve the performance of the tunnel system, that would result in associated improvements to the BCR and the assessment of total benefits.
- **Hydrologic Change:** the analysis reflects two different assumptions for future hydrologic change, as it relates to rainfall depths/intensities (no change and a 15% increase). However, currently available (and soon to be available) analyses may demonstrate the potential for further adjustments to future year assumptions for rainfall. Economic performance is highly dependent on accurately capturing the probability of rain events. As such, the BCR is sensitive to hydrologic conditions.
- **Complex Flooding:** the economic analysis does not differentiate between structures that previously flooded twice but now only flood once. This is of particular relevance to the areas upstream of Addicks and Barker, where thousands of structures are modeled to flood twice (once from the tributaries, and again from the reservoirs). Importantly, improvements to the reservoirs have no impact on the performance of the tributaries, as they peak well before the reservoirs rise to peak stage. As such, economic modeling shows no benefit of preventing reservoir induced flooding for thousands of structures. However, we do attempt to capture these benefits when discussing hydraulic performance.
- **Complex Geotechnical Analyses:** Tunneling under the city and across fault zones includes inherent uncertainties which may impact design and construction.
- **Unresolved issues with real estate acquisition.** There are currently 3 pending litigations involving this watershed which may involve judicial determinations of property interests. No preliminary or formal takings analysis has been completed for any alternative. As noted in the report, upstream real estate presents substantial potential costs not reflected in the analysis.

3 Compliance with Environmental Laws

Federal projects must comply with Federal and State environmental laws, regulations, policies, rules, and guidance. Significant coordination with local, state, and federal resource agencies occurred from the beginning of the feasibility study through the Interim Report, with significantly less coordination occurring from draft Interim Report Release to Iteration 3 and no coordination in Iteration 4 due to the nature of the work and limitations on the available information to conduct additional coordination. To date, environmental compliance remains incomplete for ALL environmental laws.

3.1 National Environmental Policy Act (NEPA)

A Draft Environmental Impact Statement (DEIS) following the pre-2020 CEQ implementing regulations was prepared for the Iteration 2 final array; however, the decision was made to release an interim report rather than the DEIS for public review. As a result, the DEIS went through DQC, then all work was paused on the effort. After the interim report was released, it was determined that the DEIS would need significant

revisions in response to public comments, a change in alternatives being considered and changes in NEPA regulations. A revised DEIS was not started due to uncertainties in the Iteration 3 final array, lack of a project recommendation and related information (e.g. footprints, water quality information, etc.) at the time; and ultimately the pauses in the study.

3.2 Clean Air Act (CAA)

The Clean Air Act (CAA), as revised in 1990 (42 USC §7401) requires EPA and the states to carry out programs intended to ensure attainment of National Ambient Air Quality Standards (NAAQS). The Houston-Galveston-Brazoria (HGB) Air Quality Control Region (AQCR) is currently meeting all the NAAQS, except for ozone. The HGB is currently classified by the United States Environmental Protection Agency (EPA) as severe for the 2008 eight-hour ozone NAAQS and serious for the 2015 eight-hour ozone NAAQS. For projects occurring in the HGB, general conformity requirements apply according to the serious classification because that is the more stringent standard. While updated emissions modeling has not been completed, it is anticipated that any of the alternatives would result in nitrogen oxides (NOx) emissions that exceed the general conformity *de minimis* threshold of 25 tons per year (tpy) due to the scale and duration of the project and significant need for disposal. If updated modeling validates this assumption, the General Conformity process would need to be completed which includes developing a General Conformity Determination (GCD) and providing public review and comment of the draft and final GCD.

3.3 Clean Water Act (CWA)

Several waterbodies within the alternative footprints including but not limited to Buffalo Bayou, Cypress Creek, and Addicks and Barker are considered a Water of the US (WOTUS). The Reservoir and Channel Improvement alternatives would include dredging (e.g. excavation) and placing fill material (e.g. armoring and terracing) in WOTUS, and the Tunnel alternative would include modification of existing flows and discharge of flow and fill material (e.g. outlet structures and armoring) into WOTUS. Any project action would be subject to the requirements of Section 401 and 404.

Section 401 of the CWA requires that an entity granted permission under Section 404 of the CWA must obtain a State certification that the discharge complies with the provisions of the CWA. TCEQ is the lead state agency that administers the Section 401 certification program in Texas. In order to comply with this requirement, TCEQ evaluates the potential impacts of the discharge in light of water quality standards and Section 404 criteria governing discharge of dredged and fill materials into Waters of the US (WOTUS). All alternatives would need to have updated water quality modeling completed to meet the data needs for TCEQ to issue a Water Quality Certification. Based on previous impact assessment and modeling efforts, all alternatives are anticipated to meet water quality standards with implementation of best management practices, minimization standards (e.g. flow regulations to allow for more efficient dilution rates, practices and measures to minimize debris and trash entry into the water body, etc.), and potentially with additional mitigation requirements.

Section 404 of the CWA regulates the discharge of dredged or fill materials into WOTUS, including wetlands. An updated Section 404(b)(1) analysis is required for all alternatives based on updated designs/footprints, modeling, and mitigation need. Based on the available information, the least environmentally damaging practicable alternative (LEDPA) would be the Tunnel alternative due to the minimal disturbance to the aquatic environment. Any project action would be required to avoid and minimize adverse impacts to WOTUS and wetlands to meet the “no net loss” policy, including offsetting unavoidable impacts with compensatory mitigation to be fully compliant with Section 404.

3.4 Coastal Zone Management Act (CZMA)

The CZMA defines coastal zones wherein development must be managed to protect areas of natural resources unique to coastal regions. Texas has developed and enacted the Coastal Management Plan (CMP), in which any federal and local actions must be determined to be consistent with the management plan. The Texas General Land Office (GLO) enforces consistency of the plan for Texas.

Only the tidally influenced portion of Buffalo Bayou is within the Texas Coastal Zone; therefore, only the Downstream Non-Structural, Channel Improvement and Tunnel alternatives would be subject to CZMA regulation. Based on available information, the three alternatives would be compliant with the CMP. The Channel Improvement alternative would likely have adverse impacts to critical natural resource areas (CNRAs). The Non-Structural and Tunnel alternatives would be expected to have less than adverse impacts on CNRAs. All alternatives would comply with the 16 enforceable policies. Any updated Consistency Determination would need to be developed for any project action, consultation initiated with the GLO, and a concurrence received before the project would be considered compliant with the law.

3.5 Endangered Species Act (ESA)

The Endangered Species Act (ESA) (16 USC 1531 et seq.) established a program to promote conservation and recovery of imperiled species and the habitats in which they are found. Section 7 of the ESA requires federal agencies to ensure that the actions they authorize, fund, and carry out do not jeopardize endangered or threatened species or their critical habitats. A federal agency is required to consult with the US Fish and Wildlife Service (USFWS) and/or National Marine Fisheries Service (NMFS) if it is proposing an action that may affect listed species or their designated critical habitat.

Since a portion of the project area is tidally influenced, an official species list was requested from NMFS. For species in their jurisdiction, the project is anticipated to have no effect on all species due to the lack of suitable habitat, the project area being outside the species known range, or no direct or indirect effects anticipated from any of the alternatives.

An updated official species list needs to be requested for species under the USFWS jurisdiction. Since the last species list was requested, several species have been listed or identified as proposed for listing including the eastern black rail, alligator snapping turtle and the tricolored Bat, all of which have known and even prominent presence in the project area. Table 12 identifies the anticipated worst-case effect determination based on the available information regarding species presence and project designs. It is possible that the project designs could further avoid and minimize impacts and reduce the potential impact to species.

The greatest concerns are surrounding the Texas Prairie Dawn-Flower (Reservoir alternative) and the Alligator Snapping Turtle (any alternative that affects Buffalo Bayou). Both have highly prolific and well-known populations within the project area that contribute to the overall population and range of the species. Early indications from USFWS identify the need for a thorough jeopardy analysis be completed for the two species because impacts from the alternatives could contribute to declines and overall recovery of the species that may not be tolerable. If the USFWS makes a jeopardy determination for either species, the applicable alternative would have to be significantly modified or removed from further consideration.

Additionally, the tricolored bat and eastern black rail are likely to be directly impacted by the project and remove suitable habitat which would trigger the need for mitigation to offset those loses.

Table 12. Anticipated Effect Determination for Listed Species Identified In or Near the Project Area

Species	Status	Cypress Creek Reservoir	Channel	Downstream Non-structural Plan	Combo (Cypress Creek + Channel)	Tunnel
Bird						
Eastern Black Rail	T	LAA + M	LAA	NE	LAA + M	NLAA
Piping Plover	T	NLAA	NLAA	NE	NLAA	NE
Rufa Red Knot	T	NLAA	NLAA	NE	NLAA	NE
Whooping Crane	E	NLAA	NLAA	NE	NLAA	NE
Mammals						
Tricolored Bat	PE	LAA + M	LAA + M	NE	LAA + M	LAA + M
West Indian Manatee	T	NE	NLAA	NE	NLAA	NLAA
Reptiles						
Alligator Snapping Turtle	PT	NE	LAA + M, Potential Jeopardy Call	NE	LAA + M, Potential Jeopardy Call	LAA + M
Insects						
Monarch Butterfly	PT	LAA	LAA	NE	LAA	NLAA
Plants						
Texas Prairie Dawn-Flower	E	LAA + M, Potential Jeopardy Call	NE	NE	LAA + M, Potential Jeopardy Call	NE

E= Endangered **T**= Threatened **PE** = Proposed Endangered **PT** = Proposed Threatened

LAA = "Likely to Adversely Affect," Formal Consultation and Biological Opinion will be needed

NLAA = "Not Likely to Adversely Affect," Informal Consultation and Concurrence Letter needed

+ M = Mitigation would likely be required

NE = No Effect due to one or more of the following: lack of suitable habitat, no work completed in or near the species or its habitat, or outside the specie's known range.

3.6 Fish and Wildlife Coordination Act (FWCA)

The Fish and Wildlife Coordination Act (FWCA) (16 USC 661 et seq.) requires federal agencies to coordinate with USFWS or NMFS and appropriate state wildlife agencies to avoid or minimize adverse impacts of federal actions that propose to modify any natural stream or water body. Significant agency coordination was conducted from Study Start through the Interim Report Release. However, the revision of alternatives would trigger additional coordination and significant revision to any work completed on the draft Coordination Act Report (CAR). The USFWS, to date, has not provided a CAR or Planning Aid Letter. The project may need to be revised in response to their recommendations

3.7 Magnuson-Stevens Fisheries Conservation and Management Act (MSA)

The Magnuson-Stevens Fisheries Conservation and Management Act (MSA) establishes procedures for identifying essential fish habitat (EFH) and requires interagency coordination to further the conservation of federally managed fisheries. Its implementing regulations specify that any federal agency that authorizes, funds, or undertakes, or proposes to authorize, fund or undertake an activity that could adversely affect EFH is subject to the consultation provisions of the Act and identifies consultation requirements.

EFH consists of those habitats necessary for spawning, breeding, feeding, or growth to maturity of species managed by Regional Fishery Management Councils in a series of Fishery Management Plans. EFH is applicable to the tidally influenced portion of Buffalo Bayou. Additionally, this portion of Buffalo Bayou is defined as EFH for red drum (*Sciaenops ocellatus*) for larvae, juvenile and adult life stages; brown shrimp (*Farfantepenaeus aztecus*) for larval and juvenile life stages; white shrimp (*Litopenaeus setiferus*) for all life stages; and highly migratory species including neonate blacktip shark (*Carcharinus limbatus*), neonate, juvenile, and adult bull shark (*Carcharhinus leucas*), neonate scalloped hammerhead (*Sphyrna lewini*) and neonate lemon shark (*Carcharhinus brevipinna*).

Construction activities would remove existing EFH substrates and temporarily change environmental conditions during construction. However, the effects would be short-term and localized and the area would be expected to return to baseline conditions following completion of excavation and construction activities. Long-term direct (channel substrate) and indirect impacts (changes to salinity in Galveston Bay) would have minimal to no adverse or beneficial impacts.

The EFH assessment would need to be updated to address the revised array of alternatives and consultation initiated with NMFS. The project may need to be revised in response to their recommendations and any requirements for mitigation.

3.8 Migratory Bird Treaty Act

The MBTA authorizes the Secretary of the Interior to regulate the taking of migratory birds and provides that it shall be unlawful, except as permitted by regulations, to pursue, take, or kill any migratory birds, or any part, nest or egg of any such bird (16 USC 703-712, as amended). This prohibition includes both direct and indirect act, although harassment and habitat modification are not included unless they result in direct loss of birds, nests, or eggs. Currently several hundred species are protected under the MBTA.

Based on the presence of potential nesting habitat for migratory bird species within the project area, it is anticipated that each alternative, with the exception of the Non-Structural alternative, would be subject to the requirements of the MBTA. Migratory bird surveys will be conducted prior to construction and

necessary to protect migratory bird and raptor nesting period (February 1 through August 31 for most birds). If tree removal or construction must occur during the nesting season, a qualified wildlife biologist will conduct pre-maintenance surveys for raptors and nesting birds within suitable habitat within 300 feet of the worksite.

3.9 National Historic Preservation Act

The NHPA requires federal agencies to take into account the effects of a proposed action on properties that are determined to be eligible for listing in, or are listed in, the National Register of Historic Places.

Section 106 of NHPA requires federal agencies to evaluate the effects of Federal undertakings on historical, archeological, and cultural resources. Based on an evaluation of the proposed alternatives, it has been determined that each are located within moderate to high probability areas for historic properties. The Tunnel Alternative has been formulated to avoid impacts to cultural and historic sites.

USACE will need to develop a programmatic agreement (PA) in consultation with Tribes, Tribal Historic Preservation Office (THPOs), State Historic Preservation Offices (SHPOs), agencies, and interested parties to address problems associated with cultural and historic resource impacts involved with implementing the TSP. The PA would specify that all work would be stopped if during construction archaeological deposits are found. Discoveries would be assessed to determine the significance of the find as required under Section 106.

3.10 Resource Agency Concerns

Resource agency concerns have predominantly been with implementing any proposed measures within Katy Prairie habitat and along Buffalo Bayou. The Katy Prairie is the last remaining coastal prairie in Harris County and less than 1% remains throughout the state. The Cypress Creek Reservoir would have enveloped and impacted nearly all of the known quality Katy Prairie habitat remaining.

Modifying Buffalo Bayou is a significant concern shared by various resource agencies because of the value the bayou provides as the last remaining “naturalized” channel that can support aquatic species and other common terrestrial and avian fauna. All other waterways in the Houston Metropolitan Area have been converted to trapezoidal, grass-lined channels with no riparian habitat and provide little to no ability to support aquatic species. The resource agencies are extremely concerned about how the bayou would function after channel improvements are completed.

Resource agencies are concerned about the length of time it will take for riparian species to provide quality habitat. They note that most of the existing riparian habitat along the channel took several decades or more to provide the habitat that it does today and that it would take a significant amount of time to regain the structure and quality, predicting that it could not occur within the project life timeframe. Even with the temporal accounting in the impact and mitigation analyses, the loss of mature habitat is significant in this urban environment and may be unavoidable.

The resource agencies also have significant concerns in how Alligator Snapping Turtle, a State Threatened Species and species proposed for Federal Listing as Threatened, losses will be avoided during construction, since the species is extremely territorial and cannot be simply moved to another part of the bayou nor held in captivity for several years until the bayou is stabilized. Additionally, there is significant concern in the ability of the channel enlargement measure with the natural environment designs to support Alligator Snapping Turtle especially with their territorial nature and affinity to an area for life. The bayou currently provides habitat for the largest known breeding population in Texas and possibly the world.

A tunnel would avoid or reduce most of the concerns expressed by resource agencies; however, as previously stated, the tunnel impacts have not been coordinated with agencies and an EIS is an unmet requirement for the BBTRS study.

4 Sponsor and Local Views

As discussed throughout this report, Hurricane Harvey profoundly impacted the greater Houston region (America's fourth largest city and third largest county) by highlighting significant vulnerabilities in our flood risk management system, regardless of jurisdiction. In particular, the Buffalo Bayou and tributaries system is no longer adequately equipped to meet today's needs or to manage the increasingly frequent and intense rain events projected in the years ahead.

For the Harris County Flood Control District and residents across the region, continuing under the existing system presents growing challenges. The flooding of more than 8,000 structures upstream and 17,000 downstream of the Addicks and Barker reservoirs during Hurricane Harvey underscored the need to reevaluate our traditional approaches and consider more effective solutions with new ideas and concepts.

Extreme rainfall events are occurring with greater frequency in Harris County. Over the past decade, the region has experienced four storms rated at the 500-year level or above. Addicks and Barker reservoirs each recorded the highest pool elevations in their history during this time. These trends point to a pattern of increasing risk that we believe calls for thoughtful and timely action to reduce the potential for future impacts.

The Buffalo Bayou and tributaries system is a Federal project and subject to the limitations of that framework. Within this context, the Buffalo Bayou and Tributaries Resiliency Study, this Section 216 study, offers a valuable opportunity to explore and recommend approaches that could better manage the residual risk associated with continued operation of the reservoirs.

The Harris County Flood Control District joins with residents, community groups, businesses, nonprofits, and local governments who are seeking viable, community-centered flood mitigation strategies. We share the belief that flood risk management solutions must protect public safety while also preserving environmental quality and community integrity. New approaches are needed that reflect shared values and long-term resilience goals.

Our organization supports recent federal guidance that emphasizes comprehensive benefits and recognizes the connection between flood risk management, reservoir operations, dam safety, and federal liability. Within this framework, we believe the Tunnel Alternative presents a promising and adaptable option. It provides targeted flood risk reduction upstream of Addicks and Barker, along Buffalo Bayou, and in lower reaches of Buffalo and White Oak Bayous. This approach has the potential to strengthen dam resiliency, enable more responsive operations for vulnerable communities, and address residual risks within the current regulatory structure.

Advancements in tunneling technology have made it possible to expand conveyance capacity through methods that are cost-competitive and less disruptive than traditional approaches. As a result, we can now consider transformative flood mitigation solutions that minimize community displacement and preserve natural and cultural amenities essential to the region's quality of life and economy. We view this as a forward-looking strategy for enhancing climate resilience in a highly urbanized landscape.

The Tunnel Alternative also offers meaningful reductions in risk and potential liability. It is projected to decrease downstream structural flooding by 46% during a 1% annual exceedance probability (AEP) event and would provide the Corps of Engineers with greater flexibility to operate the reservoirs in a manner that could avoid exceedances of government-owned lands and upstream flooding in more extreme events.

Equally important, it equips the Corps with the tools to respond more effectively to high-impact scenarios, such as dam failure, sequential storms, or rainfall events beyond the 0.2% AEP threshold.

From the perspective of the Harris County Flood Control District, continued operation under the current system's constraints presents challenges that warrant serious consideration. While a range of options have been explored, including reservoir pool buyouts, the Tunnel Alternative clearly offers the most feasible and implementable solution under existing political, social, and economic conditions. Although no single alternative can address all risk, this approach represents a significant step forward in reducing both public exposure and federal liability.

Regarding Recommendation #4, which involves acquiring land within the reservoir pools, the Flood Control District recognizes the engineering rationale and policy considerations that inform this proposal. However, given the potential scale of the buyouts, which would impact approximately 16,000 properties, we have concerns about its broader implications. Such an effort would constitute one of the largest relocation initiatives since Hurricane Katrina, with major impacts on communities in west Houston. In addition to displacing residents and businesses, the viability of municipal utility and school districts that serve many more outside the flood pools could also be affected. Furthermore, the time and resources required for such a voluntary program could extend over decades, during which residents would remain at risk.

The Harris County Flood Control District supports the recommendations outlined in this study and looks forward to continuing its collaboration with the U.S. Army Corps of Engineers as the project progresses toward construction authorization. We believe that identifying and advancing a workable solution is a shared responsibility and that the Buffalo Bayou and Tributaries Resiliency Study provides a thoughtful, holistic foundation for strengthening the region's resilience to future flood events in a changing climate. The Harris County Flood Control District also stands prepared to support and/or lead future efforts in compliance with applicable federal authorities.

5 Findings and Recommendations

This report of findings has summarized the evaluation of alternative actions to reduce flood risks on the Buffalo Bayou system and support community and infrastructure resiliency. Applicable engineering, economic, social, environmental and legal criteria have been considered. Furthermore, Sec 1221 of WRDA 2024 states that the report "shall contain recommendations for projects that:

> *(1) align with community objectives;*
> *(2) avoid or minimize adverse effects on the environment and community; and*
> *(3) promote the resiliency of infrastructure.*

Accordingly, four critical findings and associated recommendations are submitted:

1. Increase Conveyance – The tunnel is the most effective of the structural alternatives considered. It is technically sound and has the least environmental and social impacts. It significantly improves emergency operations capabilities, allowing safe release up to 15,000 CFS while reducing the duration and extent of upstream reservoir-induced flooding. Therefore, I recommend that the USACE be authorized to complete a 35% design of the tunnel system and complete necessary environmental and coordination requirements, including public comment. This will provide a much higher fidelity estimate of the costs, benefits and environmental impacts to better inform a construction investment decision. The estimated cost to complete an EIS, 35% design, and related site investigations is $80 million to $100 million. It may also be possible to update the cost estimate to Class III for around $30 million without completing 35% design requirements.

2. Dam Safety – armoring the emergency spillways may be necessary to bring life safety risks within tolerable risk guidelines. Therefore, I recommend that the Corps complete the Dam Safety Modification Study (DSMS) for the emergency spillways and implement the study's recommendations. The estimated cost to complete the DSMS is $1,500,000.

3. Water Control Manual – Normal operations in the water control manual currently limit flows to 2,000 CFS at Piney Point (the downstream control point); however, flows up to 4,000 CFS at Piney Point do not cause damage to structures on Buffalo Bayou during normal operations. Furthermore, induced surcharge operations are not optimized for the dams as they exist today, potentially adding risk. Therefore, USACE Galveston District will immediately implement an interim update to the Water Control Manual to both increase the normal allowable discharge at Piney Point and to reanalyze the induced surcharge plan to optimize use of available storage upstream and downstream. This updated Water Control Manual will serve to reduce risk as much as possible until tunnel construction and/or implementation of DSMS recommendations are complete. Each of those elements will require specific water control manual updates prior to the end of construction. Proposed WCM updates must undergo public reviews. The estimated cost of Water Control Manual updates is $1 million.

4. Upstream Acquisition – Government Owned Lands (GOL) do not satisfy current acquisition policies. The tunnel would reduce the frequency of flooding above GOL but does not meet current policies for reservoir land acquisition or prevent water beyond GOL. Therefore, I recommend that the Corps be authorized to acquire necessary real estate interests to 104 FT NAVD in Barker Reservoir and 108 FT NAVD in Addicks Reservoir. Costs are estimated to be $14,872,300,000.

5.1 USACE Policy & Legal Limitations and Requirements

The USACE acknowledges these recommendations have not reached legal and policy requirements for a construction authorization. Additional site investigations, technical analyses, environmental assessments, and independent expert and public reviews are required prior to a USACE recommendation for a construction authorization. These policy and legal requirements could be addressed as described below, with approval and subsequent funding.

5.1.1 Legal Limitation

- Environmental compliance is incomplete for all environmental laws, as documented in Section 4 of this report. NEPA requires that USACE prepare an EIS prior to project construction, and USACE policy (ER 200-2-2) ordinarily requires the EIS to be completed during the feasibility study phase. The Report of the Chief of Engineers cannot recommend a federal project for construction if the NEPA process hasn't been completed. The Chief's Report can, however, recommend additional analysis without having NEPA compliance completed. ER 200-2-2 provides for Categorical Exclusions for NEPA, one of which is for "Planning and technical studies which do not contain recommendations for authorization or funding for construction but may recommend further study."
- An Independent External Peer Review (IEPR) has not been conducted. Section 2034 of WRDA 2007, as amended, requires that USACE decision documents undergo an IEPR to obtain expert assessments of economic, environmental, and engineering assumptions and technical analyses, including formulation of alternatives, model application, and methods for integrating risk and

uncertainty. If the project is authorized to receive funding for further site investigations and design development, an IEPR will be completed on the resulting EIS and design documents.

5.1.2 Policy Limitations

- USACE and Administration policies require that the ASA(CW) approve a recommended plan that is not the NED plan, the plan that maximizes net national economic benefits. The study applied current guidance and policies for a comprehensive benefits framework to measure economic, social and environmental benefits of the tunnel alternative. However, the new guidance still includes the requirement that the ASA(CW) approve recommendations for an alternative that is not the NED Plan. A NED exception request will be submitted for review and approval in parallel with the processing of this report of findings.
- USACE policy does not have a minimum performance requirement. Instead, multiple scales of alternatives are to be evaluated to find a cost-effective scale that maximizes net benefits. Early iterations of the study evaluated smaller increments of conveyance; however, the final two iterations focused on 15,000 CFS once it was determined that lower flows would not meaningfully improve performance of the system in larger events where USACE faces significant risk when operating the system. This focus on 15,000 CFS was implicitly approved in 2021 with the last approved study scope, schedule and budget. However, explicit approval is needed to resolve the policy concern. This request will be incorporated into the NED exception described in the first bullet above.
- USACE policy requires Agency Technical Review (ATR) of all technical analyses and supporting documentation of project recommendations. The engineering models, cost estimating, and comprehensive benefits analyses have been reviewed by a USACE ATR team; however, resolution of review concerns have not been fully backchecked to reach resolution. The technical evaluations of other alternatives and this Report of Findings have not undergone Agency Technical Review
- USACE policy requires a Class III cost estimate in decision documents and Chief's Reports that request Congressional authorizations. The current cost estimate for the tunnel is a Class IV. A Class III estimate requires an appropriate level of design maturity that cannot be achieved without the necessary level of funding to complete site investigations and 35% design. Hence the request for authorization to receive funding for design rather than a construction authorization. If funded, the design documentation and resulting Class III cost estimate would be used as the basis for further recommendations to Congress in a final Chief's Report.

5.2 District Commander's Statement

The recommendations contained herein reflect the information available at this time. They do not reflect program and budgeting priorities inherent in the formulation of a national Civil Works program nor the perspective of higher review levels within the Executive Branch. Consequently, the recommendations may be modified before they are transmitted to the Congress as proposals for authorization and funding. However, prior to transmittal to the Congress, the non-Federal sponsor, the state, interested Federal agencies, and other parties will be advised of any modifications and will be afforded an opportunity to comment further.

30 MAY 2025

Date

Rhett A. Blackmon
Colonel, U.S. Army
Commanding