City of Austin, Texas

Lower Shoal Creek Flood Hazard Mitigation Project

Flood Risk Reduction Report

November 15, 2019

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HALFF SMARTER SOLUTIONS

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Introduction

Halff Associates was contracted by the City of Austin as part of the 2015 Watershed Engineering Flood Mitigation Rotation List (MA# 160000003) for a multi-phase feasibility study to assess possible solutions to flooding along Shoal Creek between 15th Street and Lady Bird Lake. For a location map of the study area in relation to the watershed, please see **Figure 1**. The project's Phase 1 included compiling and reviewing prior planning studies, coordinating with stakeholders, and engaging the public to identify potential mitigation ideas for the Lower Shoal Creek corridor. Phase 2 included the hydrologic and hydraulic analyses establishing baseline conditions as well analyses of several flood risk reduction alternatives, cost estimation, evaluation criteria, and recommendations. Both phases are discussed in this report.

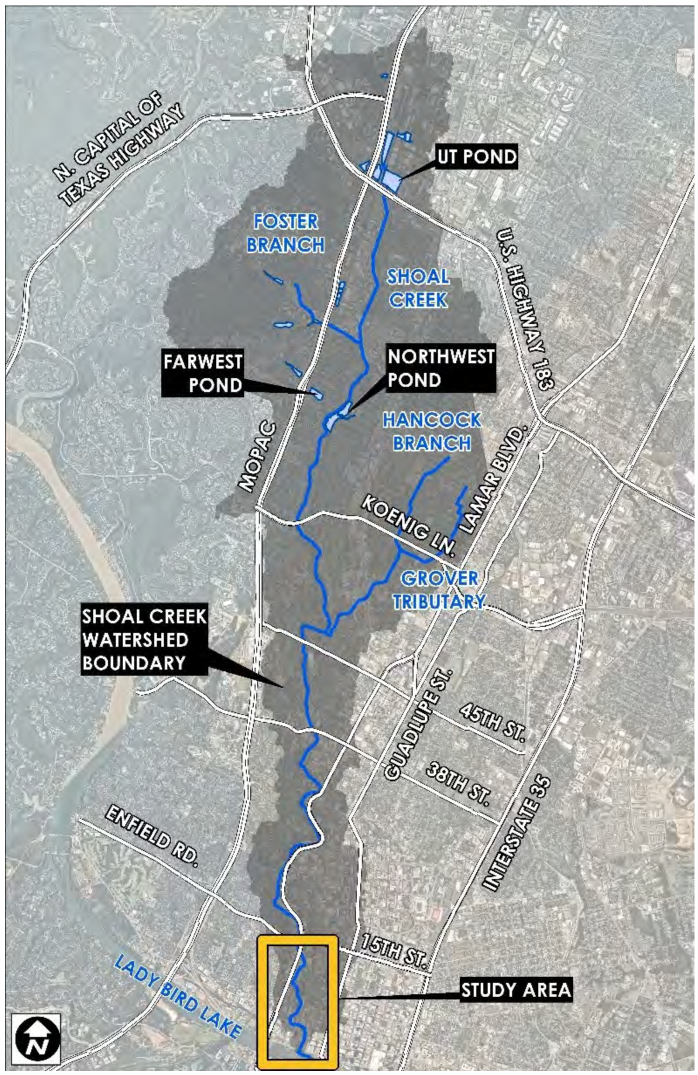


Figure 1: Shoal Creek Watershed Map

Background

The Shoal Creek watershed is the largest of Austin's north urban watersheds with a total drainage area of 13 square miles, stretching from Lady Bird Lake up to the Domain. All water within this area drains into its 13 miles of stream, including Shoal Creek, Foster Branch, Hancock Branch, and Grover Tributary.

On Memorial Day 1981, 13 lives were lost due to flooding in Austin with many of the fatalities along Shoal Creek. More recently, the creek experienced severe flooding on Memorial Day 2015. The 2015 flood was near a 10% annual chance event (ACE) (10-year). Although the 2015 flooding was extensive, more severe flooding is possible along Shoal Creek. There have also been numerous smaller flood events along Shoal Creek. There are both commercial and residential buildings vulnerable to flooding in the study area. In addition, long stretches of Lamar Boulevard and several low water crossings become dangerous and impassible for several hours with enough rainfall.

Over the last several decades, the City of Austin has experienced significant development and population growth. With a substantial percentage of Austin's land area in the regulatory floodplain, the City has diligently worked to balance the need for flood protection with the economic benefits of development within these flood-prone areas. According to the Shoal Creek Conservancy's Shoal Creek Characterization Report, Shoal Creek is the 10th of all 50 most densely populated watersheds in the City. Over 56% of development along Shoal occurred before 1974, when drainage regulations were first adopted. Shoal Creek has experienced many instances of severe flooding, which caused significant property damages, creek erosion, and water pollution. According to the City of Austin Watershed Protection department, Shoal Creek watershed contains 15% of the citywide structures within the 1% ACE (100-year) floodplain. This Lower Shoal Creek area has been identified by the City of Austin Watershed Protection Department flood ranking system as the number one worst flooding problem in the city.

Literature Review & Data Collection

Phase 1 of this study included collection of previous studies as well as review of relevant data and literature. These previous studies will be referenced throughout the report and a brief summary for each study is included below. Also, as part of Phase 1, Halff supported the City of Austin in holding a public meeting on March 9, 2017 in the Lower Shoal Creek project area. The goal of the meeting was to present the initial project goals and objectives, meet stakeholders, survey concerns and ideas, and discuss potential mitigation alternatives. This public meeting included both outreach and a written public survey of attendees. Existing data was collected to create exhibits for the initial public meeting related to this study. The exhibits developed during Phase 1 can be found in **Appendix A**. Please note these exhibits were developed prior to updating the modeling conducted in Phase 2. The Phase 1 existing flood risk estimations were based on the one-dimensional hydrologic and hydraulic models completed during 2012 Shoal Creek Floodplain Modeling and Mapping project.

Previous Studies

In response to the flood risk within the Shoal Creek watershed, Lower Shoal Creek has been included in several studies in recent years. Previous Shoal Creek studies provided by the City included the:

- The 1991 United States Army Corps of Engineers (USACE) study – Identified flooding problems throughout the Shoal Creek Watershed and formulated alternative solutions. The most cost-effective solution was a 14-foot combination tunnel/channel plan for Shoal Creek and Hancock Creek. Based on the results of this report at the time the City reviewed the options and made the decision to consider implementing only the Hancock Creek portion of the project.
- The 2012 Shoal Creek Floodplain Modeling and Mapping Project – This was a part of a larger ongoing project for the update of floodplain models and mapping in selected watersheds in the Austin metropolitan area that was established between the Federal Emergency Management Agency (FEMA) and the City of Austin. This study updated the FEMA effective hydrologic models, hydraulic models, and floodplain maps. The City of Austin's fully developed models and mapping were updated as well.
- The 2014 City of Austin Watershed Protection Department Shoal Creek Mitigation Analysis – The City of Austin Watershed Protection Department reassessed the flood risk reduction benefits and potential project cost of the 19th Street Tunnel analyzed in the 1991 USACE study also known as the Shoal Creek Tunnel.

- The City of Austin Brentwood Case Study – This study assessed the large-scale application of green infrastructure (GI) for the purpose of flood mitigation along the Grover Channel that flows into Hancock Branch. Based on the results of this case study, while GI could be a best management practice utilized to improve water quality and provide flood risk reduction benefits for small rain events, however utilizing GI for flood risk reduction of larger rainfall events would be less feasible.
- The 2016 COA Shoal Creek Restoration 15th - 28th Streets Capital Improvement Project – This project's objective is to design and construct engineering solutions to improve water quality and reduce erosion issues within Shoal Creek between 15th Street and 28th Street.

The Shoal Creek Conservancy (SCC) provided the:

- Shoal Creek Debris and Sediment Inventory – In 2016 the SCC and Alan and Plummer assessed the flood reduction benefits of removing debris, sediment, and gravel along Shoal Creek between 15th Street and Lady Bird Lake. Based on the findings of this study, they determined that removal of sediment bars and gravel provided minimal flood mitigation benefit, decreasing the water surface elevation 0 to 3 inches for the various frequencies. Removal of small woody trees was recommended to prevent future blockages in the creek.
- The City + Water showcase – This showcase reached out to the Shoal Creek stakeholders to share innovative flood mitigation solutions that have been implemented all over the world. It also encouraged public input on potential solutions for Shoal Creek in the hopes of making the Shoal Creek watershed a beautiful, healthy, and safe place to live, play, and work.
- The Shoal Creek Trail Plan – Summarized the vision to implement a continuous pathway for pedestrians and cyclists from Highway 183 to Lady Bird Lake.

Public Survey

As mentioned previously, a public survey was conducted at the March 2017 stakeholder engagement meeting to assess the public's concerns and ideas. The notable takeaway from the Phase 1 public survey is that no conclusions can be drawn from the results, for several reasons. There were only 44 participants total, 35% of which do not live or own property in the Lower Shoal Creek area where this study is focused. Additionally, there was no consensus regarding mitigation options, evaluation criteria, or level of service goal to guide the Phase 2 effort. **Figure 2** shows the results from the best and worst mitigation options questions; underground conveyance came out as the top alternative for both categories in the poll. The full results of the public survey can be found in **Appendix B**.

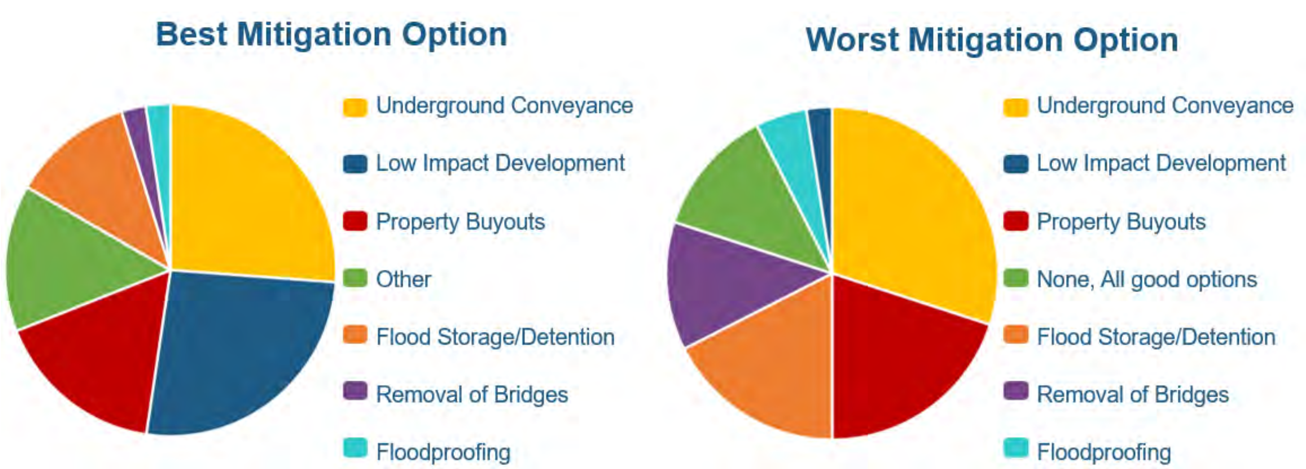


Figure 2: March 2017 Public Survey Results

Field Survey Data

Finished floor elevation (FFE) survey of structures and topographic survey were obtained by MWM Design Group in September 2018. FFEs are important for assessing whether structures are impacted by a flood event; only if the simulated water surface elevation is higher than the FFE is the structure considered to be flooded. For buildings that had filed with the City for variances, their FFEs were collected from this data. Where survey or variance data were not available, the 2017 LiDAR elevation data was utilized to estimate the FFE. Finished floor elevations were defined based on survey for 62% of the buildings in the 1% ACE (100-year) floodplain.

Field survey of ground elevations was also taken in the area in between Shoal Creek and N Lamar Blvd upstream of 15th Street for areas of potential structural flood risk reduction alternatives to assess feasibility and improve simulations of alternatives. This survey was also obtained by MWM Design Group in September 2018.

Existing Condition Analysis

Before any flood risk reduction alternatives could be analyzed the existing condition flood risk was established utilizing hydrologic and hydraulic models. Hydrologic analysis is the computation of how much water (flow) enters a creek at specified locations of interest. Once the flow is established in the hydrologic model the flow is entered into the hydraulic model. Hydraulic analysis is the computation of how water (flow) travels down a creek system. Hydraulic analysis estimates the of water elevations, speed (velocity), and floodplain extents along a creek. A two-dimensional (2D) hydraulic model was utilized to better simulate the interaction between above ground channel flow and underground pipe flow. A 2D model also allows more accurate simulation of areas with multi-directional flow patterns, such as when water exceeds the capacity of the creek and flows along adjacent roadway corridors.

Two-Dimensional Modeling Evaluation

The hydrology and hydraulic models developed during the 2012 Shoal Creek Floodplain Modeling and Mapping Project are the current effective COA and FEMA models and associated floodplains. These models were considered the best available data. During the 2012 Shoal Creek Floodplain Modeling and Mapping Project a 2D InfoWorks model was developed for a portion of Lower Shoal Creek. This model was developed in InfoWorks RS v12.5 (IWRS). For more information regarding the development of this model please refer to the memorandum entitled “Shoal Creek Watershed – Two Dimensional Hydraulic Analysis” dated July 31, 2013. This previous model was utilized for this study.

The 2D InfoWorks model was evaluated and updated appropriately, based on current conditions and data collected for this project. Initially the IWRS was converted to InfoWorks Integrated Catchment Modeling (ICM) software (version 8.0.2, dated June 2017). The previous model only extended from the confluence up to 10th Street. To include the entire project area, the 2D model was extended from 10th Street to just upstream of 15th Street. The model is made up of a one-dimensional (1D) channel that can spill over defined bank lines on to the overbanks represented by a 2D mesh surface. The 2D surface was updated to utilize the 2017 LiDAR data. The 2017 LiDAR data came from an updated Digital Elevation Model (DEM) dataset created for this study from the TNRIS 2017 Central Texas LiDAR acquisition project. The entirety of the City of Austin was flown for the 2017 LiDAR acquisition. The new LiDAR tiles covering the project area were utilized. The 2017 DEM dataset has a 1-meter resolution but was converted to 3-foot by 3-foot raster resolution for use in the model. The lidar was acquired in UTM 14N meters and converted into Texas State Plane Central 4203 (US feet). Vertical units were converted from meters into feet. The bank lines were updated to be represented by the 2017 LiDAR data as well. The 1D channel incorporated the channel survey collected during the 2012 Modeling and Mapping study, therefore the survey was considered the best available data and the 1D channel elevation data was left unchanged. Manning’s roughness coefficients were evaluated, expanded to the updated model extents, and revised as needed to reflect any changes in development based on best available aerial and field data. The roughness coefficients compared to land use for both the 1D channel and the 2D overbank area can be found in **Table 1**.

Table 1: Manning's Roughness Coefficients

Description	n-value
2D Overbank	
Grass with no trees and brush	0.045 - 0.05
Grass with light brush & trees	0.07
Grass with medium brush & trees	0.09
Grass with dense brush & trees	0.11
Paved (100% impervious)	0.025
Residential or Light Business (no voids)	0.09
Industrial (no voids)	0.11
1D Channel	
Paved/ROW	0.03
Centerline of Channel	0.04 - 0.06
Grass with medium brush & trees	0.06 - 0.08
Grass with dense brush & trees	0.12

Inflow hydrographs were placed along the creek for each evaluated frequency based on the hydrology model developed during the 2012 Modeling and Mapping Project. The flow volumes and hydrographs were validated to the October 1998, August 2001, and November 2001 flood events during the 2012 study hydrologic model.

Once the necessary updates were made, the 2D model was compared to the May 2015 flood event to determine if calibration efforts were required. OneRain rainfall data of the May event was provided from the City to use in the hydrologic model. No high-water mark data was available therefore the data from USGS gage 8156800 near W 12th Street was utilized. The USGS gage along Lower Shoal Creek at 12th Street measured a peak depth of 20.76 feet and a peak flow of 11,000 cubic-feet per second (cfs). The May 2015 OneRain data showed approximately 4 to 5.7 inches fell in approximately 6 hours.

The USGS gage measured water surface depth of 20.76 feet at 12th Street equates to the depth of water between the 1% ACE (100-year) and 0.2% ACE (500-yr) along Shoal Creek. The USGS gage measured peak flow of 11,000 cfs at 12th Street equates to the frequency peak flow between the 10% ACE (10-year) and 4% ACE (25-yr) along Shoal Creek. The OneRain rainfall data of 4 to 5.7 inches in 6 hours approximately equates to a frequency between the 10% ACE (10-year) and 4% ACE (25-yr) along Shoal Creek. Unfortunately comparing these data points to the simulated frequencies did not return consistent results.

The OneRain May 2015 rainfall data was incorporated into the 2012 hydrologic model utilized for this study. The peak flow results of the May 2015 event from the hydrologic model were lower than the USGS gage data. The USGS gage read a peak flow of 11,000 cfs at 12th Street and the hydrologic model flow peaked at 6,600 cfs. The antecedent moisture conditions of the curve numbers were modified to calibrate the flows in the Lower Shoal Creek area. However, this did not have significant calibration benefits to the peak flow. Increasing the antecedent moisture conditions from Type I to III increased the peak flow at 12th Street to only 7,700 cfs, which is still well below the gage measured 11,000 cfs. Based on these results, the calibration efforts were redirected from the 2012 hydrologic model to the 2D model. The focus of this data calibration effort shifted to ensuring the 2D model was consistent with the 2012 hydraulic model, specifically that the 10% ACE or 4% ACE water surface elevations near 12th Street were at or near the May 2015 USGS gage reading.

The initial water surface elevation results of the 2D model were low. To increase the water surface elevation the channel n-value of 0.04 was increased to 0.06. This change of n-value was validated when comparing the 2D floodplain results to the 2012 floodplains. An appropriate internal quality assurance and quality control (QA/QC) process was followed to ensure the parameters and results of the 2D model were consistent and accurate. The 2D model was also externally reviewed. The model review comments are responses can be found in **Appendix C**.

Existing Conditions Flood Risk

Using the updated 2D model, existing condition flood risk was established within the study area. Flood risk in the study area was evaluated for several flood events with varying frequency (probability of occurrence). The relationship between the flood event and annual probability of occurrence is summarized in **Table 2**. Please note the new Atlas 14 rainfall totals were not released prior to this analysis. Please refer to the 0.2% annual chance event (ACE) (500-year) results to estimate the future 1% ACE (100-year) using the Atlas 14 rainfall.

Table 2: Annual Probability of Frequency Flood Events

Flood Frequency Event	Probability of occurrence in a year (%)
10-year	10%
25-year	4%
50-year	2%
100-year	1%
500-year	0.2%

Buildings and roadways flood in events smaller than the 10% ACE (10-yr). The number of at-risk structures and expected depth of flooding in those structures were defined by subtracting the finished floor elevation from the water surface elevation for each frequency event. When the water surface elevation exceeds the finish floor elevation, interior or structural flooding is likely to occur. Not all structures located in the floodplain extents are considered at-risk because water is not expected to enter the interior of the building until the water surface elevation exceeds the build's FFE. The Shoal Creek 10% ACE and 1% ACE water surface elevations are compared to the surrounding FFE in **Figure 3**. **Table 3** displays the number of buildings estimated to have interior or structural flooding as well as the length of roadway inundation for the various flood events. A roadway was considered "inundated" if it appeared to be a safety concern for drivers and a loss of emergency access based on the inundation extent, depth, and velocity. According to the Center for Disease Control, over half of flood-related deaths occur in vehicles.

Table 3: Summary of Existing Flood Risk

	10-year (10% chance)	25-year (4% chance)	50-year (2% chance)	100-year (1% chance)	500-year* (0.2% chance)
Inundated Structures	36	48	54	61	85
Inundated Roadway	7,400 ft	9,700 ft	10,900 ft	12,300 ft	19,400 ft
Overtopped Roadways	West & Lamar	5th, 10th, West, & Lamar	5th, 6th, 9th, 10th, West, & Lamar	5th, 6th, 9th, 10th, West, & Lamar	5th, 6th, 9th, 10th, 12th, West, & Lamar

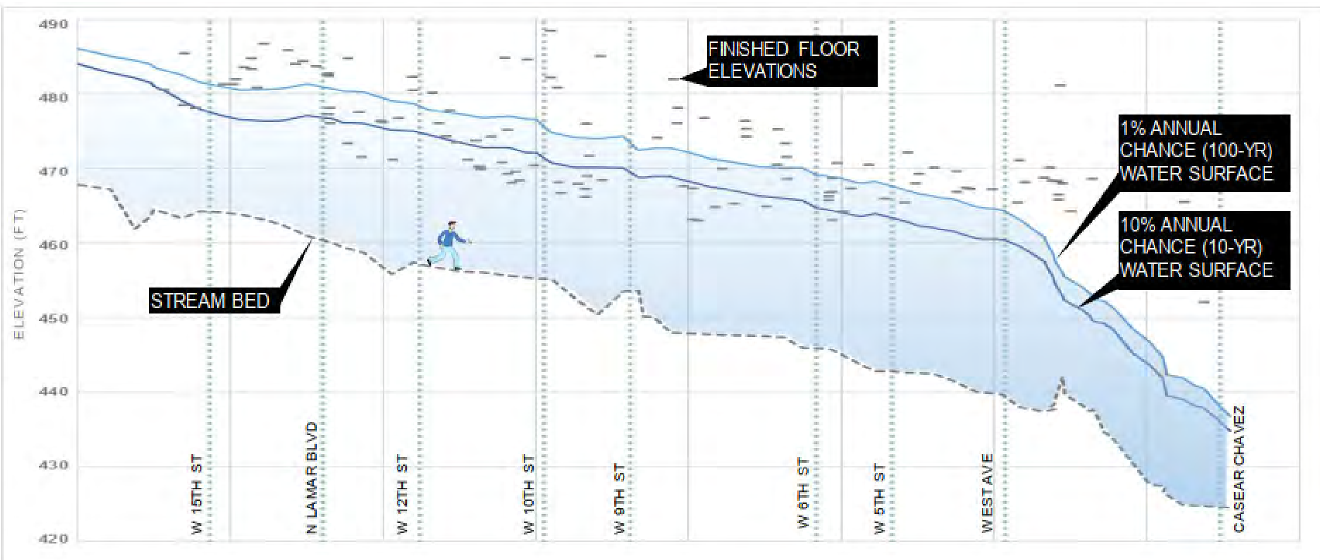


Figure 3: Water Surface Elevation Profile

Flood Risk Reduction Goal & Considerations

The flood reduction objective is to reduce the frequency and severity of flooding for people and structures by reducing the flood elevations at buildings and roadways along the reach of Shoal Creek between W 15th Street and Lady Bird Lake. As stated in a previous section, evaluation of available finished floor elevations indicated that approximately 61 buildings in the Shoal Creek corridor downstream of W 15th Street are estimated to experience structural flooding during the computed 1% ACE (100-year). This study assumes that a structure is at-risk only if the water surface elevation exceeds the FFE. They are not considered at-risk if they are simply located in the floodplain extents. **The goal of this feasibility analysis was to identify alternatives that would reduce the 1% ACE (100-year) peak flows or produce equivalent reductions in risk through the Shoal Creek corridor downstream of W 15th Street.** In order to significantly reduce structural flooding in this area, either the water surface elevations adjacent to at-risk buildings need to be reduced during flood events utilizing engineering measures or at-risk people and property could be relocated outside of the floodplain using buyouts or property acquisition. A water surface elevation reduction could be accomplished using hydrologic alternatives (detention/retention ponds), hydraulic alternatives (underground conveyance, channel improvements, etc.), or a combination of these alternatives. The following Hydrologic and Hydraulic Considerations sections explain in general how the flood risk reduction goal can be achieved based on a hydrologic and hydraulic sensitivity analysis of the models that determines what is the water volume and water surface elevation reduction needed to achieve that goal.

When water surface elevation reduction is not feasible using hydrologic or hydraulic alternatives, buyouts could be utilized to completely remove at-risk buildings and their occupants from the floodplain. When people and buildings are removed from the floodplain, risk is eliminated indefinitely. Many costly buildings are estimated to flood at events as low as the 50% ACE (2-year), therefore mitigating or acquiring all at-risk buildings is difficult. Therefore, a community resilience plan could be implemented to increase standards for new development, incentivize safe reconstruction, inform citizens to increase flood preparedness, and implement better warning systems.

Hydrologic (Stream Flow) Considerations

Hydrology is the science that defines the peak flow along the stream by considering rainfall, terrain, soils, and land use. **Figure 4** is a visual of the combination of these components in the Shoal Creek watershed. For flood mitigation, reductions in the peak flow of Shoal Creek downstream of 15th Street could either be achieved through the in-line or off-line detention of flood flows (peak flows) from the creek. Detention is used to temporarily store flood waters to be released later at a slower rate to reduce peak flows downstream and perhaps alter hydrologic timing to prevent additive impact of tributary peak flows within a watershed.

Due to physical arrangement of Shoal Creek watershed and the project area's location in the watershed, there are no tributaries that provide significant volume or flow of water that could be detained to provide flood risk reduction along the Lower Shoal project area. Therefore, any detention options evaluated were located along the mainstem of the creek. Potential detention options that would be most affective could be located in the project area downstream of 15th Street or located closely upstream.

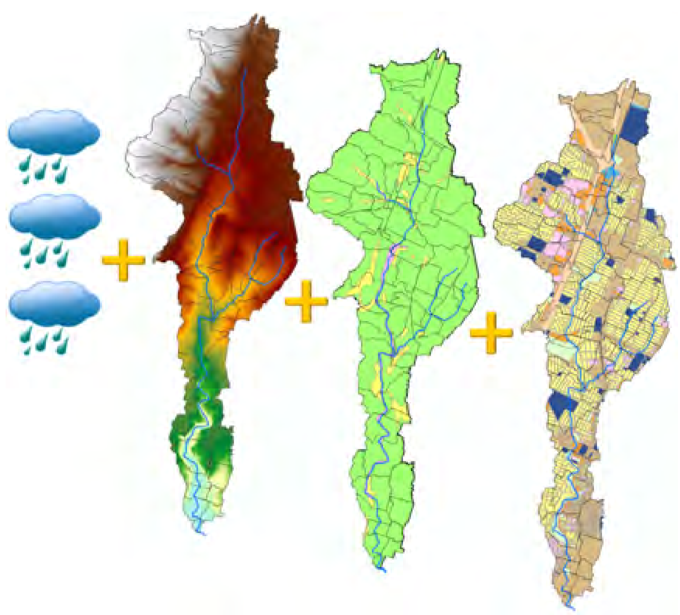


Figure 4: The Science of Hydrology

The storage required to reduce the 1% ACE (100-year) flood down to a 10% ACE (10-year) flood is approximately 2,400 acre-feet. This means if there was a location to store over 2,000 acre-feet in flood volume, the same amount of rain could fall during the 1% ACE, but this area would experience less flooding. So much less that it would be similar to the 10% ACE estimated flood risk. As noted, before on Table 3 that means instead of 61 structures that are estimated to flood during 1% ACE, potentially 36 structures would experience flooding, and there would be less inundated and overtopped roadways.

How large of an area would be needed to store 2,400 acre-feet? Theoretically, that is the equivalent of House Park stadium, 2 acres in area, to the height of four (4) UT Towers, as represented in **Figure 5**. This 2,400 acre-foot volume would still see the 10% ACE (10-year) flood risk impacts. The volume of this flood water in such an urbanized watershed makes it cumbersome to locate enough available area to make any notable flood risk reduction utilizing detention.

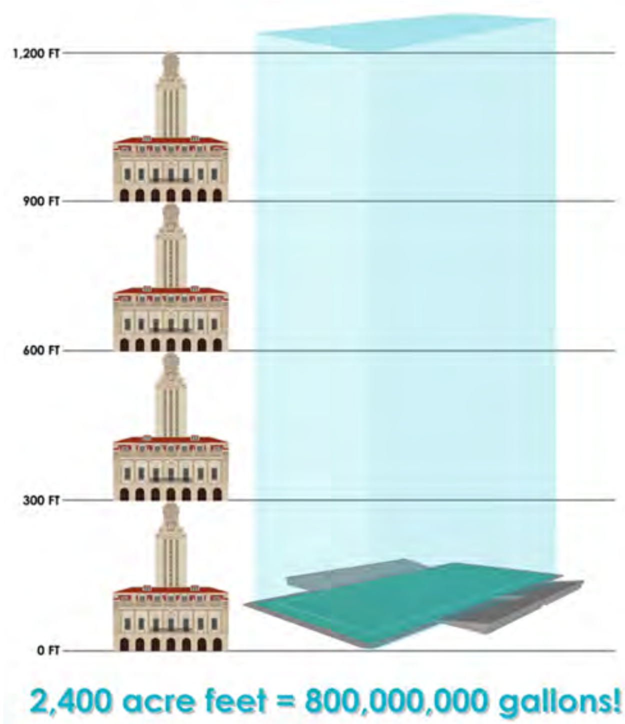


Figure 5: Theoretical Required Storage to Mitigate the 1% ACE to the 10% ACE

Hydraulic (Water Surface Elevation) Considerations

For flood mitigation, reductions in water surface elevation downstream of W 15th Street could be achieved by increasing the flow area or conveyance of the channel within the study area. The flow area required to convey the 1% ACE (100-year) down Shoal Creek would be approximately a 15 feet deep channel with a 100 feet bottom width. The average existing channel width through this section of Shoal Creek is 70 to 90 feet. The channel capacity would need to roughly double to carry the 1% ACE. **Figure 6** shows an example of the existing channel between W 9th Street and W 6th Street, with the theoretical channel expansion in red. Again, since this corridor of Shoal Creek is highly urbanized, there is limited to no open space for such channel expansions on the surface, but partial flow can also be transferred underground.

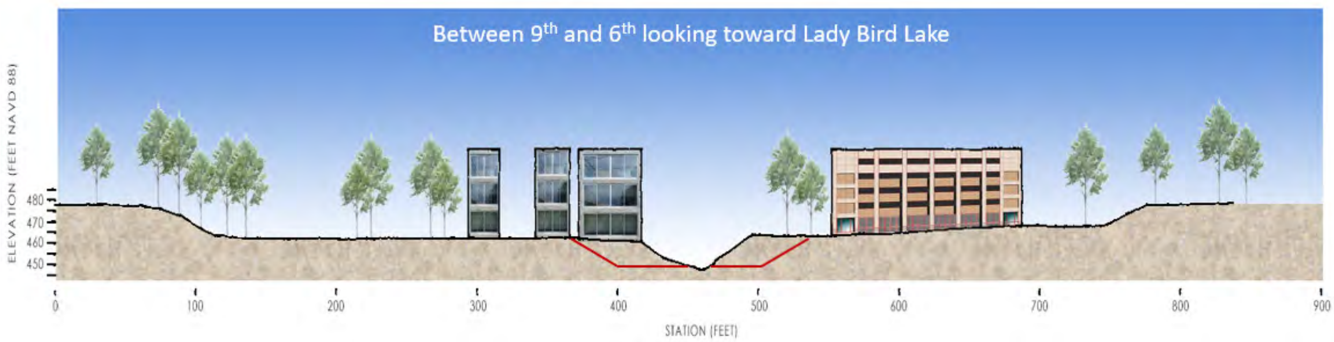


Figure 6: Theoretical Required Channel Size to Mitigate a 1% to a 10% ACE

Comprehensive Flood Risk Reduction Alternatives

Below is a comprehensive list of each flood risk reduction alternative evaluated during this study. The alternatives chosen for evaluation are from stakeholder suggestions or engineer proposals for the best options to reduce flood risk in this area. The alternative analysis was performed to discern flood risk reduction benefits of many different potential projects. Following this analysis, the City held a public meeting on November 13, 2018 to present the results. Using the results from the comprehensive alternatives analysis as well as the results of the comprehensive evaluation criteria scoring, the study team was able to identify alternatives to advance to cost estimation, benefit-cost analysis, secondary evaluation criteria, and eventually recommendation. The advanced alternatives and how they were chosen will be discussed further in the 'Comprehensive Alternatives Scoring Criteria and Results' and 'Advanced Flood Risk Reduction Alternatives' sections.

Enlarging Storm Drain Inlets

Storm drain infrastructure is the first line of defense from localized flooding when rain starts to fall. Enlarging the capacity of storm drain infrastructure could be utilized to reduce flooding in roadways which, as previously stated, is a major issue in the Lower Shoal Creek area. The City of Austin Drainage Criteria Manual states that "street curbs, gutters, inlets and storm drains shall be designed to intercept, contain and transport all runoff from the 25-year frequency storm". However, the storm drains in the study area outfall into Shoal Creek, and the channel does not have capacity to contain all of the 10% ACE (10-year) or 4% ACE (25-year) flow. There are flood depths as high as 8.5 feet along N Lamar Boulevard during the 4% ACE, meaning the water surface elevation in the creek would be above the outfall of the storm drain and possibly even over the storm drain inlets. Therefore, the storm drain would not drain or provide flood reduction benefits during larger flood events like the 10% ACE and 4% ACE. **Figure 7** displays this scenario. Increasing the capacity of storm drain gutter, inlets, or pipes would not provide significant flood reduction benefit for the project area during larger storm events. Additional inlets and pipe capacity are only effective when creek levels are low enough to allow the pipes to drain.

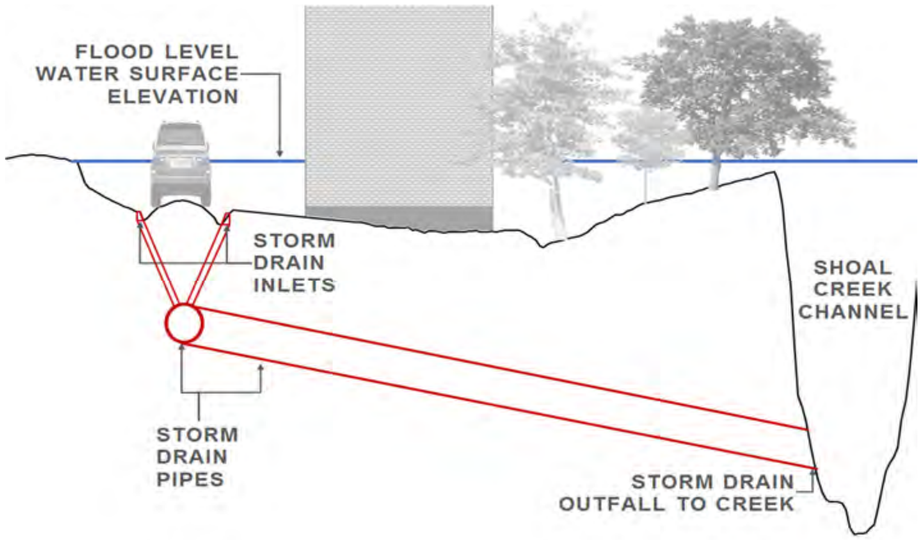


Figure 7: Storm Drain Inlets along Shoal Creek

Green Infrastructure

Green infrastructure encompasses a wide array of practices. Green infrastructure aims to improve the benefits of storm drain infrastructure while also improving the environment and community that surrounds it. City of Austin provided Halff with the 2015 Brentwood Study which assessed the water quality and flood risk reduction benefits of green infrastructure (GI) within the Grover Tributary drainage area, located within the Shoal Creek watershed. This study evaluated implementing green parking lots, green streets, permeable pavement, cisterns, and more. GI is an important aspect of best management practices. The results of the study noted water quality benefits and significant reduction in erosion potential along the drainage channel. Also based on the results of the study, GI has noteworthy flood reduction benefits for smaller rain events; however, GI has limited flood risk reduction benefits for larger rain events such as the 1% ACE. Water quality benefits also become limited with larger rainfall events. Another limitation of GI as a flood risk reduction alternative is that the mitigation benefits of GI are localized to the immediate area where the GI is installed. GI also requires many individual locations of open space for installation. With the rapid population growth in the study area, open space is not readily available.

Please note, Grover Tributary's drainage area is approximately 0.6 square miles, whereas the drainage area to the Lower Shoal Creek project area is approximately 12 square miles. The increase in drainage area expands the range and quantity of GI that would be required to achieve similar mitigation benefits in the Lower Shoal Creek project area as seen in the Brentwood Study along the Grover Tributary. While GI could be a useful best management practice to improve water quality and provide flood risk reduction benefits for small rain events, GI for flood risk reduction of larger rainfall events along Lower Shoal Creek is not viable.

Detention

Hydrologic detention is used to temporarily impound flood waters for later release in order to alter the timing of peak flows to prevent or reduce the additive impact of tributary peak flows within a watershed. The Shoal Creek watershed has several existing large regional detentions ponds, particularly in the upstream portion of the watershed, such as the Far West Pond, Northwest Park Pond, and the UT Pond. When the Shoal Creek hydrologic model is run without these existing detention ponds the 1% ACE peak discharge is 20% higher at 15th Street. This means the existing detention ponds provide significant flood mitigation benefit, therefore additional detention where available was evaluated.

A conceptual-level detention analysis included the identification of several potential new detention pond locations. Potential ponds were located in any open space within the project area or upstream of the project area. Some of these options were modeled utilizing the updated 2D model. Any potential detention ponds were conceptually simulated to maximize the capacity of the available footprint of the pond. One potential detention option included maximizing the capacity of an existing detention pond upstream of the project area. Underground detention was also considered near House Park Stadium. The existing detention ponds in the watershed contain approximately 1,050 acre-feet of storage. As stated previously, the storage required to reduce the 1% ACE (100-year) flood to a 10% ACE (10-year) flood is 2,400 acre-feet. That amount of required storage would require ample open space that is difficult to identify in the urbanized Shoal Creek watershed.

When considering potential detention options, it is important to note the hydrologic simulation typically used to evaluate the proposed detention ponds assumes uniform rainfall across the watershed. Historical evaluation of rainfall over the Shoal Creek watershed indicates that rain typically does not fall uniformly across the watershed. If rain falls primarily downstream of the proposed detention pond, the pond would not be able to store a sufficient quantity of flood waters, and the study area could not see the full anticipated flood mitigation benefits. Therefore, the location of the rainfall within the watershed could have a significant impact on the true effectiveness of any regional detention alternative. Therefore, detention ponds with a shorter distance between the pond and the flood risk area are more ideal. The locations of the potential detention ponds analyzed can be seen in **Figure 8**.

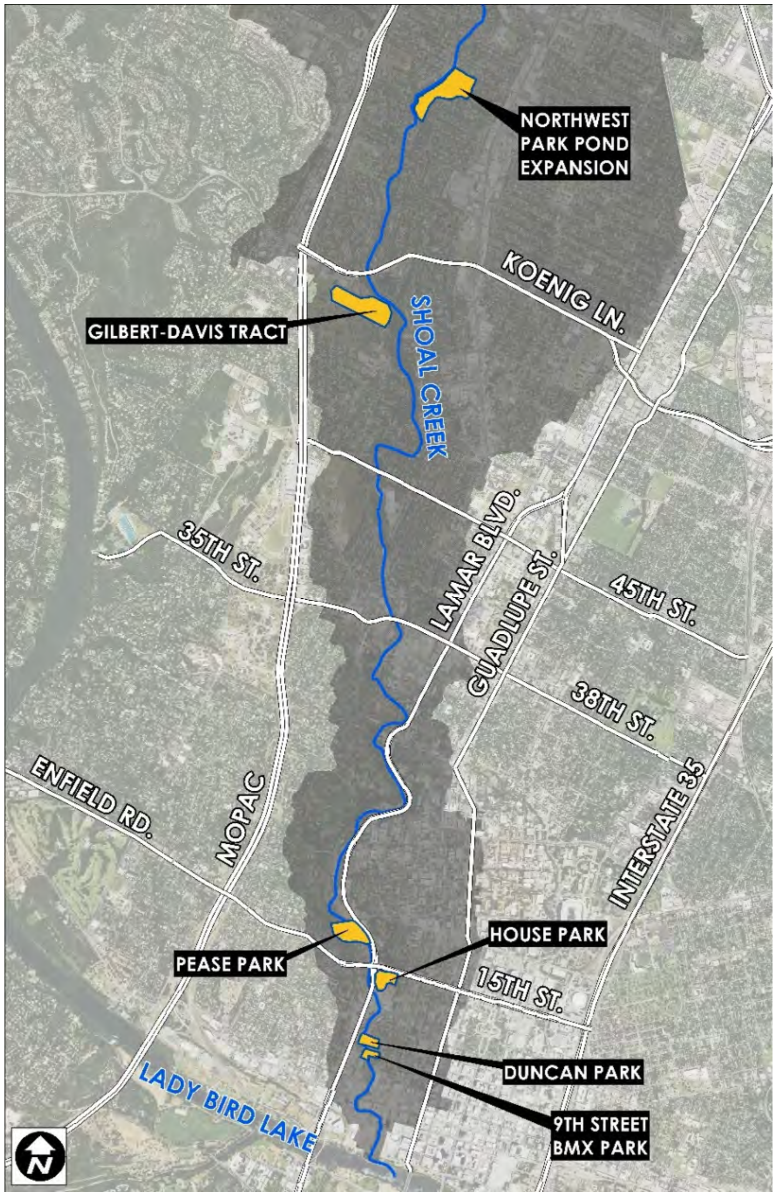


Figure 8: Potential Detention Pond and Pond Expansion Locations

Detention within Study Area

As stated previously, detention located closer to the area of flood risk is ideal. The close proximity increases the effectiveness of the pond and limits the risk of the rain falling downstream of the detention pond, and not allowing it to detain any flood waters. The potential detention pond closest to the project area is the 9th Street BMX Park location. This potential pond has an approximate capacity of 32 acre-feet. This potential detention pond would be an inline pond that would require a downstream weir to use as a control structure to detain water. The dam height would be less than 6 feet and therefore not subject to Texas Commission of Environmental Quality (TCEQ) dam regulations. This detention alternative results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **0.13 feet**. This decrease in water surface elevation is not enough to mitigate any structural inundation.

Similar to the 9th Street BMX Park Pond is the Duncan Neighborhood Park Pond, also an inline pond. The existing W 9th Street bridge could act as a control structure for the outflow of the pond. This simulation assumed excavation in the park area to maximize storage potential. The Duncan Park Pond has an approximate storage capacity of 42 acre-feet.

This detention alternative results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **0.72 feet**, removing **2 structures** from being inundated. Due to the locations of these ponds, they have limited storage capacity and limited flood reduction benefits in the study area. Therefore, these ponds were not further analyzed as viable alternatives.

Detention Upstream of Study Area

Outside of the project area, Halff investigated two new proposed detention ponds, detention in Pease Park and on the Gilbert-Davis Tract. An additional potential detention option included optimizing the existing Northwest Park detention pond.

Pease Park Pond is immediately upstream of the project area, just north of W 15th Street, which could be considered an ideal location for detention because of the considerable amount of open space. However, Pease Park is a historical landmark of the City of Austin and has specific requirements in the original deed which donated the park to the City in 1875. Placing detention within Pease Park would also conflict with future plans for the park that have been outlined in the Pease Park Master Plan. Because of these constraints Pease Park was not further evaluated as a viable detention location.

Approximately 3.5 miles upstream of the project area and just south of Northland Drive is the Gilbert-Davis Tract, adjacent to the Austin Memorial Cemetery. There is approximately 336 acre-feet of potential storage in the open area of this tract. This pond was initially modeled in the 2012 hydrologic model, then the potentially detained flows were simulated through the updated 2D model. This detention alternative results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **0.9 feet**, removing **6 structures** from being inundated. This was the most effective conceptual detention pond that was evaluated.

Maximizing the storage of the existing Northwest Park Pond increases the storage capacity from 246 acre-feet to 350 acre-feet. Northwest Park is approximately 6 miles upstream of W 15th Street. This increase in storage would require reconstruction or removal of several park amenities including the swimming pool, tennis courts, basketball courts, volleyball courts, parking, and water quality ponds. Certain amenities could be relocated at the bottom of the pond; however, this depends on their flood durability and space requirements. The inflow and outfall structure to this pond is more complicated than standard ponds. Expanding of this pond could potentially require redesign and construction of either the inflow or outfall weirs or potentially both. Due to the required loss of the amenities, limited increase in storage capacity, and the potential cost of pond control structure, this expansion of Northwest Pond was not further evaluated as a viable detention alternative.

Underground Detention

Underground detention can be a good alternative when the land is almost fully developed, like the Shoal Creek watershed. However, there are several limitations to underground detention. Construction and materials of underground detention is typically costlier than above ground detention. Just like above ground detention, depth of detention is limited to allow the proposed pond to eventually drain to the adjacent creek without the requirement of pumps. If the depth of detention drops below the invert of the creek where the detained waters would eventually need to drain, then pumping becomes necessary to remove the detained water from the detention structure after the flood event has passed.

Underground detention was considered at House Park. The area available on this property covers approximately 6 acres. This would require that the underground detention basin be a depth of more than 55 feet to detain 336 acre-feet, the same amount of storage as proposed in the Gilbert-Davis Tract detention pond. This depth is seemingly not feasible based on the estimated depth of the water table, elevation of normal pool elevation of Lady Bird Lake, and cost of construction. A typical underground facility is between 5 and 15 feet in depth. This depth does not consider required depth of cover above the underground detention facility or needed grade to drain the potential detention facility between House Park and Lady Bird Lake. A smaller underground detention facility would allow for a more feasible depth; however, this makes the potential detention option less effective for flood risk reduction without significantly decreasing the potential project cost. Due to the limited area and increase cost requirements at the potential pond's location this alternative was not further evaluated as a viable detention alternative.

Channel Modifications

A range of conceptual channel modification alternatives were evaluated to mitigate flooding in the study area. These alternatives include the removal of constrictions, channel clearing, and channel widening in order to reduce the computed 1% ACE water surface elevation. A schematic of each of these alternatives is seen in **Figure 9**. Any downstream adverse impacts or increases in water surface elevation associated with these alternative options would need to be evaluated and mitigated as needed if any of the alternatives mentioned below were recommended for further evaluation. Each mitigation alternative discussed in this section was independently evaluated utilizing the updated 2D Lower Shoal Creek model.

Figure 9: Conceptual Channel Modification Options

Removal of Constrictions/Bridges

Increases in water surface elevation along a creek could be caused by channel constrictions that reduce the flow area of a channel. Typical man-made constrictions include encroachment of the channel due to development and roadway crossings. Modeling shows that increases in water surface elevations within the study area are caused by the W 9th Street bridge, W 6th Street bridge, and the West Avenue bridge. Only the removal of the W 9th Street and West Avenue bridges were analyzed. These constriction locations can be seen in **Figure 9**. The flood mitigation benefit of the removal of each of these constrictions were evaluated and summarized below. Based on the results in the model the water surface elevation reduction from bridge removal remained localized to area where the bridge was removed.

- **W 9th STREET BRIDGE REMOVAL** – This bridge removal results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **1.6 feet** and could potentially protect **2 structures** from being inundated.

- **WEST AVENUE BRIDGE REMOVAL** – This alternative also includes the removal of the pedestrian bridge that parallels the West Avenue bridge. This bridge removal results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **0.6 feet** and could potentially protects **1 structure** from being inundated.

Bridge removal was considered as the most extreme case of opening up the channel constrictions at the bridges. If removal had ceded notable flood risk reduction results, more moderate options could have been pursued, however further analysis was not necessary because even the most extreme option of bridge constriction removal was not worth pursuing further as a flood risk reduction alternative.

Channel Clearing

Reducing friction losses within a channel and the immediate overbanks could be an effective alternative to reduce flood elevations. Friction losses could be reduced by selective clearing of trees, underbrush, and other obstacles from the channel and overbanks. In order to provide a flood mitigation benefit within the study area, channel clearing would require more than simply removing debris and fallen trees along Shoal Creek. This channel clearing alternative would remove all underbrush and small trees in the dense vegetation areas. Channel clearing would have significant environmental impacts and require significant perpetual maintenance and mitigation costs. Clearing the channel also goes against FEMA's initiative, one also shared by the City of Austin, to preserve the natural character and function of creek corridors.

This alternative includes channel clearing of the densest areas of vegetation within the Lower Shoal Creek 1% ACE floodplain between W 15th Street and Lady Bird Lake, approximately 7 acres. The extent of the clearing area is represented in green in **Figure 9**. Channel clearing was simulated in the hydraulic model with decreases in roughness coefficients. Roughness coefficients represent the friction applied to the flow of the channel based on the condition of the creek. Roughness coefficients depend on vegetation, material, and sinuosities of the channel. The post-clearing roughness coefficients were directly correlated to the existing roughness coefficient.

This channel clearing option results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **1.3 feet** and could potentially protect **4 structures** from being inundated. This was the most effective channel modification alternative that was evaluated.

Channel Widening

Similar to constriction removal, channel widening, or benching could be used to increase the flow area (conveyance) of a channel. For the channel widening analysis, the volume of channel widening was maximized in order to estimate the maximum flood mitigation benefits possible from stand-alone channel widening. The extent of the clearing widening area is represented in yellow in **Figure 9**. Due to development close to the channel, space for potential channel widening is limited. Similar to the channel clearing, this alternative would require significant efforts to maintain the "cleared" channel and would negatively impact the riparian corridor along Shoal Creek, negatively effecting water quality, creek stability, wildlife, and trees. Similar to channel clearing, channel widening would require removal of vegetation with roots systems that help stabilize the existing Shoal Creek channel banks. Removal of this vegetation could cause instabilities along the bank and within the channel causing more erosion along the creek. Similar to any other mitigation alternative, any negative downstream impacts would have to be mitigated and prevented should the alternative be recommended for further evaluation. This channel widening option results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **1.7 feet** and could potentially protect **1 structure** from being inundated.

Underground Bypass

A bypass or diversion of flood water could, in some cases, be constructed to more efficiently convey flood waters than the existing channel alone could convey by adding an additional channel across the neck of a bend or parallel to an existing creek. Many Texas cities such as San Antonio, Dallas, Lubbock, and other areas in Austin are using bypass systems in urbanized areas to reduce their local and riverine flooding. In the Lower Shoal Creek area however, there is no undeveloped space for a bypass above ground, therefore only an underground bypass was evaluated. Several options of intakes, alignments, and outfalls were considered. The conceptual underground bypass options considered, including all intake and outfall locations, are shown in **Figure 10**.

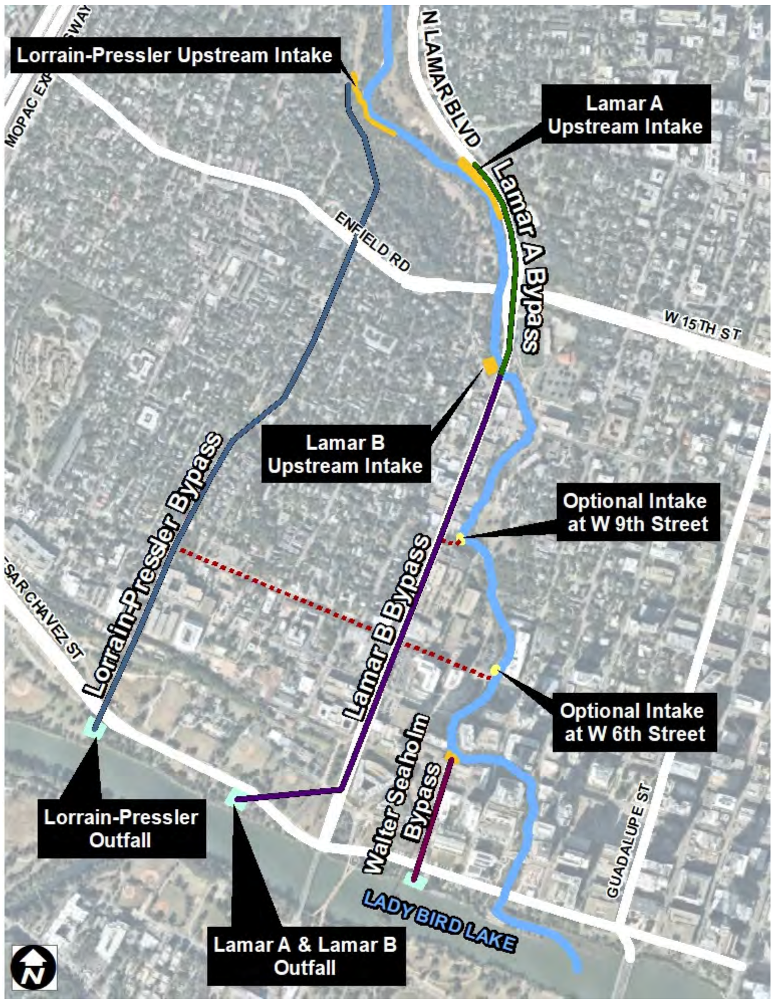


Figure 10: Conceptual Underground Bypass Options

The proposed intake structure would be located at the upstream end along the bypass where water could be diverted from the creek and should be able to enter into the bypass trunk line. Additional intake structures could be added at interim locations along the bypass for additional flood risk reduction. The goal of the intake structure is to divert a significant amount of flood water from the creek to the bypass to reduce flood levels while being non-intrusive to the creek corridor. Placing the upstream intake upstream of the study area and north of 15th Street would provide the greatest flood risk reduction benefits. Like detention ponds, if the intake structure is located closer to the study area, flood risk reduction would be optimized. These intake locations were generally placed at bends in Shoal Creek to allow water to more efficiently enter the bypass laterally. Four intake locations were investigated with two additional optional inlets that would connect to the trunk line by lateral pipes. These intake structure locations, seen in **Figure 10,** are conceptual and would be refined and possibly relocated should an underground bypass alternative be recommended for further evaluation.

Because Lower Shoal Creek has several parks as well as hike and bike trails along the stream bank, the landscape and habitat of the creek is important to maintain. In order to reduce environmental impact to the creek the invert elevations of the intake structures were simulated at or near the 50% ACE (2-year) water surface elevation. Typical flow and smaller flood events would remain in the creek while diverting larger floods underground. Preserving regular creek flow would help maintain Shoal Creek's ecosystem and eliminate the need for a pump system to recirculate flow, which would be necessary if the concept was to capture all stream flow at the intake. A pump system could still be necessary to dewater for maintenance; however, a pump would not be required to dewater after every storm or for circulation. A significant amount of sediment is not expected to enter the bypass if the intake is elevated above normal flow. Without the additional sediment and contaminants, stale water should not be a significant issue.

The four proposed upstream intake locations led to three distinct horizontal alignment options for the underground bypass noted as Lamar A and B, Lorrain-Pressler, and Walter-Seaholm. The horizontal alignments of the underground bypass options were aligned based on the shortest distance to the outfall in order to minimize potential cost of the alternative. Horizontal alignments were also kept underneath roadways to reduce impact to adjacent properties. Staying within existing right-of-way boundaries also eliminates the need for easement acquisition for implementation of the bypass options. The outfall was conceptually designed as an inverted siphon. The outfall was placed on City of Austin park property near Lady Bird Lake.

This is not the first time a bypass or tunnel has been evaluated for flood risk reduction along Shoal Creek. During the USACE study in 1991 thirteen (13) different tunnel options were evaluated which stretched for 1 to 3 miles, varying in diameters between 14 feet to 23 feet. **Figure 11** displays the alignments that were evaluated in the 1991 USACE study. Most of the 1991 USACE tunnel options were too far upstream to make a significant impact in the current study's project area, but the 1991 USACE 19th Street Tunnel was updated to the Lorrain-Pressler Bypass option for this new study. It should be noted, each of the three variations of the 19th St. Tunnel simulated in 1991 had a benefit-cost ratio of one. Two of the three variations of the 24th St. Tunnel also had a benefit-cost ratio of one.

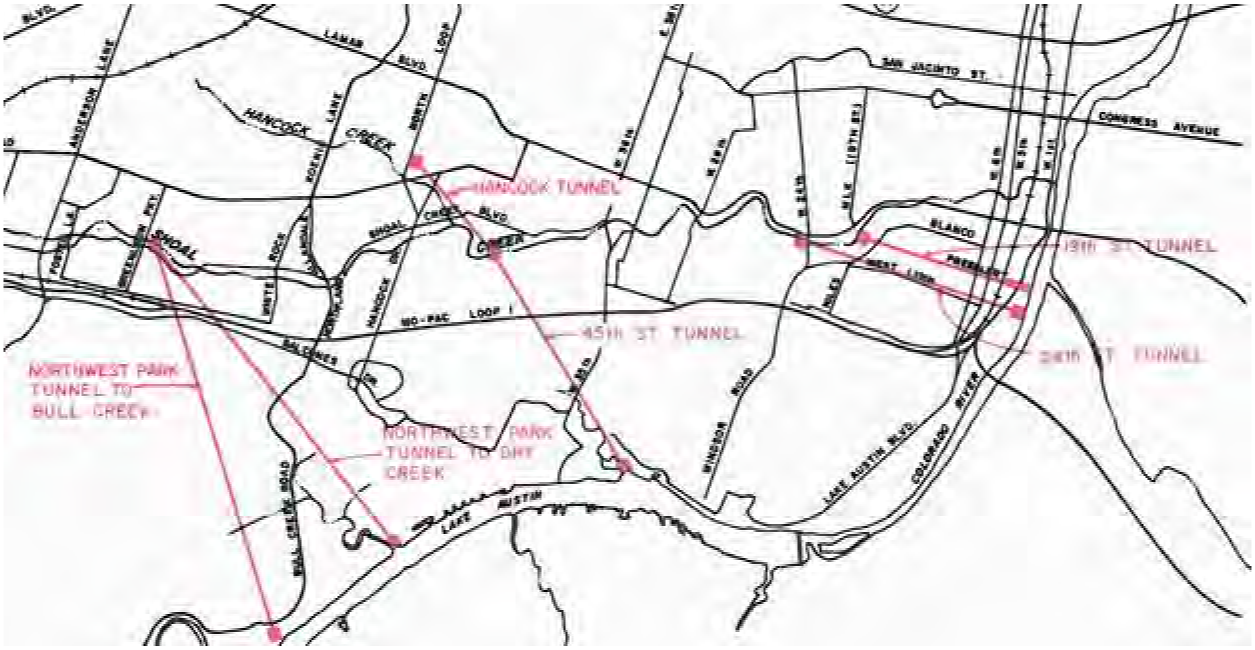


Figure 11: 1991 USACE Study Tunnel Alignments

Various combinations of inlets and iterations of size were investigated along the four alignments in this study. Every time the capacity or number of intake structures is changed in a configuration, the size of the bypass pipe must change to compensate for the additional flow being diverted. More flow diverted into the bypass pipes demands larger pipe sizes and vice versa. The range of sizes and lengths simulated for each alignment is summarized in **Table 4** below.

Table 4: Comprehensive Underground Bypass Dimensions

Bypass Option	Length	Diameter	Intakes
Lamar A	6,630 – 7,970 feet	11' – 28'	1 – 3 Intakes
Lamar B	4,850 – 5,030 feet	11' – 13'	1 – 2 Intakes
Lorrain-Pressler	6,440 – 9,550 feet	22' – 26'	1 – 2 Intakes
Walter Seaholm	1,200 feet	N/A	1 Intake

The optimal or best bypass configuration for each alignment which simulated the maximum reduction of 1% ACE peak water surface elevation within the study area are summarized below.

- The best Lamar A Bypass alignment results in a maximum reduction of 1% ACE peak water surface elevation within the study area of more than **7 feet** and could potentially protect **30 structures** from being inundated.
- The best Lamar B Bypass alignment results in a maximum reduction of 1% ACE peak water surface elevation within the study area of a **1.5 feet** reduction and potentially **7 protected structures**.
- The best Lorrain-Pressler Bypass alignment results in a maximum reduction of 1% ACE peak water surface elevation within the study area of **3 feet** reduction and potentially **12 protected structures**.
- The Walter-Seaholm Bypass resulted in no flood risk reduction and was not evaluated further.

Underground bypass is a large-scale risk reduction alternative, even the smallest of which would have long construction times and implementation costs. It could, however, provide significant flood risk reduction results. This conceptual structural alternative proved to have the most flood risk reduction potential. Therefore, several bypass options with varying levels of service were further evaluated in the advanced alternatives analysis. The balance of these costs and benefits of an underground bypass option is further investigated in the following “Advanced Flood Risk Reduction Alternatives” section of this report.

Buyouts

Non-structural flood mitigation alternatives generally include floodplain management, construction and design regulations, and property buyouts. Property acquisition is often the most effective means of improving public safety and reducing flood damages in previously developed floodplain areas. When people and structures are removed from the floodplain, risk is eliminated permanently. Buyouts would have the least environmental impact to the riparian corridor because it requires no clearing or modifications within the channel. Buyouts also have the benefit of being able to be implemented as funding becomes available, whereas structural projects would require all of the funding to be in place prior to implementation.

As mentioned, there are 61 properties that are estimated to experience structural flooding during the 1% ACE (100-year). As stated previously, structural flooding is defined as when the water surface elevation exceeds the FFE. Approximately 77% are some type of commercial property including storefronts, restaurants, offices, and more. The price of real estate in the downtown Austin area is ever increasing and that includes the properties within the Lower Shoal Creek 1% ACE floodplain. The sum of the Travis County Appraisal District (TCAD) appraised property values for the impacted properties comes to approximately $310 million. This total does not account for the anticipated sales price of those properties and is missing appraisal values for several properties with missing data in TCAD. This total also did not include the additional costs associated with real estate services, appraisals, closing costs, relocation and moving expenses, asbestos testing and abatement, demolition, and property management. Because of these constraints a buyout program for all properties within the 1% ACE (100-year) floodplain is unlikely, therefore a smaller buyout program was considered as an alternative.

The buyout option assessed in this study is for 16 of the 61 properties that experience structural flooding during the 1% ACE (100-year) event. These 16 properties are high risk structures between Shoal Creek Boulevard and 9th Street. The preliminary estimate of cost is approximately $45 million as estimated by the City’s Office of Real Estate Services. Those properties that were included in this alternative can be seen on a map in **Figure 12**. Although this buyout option results in the protection of **16 structures** from being inundated, this option would not reduce risk to roadways or other properties along the Lower Shoal Creek corridor.

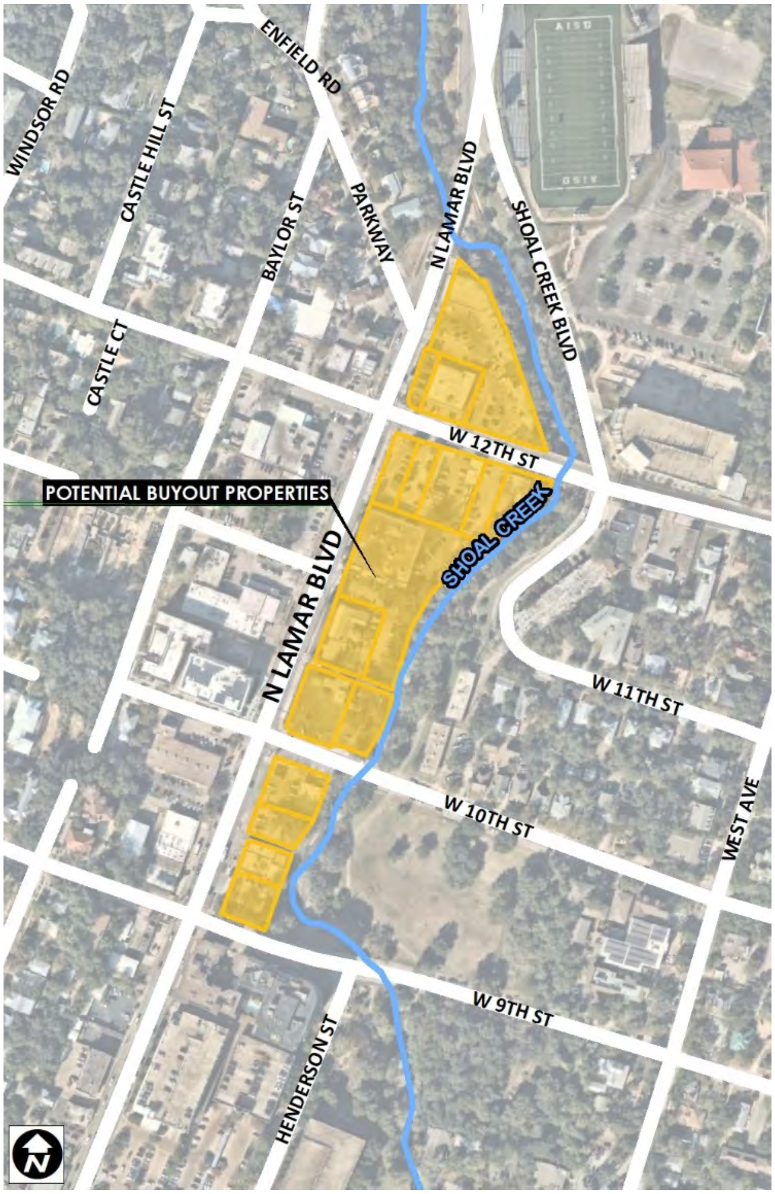


Figure 12: Potential Buyouts Area

Community Resilience

Many people, high-value buildings, and high-traffic roadways are projected to flood at events as low as the 50% ACE (2-year). Consequently, it is not cost efficient to mitigate or acquire all at-risk buildings. In these cases, it may be more cost effective and prudent to evaluate opportunities for improving the resilience of individual buildings, structures, and roadways in the area. In this regard, a community resilience plan could be implemented to increase standards to enforce risk reduction for new development, incentivize safe redevelopment and retrofits, inform citizens to increase flood preparedness, and implement better warning systems. **Figure 13** is a simplified infographic that summarizes what a community resilience plan could include and separates the potential plan into four components. The four components include:

Figure 13: Community Resilience

- **FLOOD RESILIENCE** – This component could identify opportunities for increasing standards for new development in the Lower Shoal Creek area by requiring buildings to have a flood response plan, similar to how most buildings are required to have a fire escape plan. This could also include identification of design improvements to reduce damage when flooding occurs (e.g., flood gates like many buildings already have in the Lower Shoal Creek area).
- **REDEVELOPMENT** – This component could identify opportunities for the City to incentivize redevelopment or retrofits to existing structures which improves the building's capacity to respond to various flood events. In these cases, things like access and critical infrastructure are elevated above the 1% ACE (100-yr) water surface elevation and are combined with other design improvements to improve the building's capacity to accommodate a flood and reopen quicker after a flood.
- **PEOPLE** – This component could identify opportunities for the City to host informational and training sessions for people and property owners in the Lower Shoal Creek area on how to better prepare for high potential flooding, remain safe during floods, and decrease turnaround time for businesses after floods.
- **ACCESS** – This component could identify opportunities for improving control of access into Lower Shoal Creek area (e.g., installing flood gates at access points to roadways that consistently flood) and to provide better warning signage and notification.

Improving community resilience is a topic that is increasingly being evaluated as a viable path for moving forward. Lower Shoal Creek, similar to many already developed areas which experience frequent flood events, is an area where full flood mitigation is not financially feasible. As such, some combination of mitigation and improved resilience may be the most viable option for moving forward. These plans typically involve many moving parts and these potential ideas may involve individuals, groups, or entities beyond the City of Austin.

Combined Alternatives

Limited combined alternatives were evaluated for two main reasons, one being, several of the conceptual alternatives provided minimal potential flood risk reduction benefits, for example the detention and channel modification options. In many cases these potential alternatives protect the same structures and roadways. Therefore, when combined the flood risk reduction potential would not increase or would only increase minimally. The second reason more combinations of alternatives, specifically bypass options, were not considered is due to the anticipated cost of each alternative. Only one conceptual underground bypass option was considered at a time, there were no combinations assessed with more than one bypass option. More information regarding the estimated cost of the underground bypass alternatives can be found in "Advanced Flood Risk Reduction Alternatives" section.

Comprehensive Alternatives Scoring Criteria & Results

Using the results from this comprehensive analysis, the study team developed scoring criteria to select alternatives to advance to cost estimation, benefit-cost analysis, secondary evaluation criteria, and eventually recommendation. The comprehensive flood risk reduction alternative analysis was performed to evaluate flood risk reduction benefits of many different potential projects. Following that analysis, the City held a public meeting on November 13, 2018 to present results.

Each of the comprehensive alternatives were evaluated and compared based on a set project scoring criterion. However, many of the comprehensive flood risk reduction alternatives had multiple scenarios which were evaluated individually; 6 scenarios for detention were evaluated, more than 3 for channel modifications, and 8 for underground bypass. To simplify the comprehensive evaluation criteria, only the highest performing scenario of each of these comprehensive alternatives were included in the evaluation. Because the potential flood risk reduction was estimated to be exceedingly low or ineffective for enlarging storm drain inlets and green infrastructure, these alternatives were not included in the comprehensive evaluation criteria. Combined alternatives were also not included in the comprehensive evaluation criteria, because the potential costs were estimated to be exceedingly high compared to the other alternatives with limited additional flood risk reduction benefit.

The scoring criteria cover a wide range of issues and were established based on a review of prioritization approaches used previously by the City of Austin and methods used by other municipalities and agencies. The selected criteria balance a broad range of considerations. The project scoring criteria act as a decision-making tool. By creating and utilizing a multi-attribute decision making tool, stakeholders are able to discern which alternative should have priority for implementation in order to help overall public safety objectives amidst increased community exposure to flood emergencies. Please note the comprehensive scoring criteria did not take into account the cost effectiveness because cost estimates were not yet available at this stage of the study. Cost effectiveness was taken into account in the secondary scoring criteria for the advanced alternatives. The comprehensive flood risk reduction alternatives were given a score, 1 through 5, for each criterion. The score of 1 through 5 represents the level at which the project meets the criteria, where 5 is the best and 1 is the worst. Therefore, the higher the score of the alternative the more superior the project is for that criteria. There are seven different criteria:

- **STRUCTURAL FLOOD RISK REDUCTION** – Accounts for the amount of buildings mitigated from structural flooding for the 1% ACE. Structural flooding occurs when the water surface elevation is estimated above the finished floor elevation.
- **MOBILITY FLOOD RISK REDUCTION** – Considers the amounted of restricted drivers during the time that the 1% ACE inundates roadways, based on TxDOT average daily traffic counts. This is important to consider for emergency access and social impact.
- **LENGTH OF INUNDATED ROADWAY** – Length of inundated roadway reduced from existing to proposed condition for the 1% ACE. This is important to consider for public safety and emergency access.
- **ENVIRONMENTAL IMPACT** – The estimate of environmental impact is generally based on whether the environmental impact would be moderate or significant, and if the impact would be short-term or long-term. The environmental impact considers the impact to Critical Environmental Features, water quality such as Critical Water Quality Zones and Water Quality Transition Zones, creek stability and Erosion Hazard Zones, wildlife, and trees. Through evaluation of the alternatives, it was found that some alternatives may only be an impacted during construction such as buyouts while other alternatives could result in a long-term impact such as the channel clearing alternative.
- **LAND & EASEMENT ACQUISITION REQUIRED** – This criterion takes into account the land or easement acquisition required for the flood mitigation alternative to be implemented where the City of Austin does not

currently own easement or property in the potential project area. This criterion considers the type (easement or land purchase) and amount (minimal or significant) of property required for implementation of each mitigation alternative.

- **PUBLIC INPUT** – The neighborhood survey results from the public meeting on March 9, 2017 and public input from both public meetings were considered in this criterion. Several questions were asked through the public survey to gain input regarding the neighborhood's most favorable and least favorable flood mitigation alternative project, as well as most important and least important project constraint. Approximately 40 citizens participated in the public survey.
- **TIME OF IMPLEMENTATION** – Time of Implementation criterion considers the time it takes to design, permit, and construct each project. This criterion did not include the time to obtain funding. In coordination with the City of Austin, timeline estimates were established for each alternative. These timeline estimates would be refined should any of the projects be recommended for further evaluation.
- **FUNDING CONSTRAINTS** – This criterion is based on what could be the project's funding source and the estimated time required to obtain funding. This criterion considers the alternative's potential to be implemented as funding is available. Through evaluation of the alternatives, it was found that some alternatives could be implemented as funding becomes available, such as buyouts, while other alternatives require full funding prior to beginning construction, such as the Lamar A Underground Bypass.
- **COMPLEXITY OF PERMITTING** – This criterion is based on what permits would be required for the proposed flood mitigation projects and what is the difficulty in obtaining those permits due to other entities' involvement. Project permitting could have a major impact on the timeline and associated costs of design and construction. Through evaluation of the alternatives, it was found that some alternatives may be implemented using only local permits such as buyouts while other alternatives require multiple jurisdiction, state and federal permits such as one of Lamar A Underground Bypass.

The results of the evaluation criteria are summarized in **Table 5**. The full results and scoring can be found in **Appendix D**. Based on the results, the community resilience plan received the highest score followed by the Lamar A Underground Bypass 4 and Buyouts. Channel Clearing and Detention received significantly lower scores.

Table 5: Comprehensive Evaluation Criteria Results

Description	Score	Rank
COMMUNITY RESILIENCE PLAN	340	1
BYPASS Lamar A Bypass 4	325	2
BUYOUTS	320	3
CHANNEL MODIFICATION Channel Clearing	245	4
DETENTION Gilbert Davis Tract	205	5

The goal of this alternatives analysis is to identify alternatives that would reduce the flood risk of the 1% ACE (100-year) through the Shoal Creek corridor downstream of W 15th Street. Because the channel modifications and detention options have insignificant to no flood risk reduction and/or low feasibility, no detention options or channel modification options were included in the advanced alternatives. The cost of property is very high in the downtown Austin project area. Also, most of the properties potentially inundated are commercial and, therefore, even more expensive to purchase. For these reasons a buyout option was also not included in the advanced alternatives. The community resilience plan is a unique concept. This type of plan could include many different components. Without defining in advance, the specific implementation measures that would be utilized it would be difficult to predict the flood risk reduction benefit or estimate project cost. This option will need to be further evaluated by the City and was subsequently not included in the advanced alternatives. Therefore, in the advanced alternatives eight (8) underground bypass options with varying levels of service were evaluated in greater detail to better assess the cost and feasibility of an underground bypass option in Lower Shoal Creek.

Advanced Flood Risk Reduction Alternatives

Based on the results of the Comprehensive Flood Risk Reduction Scoring Criteria, several potential underground bypass alignments were further evaluated in what is the called the Advanced Flood Risk Reduction Alternatives. The various potential bypass alternatives were categorized into three different conceptual horizontal alignments and upstream intake locations seen in **Figure 14**. The eight (8) underground bypass options follow one of the three horizontal alignments however they vary in the potential number of additional intakes, trunk line dimensions, and upstream intake size. Two alignments, Lamar A and B, run different lengths along Lamar Boulevard; one conceptual bypass option begins just upstream of 15th Street and the other one begins at Parkway, both would follow Lamar Boulevard past 3rd Street before turning west to outfall near Lady Bird Lake. The Lorrain-Pressler alignment conceptually starts further upstream than the Lamar A and B alignments at another bend in Shoal Creek and runs parallel west of Lamar Boulevard along Lorrain Street and Pressler Street before out falling into Lady Bird Lake. These alignments can be seen in **Figure 14**.

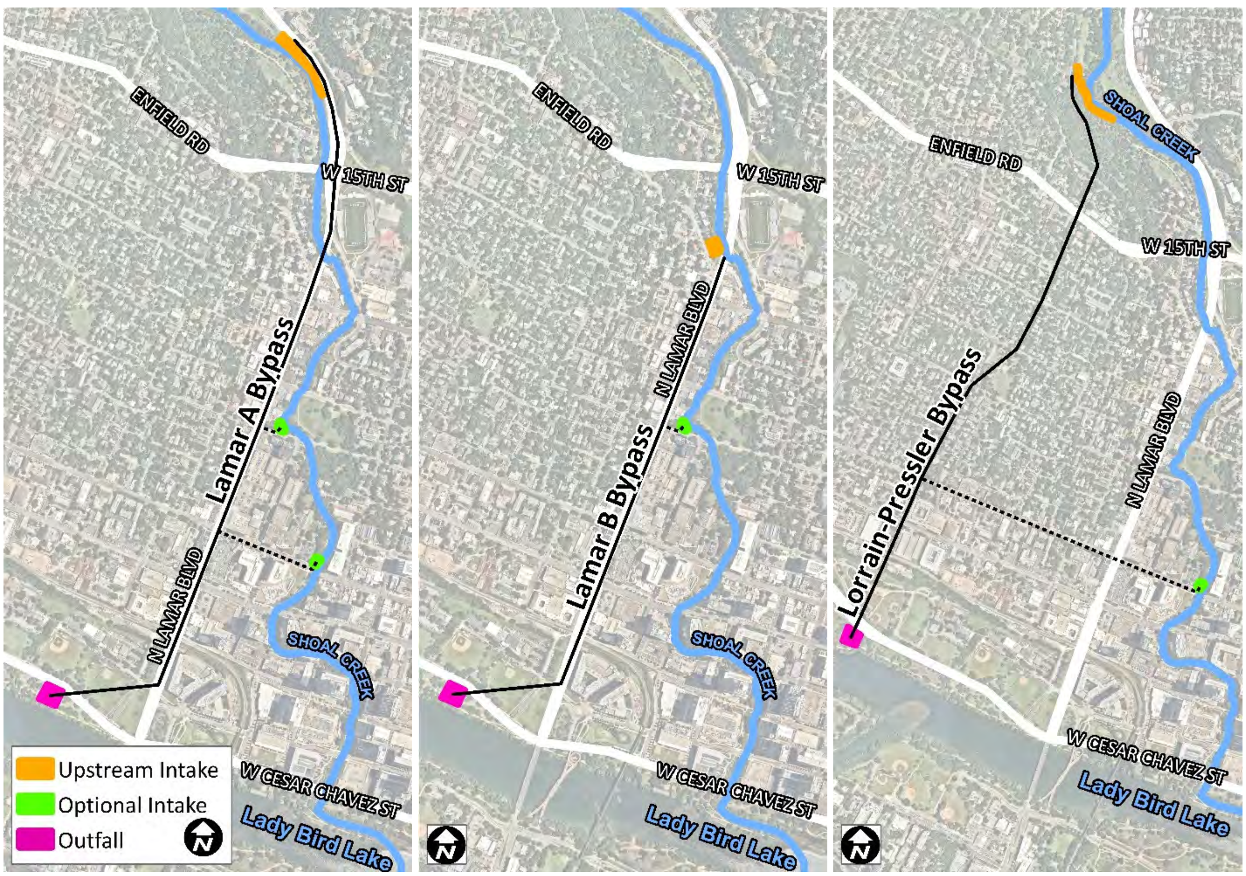


Figure 14: Advanced Underground Bypass Options

Four variations of Lamar A Bypass were simulated. Lamar A Bypass 1 has a smaller upstream intake and a smaller diameter, with no additional intakes along the bypass. Lamar A Bypass 2 has a larger upstream intake than Lamar A Bypass 1, a larger diameter, with no additional intakes along the bypass. Lamar A Bypass 3 still has the upstream intake, a larger diameter, with one additional intake along the bypass. Lamar A Bypass 4 is the largest bypass option simulated with the largest intake area, the largest diameters, and two additional intakes along the bypass. Two versions of Lamar B and Lorrain-Pressler were simulated. One with just the upstream intake and a second with an additional intake along the bypass. The details of the bypass option names and dimensions are summarized in **Table 6**. Highlights of these alternatives are displayed in the alternative fact sheets located in **Appendix E**. The three major design components of the underground bypass flood risk reduction alternative that were considered in this feasibility analysis are the intake size and location, the trunk line's vertical and horizontal alignment and size, and the outfall configuration and location.

Table 6: Advanced Underground Bypass Trunk Line Dimensions

Bypass Option	Length	Diameter	Intakes
Lamar A Bypass 1	6,630 feet	11'	1 Upstream
Lamar A Bypass 2	6,840 feet	22'	1 Upstream
Lamar A Bypass 3	7,020 feet	22' – 23'	1 Upstream 1 additional at 9th St
Lamar A Bypass 4	7,970 feet	26' – 28'	1 Upstream 2 additional at 6th & 9th St
Lamar B Bypass 1	4,850 feet	11'	1 Upstream
Lamar B Bypass 2	5,030 feet	11' – 13'	1 Upstream 1 additional at 9th St
Lorrain-Pressler Bypass 1	6,440 feet	22'	1 Upstream
Lorrain-Pressler Bypass 2	9,550 feet	22' – 26'	1 Upstream 1 additional at 6th St

Intake

As mentioned previously, because Lower Shoal Creek has several parks as well as hike and bike trails along the stream bank, the landscape and habitat of the creek is important to maintain. In order to reduce environmental impact to the creek the invert elevations of the intake structures were place at or near the 50% ACE (2-year) water surface elevation. Typical flow and smaller flood events could remain in the creek while diverting larger floods underground. Preserving regular creek flow could help maintain Shoal Creek's ecosystem. **Figure 15** is a conceptual graphic of what the intake structures could look like, keeping the elevation of the intake higher than typical stream flow and that of the smaller flooding events. These intake structure locations are conceptual and would be refined and possibly relocated should an underground bypass alternative be recommended for further evaluation.

Figure 15: Conceptual Intake Structure Schematic

In order to divert enough flow into the bypass, the intake structure was lengthened as necessary to increase the capacity of the intake while remaining above the normal flow of the creek. Depending on the bypass' level of service and diameter, the required size of the intake varied. The conceptual depths and lengths of the intakes are displayed in **Table 7**. The Lamar A upstream intake location was simulated upstream of 15th Street in between N Lamar Boulevard and Shoal Creek. This intake was placed at a bend in Shoal Creek to allow flow to laterally enter the bypass more efficiently. This conceptual intake is located on Pease Park property outside of the portion of land originally given to the City in the Pease Park Deed dated 1875. Since several options of Lamar A were simulated with varying sizes the intake length and depth varied. The intake invert elevation remained above the 50% ACE (2-year) water surface elevation. However, for Lamar A Bypass 4 the intake invert elevation was lowered just below the 50% ACE (2-year) water surface elevation to utilize the entire capacity of the bypass and provide an alternative that lowered the 1% ACE flood risk to the 10% ACE (10-year) flood risk.

The Lamar B upstream intake is located on the south side of the N Lamar Blvd over Shoal Creek. Unfortunately, this intake location would require property acquisition of two properties. Since the space is limited in this location instead of lengthening the intake length and requiring more property acquisition, the depth of the intake was lowered.

The Lorrain-Pressler Bypass upstream intake is located the furthest upstream. This intake is also located at bend in Shoal Creek. Based on the model results, the depth of water was shallower, and the velocity was faster in the bend therefore water was not diverted as efficiently into this intake. Therefore, the lengths are longer than the Lamar A upstream intake to allow more area to divert water into the bypass.

Only the flow that comes from the area that drains upstream of the main intake where the bypass begins can be diverted to the bypass, therefore additional intakes were simulated at 9th Street and 6th Street. These additional intakes allow the drainage that flows to Shoal Creek downstream of the main intake to also enter and be diverted by the bypass. This increases the amount of water that is sent to the bypass and therefore potentially increases the flood risk reduction benefit. These locations were chosen for additional intakes based on their proximity to the flood risk areas. However, space is limited in these areas for intake structures. Since space is limited, instead of lengthening the intake length and requiring more property acquisition, the depth of the intake was lowered.

Table 7: Advanced Underground Bypass Intake Conceptual Dimensions

Upstream Intakes	Length along Stream	Depth from Top of Bank
Lamar A Bypass 1	460 feet	2.3 feet
Lamar A Bypass 2	690 feet	2.2 feet
Lamar A Bypass 3	690 feet	2.2 feet
Lamar A Bypass 4	690 feet	6.7 feet
Lamar B Bypass 1	110 feet	11.7 feet
Lamar B Bypass 2	110 feet	11.7 feet
Lorrain-Pressler Bypass 1	750 feet	21.5 feet
Lorrain-Pressler Bypass 2	750 feet	21.5 feet
Additional Intakes		
6th Street	77 feet	14 feet
9th Street	65 feet	10 feet

Vertical Alignment

The vertical alignment and depth of the bypass options depends on the soil conditions along the horizonal alignment as well as the required depth of cover. For all alignments, the area near W Cesar Chavez has ground elevation requiring a minimum depth of cover. This is a high-level analysis, therefore only geotechnical information gathered from previous studies and construction projects was utilized. The optimal soil material for tunneling in this location is limestone. Based on the geotechnical data from the 1991 USACE study along the Lorrain-Pressler Bypass the Georgetown FM Limestone and Marly Limestone is between elevations 400 and 480 feet. Utilizing this data, invert elevations of the conceptual alignments were set. The vertical slope was kept near 0.1% to prevent erosive velocities and to remain within the limestone material. An example of the conceptual vertical alignment for the Lamar A Bypass 2 option is displayed in **Figure 16**Error! Reference source not found.. Because the lowest ground elevation is near the outfall, the conceptual outfall was simulated as an inverted siphon. The outfall elevation was assumed to be above the normal pooling elevation of Lady Bird Lake. The normal pool elevation of Lady Bird Lake was assumed to be 428.3 feet as defined in the Colorado River Flood Damage Evaluation Project in 2002. This was a part of the Lower Colorado River Authority's (LCRA) Colorado River Flood Damage Evaluation Study to develop new hydrologic and hydraulic analyses of the Colorado River from the Highland Lakes to the Gulf of Mexico. This elevation also matches real time elevation data from the Lower Colorado River Authority along Lady Bird Lake. The conceptual profiles for all advanced underground bypass options can be found in **Appendix F**.

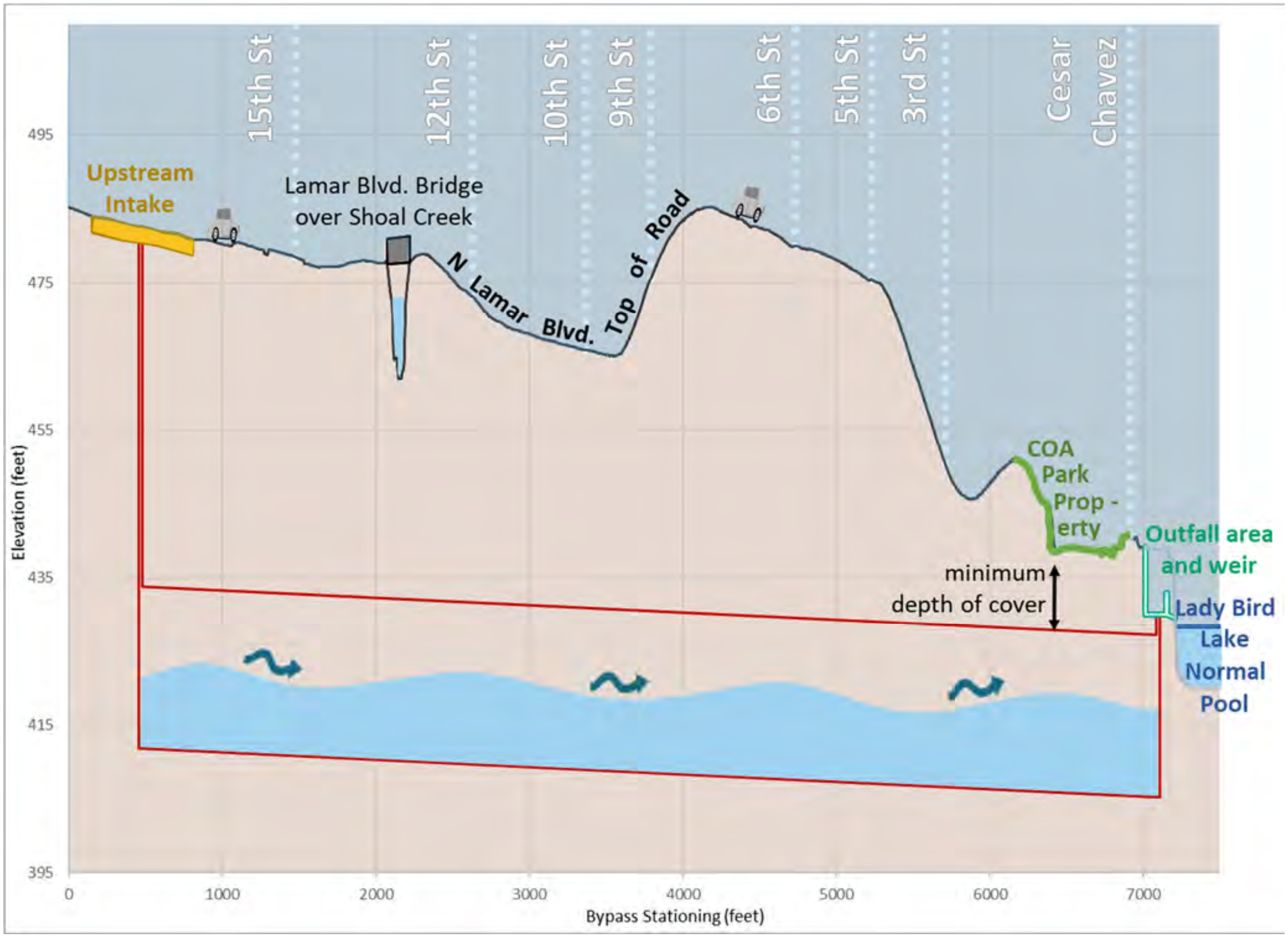


Figure 16: Conceptual Lamar A Bypass 2 Profile

Outfall Structure

The conceptual outfall locations can be seen in **Figure 14**. These were placed on City of Austin property to prevent the need for easement or property acquisition. Lamar A and B bypass options are proposed to outfall in the same location. The Lorrain-Pressler alignment outfalls further upstream along the Lady Bird Lake. Both outfall locations are on the south side of Cesar Chavez Street in Lamar Beach Metro Park. At the outfall there would be a small pond-like area where the inverted siphon would allow flow to exit the bypass. An inverted siphon refers to the vertical profile of the bypass at the outfall. Instead of flowing down slope, the flow of water upstream generates pressure which pushes water out of a vertical pipe. In the proposed outlet configuration, the top of the proposed inverted siphon where the water should exit would be elevated above the normal pool elevations of Lady Bird Lake, therefore lake water will not be able enter the proposed bypass. As stated previously, a pump would not be required to dewater after every storm or for circulation. Significant amount of sediment is not expected to enter the bypass if the bypass as an elevated intake above normal flow. Without the additional sediment and contaminants, stale water should not be a significant issue. However, a pump system would still be necessary to dewater for maintenance. This outlet structure would allow for energy dissipation of the bypass flow before entering Lady Bird Lake in order to reduce potential for erosion or other adverse impacts. From the bypass outfall pond, flow into Lady Bird Lake would be controlled by a weir. A conceptual display of the outfall of Lamar A and B is in **Figure 17**. The outfall structure would require approximately 0.5 acres of the park property once in place. Just like the intake structures these outfall locations are conceptual and would be refined should an underground bypass alternative be recommended for further evaluation.

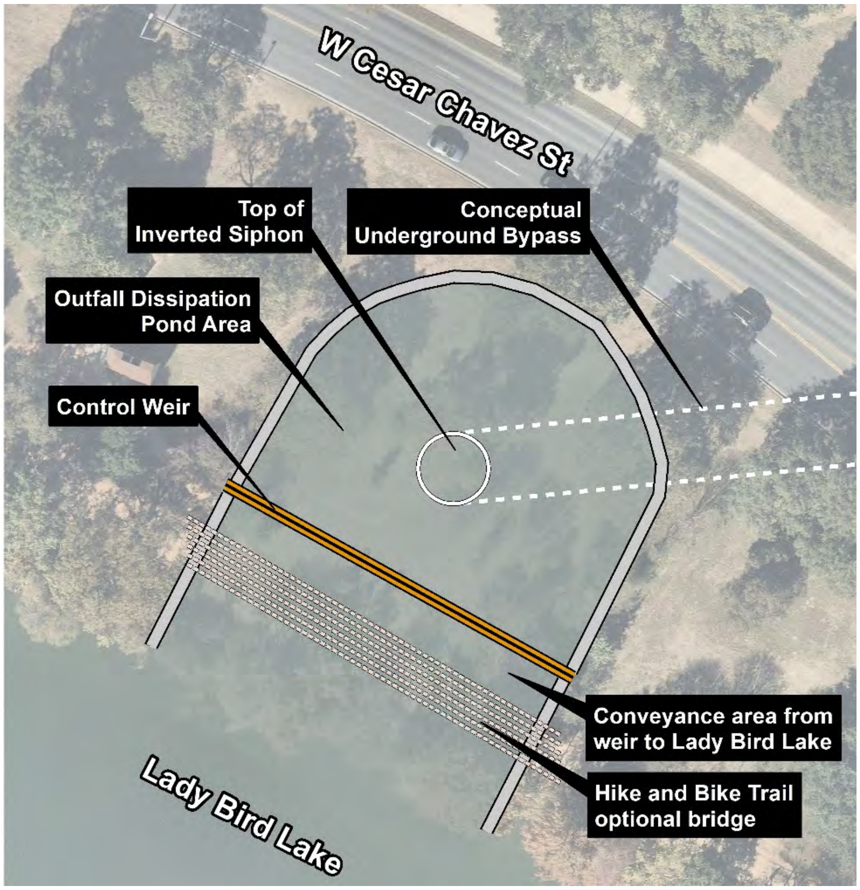


Figure 17: Conceptual Outfall Structure Schematic

Flood Risk Reduction Level of Service

Though there are many underground bypass options with many alignments, upstream intake locations and sizes simulated, another important different to note is the difference in level of service. The level of service of each advanced bypass option, displayed in **Table 8** below, is based on the number buildings no longer inundated during the 1% ACE (100-year). To clarify, if an underground bypass option has a level of service of the 2% ACE (50-year) that means it is reducing the number of structures inundated during the 1% ACE down to the number of structures that are estimated to be inundated during the existing 2% ACE. The alternative with the highest potential level of service is the Lamar A Bypass 4 which lowers the 1% ACE (100-year) to the 10% ACE (10-year). Lamar A Bypass 1 and Lamar B Bypass 1 have very minimal level of service. The potential proposed 1% ACE (100-year) floodplain is compared to existing conditions for each advanced underground bypass option in **Appendix G**.

Table 8: Conceptual Underground Bypass 100-year (1% Chance) Flood Risk Reduction

	Removal of Inundated Structures	Removal of Roadway Inundation	Level of Service
Lamar A Bypass 1	**4** of 61	**1,000 ft** of 12,300 feet	Between 2% and 1% ACE
Lamar A Bypass 2	**13** of 61	**2,500 ft** of 12,300 feet	4% ACE
Lamar A Bypass 3	**19** of 61	**4,200 ft** of 12,300 feet	Between 10% and 4% ACE
Lamar A Bypass 4	**30** of 61	**6,700 ft** of 12,300 feet	Less than 10% ACE
Lamar B Bypass 1	**4** of 61	**1,100 ft** of 12,300 feet	Between 2% and 1% ACE
Lamar B Bypass 2	**7** of 61	**1,400 ft** of 12,300 feet	2% ACE
Lorrain-Pressler Bypass 1	**11** of 61	**2,100 ft** of 12,300 feet	Between 4% and 2% ACE
Lorrain-Pressler Bypass 2	**12** of 61	**2,400 ft** of 12,300 feet	4% ACE

Cost Estimation

An opinion of probable cost was developed for each underground bypass alternative. Some unit prices for probable costs were developed using the Texas Department of Transportation (TxDOT) bid tabulations from projects within the Austin District within the last calendar year. However, since these potential underground bypass projects are not a typical TxDOT construction project, prices were estimated using bid tabs from known similar projects such as the Mills Creek Tunnel in Dallas, Texas and the Waller Creek Tunnel in Austin, Texas. Please note these opinions of probable cost use standard practice and are only considered an estimate. These estimates were based on schematic level design with limited detail of all constraints. The upstream inlet construction cost estimate considers inlet protection, stream restoration, concrete for structure, as well as less costly items such as guard rails and screens. The outlet structure cost estimate considers outlet stabilization, stream restoration, and concrete for structure. A cost of utilizing park property for the inlet or outlet structures was not included in the cost estimate as it is owned by the City of Austin. Additional expenses for updating the park after construction of the structure would need to be estimated separately. These estimates will require refinement should any of these projects mentioned be recommended for further evaluation. Opinions of probable cost for each advanced alternative can be found in **Table 9**. Annual operation and maintenance cost (O&M) were also estimated based on percent of project cost.

Table 9: Underground Bypass Probable Cost Estimations

	Lamar A Bypass 1	Lamar A Bypass 2	Lamar A Bypass 3	Lamar A Bypass 4	Lamar B Bypass 1	Lamar B Bypass 2	Lorrain-Pressler Bypass 1	Lorrain-Pressler Bypass 2
DESCRIPTION	SUB TOTAL	SUB TOTAL	SUB TOTAL	SUB TOTAL	SUB TOTAL	SUB TOTAL	SUB TOTAL	SUB TOTAL
Upstream Inlet	$ 7,029,000	$ 9,640,000	$ 9,640,000	$ 9,640,000	$ 7,029,000	$ 7,029,000	$ 9,640,000	$ 9,640,000
Tunnel	$ 34,174,000	$ 41,304,000	$ 42,372,000	$ 59,424,000	$ 25,155,000	$ 25,854,000	$ 38,934,000	$ 58,156,000
6th St Inlet	$ -	$ -	$ -	$ 7,320,000	$ -	$ -	$ -	$ 7,320,000
9th St Inlet	$ -	$ -	$ 7,029,000	$ 7,029,000	$ -	$ 7,029,000	$ -	$ -
Outlet	$ 9,404,000	$ 9,404,000	$ 9,404,000	$ 9,404,000	$ 9,404,000	$ 9,404,000	$ 5,324,000	$ 5,324,000
Utility Relocations	$ 5,376,000	$ 5,376,000	$ 5,376,000	$ 5,376,000	$ 4,947,000	$ 4,947,000	$ 869,000	$ 6,049,000
PROJECT SUB TOTAL	$ 55,983,000	$ 65,724,000	$ 73,821,000	$ 98,193,000	$ 46,535,000	$ 54,263,000	$ 54,767,000	$ 86,489,000
CONTENGENCY (50%)	$ 27,991,500	$ 32,862,000	$ 36,910,500	$ 49,096,500	$ 23,267,500	$ 27,131,500	$ 27,383,500	$ 43,244,500
TOTAL PROJECT COST	$ 83,974,500	$ 98,586,000	$ 110,731,500	$ 147,289,500	$ 69,802,500	$ 81,394,500	$ 82,150,500	$ 129,733,500
Engineering and Survey Fees (10%)	$ 8,397,000	$ 9,859,000	$ 11,073,000	$ 14,729,000	$ 6,980,000	$ 8,139,000	$ 8,215,000	$ 12,973,000
Regulatory Permitting (3%)	$ 2,519,000	$ 2,958,000	$ 3,322,000	$ 4,419,000	$ 2,094,000	$ 2,442,000	$ 2,465,000	$ 3,892,000
Property Acquisition	$ -	$ -	$ -	$ -	$ 5,887,000	$ 5,887,000	$ -	$ -
TOTAL PROJECT COST	$ 94,890,500	$ 111,403,000	$ 125,126,500	$ 166,437,500	$ 84,763,500	$ 97,862,500	$ 92,830,500	$ 146,598,500
Potential Annual O&M Cost	$ 840,000	$ 986,000	$ 1,108,000	$ 1,473,000	$ 699,000	$ 814,000	$ 822,000	$ 1,298,000

Benefit-Cost Analysis

A high-level Benefit-Cost Analysis (BCA) was performed for the eight advanced flood risk reduction alternatives. FEMA's BCA model version 5.2.1 was used to calculate a present value of pre- and post-project damages that are estimated to occur over the useful life of the project (in this study, 50 years) and divides the estimated damage reduction (benefits) by the estimated cost of the project. Please note while the BCA is based on a 50-year project life cycle, an underground bypass can operate beyond 50 years with routine maintenance. Performing a benefit-cost analysis allows the level of service and cost to be compared for each option ensuring the greatest benefit for each dollar spent. The BCA was established as the standard in order to provide technical and financial assistance for implementation of flood or hazard mitigation undertakings. From the BCA analysis it was determined that all of the bypass options have a BCA lower than the minimum criteria, one. Based on this analysis, none of these advanced alternatives would be eligible for state or federal funding because they fail to meet the minimum criteria. It should be noted that the high-level BCA could be refined in the future with additional information to account for benefits such as loss of function or delay of businesses and critical services such as police, fire, emergency management services.

The Lamar A Bypass 4 alternative had the highest BCA ratio, and the Lorrain-Pressler Bypass 2 alternative had the lowest. See the potential underground bypass alternatives BCA ratios compared in **Table 10** below. For more details on the BCA please refer to **Appendix H**. The results of the BCA analysis were considered in the advanced alternative scoring criteria.

Table 10: BCA Results

Bypass Option	BCA
Lamar A Bypass 1	0.52
Lamar A Bypass 2	0.53
Lamar A Bypass 3	0.71
Lamar A Bypass 4	0.75
Lamar B Bypass 1	0.50
Lamar B Bypass 2	0.65
Lorrain-Pressler Bypass 1	0.52
Lorrain-Pressler Bypass 2	0.44

Advanced Alternative Scoring Criteria & Results

The advanced alternative scoring criteria used the same criteria as the comprehensive criteria with the addition of cost effectiveness that takes into account the results of the BCA analysis. The advanced flood risk reduction alternatives were given a score, 1 through 5, for each criterion. The score of 1 through 5 represents the level at which the project meets the criteria, where 5 is the best and 1 is the worst. Therefore, the higher the score of the alternative the superior the project is for that criteria. **Table 11** provides a description of each scoring criteria and weight factors. In **Table 12**, the results of the project scoring are summarized. The full results and scoring can be found in **Appendix D**.

Table 11: Advanced Alternative Scoring Criteria

Criteria	Criteria Weight	Score Range
Cost Effectiveness	20	5: BCA ≤ 0.75 4: Between 0.65 – 0.75 BCA 3: Between 0.55 – 0.65 BCA 2: Between 0.45 – 0.55 BCA 1: BCA ≥ 0.45
Mobility	10	5: Drivers no longer restricted > 8,000 4: 5,400 - 8,000drivers no longer restricted 3: 2,800 - 5,400 drivers no longer restricted 2: 200 - 2,800 drivers no longer restricted 1: Drivers no longer restricted < 200
Length of Inundated Roadway	10	5: Mitigated Roadway Length ≥ 6,000 feet 4: Mitigated Roadway Length between 4,500 feet - 6,000 feet 3: Mitigated Roadway Length between 3,000 feet - 4,500 feet 2: Mitigated Roadway Length between 1,500 - 3,000 feet 1: Mitigated Roadway Length ≤ 1,500 feet
Environmental Impact	15	5: Limited to no environmental impact 4: Short term, moderate impact during construction 3: Short term, significant impact during construction 2: Long term, moderate impact in perpetuity 1: Long term, significant impact in perpetuity
Land/Easement Acquisition	15	5: No additional land/easement acquisition needed in order to implement project 3: Possible/Minimal land/easement acquisition needed 1: Significant land/easement acquisition needed in order to implement project
Public Input	10	5: Most favorable 3: Neutral results 1: Least favorable
Time of Implementation	5	5: 0-2 years, once funding is available 4: 2-5 years, once funding is available 3: 5-7 years, once funding is available 2: 7-10 years, once funding is available 1: > 10 years, once funding is available
Funding Constraints	5	5: Project could be implemented incrementally as funding is available 3: Project is comprised of multiple smaller projects which could be implemented separately as funding is available for each 1: Full project funding required prior to implementation
Complexity of Permitting	10	5: Limited local permits 4: Local site plan permit 3: Local permit with variances/Nationwide 2: Multi-jurisdiction less permits 1: Multi-jurisdiction more permits

Table 12: Advanced Alternative Scoring Results

Description	Score	Rank
Lamar A Bypass 1	170	6
Lamar A Bypass 2	180	4
Lamar A Bypass 3	215	2
Lamar A Bypass 4	285	1
Lamar B Bypass 1	145	7
Lamar B Bypass 2	185	3
Lorrain-Pressler Bypass 1	180	4
Lorrain-Pressler Bypass 2	145	7

Conclusion & Recommendations

The Lower Shoal Creek Flood Risk Reduction Analysis allowed the City to re-evaluate flood risk within the Lower Shoal in light of the May 2015 flood and evaluate potential flood risk reduction alternatives. There are 61 structures in the study area where the estimated 1% ACE (100-yr) water surface elevation is estimated to exceed the finished floor elevations. The goal of this feasibility analysis was to identify alternatives that would reduce the 1% ACE (100-year) peak flows or produce equivalent reductions in flood risk through the Shoal Creek corridor downstream of W 15th Street.

In comparison to other comprehensive alternatives such as channel clearing and detention, underground conveyance provides the greatest flood risk reduction benefits along the Lower Shoal Creek corridor. As identified through the advanced alternatives analysis, underground conveyance is a long-term option when considering large flood events like the 1% ACE (100-year) and greater. However high project cost, funding, social impact, and time of implementation could all be obstacles that would need to be overcome if an underground bypass system was ever implemented.

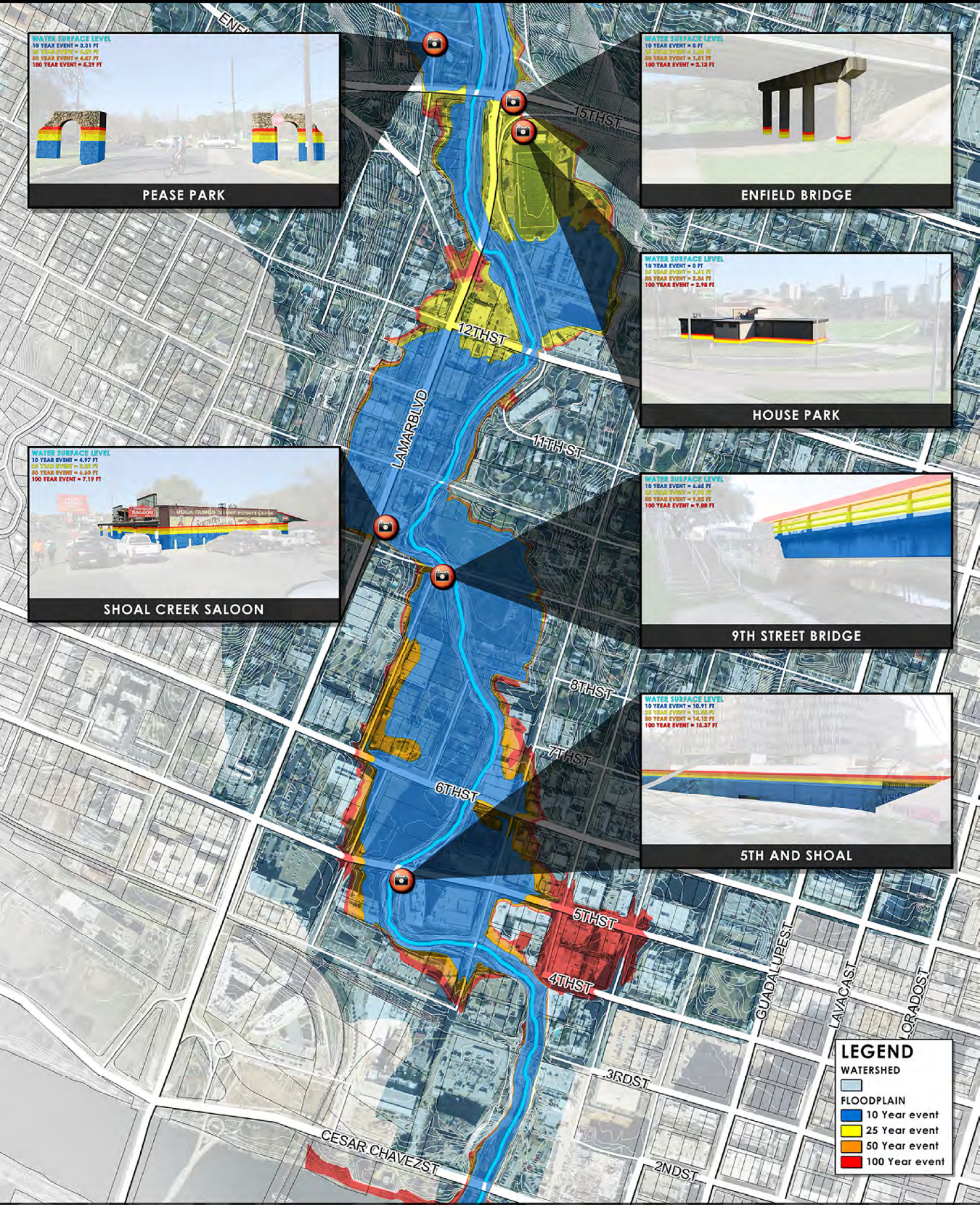
Many high-value buildings are projected to flood at events as low as the 50% ACE (2-year). Lower Shoal Creek, similar to many already developed areas that experience frequency flooding, is an area where full flood mitigation is not financially feasible. In these cases, it may be more cost effective and prudent to evaluate opportunities for improving community resilience in the flood area. Improving community resilience is a topic that is increasingly being evaluated as a viable path for moving forward in several communities. As such, a community resilience plan could be implemented to increase standards for new development, incentivize safe redevelopment and retrofits, inform citizens to increase flood preparedness, and implement better warning systems. A community resilience plan offers the shortest time of implementation and allows for prioritization of the most at-risk areas. In addition to these benefits, this alternative has the least social and environmental impact to the largely populated study area.

Based on the results of the analysis and the project scoring criteria, Halff recommends a community resilience plan as the preferred short-term flood risk reduction alternative, with an underground bypass as the preferred long-term flood risk reduction alternative.

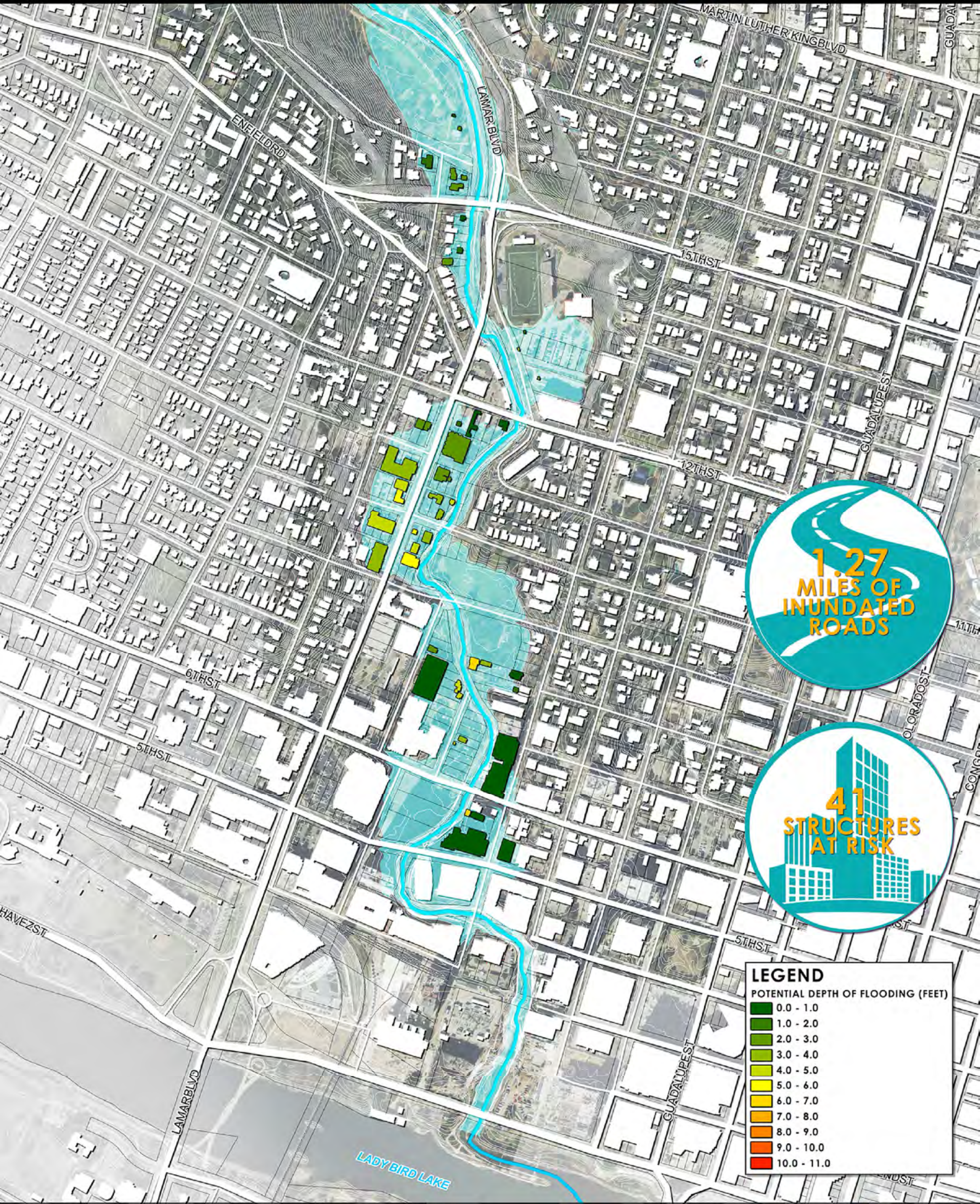
This Lower Shoal Creek Flood Risk Reduction Analysis is a feasibility study. Any results from this study, including post-project flood risk, would be refined should any of the projects mentioned in this analysis be recommended for further evaluation.

APPENDIX A: Phase 1 Figures

EXISTING RISK



LEVEL OF SERVICE - 10 YEAR EVENT



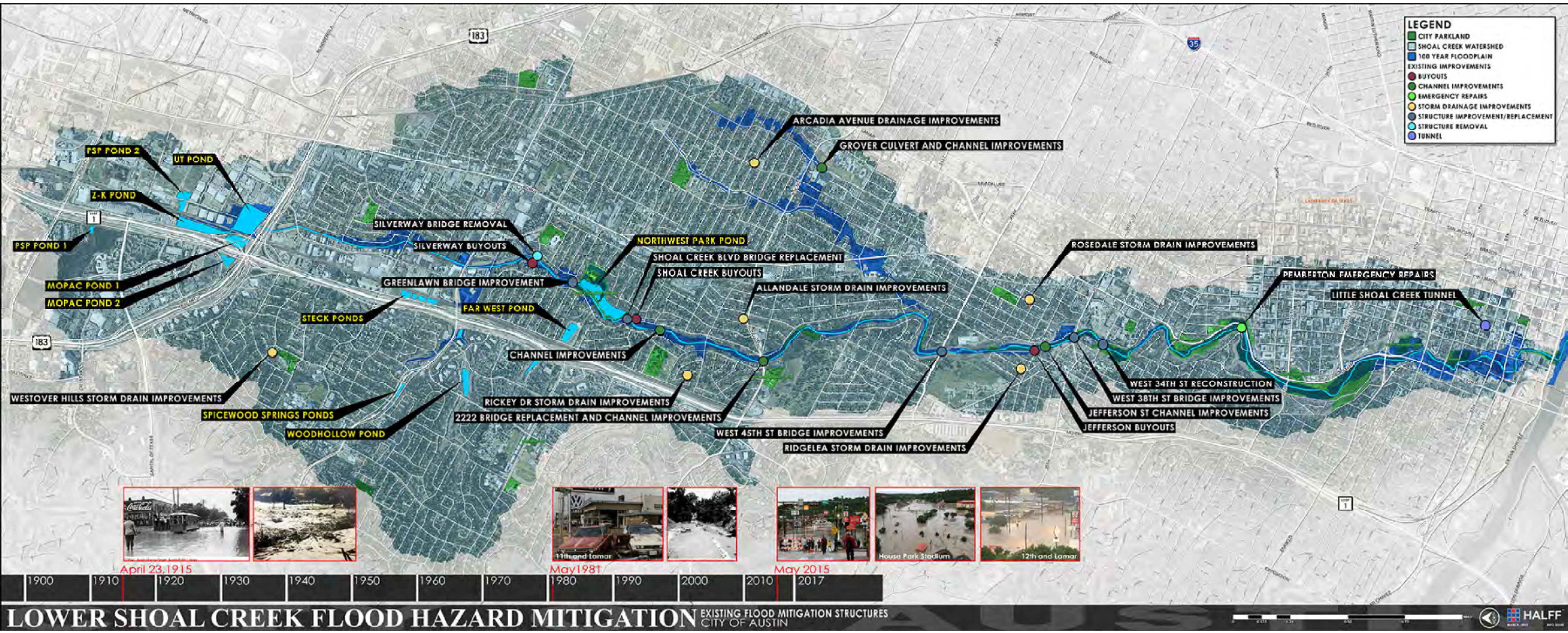
LEVEL OF SERVICE - 25 YEAR EVENT

LEVEL OF SERVICE - 50 YEAR EVENT

LEVEL OF SERVICE - 100 YEAR EVENT

LOWER SHOAL CREEK FLOOD HAZARD MITIGATION LEVEL OF SERVICE - 100 YEAR EVENT CITY OF AUSTIN

HALFF MARCH, 2017 AVO 32229


LEGEND
CITY PARKLAND
SHOAL CREEK WATERSHED
100 YEAR FLOODPLAIN
EXISTING IMPROVEMENTS
BUYOUTS
CHANNEL IMPROVEMENTS
EMERGENCY REPAIRS
STORM DRAINAGE IMPROVEMENTS
STRUCTURE IMPROVEMENT/REPLACEMENT
STRUCTURE REMOVAL
TUNNEL
183
35
PSP POND 2
UT POND
Z-K POND
PSP POND 1
MOPAC POND 1
MOPAC POND 2
STECK PONDS
FAR WEST POND
SILVERWAY BRIDGE REMOVAL
SILVERWAY BUYOUTS
GREENLAWN BRIDGE IMPROVEMENT
NORTHWEST PARK POND
SHOAL CREEK BLVD BRIDGE REPLACEMENT
SHOAL CREEK BUYOUTS
ARCADIA AVENUE DRAINAGE IMPROVEMENTS
GROVER CULVERT AND CHANNEL IMPROVEMENTS
ALLANDALE STORM DRAIN IMPROVEMENTS
ROSEDALE STORM DRAIN IMPROVEMENTS
PEMBERTON EMERGENCY REPAIRS
LITTLE SHOAL CREEK TUNNEL
CHANNEL IMPROVEMENTS
WESTOVER HILLS STORM DRAIN IMPROVEMENTS
SPICEWOOD SPRINGS PONDS
WOODHOLLOW POND
RICKEY DR STORM DRAIN IMPROVEMENTS
2222 BRIDGE REPLACEMENT AND CHANNEL IMPROVEMENTS
WEST 45TH ST BRIDGE IMPROVEMENTS
RIDGELEA STORM DRAIN IMPROVEMENTS
WEST 34TH ST RECONSTRUCTION
WEST 38TH ST BRIDGE IMPROVEMENTS
JEFFERSON ST CHANNEL IMPROVEMENTS
JEFFERSON BUYOUTS
11th and Lamar
House Park Stadium
12th and Lamar
April 23,1915
May 1981
May 2015
1900
1910
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1950
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1970
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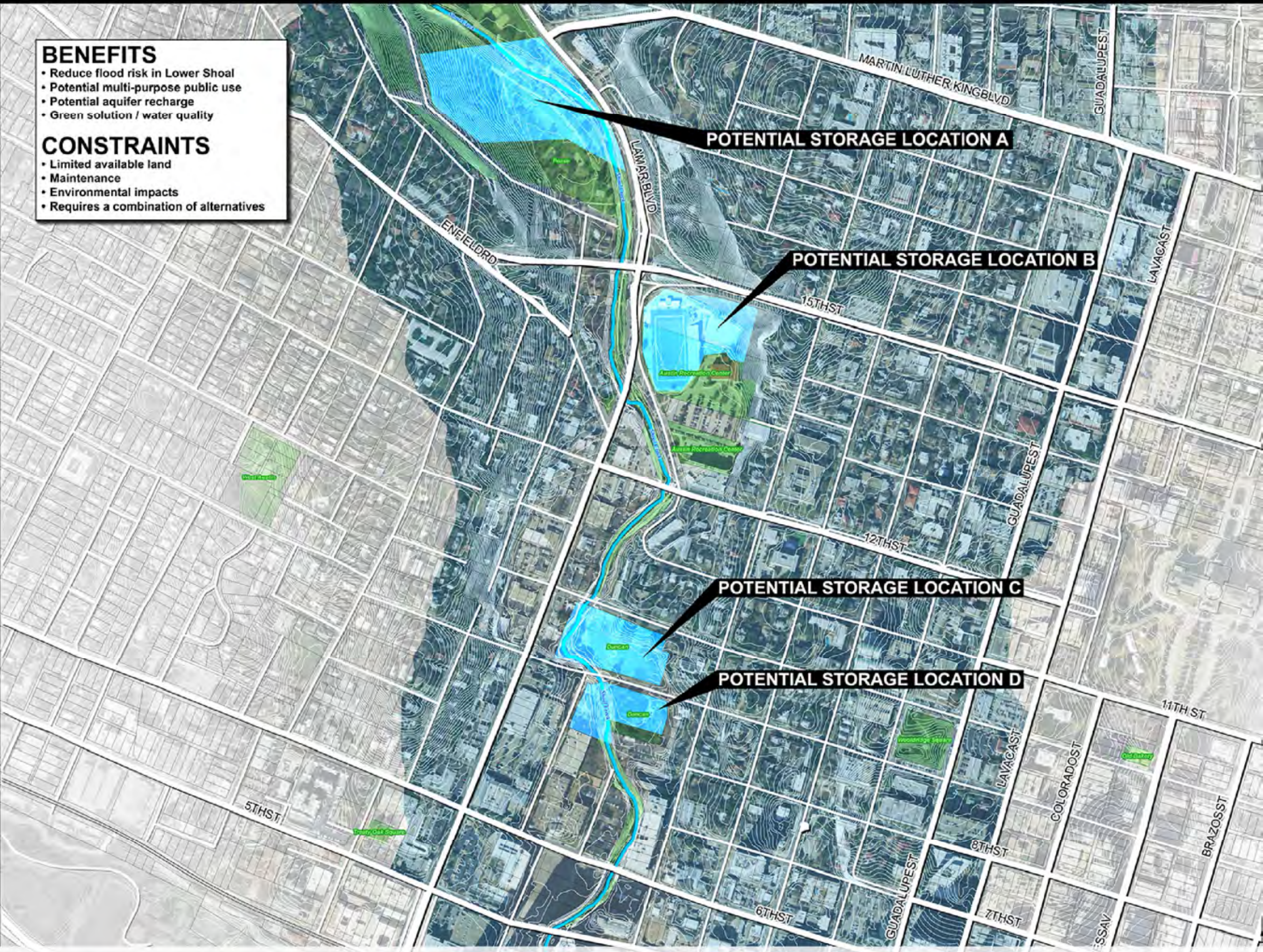
1990
2000
2010
2017
LOWER SHOAL CREEK FLOOD HAZARD MITIGATION
EXISTING FLOOD MITIGATION STRUCTURES
CITY OF AUSTIN
HALFF

STORAGE IDEAS

BENEFITS
- Reduce flood risk in Lower Shoal
- Potential multi-purpose public use
- Potential aquifer recharge
- Green solution / water quality

CONSTRAINTS
- Limited available land
- Maintenance
- Environmental impacts
- Requires a combination of alternatives

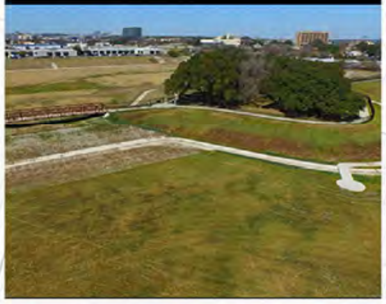


4TH WARD PARK
Atlanta, GA
-28 acre-feet storage capacity
-$23 million to design and construct

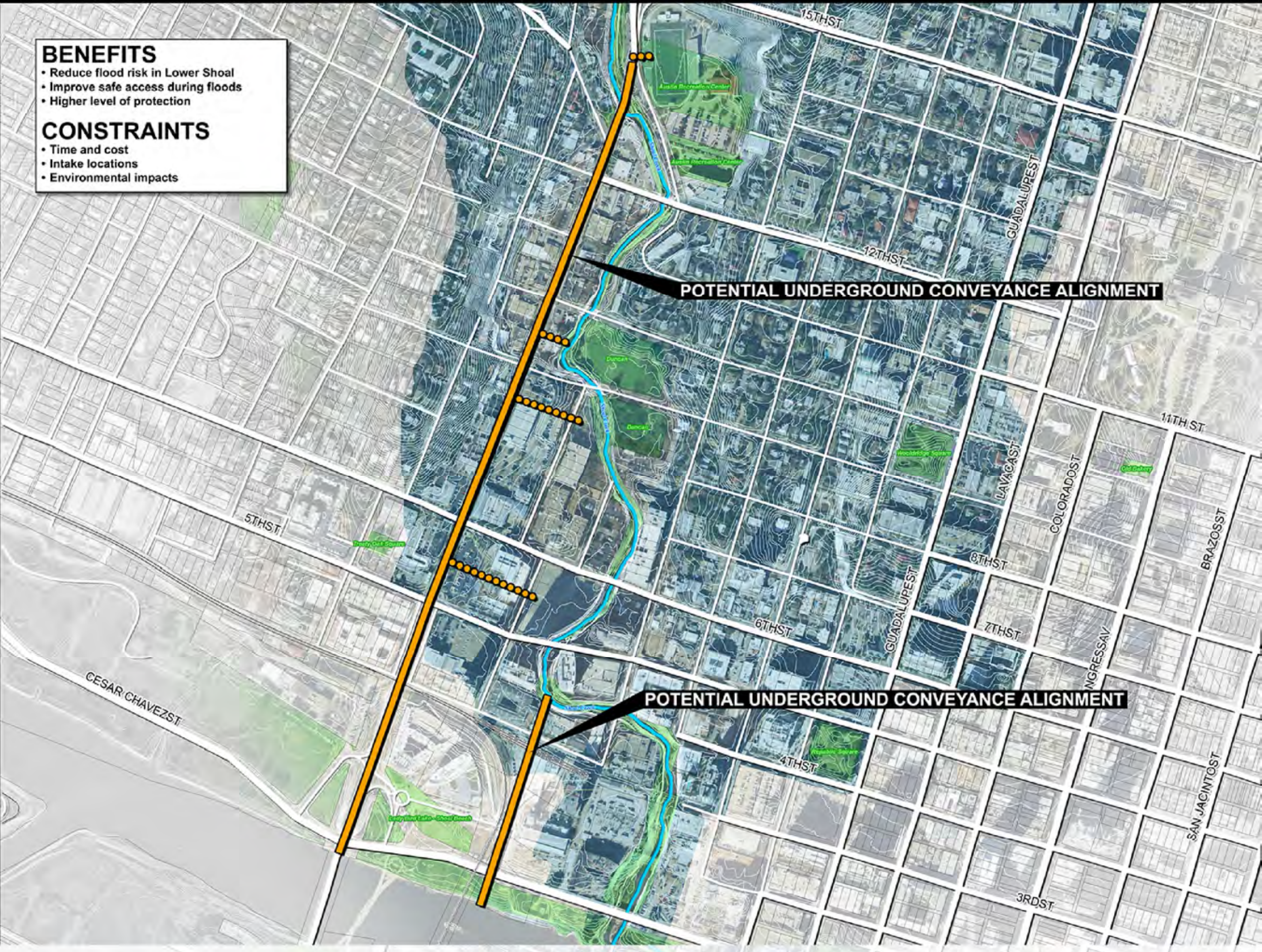
G-CANS PROJECT
Tokyo, JPN
-9,500 acre-feet storage capacity
-$2.9 billion to design and construct
-17 years to construct

COLE PARK
Dallas, TX
-218 acre-feet storage capacity
-$27 million to design and construct
-3 years to construct

LADDIE PLACE
San Antonio, TX
-190 acre-feet storage capacity (2 ponds)
-$27.5 million to design and construct
-2.5 years to construct



UNDERGROUND CONVEYANCE IDEAS



BENEFITS
- Reduce flood risk in Lower Shoal
- Improve safe access during floods
- Higher level of protection

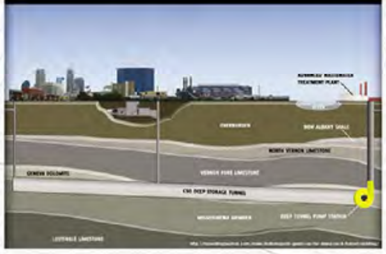
CONSTRAINTS
- Time and cost
- Intake locations
- Environmental impacts

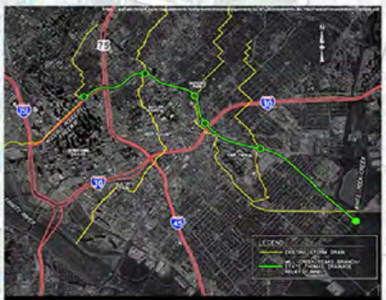
SAN ANTONIO RIVER TUNNEL
San Antonio, TX

-100 year conveyance
-10 years to construct
-3 miles long, 24 feet wide, 150 feet below ground
-$111 million to design and construct

DEEP ROCK TUNNEL
Indianapolis, IN

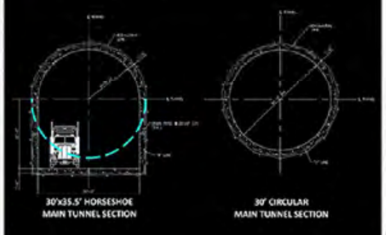
-Under construction 2011-2017 (6 year estimate)
-7.5 miles long, 18 feet wide, 270 feet below ground
-$180 million to design and construct





MILL PEAK/PEAKS BRANCH DRAINAGE RELIEF TUNNEL
Dallas, TX

-100 year conveyance
-5 years to construct (estimate)
-5 miles long, 30 feet wide, 100+ feet below ground
-$320 milion to design and construct



SUGAR CREEK LONGVIEW DRAINAGE IMPROVEMENTS
Sugar Land, TX

-3,000 feet long, 10'x5' and 8'x5' RCBs
-9 months to construct
-$5.1 milion to desgn and construct

BRIDGE REMOVAL IDEAS

BENEFITS
- Reduce flood risk upstream of bridge
- Reduce roadway overtopping

CONSTRAINTS
- Limited flood risk benefits
- Mobility impacts

OTHER MITIGATION IDEAS

SELECTIVE CHANNEL CLEARING

WICHITA RIVER CLEARING
Wichita Falls, TX

-USGS recommended project
-15 mile stretch, 124 acres cleared and maintained
-Cost: $150,000/year
-Timeframe: 2012 - ongoing

BENEFITS
- Improves channel conveyance
- Reduces clogging of bridges

CONSTRAINTS
- Limited flood risk benefits
- Maintenance
- Environmental impacts
- Requires a combination of alternatives

BUYOUT

LOWER ONION CREEK
Austin, TX

-Purchased 780 properties to date
-Utilized US Army Corps cost-share funding and FEMA grants
-Utilized City of Austin funding
-Cost to date: $132 million
-Timeframe: 1999 - present

BENEFITS
- Reduces flood risk in Lower Shoal
- Potential open space opportunities

CONSTRAINTS
- Cost of commercial properties
- Maintenance
- Community impacts

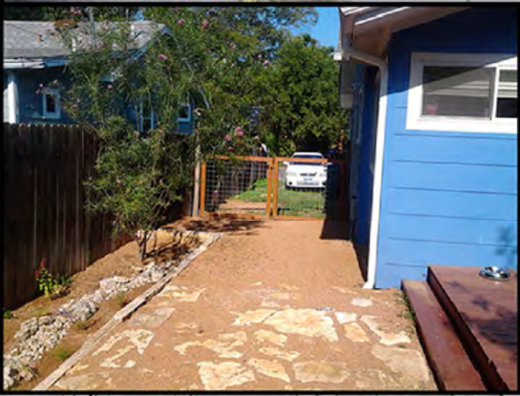
GREEN INFRASTRUCTURE

BRENTWOOD GREEN INFRASTRUCTURE
Austin, TX

-Green infrastructure study
-Mitigate less than 10-year events
-$15-20 million implementation (estimate)
-Water quality load reductions
-Localized impackts

BENEFITS
- Integration with other mitigation options
- Improves water quality
- Potential public attraction

CONSTRAINTS
- Minimal flood risk benefits
- Maintenance
- Requires a combination of alternatives



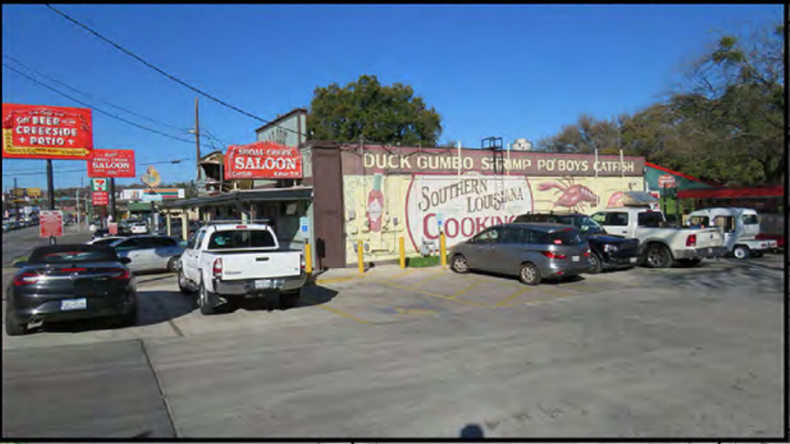
FLOODPROOFING & PLANNING

SHOAL CREEK SALOON
Austin, TX

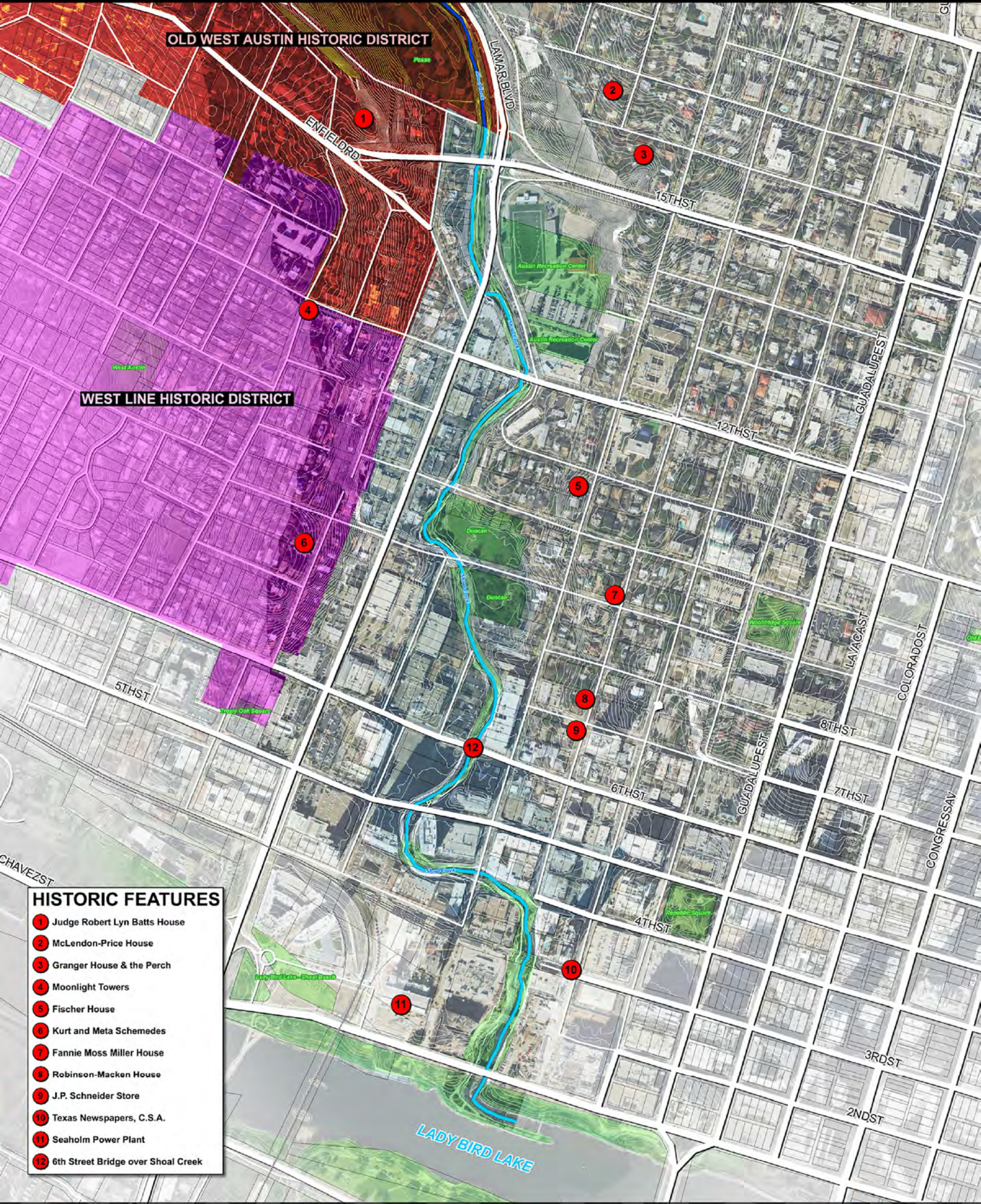
-Flood safety
-Before flood preparation
-Post event recovery
-$15-20 million estimated to implement

BENEFITS
- Improves flood awareness
- Private property ownership

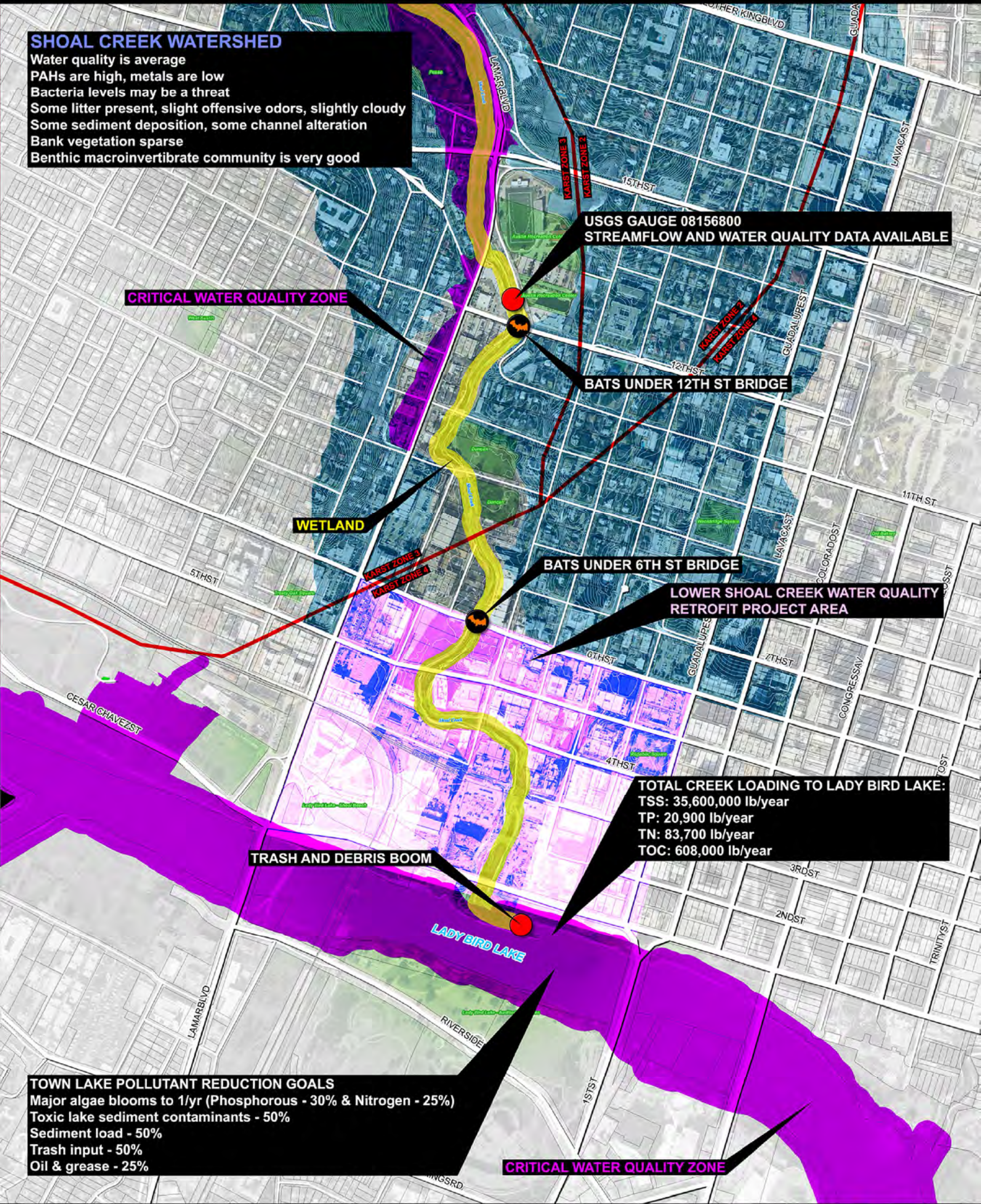
CONSTRAINTS
- No roadway inundation benefits
- Destructive flood water velocities



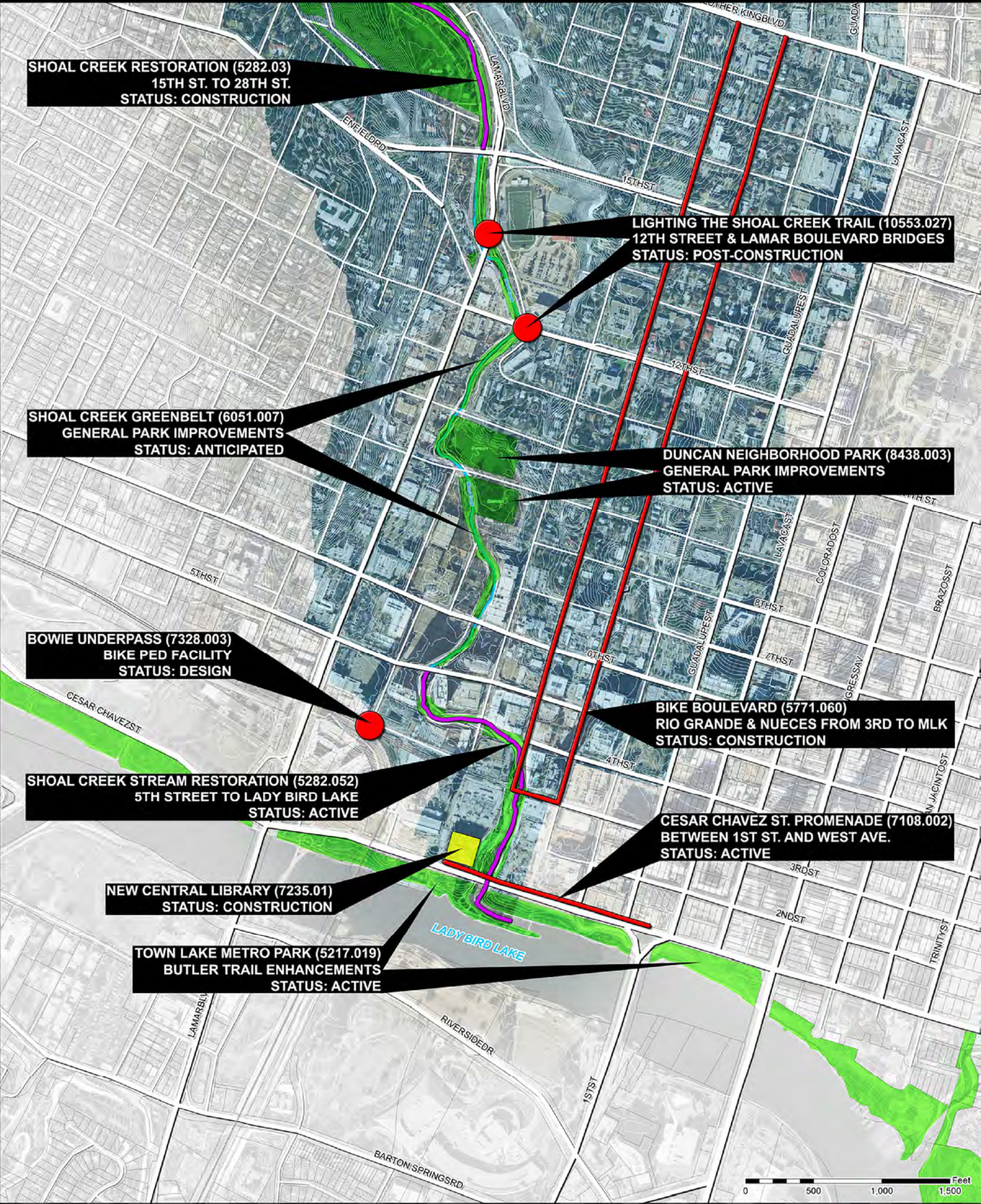
HISTORICAL CONSTRAINTS



WATER QUALITY & ENVIRONMENTAL CONSTRAINTS



CITY OF AUSTIN PROJECTS



LOWER SHOAL CREEK FLOOD HAZARD MITIGATION CITY OF AUSTIN PROJECTS CITY OF AUSTIN

NORTH

HALFF

MARCH, 2017

AVO 32229

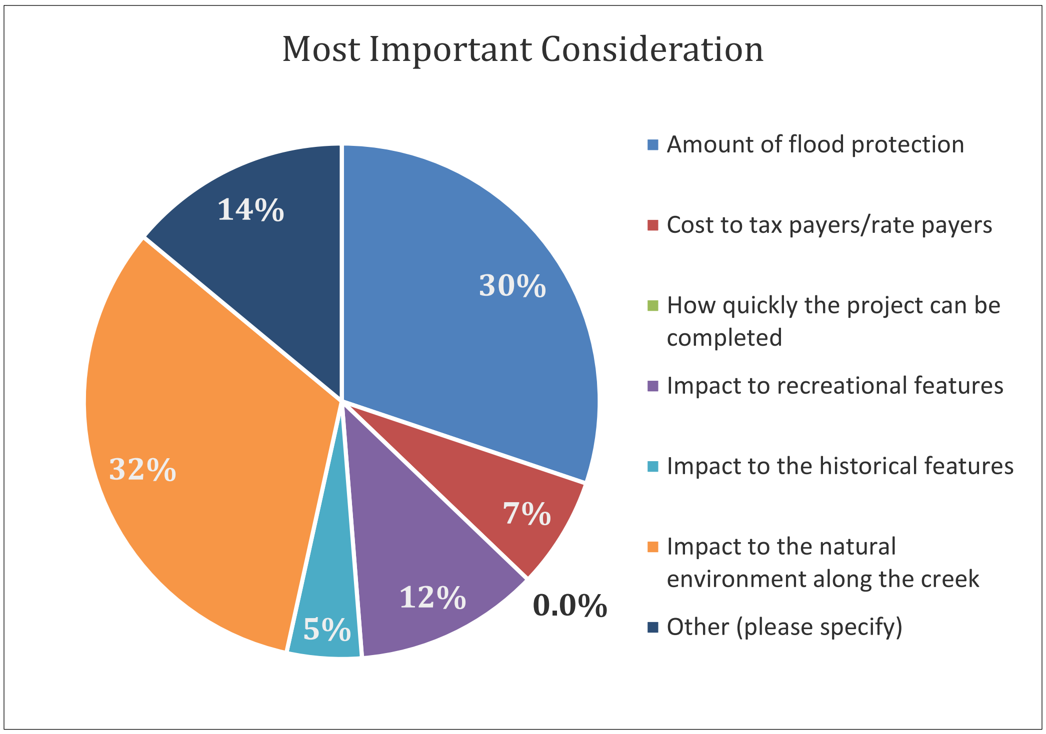
APPENDIX B: Public Meeting March 2017 Survey Results

Lower Shoal Creek Flood Hazard Mitigation Study

Public Meeting Survey Results

1. Which of the following considerations do you think is ***most*** important when choosing options to reduce flooding?

Answer Options	Response Percent	Response Count
Amount of flood protection	30.2%	13
Cost to tax payers/rate payers	7.0%	3
How quickly the project can be completed	0.0%	0
Impact to recreational features	11.6%	5
Impact to the historical features	4.7%	2
Impact to the natural environment along the creek	32.6%	14
Other (please specify)	14.0%	6
	Answered Question	43
	Skipped Question	1

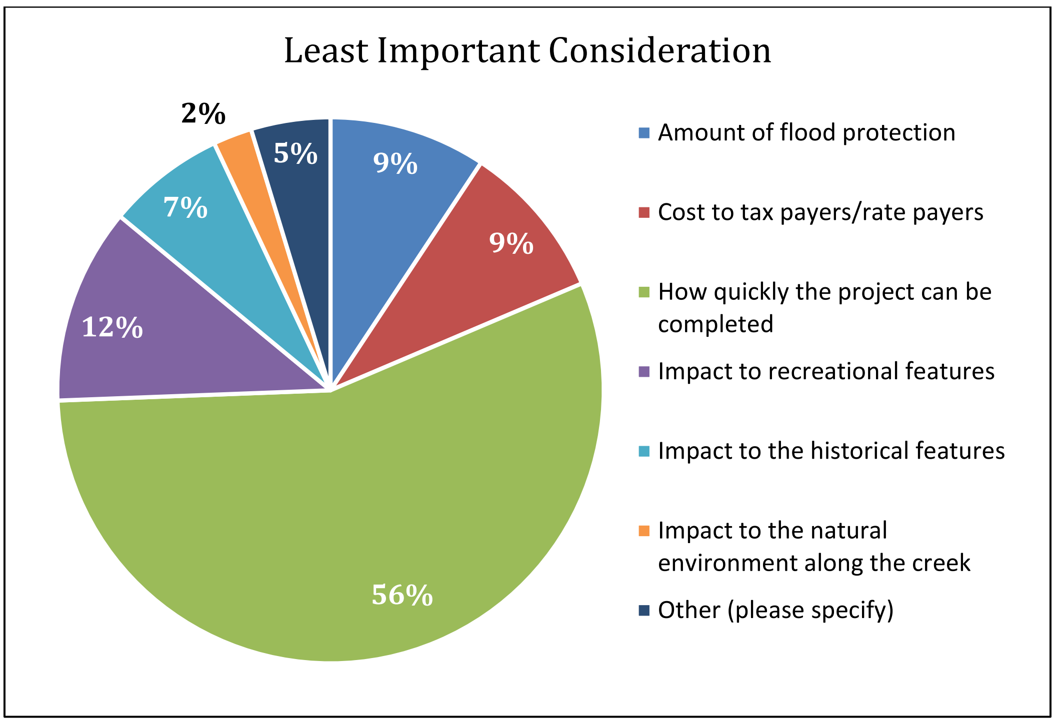


Participant Notes:

- Consistency with larger approaches as expressed by the Citizen Task Force
- Sustainability
- Consider mitigating farther north near 45th Street
- And first selection
- Balance between cost and impact (construction & permanent)
- All of the above

2. Which of the following considerations do you think is ***least*** important when choosing options to reduce flooding?

Answer Options	Response Percent	Response Count
Amount of flood protection	9.3%	4
Cost to tax payers/rate payers	9.3%	4
How quickly the project can be completed	55.8%	24
Impact to recreational features	11.6%	5
Impact to the historical features	7.0%	3
Impact to the natural environment along the creek	2.3%	1
Other (please specify)	4.7%	2
	Answered Question	43
	Skipped Question	1

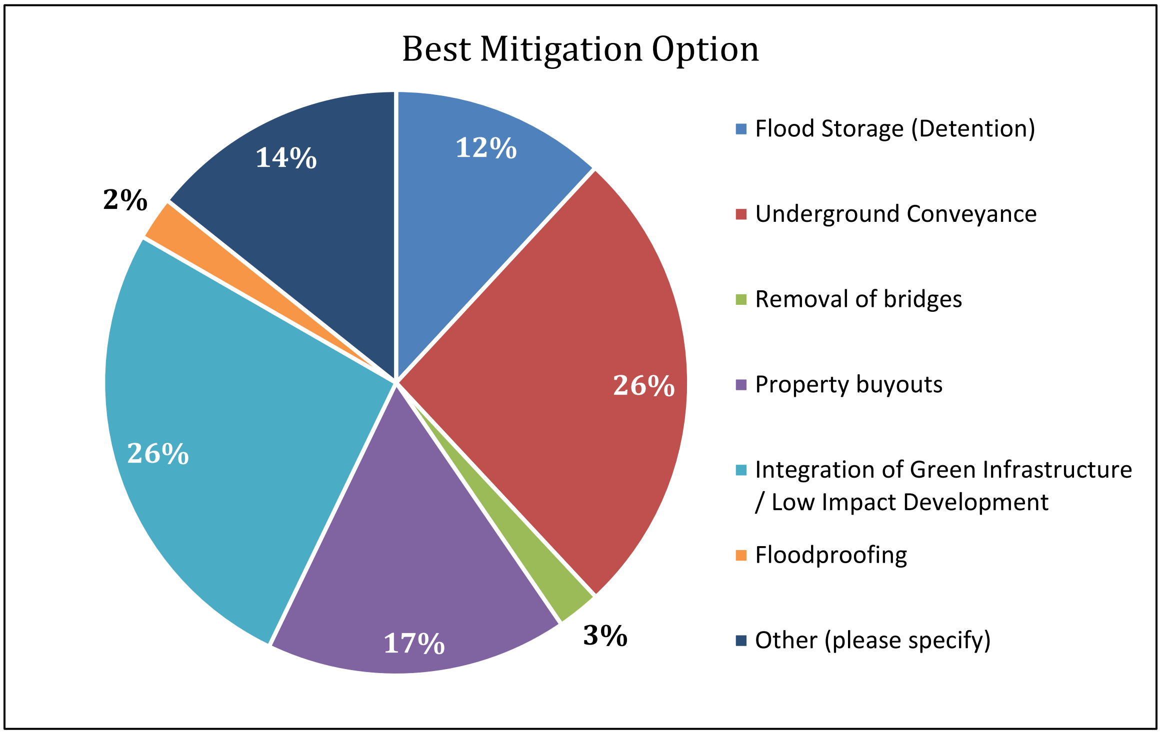


Participant Notes:

- Impact to structures which are inside the floodplain
- Consider mitigating farther north near 45th Street

3. Of all the options for reducing flooding in Lower Shoal Creek, based on the current information, I believe the ***best option*** is:

Answer Options	Response Percent	Response Count
Flood Storage (Detention)	11.9%	5
Underground Conveyance	26.2%	11
Removal of bridges	2.4%	1
Property buyouts	16.7%	7
Integration of Green Infrastructure / Low Impact Development	26.2%	11
Floodproofing	2.4%	1
Other (please specify)	14.3%	6
	Answered Question	42
	Skipped Question	2

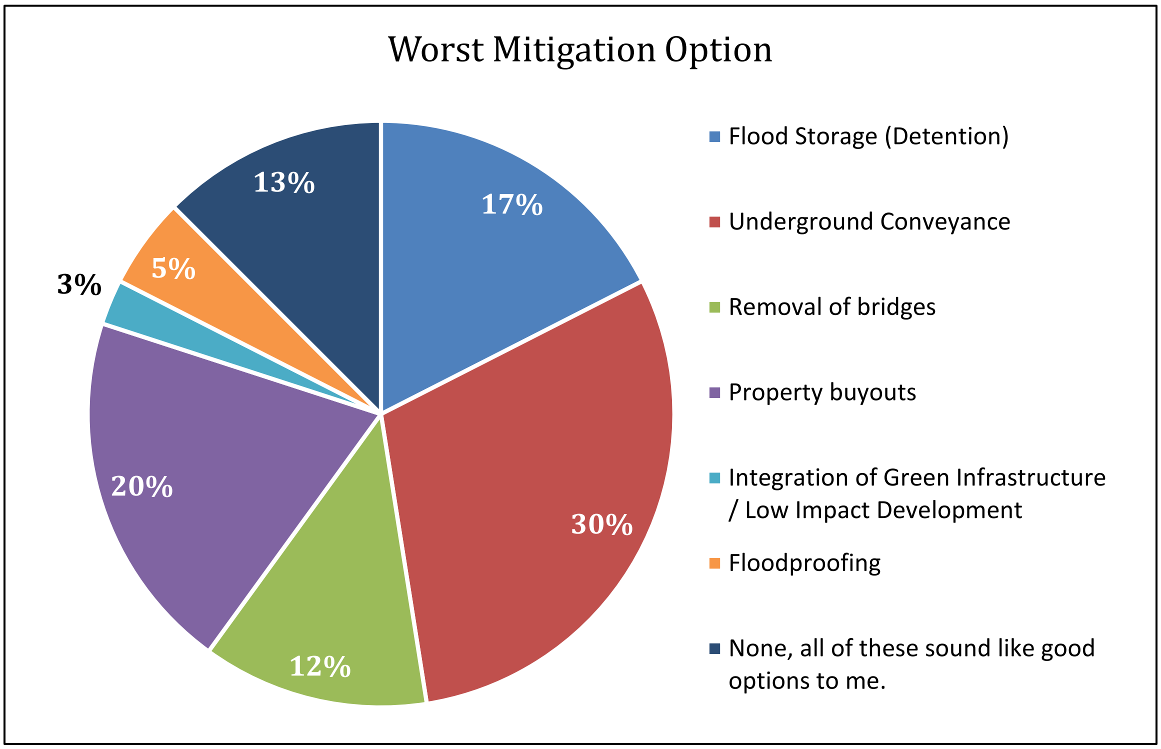


Participant Notes:

- Combination of floodproofing in medium risk structures, buyout of high risk structures and connect to the hike and bike trail
- How could this be known until the study is finished? A biased survey?
- Consider mitigating farther north near 45th Street
- Combination of detention and underground conveyance
- Combination of alternatives
- Combination of detention and conveyance

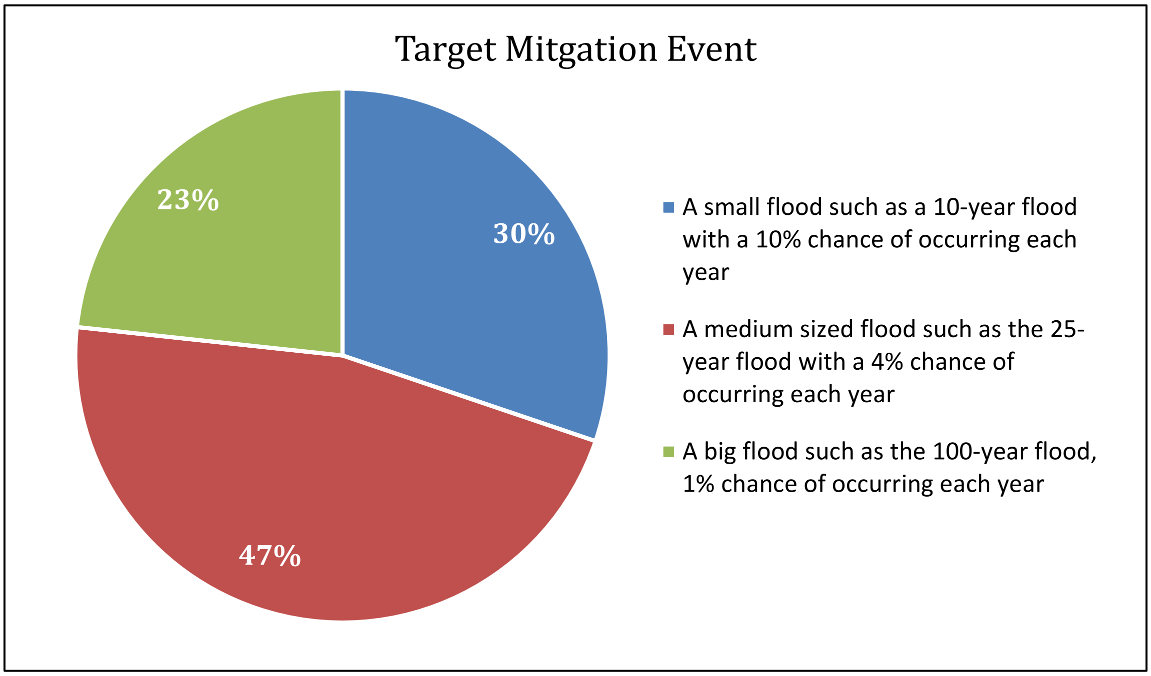
4. Of all the options for reducing flooding in Lower Shoal Creek, based on the current information, I believe the ***worst*** option is:

Answer Options	Response Percent	Response Count
Flood Storage (Detention)	17.5%	7
Underground Conveyance	30.0%	12
Removal of bridges	12.5%	5
Property buyouts	20.0%	8
Integration of Green Infrastructure / Low Impact Development	2.5%	1
Floodproofing	5.0%	2
None, all of these sound like good options to me.	12.5%	5
	Answered Question	40
	Skipped Question	4



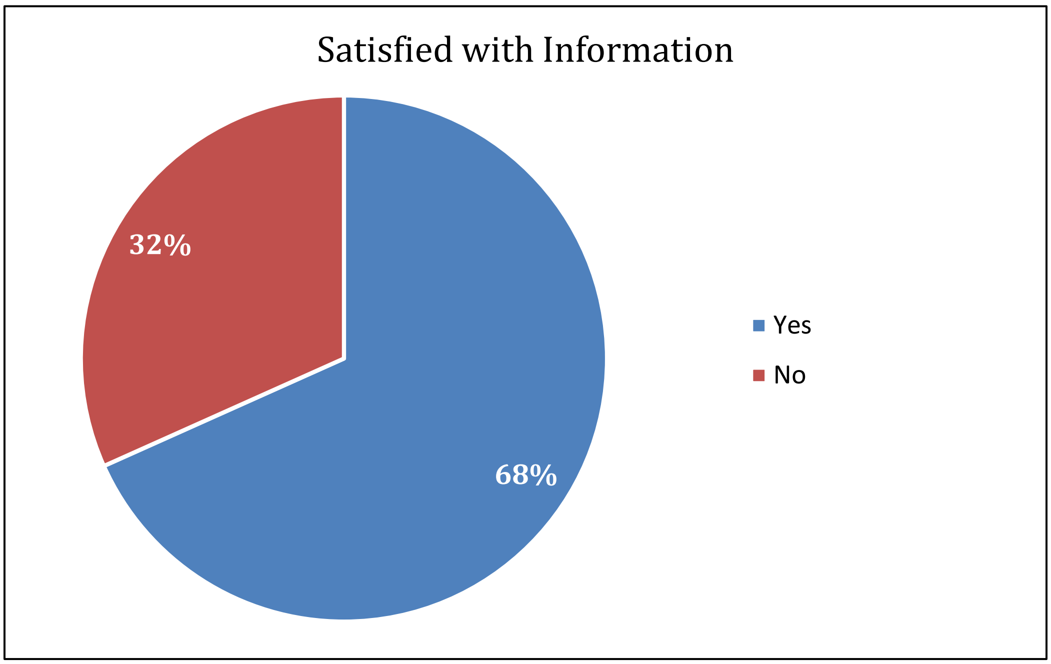
5. What is the minimum size of flood that we should try to help with? In general, a solution for a bigger flood is more expensive than for a smaller flood.

Answer Options	Response Percent	Response Count
A small flood such as a 10-year flood with a 10% chance of occurring each year	30.2%	13
A medium sized flood such as the 25-year flood with a 4% chance of occurring each year	46.5%	20
A big flood such as the 100-year flood, 1% chance of occurring each year	23.3%	10
	Answered Question	43
	Skipped Question	1



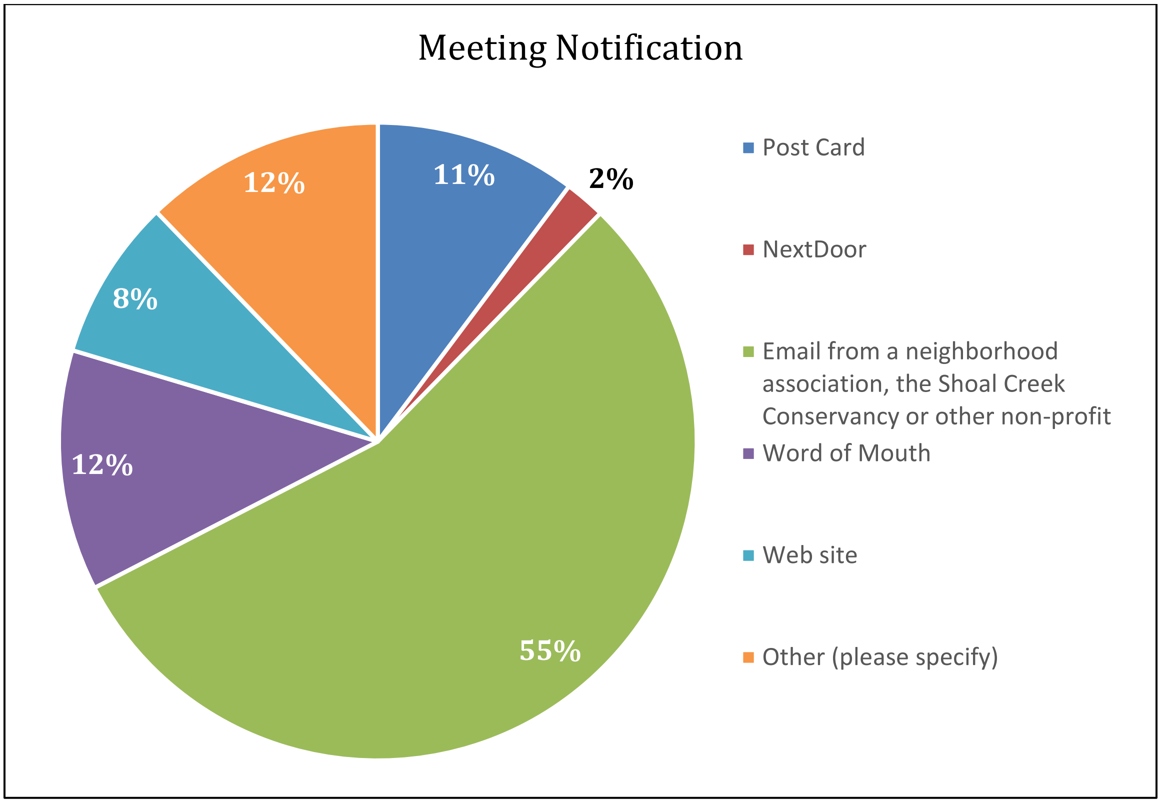
6. Are you satisfied with the amount of information you received about the various flood mitigation options at this meeting?

Answer Options	Response Percent	Response Count
Yes	68.3%	28
No	31.7%	13
	Answered Question	41
	Skipped Question	3



7. How did you find out about this meeting? Please check as many boxes as apply.

Answer Options	Response Percent	Response Count
Post Card	11.4%	5
NextDoor	2.3%	1
Email from a neighborhood association, the Shoal Creek Conservancy or other non-profit	61.4%	27
Word of Mouth	13.6%	6
Web site	9.1%	4
Other (please specify)	13.6%	6
	Answered Question	44
	Skipped Question	0

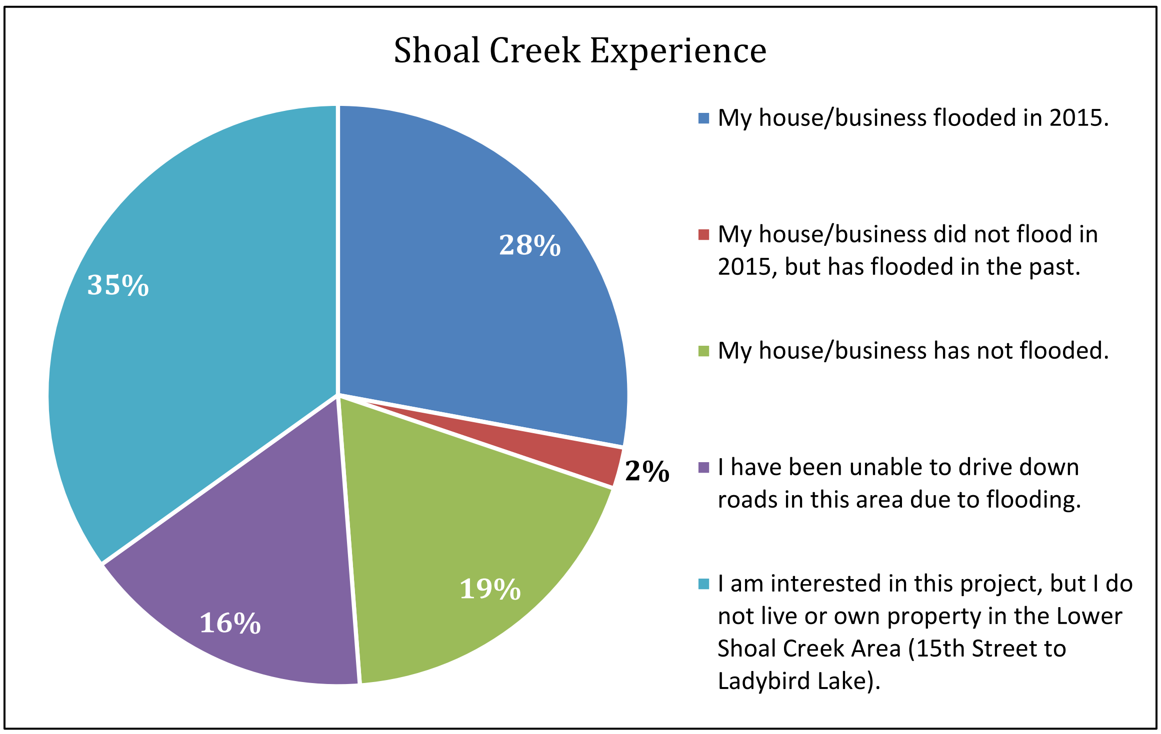


Participant Notes:

- Friend emailed me
- KXAN News YouTube broadcast
- City Staff
- Newspaper / City Hall
- Pease Park Conservancy
- Community Impact

8. Please share your experience with flooding along Shoal Creek:

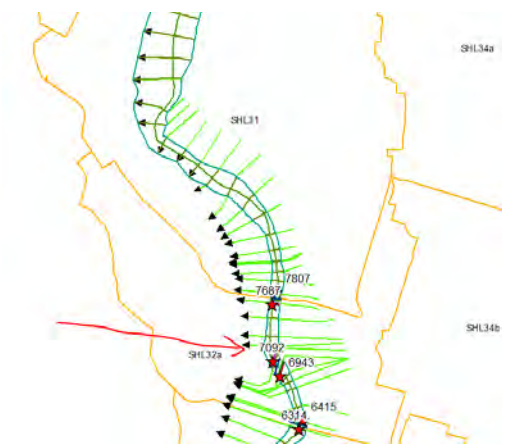
Answer Options	Response Percent	Response Count
My house/business flooded in 2015.	27.9%	12
My house/business did not flood in 2015, but has flooded in the past.	2.3%	1
My house/business has not flooded.	18.6%	8
I have been unable to drive down roads in this area due to flooding.	16.3%	7
I am interested in this project, but I do not live or own property in the Lower Shoal Creek Area (15th Street to Ladybird Lake).	34.9%	15
	Answered Question	43
	Skipped Question	1

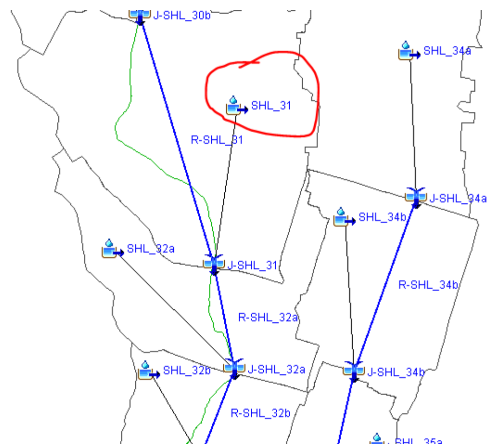


APPENDIX C: QA/QC Forms

I. <u>Inflows</u>

- Inflow comparison between ICM and HMS (RAS has steady flows only).
- Spreadsheet: Inflow Comparison.xlsx
  Inflows_Comparison.xlsx
  - 10yr: Numerical values match
  - 25yr: Numerical values match
  - 50yr: ICM flows at Node 1171 do not match SHL_33B HEC-HMS flows (see comparison xls)
    - HALFF RESPONSE: This was updated to the correct SHL_33B flows from the HMS model.
  - 100yr: Numerical values match
  - 500yr: Numerical values match
- Are inflows applied at the <u>same location</u> in ICM and HMS?
  - 6111 & J-SHL_30b
    - Correct Location
  - 7092 & SHL_31
    - Should flow be applied at ICM nodes 7807 or 7687?
      - HALFF RESPONSE: This flow break was moved to 7807 node.





  - 6415 & SHL_32a
    - Should flow be applied at ICM node 6314?
      - HALFF RESPONSE: Subbasin inflows are consistently put on the upstream node to the bridge that is located to the subbasin boundary. Inflow was left at 6415.
  - 5036 & SHL_32b
    - Correct Location
  - 2552 & SHL_33a
    - Correct Location
  - 2485.1 & J_SHL_35b
    - Incorrect location but logically makes sense
      - HALFF RESPONSE: Inflow was moved to node 2485.
  - 1171 & SHL_33b
    - This location in ICM is inconsistent with locations where other ICM flows are applied.
      - HALFF RESPONSE: This inflow is located upstream of the Caser Chavez bridge. Though this bridge is not located directly next the subbasin downstream boundary, it is close.

This inflow location is valid and conservative and consistent with the other inflow locations. This inflow was left as is.

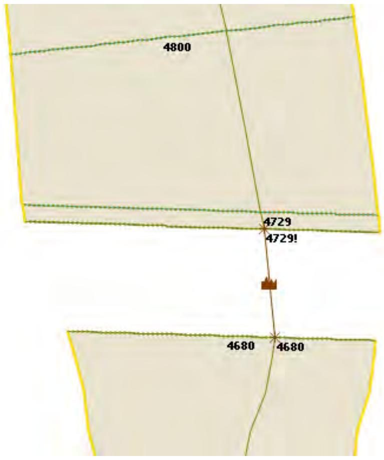
II. General Comments

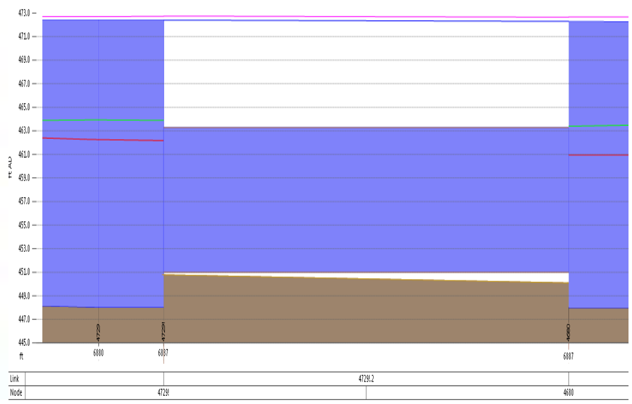
- Extent of ICM Model
  - Scope and ICM Modeling Notebook says ICM model extends from 15th St to Ladybird Lake but ICM model extends from 24th St to Ladybird Lake. Was model extended?
    - HALFF RESPONSE: Yes, model was extended upstream from 10th Street. We will clarify in model description that it wasn't just extended to 15th Street it was extended to 24th Street.
- Downstream Boundary Condition
  - No tailwaters considered for Lady Bird Lake
  - No Head-Discharge curve applied at the most DS point using User-control
  - Please explain/document downstream boundary conditions/assumptions.
  - Comparison of Flow, WSE with HEC-RAS is here:
    - 2DModeling_Checklist.xlsx
    - *Tab: Most DS River Reach Comparison*
    - HALFF RESPONSE: It was previously assumed that when no boundary condition is applied in ICM normal depth is applied. Normal depth was used in the previous HEC-RAS model. As a check a level with the normal pool elevation, 427' was applied as the downstream condition. This even more lower water surface elevation compared the 2013 RAS model results. The downstream boundary condition was changed to a head-discharge table boundary condition based on the results from the 2013 RAS model. See comparison table below.

	RAS Model	Pre-QC ICM normal depth / No DS condition	Normal Pool elevation (427') applied at DS node	Head-Discharge Table based on 2013 RAS model
10-yr	435	434.2	434.21	434.85
25-yr	435.96	435.3	435.25	435.74
50-yr	436.63	436.0	435.98	436.29
100-yr	437.21	436.7	436.74	436.85
500-yr	438.5	438.3	438.31	438.31
WSE are from cross section station 996				

- Inconsistencies in Bank Lines and River Reach Left and Right Bank Marker (Please confirm this is intentional)
  - Detailed comparison is here:
    - 2DModeling_Checklist.xlsx
    - *Tabs: BankLines Comparison_Right and BankLinesComparison_Left*
    - HALFF RESPONSE: We were aware of these differences. When the model was extended and converted some discharge coefficient and modular limits were modified to stabilize the model. The other differences come from ICM automatically adding nodes at XS ends, etc. A comparison of bank elevation and length between the reaches and bank lines was completed and the differences are non-existent or very minor. These differences were left as is.

- Inconsistencies in Cross-section Lines and River Reach Section Lines (Please confirm this is intentional)
  - Comparison is here (Not all Cross sections line and River Reach Section Lines were compared)
    - 2DModeling_Checklist.xlsx
    - *Tabs: XS_RR_Section_Comparison*
    - HALFF RESPONSE: When the model was calibrated to the May 2015 event some n-values were modified. These changes to the banks and the XS were made in the river reaches and not the actual XS and bank lines. The lines were not updated due to time constraints.
- InfoWorks Network Validation Warnings
  - ICM Model does not have errors in running the model. However, there are few warnings which can be rectified by rebuilding the river reaches. Please see comments here:
    - 2DModeling_Checklist.xlsx
    - *Tabs: XS_RR_Section_Comparison*
    - HALFF RESPONSE: When the model was calibrated to the May 2015 event some n-values were modified. These changes to the banks and the XS were made in the river reaches and not the actual XS and bank lines. The lines were not updated due to time constraints.
- InfoWorks Bridge Comparison with RAS Bridges
    - 2DModeling_Checklist.xlsx
    - *Tabs: ICM Bridge Comparison with RAS*
    - HALFF RESPONSE: Yes, the 2nd St Bridge (1501.1) was added based on as-builts. It was constructed more recently so it was not included in the RAS model.
    - 15th Street – no change needed. Only the piers that are adjacent to the XS are represented in the bridge XS. The rest of the columns are represented as voids in the overbank mesh. This is OK because the WSE does not reach near the top of deck.
- Bridge Revision
  - Some details are mentioned in this tab:
    - 2DModeling_Checklist.xlsx
    - *Tab: ICM Bridge Comparison with RAS*
  - Not all bridges are reviewed in depth
  - Recommendation to revise internal US/DS XS data in ICM (see comparison xls)
  - Internal XS n values do not always match (see comparison xls)
  - HALFF RESPONSE: Updated bridge XS to be consistent with adjacent reach n-values. This included changes on N Lamar, 12th, 10th, Pedestrian downstream of 5th, and 3rd St/RR. Internal bridge XS were based on survey and elevation data. The internal XS were not changed to exactly match. I verified that the contraction and expansion XS matched the adjacent reaches XS.
- Unusual Dip in WSEL as River Reach is missing between XS 4729! And XS 4680. This may result in change in volume and velocity. Although this is similar to RAS model, please review.





- Comparison of WSE in the irregular weir

RAS XS/ICM XS	100yr RAS WSE (ft)	100yr ICM WSE (ft)
4707 IS/4729.2	471.19	472.6

- HALFF RESPONSE: I checked the resulting WSE on the nodes and they were the same elevation as the XS. The blue line at the top represents and connects the WSE across the weir. The WSE is not dipping down, ICM is just not filling in flow across the weir.

- ICM vs RAS- Flow and WSE comparion
    - ICMvsRAS.xlsx
    - *Tab: ICMvsRAS*
- Please see flow and WSE comparison plotted in the “ICMvsRAS” tab of the Excel file noted above.
    - Other tabs (*ICM_FlowData, ICM_WSE Data, RAS*) have back up data pulled from ICM and RAS respectively.
    - Some ICM river section names (stations) are changed in ICM relative to HEC-RAS reach stations. Data from these mismatched HEC-RAS Cross Sections and ICM River Reach Section Lines are compared.
    - Minor differences in WSEs computed in RAS vs. ICM are shown.
    - Please confirm that there are no potential issues with the more significant differences in flows in ICM relative to flows in HEC-RAS, when comparing existing conditions in ICM to proposed alternatives in ICM.
        - HALFF RESPONSE: The ICM XS compared to the RAS XS do not represent the same area. In the 2D model flow spills out of the ICM XS on to the 2D mesh. This is where the significant difference in flow comes from. The ICM flow does not include the flow in the over banks. Flow spills out of the channel of Shoal throughout most of our study area.
- Roughness
    - Please provide a reference for the roughness values used in the roughness polygon and 1D river reach.
    - Few recommendations are provided here:
        - 2DModeling_Checklist.xlsx
        - *Tab: Roughness*
    - Comparison with RAS
        - At few XS roughness coefficients do match between RAS and ICM. Please confirm if this is intentional. For e.g. XS 6876, 6556

- HALFF RESPONSE: Overbank n-value shapefile was cleaned up to make sure there was consistency for the n-value reference. Any inconsistencies with the 2013 RAS model is due to the May 2015 calibration efforts.
  - 2D Overbank n-value reference:

Grass with no trees and brush	0.045 - 0.05
Grass with light brush & trees	0.07
Grass with medium brush & trees	0.09
Grass with dense brush & trees	0.11
Paved (100% impervious)	0.025
Residential or Light Business (no voids)	0.09
Industrial (no voids)	0.11

  - 1D Channel n-value reference:

Paved/ROW	0.03
Centerline of Channel	0.04 - 0.06
Grass with medium brush & trees	0.06 - 0.08
Grass with dense brush & trees	0.12

Lamar Underground Conveyance Pipe A with 1 upstream Intake Location

- Pipe located along N Lamar Blvd from just north of 15th Street to outfall into Lady Bird Lake
- Weir inlet was placed on the left overbank in Pease Park close to the bend in Shoal Creek for a more efficient diversion. The one intake location is split into two to avoid a piece of ROW located right at the bend.
    - Added 2 Mesh Level Zones, each 90 feet wide, to simulate the intake structures set at 472.5, 4.5 feet above the channel bottom seen at XS 8607
- Adjusted Bank Line 6111.1 left bank line! to accommodate the change in the terrain for the intake areas and updated river reach 6111.1 for this bank line
- Added a total of 7 nodes
    - 2 – 2D nodes, one in each mesh level zone for the intake
    - 4 – sealed manhole nodes along the length of the pipe to allow for changes in slope of the pipe
    - 1 – outfall node at Lady Bird Lake
- Added 6 links of conduits, all 10' x 40' rectangular boxes- 2 straight from the intakes (70 feet long and 200 feet long) combine flow at the center of N Lamar Blvd then continue as a single box

***Notes for all Lamar Pipes**

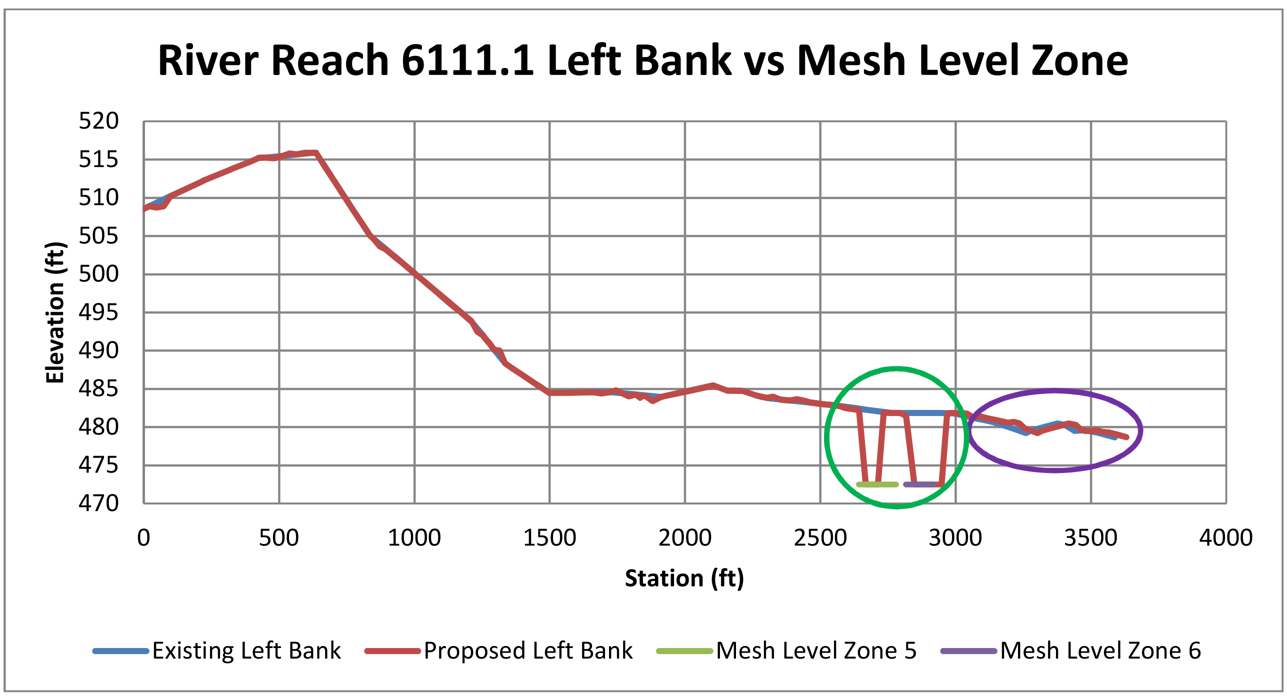
- We are still investigating possible utility conflicts along Lamar Blvd. Pipe elevations will be adjusted as needed once utility conflicts become clear.
- The downstream elevation of the pipe at the outfall was place at elevation 427'. This is the assumed normal pool elevation of Lady Bird Lake.

AECOM- Detail Check Comments

1. All Existing Post QC Comments are implemented in the Alternative Lamar Pipe A with 1 intake.
    a. HALFF RESPONSE: Noted.
2. Compared Existing and Alternatives Inflows. No Issues. (Spreadsheet: Lamar Pipe A with 1 Intake QC.xlsx, *Tab: 10yr_Flow_Inputs, 25yr_Flow_Inputs, 50yr_Flow_Inputs, 100yr_Flow_inputs and 500yr_Flow_inputs*)
    a. HALFF RESPONSE: Noted.
3. Compared DS boundary condition for all alternatives. No issues. (Spreadsheet: Lamar Pipe A with 1 Intake QC.xlsx, *Tab: DS BC_All Alternatives*)
    a. HALFF RESPONSE: Noted.
4. Two Mesh Level Zones were created to simulate the intake structures set at 472.5 ft and 4.5 ft above the channel bottom. The difference in the lowering of bank line and width of mesh level zone adjacent to the river reach is shown in the graph below (Green Circle). The proposed notch in the Shoal Creek left bank marker (the lowering of the bank line) is narrower than the mesh level zone. (Spreadsheet: Lamar Pipe A with 1 Intake QC.xlsx, *Tab: Mesh Level Zone*)
    - Mesh Level Zone '5': ~90 ft wide– Correct
    - Mesh Level Zone '6': ~100.7ft wide- Please review if this is acceptable.

    a. HALFF RESPONSE: The mesh level zone and bank has been corrected to match in length between the mesh level zone and bank.
5. No change in roughness compared to Existing conditions.
    a. HALFF RESPONSE: Noted.

6. River Reach 6111.1 Left Bank Comparison: Two notches were created in the proposed left bank to match the intake elevation (mesh level zone elevations). Notch for Mesh Level Zone ‘5’ is 90 ft wide at the top and 45.2 ft at the bottom. Should the bottom width of the notch associated with Mesh Level Zone ‘5’ be 90 ft? Notch for Mesh Level Zone ‘6’ is ~150ft at top and ~101 ft at the bottom. Should the bottom width of Mesh Level Zone ‘6’ be 90 ft? Please review the widths of the notches in the left bank line. Please see the green circle in the graph below. (Spreadsheet: Lamar Pipe A with 1 Intake QC.xlsx, *Tab: Bank Elevation*)
    a. HALFF RESPONSE: The mesh level zones have been combined into one. This has been corrected.
7. Proposed Bank Line downstream of the notches doesn’t match with the Existing conditions. Please see the purple circle in the graph below. (Spreadsheet: Lamar Pipe A with 1 Intake QC.xlsx, *Tab: Bank Elevation*)
    a. HALFF RESPONSE: This was checked. The elevations are consistent in the areas outside of the proposed project between existing and proposed. However, the stationing does change since the bank line was made longer for proposed so the elevations do not line up on a graph. No change was required.



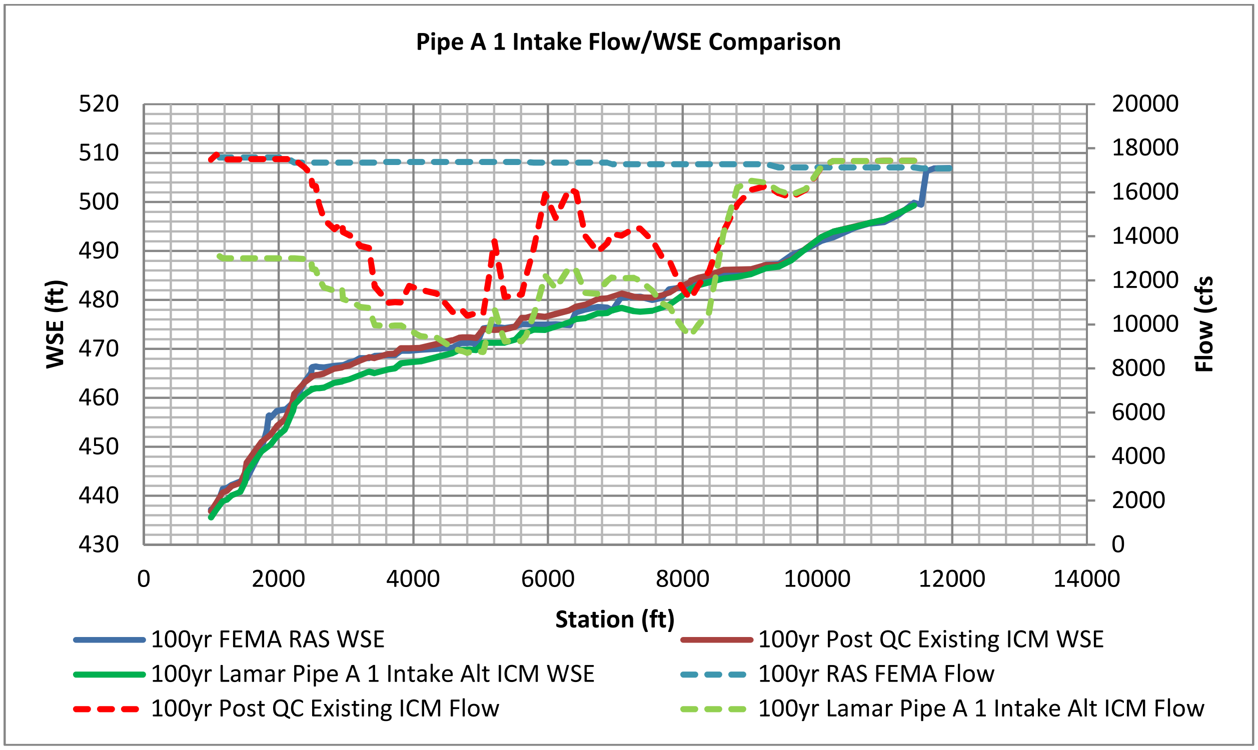
8. Seven Nodes were added to the model (6 Node type=manholes, 1 Node Type=outfall). Please review if the inlet type being different for ‘InletA’ and ‘InletAA’ are acceptable. Both are manholes, ‘InletA’ is type=*Combined* whereas ‘InletAA’ type is= *Other*.
    a. HALFF RESPONSE: All nodes and conduits were set to the “other” system type.

Database Value	Description	Help Text
STORM	Storm	Rainfall collection system
FOUL	Foul	Wastewater collection system (UK terminology)
SANITARY	Sanitary	Wastewater collection system (US terminology)
COMBINED	Combined	Rainfall and wastewater collection system
OVERLAND	Overland	Overland floodwater collection system
OTHER	Other	Other system type

9. Six Box Conduits added to the model. Please confirm whether it was intentional to specify the “System Type” of 2 conduits as “Other” and “System Type” of the remaining 4 conduits was defined as “Combined”.
    a. HALFF RESPONSE: All nodes and conduits were set to the “other” system type.
10. Conduit Inverts, was it intentional to have the top of the outfall pipe sticking up above existing ground elevations adjacent to Lady Bird Lake (see below)?
    a. PROP_4.1 DS invert is above the ground level.
    b. HALFF RESPONSE: This was not intentional. The ground elevation has been corrected to proposed conditions at the invert of the pipe. Please note the outfall of location and profile of the pipe has been changed to an inverted siphon type outlet.

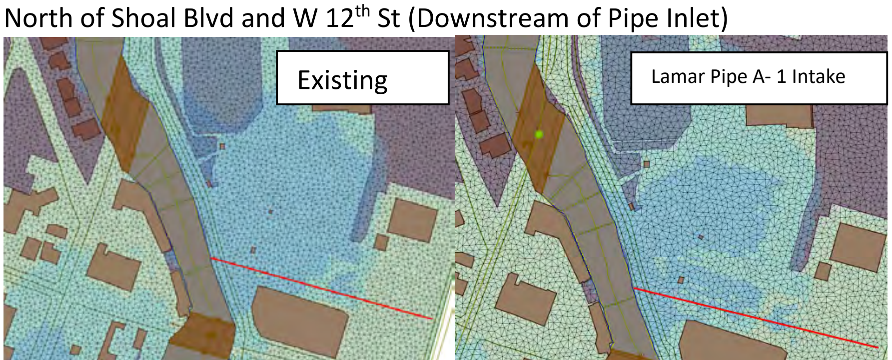
11. Pipe A DS boundary condition: Currently, it appears the assumption is no tailwater due to the pipe invert being set at the assumed normal pool elevation of 427 ft in Lady Bird Lake (LBL). What is source of this LBL normal pool elevation? The Colorado River Flood Damage Evaluation Project (FDEP) by Halff Associates, Inc. (2002) specifies a normal pool elevation of 428.3 ft. It is also recommended to coordinate with City of Austin to confirm that a higher tailwater assumption above the normal pool elevation of LBL would not be required.
    a. HALFF RESPONSE: Thank you for pointing this out. 427 was not the correct normal pool elevation to assume. 428.3 ft will be our assumed normal pool elevation for Lady Bird Lake. This matches with real time elevation data from LCRA along Lady Bird Lake.
12. River Reach WSE/Flow Figure (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: 100yr_LamarPipeA_1Inta_WSE_Flow*)
    a. Considerable amount of flow goes through the Lamar Pipe A which can be seen in the graph below.
    b. Please confirm that differences in WSE and flow are acceptable.

c. HALFF RESPONSE: The flood mitigation goal is to reduce the 100-year frequency storm event to near the 10 or 25 year event. This alternative does not quite reach the goal, but it will be moved further alternative analysis since it does have flood mitigation benefits. If you have specific concerns about the flow or WSE decrease, please let us know.



13. Flood Mitigation Testing

a. North of Shoal Blvd and W 12th St (Downstream of Pipe Inlet)



	100yr Existing (cfs)	100yr Pipe A-1 intake Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~3,062	~1,199
Max Depth (ft)	~10.17	~7.05
Max Speed (ft/s)	~2.27	~2.1

Improvements are seen in this alternative although other areas were not tested. You might consider importing a permanent Results 2D Line into the mesh of the existing and proposed ICM models as shown above so that a quick comparison can be made in specific areas to check for adverse impacts.

a. HALFF RESPONSE: Noted. How we assessed the flood mitigation impacts of the alternative is comparing inundated structures finished floor elevation (FFE) to the surrounding water surface elevation (using a buffer of 10'). We also looked at the linear feet of inundated roadway that was removed specifically at intersections. These shapefiles that were used will be provided in our QC response submittal to AECOM.

14. The two intake pipes connecting 2D flow in the two mesh level zones to the conduit system are both sized the same as the downstream single conduit (10ft x 40ft). Should the size of each inlet conduit be reduced to 10 ft x 20 ft to have an equivalent flow area as the conduit they connect to downstream (10ft x 40 ft)?
    a. HALFF RESPONSE: The modeling of the intakes has slightly changed. We tried to raise our intake elevation to the 2-yr WSE therefore we had to increase the length of our intake weir. With a larger intake area/mesh level zone, the capacity of that larger area would not be fully represented or utilized with just one node because water can only enter the 1D system at that node. Therefore, more nodes were added to ensure that water along the weir can enter the 1D pipe. There is a total of 17 nodes and the area of the entire intake area is 19,700 SF. 5' pipe laterals were used. The area of the lateral pipe or the chamber/shaft plan area for the inlet nodes does not exceed the area it would be per node.

Lamar Underground Conveyance Pipe A with 3 Intake Locations

- Pipe located along N Lamar Blvd from just north of 15th Street to its outfall into Lady Bird Lake
- This is similar to the first Lamar Pipe A option with a intake location on the left bank in Pease Park with two more intake locations at 9th Street and 6th Street.
- Added 4 Mesh Level Zones to simulate the intake structures
  - 2 about 800 feet north of 15th St at the channel bend, each 90 feet wide, set at 472.5, 4.5 feet above the channel bottom seen at XS 8607
  - 1 just north of the bridge at 9th St, at the channel bend, 35 feet wide, set at an elevation of 461 ft, 10.5 ft above the channel bottom seen at XS 5203
  - 1 just north of the bridge at 6th St, 45 feet wide, set at an elevation of 452 ft, 5.75 ft above the channel bottom at XS 3819
- Adjusted Bank Lines along mesh level zones to accommodate the change in the terrain for the intake areas and updated river reaches for new bank lines
  - Bank line 6111.1 left bank line! north of 15th St along river reach 6111.1
  - Bank line 5452.1 right bank line! north of 9th St along river reach 5357.1
  - Bank line 4680.1 right bank line! north of 15th St along river reach 4680.1
- Added a total of 11 nodes
  - 4 – 2D nodes, one in each mesh level zone for the intake
  - 6 – sealed manhole nodes along the length of the pipe where the intake boxes join the trunk line or to allow for changes in slope of the pipe
  - 1 – outfall node at Lady Bird Lake
- Added 10 links of conduits,
  - 5 - 10' x 40' rectangular boxes- 2 straight from the intakes (70 feet long and 200 feet long) combine flow at the center of N Lamar Blvd then continue as a single box until 9th Street
  - 1 – 10' x 50' rectangular box from 9th St to 6th St
  - 2 – 10' x 60' rectangular boxes from 6th St to outfall at Lady Bird Lake
  - 1 – 10' x 40' rectangular box, 160 ft long, from intake along 9th St to the trunk line at N Lamar Blvd
  - 1 – 10' x 40' rectangular box, 880 ft long, from intake along 6th St to the trunk line at N Lamar Blvd

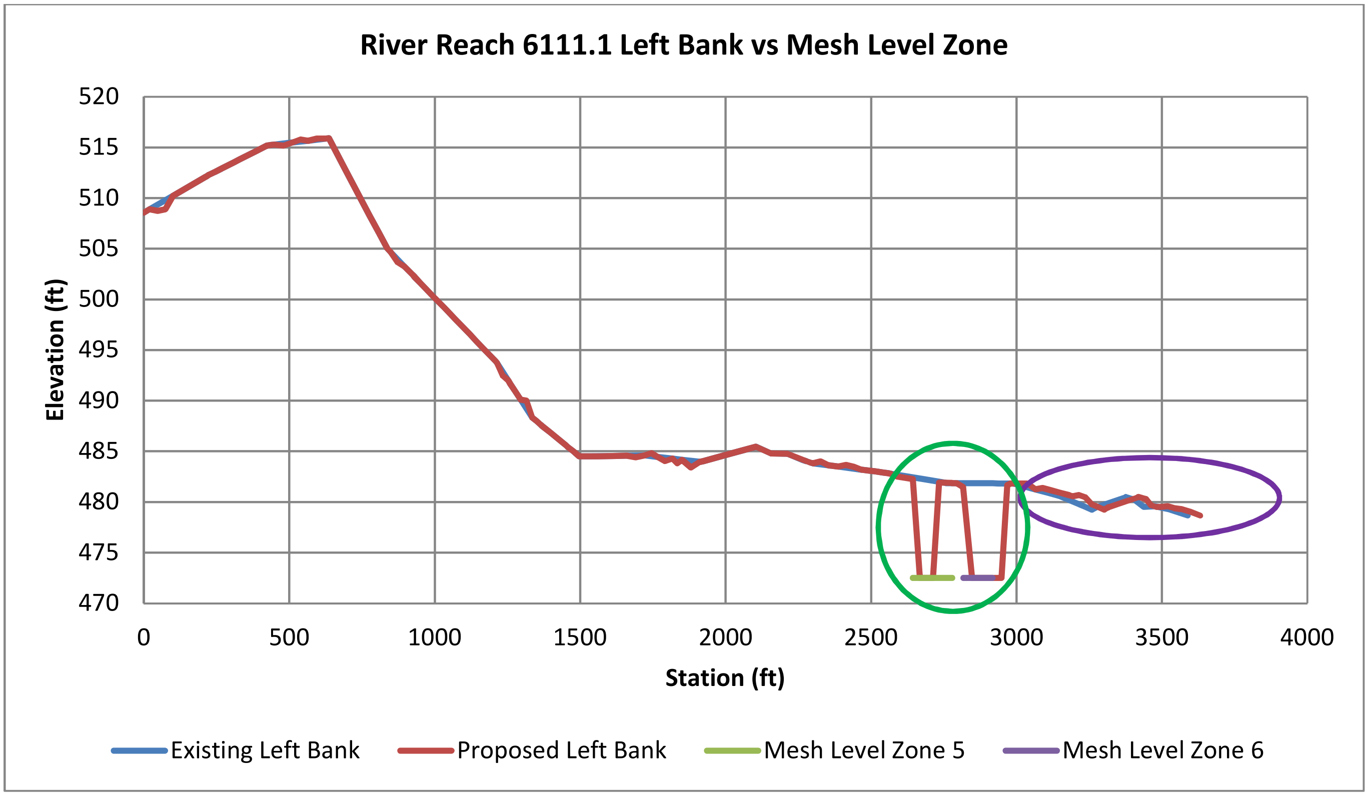
***Notes for all Lamar Pipes**

- We are still investigating possible utility conflicts along Lamar Blvd. Pipe elevations will be adjusted as needed once utility conflicts become clear.
- The downstream elevation of the pipe at the outfall was place at elevation 427'. This is the assumed normal pool elevation of Lady Bird Lake.

AECOM- Detail Check Comments

1. All Existing Post QC Comments are implemented in the Alternative Lamar Pipe A with 3 intakes.
   a. HALFF RESPONSE: Noted.
2. Compared Existing and Alternatives Inflows. No Issues. (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: 10yr_Flow_Inputs, 25yr_Flow_Inputs, 50yr_Flow_Inputs, 100yr_Flow_inputs and 500yr_Flow_inputs*)
   a. HALFF RESPONSE: Noted.

3. Compared DS boundary condition for all alternatives. No issues. (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: DS BC_All Alternatives*)
    a. HALFF RESPONSE: Noted.
4. Mesh Level Zone At River Reach 6111.1 (*Comments repeated from Lamar Pipe A with 1 Intake*)
Two Mesh Level Zones were created to simulate the intake structures set at 472.5 ft and 4.5 ft above the channel bottom. The difference in the lowering of bank line and width of mesh level zone adjacent to the river reach is shown in the graph below (Green Circle). The proposed notch in the Shoal Creek left bank marker (the lowering of the bank line) is narrower than the mesh level zone. (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: Mesh Level Zone*)
    (i) Mesh Level Zone '5': ~90 ft wide– Correct
    (ii) Mesh Level Zone '6': ~100.7ft wide- Please review if this is acceptable.
    (iii) No change in roughness compared to Existing conditions.
    b. HALFF RESPONSE: Mesh level zones and bank lines were checked and revised as needed to make sure the elevations and widths were consistent.
5. River Reach 6111.1 Left Bank Comparison: Two notches were created in the proposed left bank to match the intake elevation (mesh level zone elevations). Notch for Mesh Level Zone '5' is 90 ft wide at the top and 45.2 ft at the bottom. Should the bottom width of the notch associated with Mesh Level Zone '5' be 90 ft? Notch for Mesh Level Zone '6' is ~150ft at top and ~101 ft at the bottom. Should the bottom width of Mesh Level Zone '6' be 90 ft? Please review the widths of the notches in the left bank line. Please see the green circle in the graph below. (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: Bank Elevation*)
    a. HALFF RESPONSE: The mesh level zones have been combined into one. This has been corrected.
6. Proposed Bank Line downstream of the notches doesn't match with the Existing conditions. Please see the purple circle in the graph below. (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: Bank Elevation*)
    a. HALFF RESPONSE: This was checked. The elevations are consistent in the areas outside of the proposed project between existing and proposed. However, the stationing does change since the bank line was made longer for proposed so the elevations do not line up on a graph. No change was required.



7. Mesh Level Zone At River Reach 5357.1 (Spreadsheet: [Lamar Pipe A with 3 Intake QC.xlsx](), *Tab: Mesh Level Zone*) is shown in the figure below.
   Mesh Level Zone (ID=22) was created by editing the River Reach 5357.1.

(i) No change in roughness compared to existing conditions.

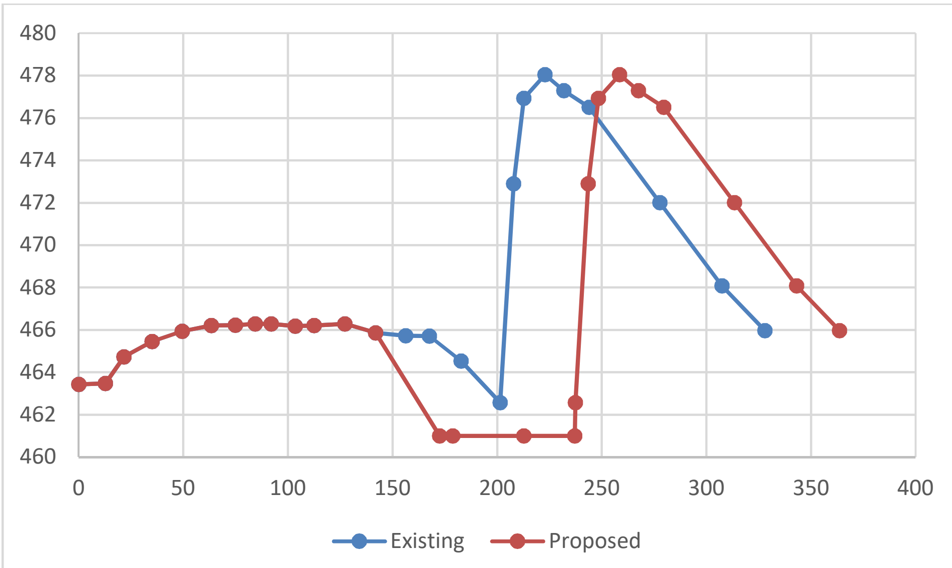
(ii) Mesh Level Zone is ~40 ft wide, because of abrupt extension in the mesh level zone (see red circle in the figure above). Please review if this is acceptable.

(iii) Mesh Level Zone elevation matches with lowered proposed bank line.

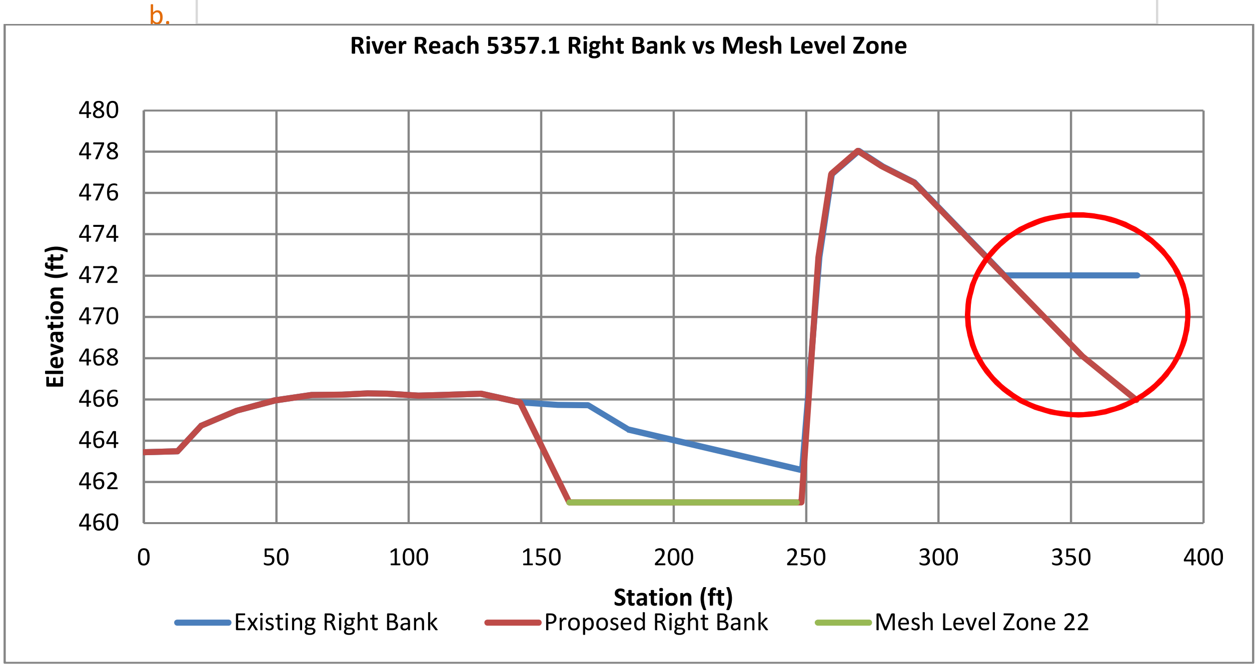
(iv) Mesh Level Zone is 10.5 ft above the channel bottom seen at XS 5203

b. HALFF RESPONSE: The abrupt extension of the mesh level zone and bank has been removed and corrected.

8. Please review the difference in proposed and existing right bank elevations of river reach 5357.1 as shown in the figure below (see red circle below). (Spreadsheet: [Lamar Pipe A with 3 Intake QC.xlsx](), *Tab: Bank Elevation*)
   Please note: Stations of existing 5357.1 right bank is adjusted to match with proposed conditions.
   a. HALFF RESPONSE: The bank was corrected in existing conditions. See updated graph below



b.



9. Mesh Level Zone At River Reach 4680.1 (Spreadsheet: [Lamar Pipe A with 3 Intake QC.xlsx](), *Tab: Mesh Level Zone, Tab: Bank Elevation*)
   Mesh Level Zone (ID=23) was created by editing the River Reach 4680.1.
   (i) No change in roughness compared to existing conditions.
   (ii) Mesh Level Zone is ~50.6 ft wide. Please review if this is acceptable.

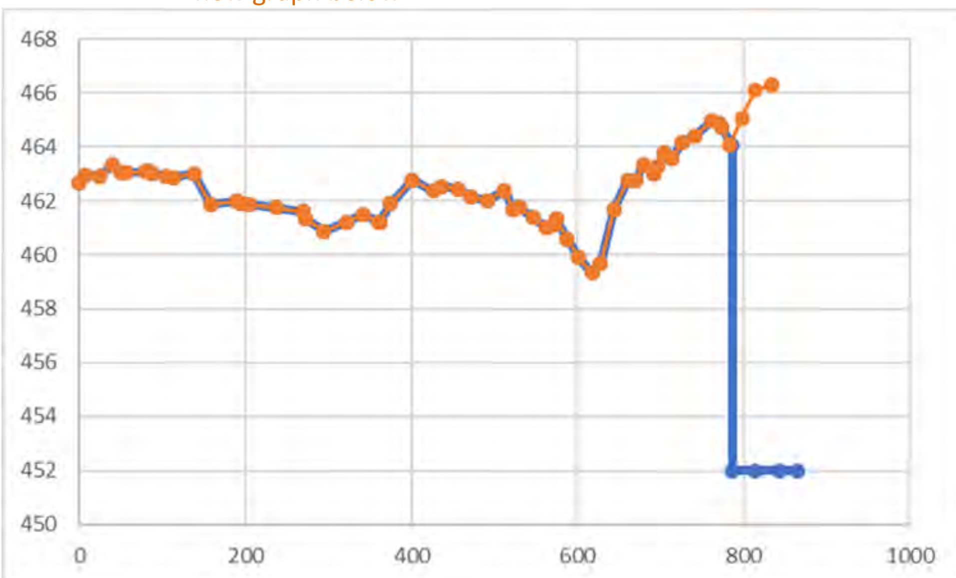
(iii) Mesh Level Zone is ~5.75 ft above the channel bottom at XS 3819

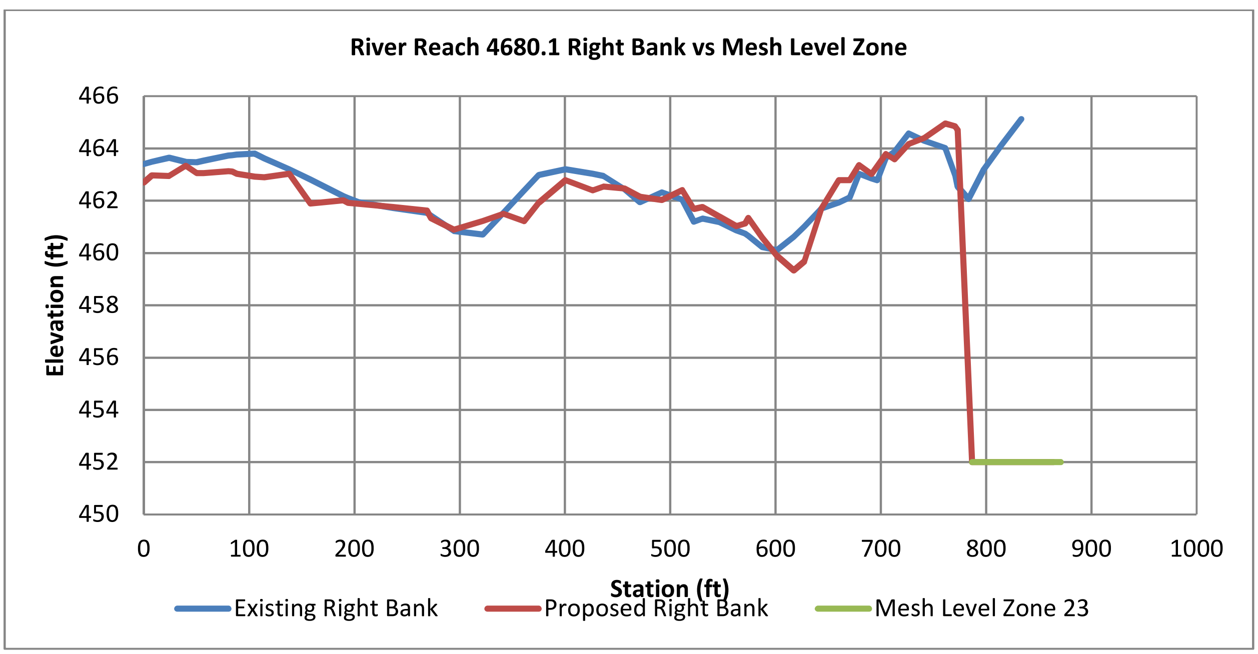
(iv) Mesh Level Zone elevation matches with lowered proposed bank line.

b. HALFF RESPONSE: The mesh level zone was slightly adjusted to not be located on adjacent properties. If you have specific concerns on the width, please let us know.

10. Please review the proposed and existing right banks of river reach 5357.1 as shown in the figure below. (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: Mesh Level Zone, Tab: Bank Elevation*) Please note, although no adjustments were made in the stationing, differences in elevations were observed all along the bank line (including upstream of mesh level zone '23').

a. HALFF RESPONSE: Banks were checked for consistencies and this was corrected. See new graph below





11. Eleven Nodes were added to the model (10 Node type=manholes, 1 Node Type=outfall). Please review if the inlet type being different for 'InletA' and 'InletAA' are acceptable. All nodes are

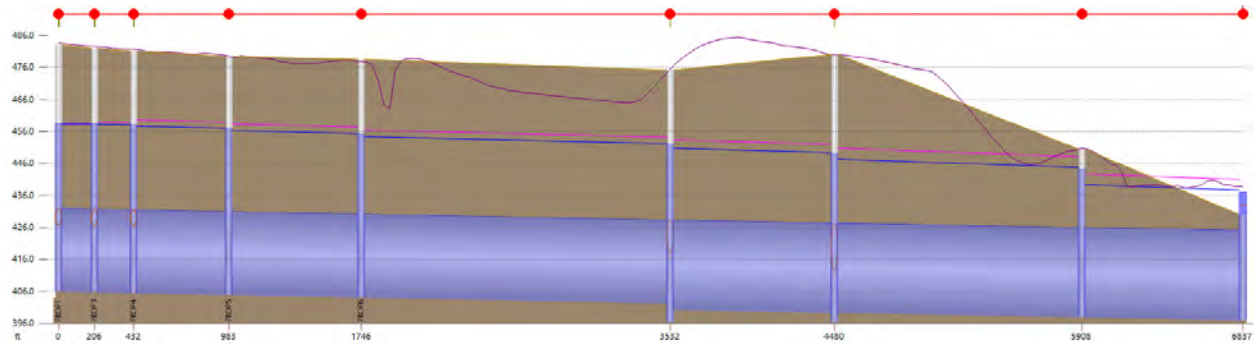
manholes, 'InletA' is type=*Combined* whereas 'InletAA' type is= *Other*. 'InletC' and 'Inlet D' are used type 'Other".

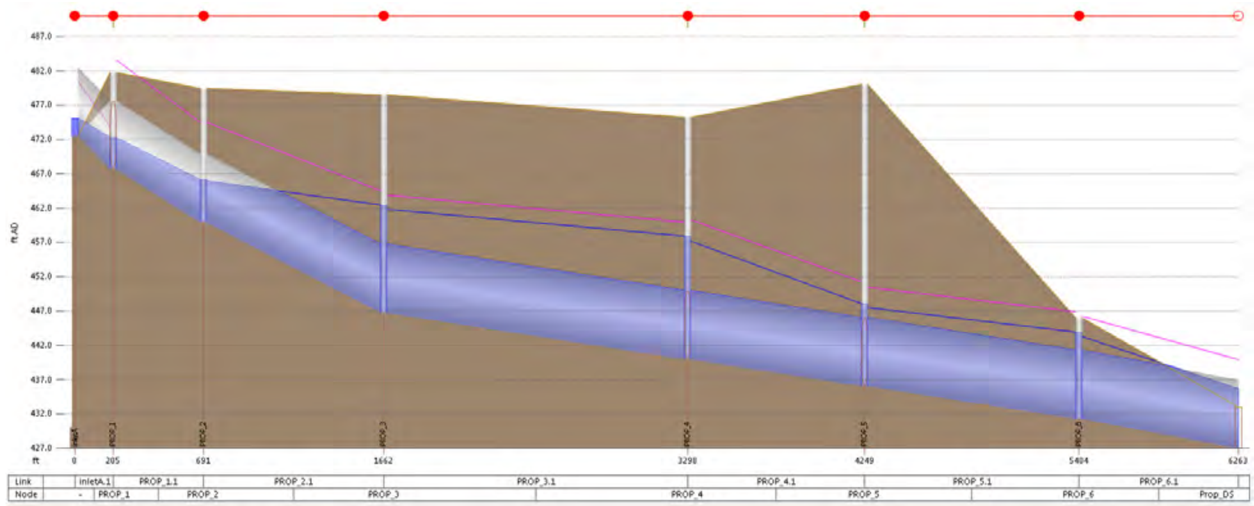
  a. HALFF RESPONSE: All nodes and conduits were set to the "other" system type.

Database Value	Description	Help Text
STORM	Storm	Rainfall collection system
FOUL	Foul	Wastewater collection system (UK terminology)
SANITARY	Sanitary	Wastewater collection system (US terminology)
COMBINED	Combined	Rainfall and wastewater collection system
OVERLAND	Overland	Overland floodwater collection system
OTHER	Other	Other system type

12. Ten Box Conduits added to the model. Please confirm whether it was intentional to specify the "System Type" of 6 conduits as "Other" and "System Type" of the remaining 4 conduits was defined as "Combined".
    a. HALFF RESPONSE: All nodes and conduits were set to the "other" system type.
13. Conduit Inverts: Was it intentional to have the top of the outfall pipe sticking up above existing ground elevations adjacent to Lady Bird Lake (see below)?
    a. PROP_6.1 DS invert is above the ground level
    b. HALFF RESPONSE: This was not intentional. The ground elevation has been corrected to proposed conditions at the invert of the pipe. Please note the outfall of location and profile of the pipe has been changed to an inverted siphon type outlet.

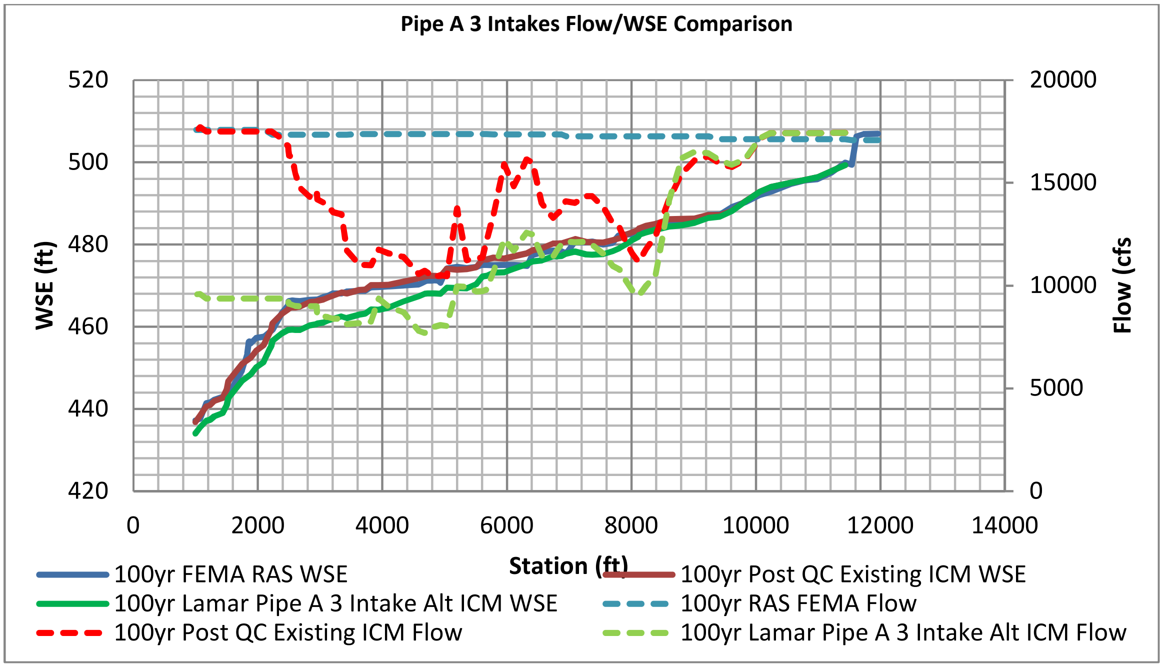
14. Please review the conduit conveyance capacity. HGL for 100-yr is above ground at the outfall since top of pipe is above ground at the outfall. Are HGLs shown below consistent with your expectations of how the proposed conduit should perform for 100-yr event?
    a. HALFF RESPONSE: The profile of the pipe has significantly changed. The lidar ground elevation is shown on the new profile copied below (magenta line). It was made sure that the HGL remained below the ground surface where access points could possibly be proposed.





15. Pipe A DS boundary condition: Currently, it appears the assumption is no tailwater due to the pipe invert being set at the assumed normal pool elevation of 427 ft in Lady Bird Lake (LBL). What is source of this LBL normal pool elevation? The Colorado River Flood Damage Evaluation Project (FDEP) by Halff Associates, Inc. (2002) specifies a normal pool elevation of 428.3 ft. It is also recommended to coordinate with City of Austin to confirm that a higher tailwater assumption above the normal pool elevation of LBL would not be required.
    a. HALFF RESPONSE: Thank you for pointing this out. 427 was not the correct normal pool elevation to assume. 428.3 ft will be our assumed normal pool elevation for Lady Bird Lake. This matches with real time elevation data from LCRA along Lady Bird Lake.

16. River Reach WSE/Flow Figure (Spreadsheet: Lamar Pipe A with 3 Intake QC.xlsx, *Tab: 100yr_LamarPipeA_3Inta_WSE_Flow*)
    a. Considerable amount of flow goes through the Lamar Pipe A which can be seen in the graph below.
    b. Please confirm that differences in WSE and flow are acceptable.
    c. HALFF RESPONSE: The flood mitigation goal is to reduce the 100-year frequency storm event to near the 10 or 25 year event. This option is reducing the 100-year flow by approximately 21% which is just above the 25-year event. If you have specific concerns about the flow or WSE decrease, please let us know.



17. Flood Mitigation Testing

a. North of Shoal Blvd and W 12th St (Downstream of Pipe Inlet)

	100yr Existing (cfs)	100yr Pipe A-3 intake Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~3,062	~1,113
Max Depth (ft)	~10.17	~7.00
Max Speed (ft/s)	~2.27	~1.88

Improvements are seen in this alternative although other areas were not tested. You might consider importing a permanent Results 2D Line into the mesh of the existing and proposed ICM models as shown above so that a quick comparison can be made in specific areas to check for adverse impacts.

a. HALFF RESPONSE: Noted. How we assessed the flood mitigation impacts of the alternative is comparing inundated structures finished floor elevation (FFE) to the surrounding water surface elevation (using a buffer of 10'). We also looked at the linear feet of inundated roadway that was removed specifically at intersections. These shapefiles that were used will be provided in our QC response submittal to AECOM.

Lamar Underground Conveyance Pipe B

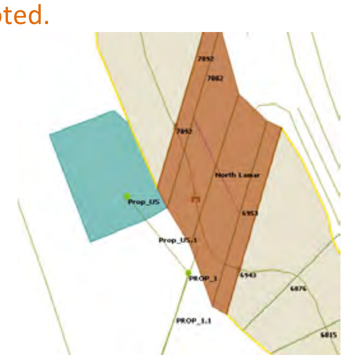
- Pipe along N Lamar Blvd from the Shoal Creek crossing at about Parkway to outfall into Lady Bird Lake
- Added 1 Mesh Level Zones to simulate the intake structures just US of the N Lamar Blvd bridge, 120 ft wide, set to an elevation of 464 ft, 3 feet above the channel bottom at XS 7092
- Adjusted Bank Line 7687_Right along mesh level zone to accommodate the change in the terrain for the intake areas and updated river reach 7687.1 for new bank line
- Added a total of 6 nodes
    - o 1 – 2D node in the mesh level zone for the intake
    - o 4 – sealed manhole nodes along the length of the pipe to allow for changes in slope of the pipe
    - o 1 – outfall node at Lady Bird Lake
- Added 5 links of conduits, all 10' x 20' rectangular boxes- 1 straight from the intake (100 feet long) across to the center of N Lamar Blvd for a length of 4,500 ft
- Deleted polygons 2084 and 2085 because they were within the intake mesh level zone area

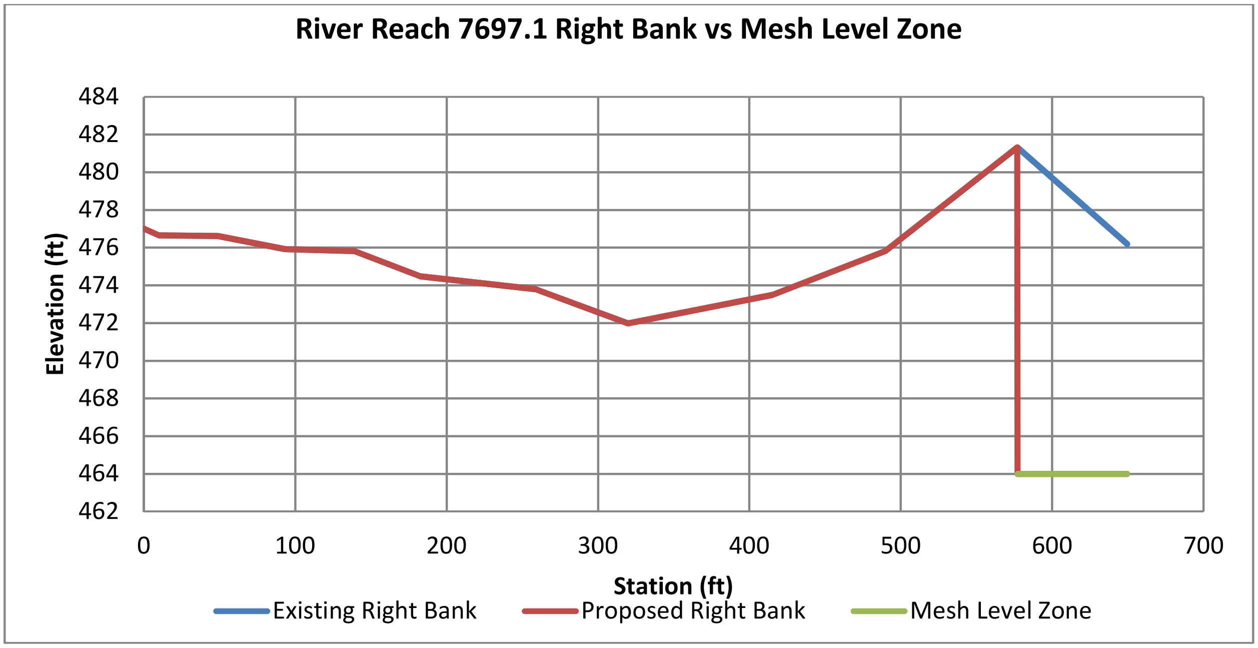
*Notes for all Lamar Pipes

- We are still investigating possible utility conflicts along Lamar Blvd. Pipe elevations will be adjusted as needed once utility conflicts become clear.
- The downstream elevation of the pipe at the outfall was place at elevation 427'. This is the assumed normal pool elevation of Lady Bird Lake.

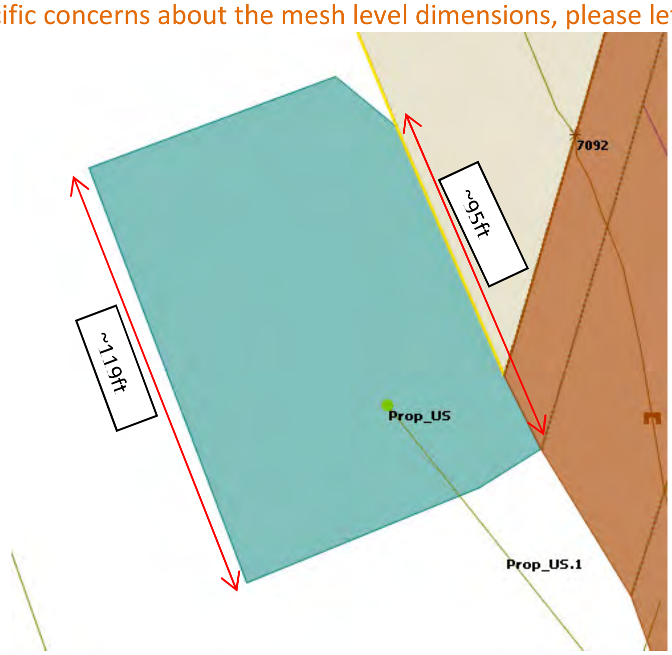
AECOM- Detail Check Comments

1. All Existing Post QC Comments are implemented in the Alternative Lamar Pipe B.
    a. HALFF RESPONSE: Noted.
2. Compared Existing and Alternatives Inflows. No Issues. (Spreadsheet: Lamar Pipe B QC.xlsx, Tab: 10yr_Flow_Inputs, 25yr_Flow_Inputs, 50yr_Flow_Inputs, 100yr_Flow_inputs and 500yr_Flow_inputs)
    a. HALFF RESPONSE: Noted.
3. Compared DS boundary condition for all alternatives. No issues. (Spreadsheet: Lamar Pipe B QC.xlsx, *Tab: DS BC_All Alternatives*)
    a. HALFF RESPONSE: Noted.
4. River Reach 7697.1 Right Bank is lowered to match the mesh level zone elevation. This matches as shown in the figure below. (Spreadsheet: Lamar Pipe B QC.xlsx, *Tab: MeshLevelZone*)
    a. HALFF RESPONSE: Noted.





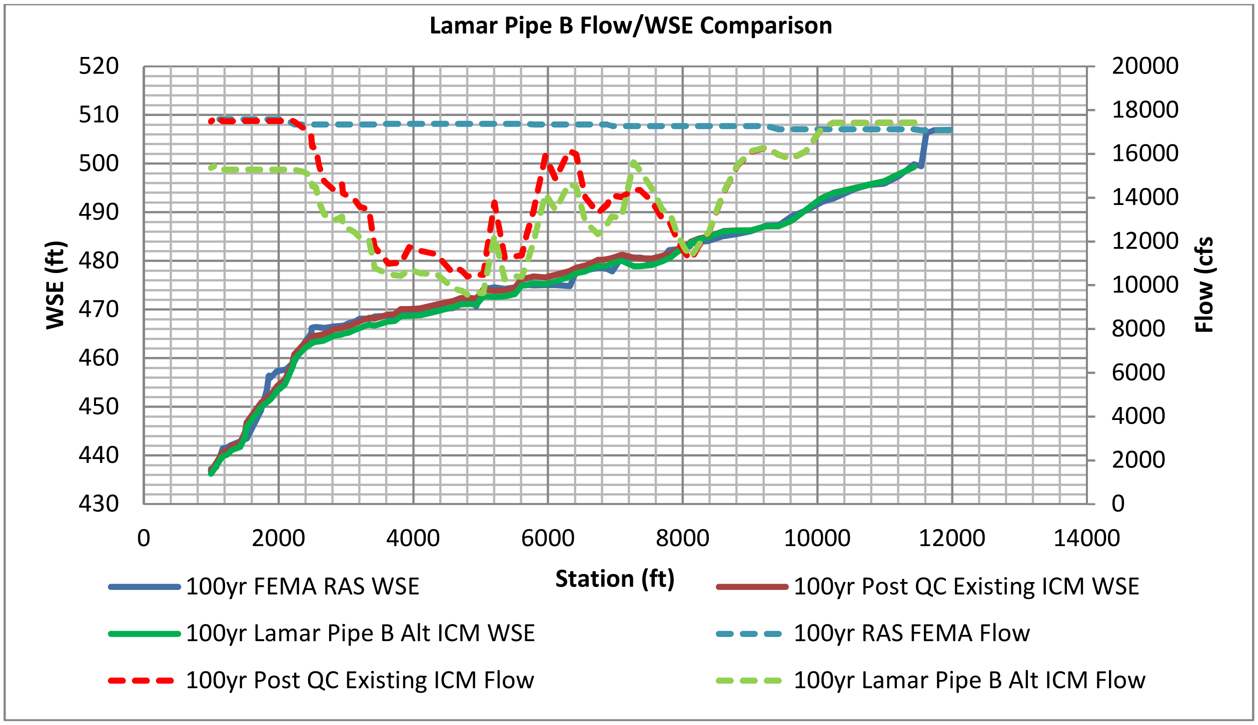
5. Please review whether the dimensions of the mesh level zone shown below are acceptable. Mesh Level Zone is ~95ft adjacent to the River Reach 7697.1/North Lamar Bridge.
    a. HALFF RESPONSE: We are including in this cost estimate potential buyouts of the properties located in the existing lots. Therefore, the dimensions are appropriate. If you have specific concerns about the mesh level dimensions, please let us know.



6. Mesh Level Zone is 3 feet above the channel bottom at XS 7092. Correct.
    a. HALFF RESPONSE: Noted.
7. Six Nodes are added for Lamar Pipe B. 2 2D Nodes, 4 Sealed as Manholes.
    a. HALFF RESPONSE: Noted.
8. 5 box conduits are added to the model. System type= *Other*.
    a. HALFF RESPONSE: Noted.
9. Conduit Inverts, was it intentional to have the top of the outfall pipe sticking up above existing ground elevations adjacent to Lady Bird Lake (see below)?

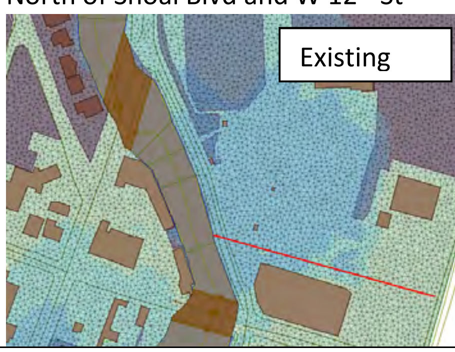
a. PROP_4.1 DS invert is ground level.
b. HALFF RESPONSE: This was not intentional. The ground elevation has been corrected to proposed conditions at the invert of the pipe. Please note the outfall of location and profile of the pipe has been changed to an inverted siphon type outlet.

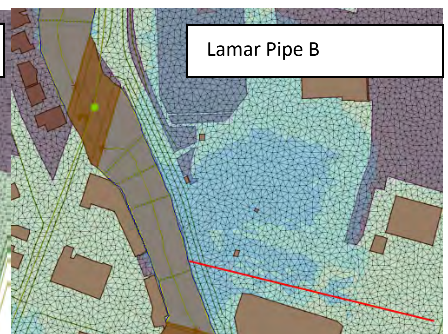
10. Pipe A DS boundary condition: Currently, it appears the assumption is no tailwater due to the pipe invert being set at the assumed normal pool elevation of 427 ft in Lady Bird Lake (LBL). What is source of this LBL normal pool elevation? The Colorado River Flood Damage Evaluation Project (FDEP) by Halff Associates, Inc. (2002) specifies a normal pool elevation of 428.3 ft. It is also recommended to coordinate with City of Austin to confirm that a higher tailwater assumption above the normal pool elevation of LBL would not be required.
    a. HALFF RESPONSE: Thank you for pointing this out. 427 was not the correct normal pool elevation to assume. 428.3 ft will be our assumed normal pool elevation for Lady Bird Lake. This matches with real time elevation data from LCRA along Lady Bird Lake.
11. River Reach WSE/Flow Figure (Spreadsheet: Lamar Pipe B QC.xlsx, *Tab: 100yr_LamarPipeB_WSE_Flow*)
    a. Considerable amount of flow goes through the Lamar Pipe B which can be seen in the graph below.
    b. Please confirm that differences in WSE and flow are acceptable.
    c. HALFF RESPONSE: The flood mitigation goal is to reduce the 100-year frequency storm event to near the 10 or 25-year event. This alternative does not quite reach the goal, but it will be moved further alternative analysis since it does have flood mitigation benefits. If you have specific concerns about the flow or WSE decrease, please let us know.



12. Flood Mitigation:

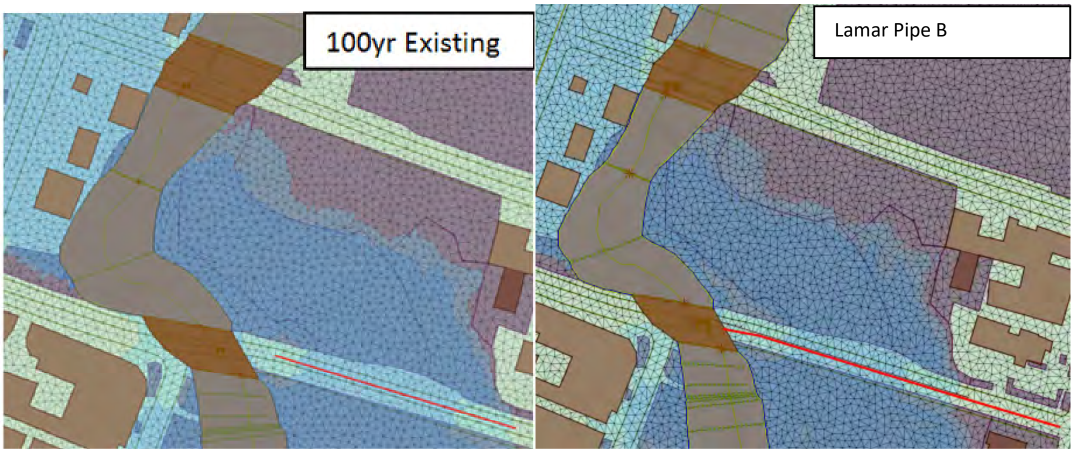
a. North of Shoal Blvd and W 12th St





	100yr Existing (cfs)	100yr Pipe B Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~3,062	~2,182
Max Depth (ft)	~10.17	~8.8
Max Speed (ft/s)	~2.27	~1.92

b. Duncan Park



	100yr Existing (cfs)	100yr Pipe B Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~6,350	~5,188
Max Depth (ft)	~8.4	~7.47
Max Speed (ft/s)	~3.25	~2.99

Slight improvements are seen in this alternative at the above shown comparison, although other areas were not tested. You might consider importing a permanent Results 2D Line into the mesh of the existing and proposed ICM models as shown above so that a quick comparison can be made in specific areas to check for adverse impacts.

a. HALFF RESPONSE: Noted. How we assessed the flood mitigation impacts of the alternative is comparing inundated structures finished floor elevation (FFE) to the surrounding water surface elevation (using a buffer of 10'). We also looked at the linear feet of inundated roadway that was removed specifically at intersections. These shapefiles that were used will be provided in our QC response submittal to AECOM.

<u>Inline Detention Pond C – Information Provided by Halff</u>

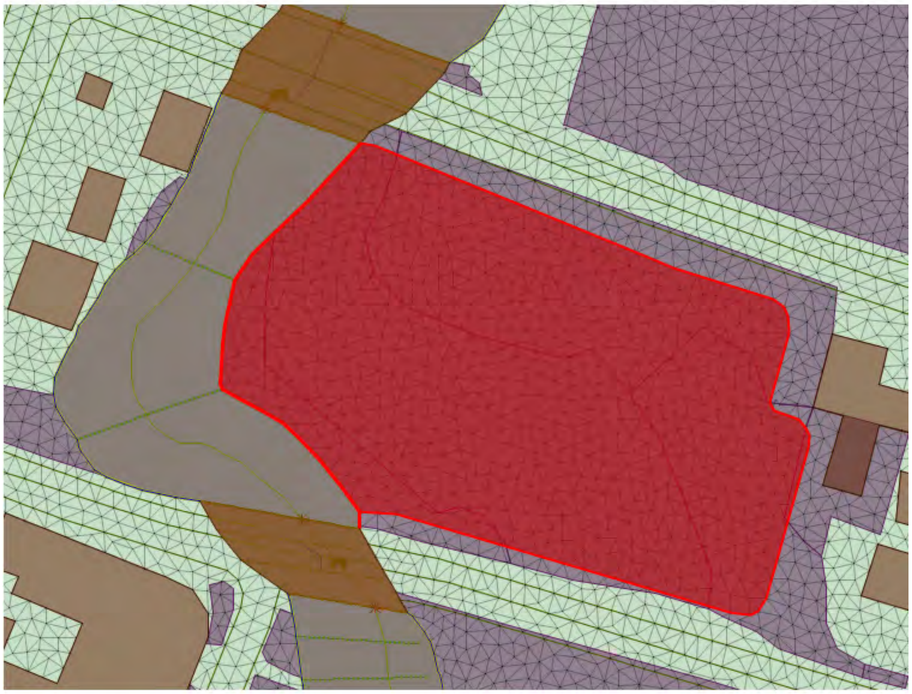
- Inline pond along Lower Shoal Creek located on the Duncan Neighborhood Park property between W 10th St and W 9th St
- Pond C was modeled as a mesh level zone.
- The pond elevations and river reach left bank elevations were set to be above the ordinary high-water marks (OHWM) for the channel located adjacent to the pond.
- Since the pond is only located on the left overbank, only the left bank was adjusted to the bottom elevation of the pond.
- Assumed ordinary high-water mark elevations:
    - XS 5511 – 458.05'
    - XS 5357 – 455.21'
    - XS 5203 – 453.13'
    - XS 5036 – 456.30'
- XS 5511, 5357, and 5203 were adjusted on the left overbank to represent pond (used assumed OHWM elevations)
- The overbank n-values located within the pond were lowered to 0.04
- Reaches 5511.1 and 5357.1 were merged.

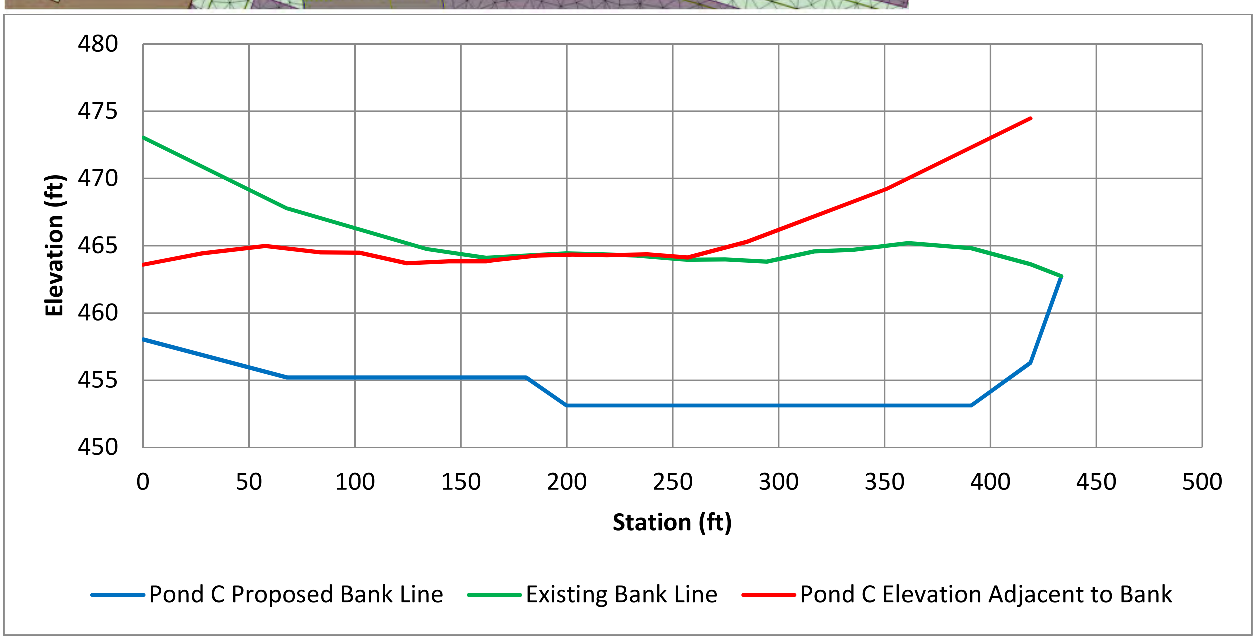
<u>AECOM- Detail Check Comments</u>

1. All Existing Post QC Comments are implemented in the Alternative Pond C.
    a. HALFF RESPONSE: Noted
2. Compared Existing and Alternatives Inflows. No Issues. (Spreadsheet: Pond C QC.xlsx, *Tab: 10yr_Flow_Inputs, 25yr_Flow_Inputs, 50yr_Flow_Inputs, 100yr_Flow_inputs and 500yr_Flow_inputs*)
    a. HALFF RESPONSE: Noted
3. Compared DS boundary condition for all alternatives. No issues. (Spreadsheet: Pond C QC.xlsx, *Tab: DS BC_All Alternatives*)
    a. HALFF RESPONSE: Noted
4. Can you please provide the design criteria for Pond C (e.g. 50-yr flood does not overtop)?
    a. HALFF RESPONSE: We did not have a set design criterion. This model was an exercise to see if increasing storage of Shoal Creek in the available area would have any impact on flood mitigation downstream. This would be considered if the pond was moved into further evaluation.
5. Mesh Level Zone for Pond C: Elevation of vertices are modified and entered in ICM using Type "Specify":
    (i) Under what condition are the elevations of vertices calculated? The difference between raster elevation and vertices' elevation can be found in the Pond C QC.xlsx Spreadsheet (*Tab: Mesh Level Zone*).
    a. HALFF RESPONSE: The bottom elevations of the pond were based on the assumed OHWM of the XS within the reach. We wanted to remain above that elevation.
    (ii) Was the intention to make vertical walls in the pond?
    a. HALFF RESPONSE: Since this was a high-level exercise and we were trying to maximize the volume available, we assumed vertical walls.
6. In the plot below, three elevation profiles are shown from alignments on the left (eastern) bank of Shoal Creek and the western border of the proposed Pond C (see corresponding profile alignment highlighted in red in plan view below). The proposed profile elevations associated with the western border of Pond C are significantly higher than the proposed elevations for the left bank of Shoal Creek. If the bottom elevation of the pond is intended to connect to the left bank of Shoal Creek,

the red and blue profile elevations plotted below should line up on top of each other, but they do not. (*Spreadsheet:* Pond C QC.xlsx, *Tab: MeshLevelZone*)

a. HALFF RESPONSE: The bank line and mesh level zone elevations were revised to be consistent with each other. The mesh level zone represents the proposed pond in the mesh adjacent to the bank line.



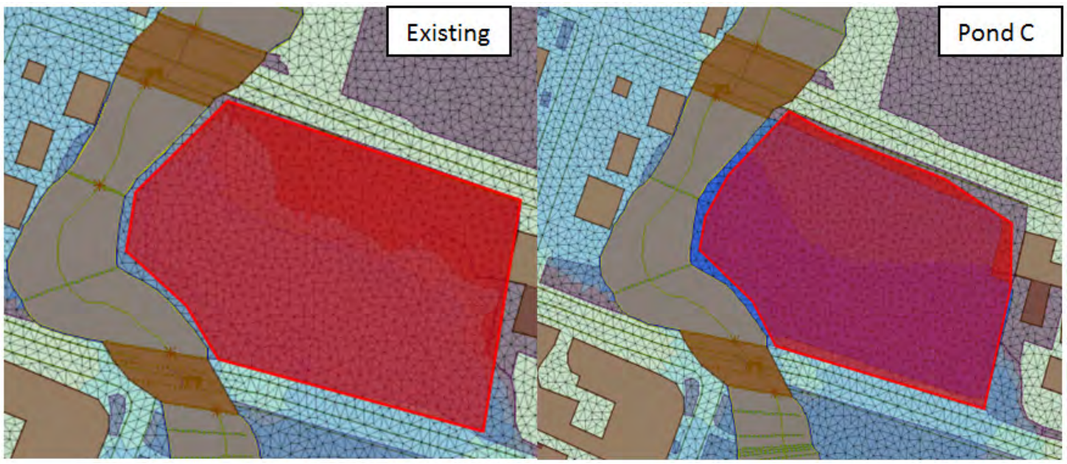


7. Discharge coefficients are manually changed from 0.3 to 0.5 for only 3 of the left River Reach Bank Marker vertices. (Spreadsheet: Pond C QC.xlsx, *Tab Pond C Bank Elevations*). Is this intentionally changed just for 3 vertices? What is justification/reference used to change bank discharge coefficients?

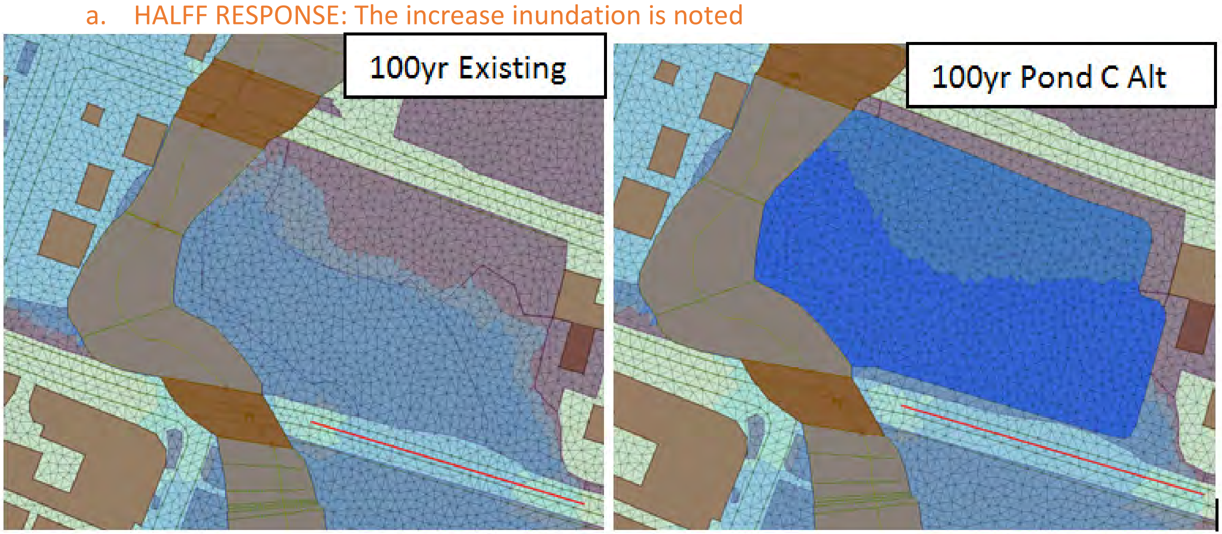
   a. HALFF RESPONSE: This was unintentional. The discharge coefficients were modified to remain consistent with existing conditions.

8. When reviewing existing vs. proposed roughness polygons, Roughness Coefficient (0.4) extends outside of Pond C. Was it intentional to change roughness outside of proposed pond?
    a. HALFF RESPONSE: This was done intentional, n-values were modified for minimal areas adjacent to the pond near ROW. This is deemed appropriate for this high-level analysis.
9. As a test, a results 2D polygon was drawn around the proposed pond (red boundary in the figure below) in both the existing and proposed ICM models. The approximate existing and proposed peak volumes enclosed by the polygon are:
    (i) Max 100yr Existing Storage approximately= ~749,065 ft^3
    (ii) Max 100yr Pond C Alternative approximately= ~2,347,348 ft^3

    Storage in Alternative Pond C > Storage in Existing Condition. Pond C is able to store ~54 ac-ft of volume. Is this roughly what the pond was designed to store?
    a. HALFF RESPONSE: The pond is expected to hold between 40-50 acre-feet. The extra capacity probably comes since the pond would be exceed in the 100-yr.



10. Results 2D line (Red line in the figure below) was drawn downstream of the pond in 100yr Existing and 100yr Pond C Alternative.
    a. HALFF RESPONSE: The increase inundation is noted



11.

	100yr Existing (cfs)	100yr Pond C Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~6,350	~7,161
Max Depth (ft)	~8,4	~8.7
Max Speed (ft/s)	~3.25	~3.26

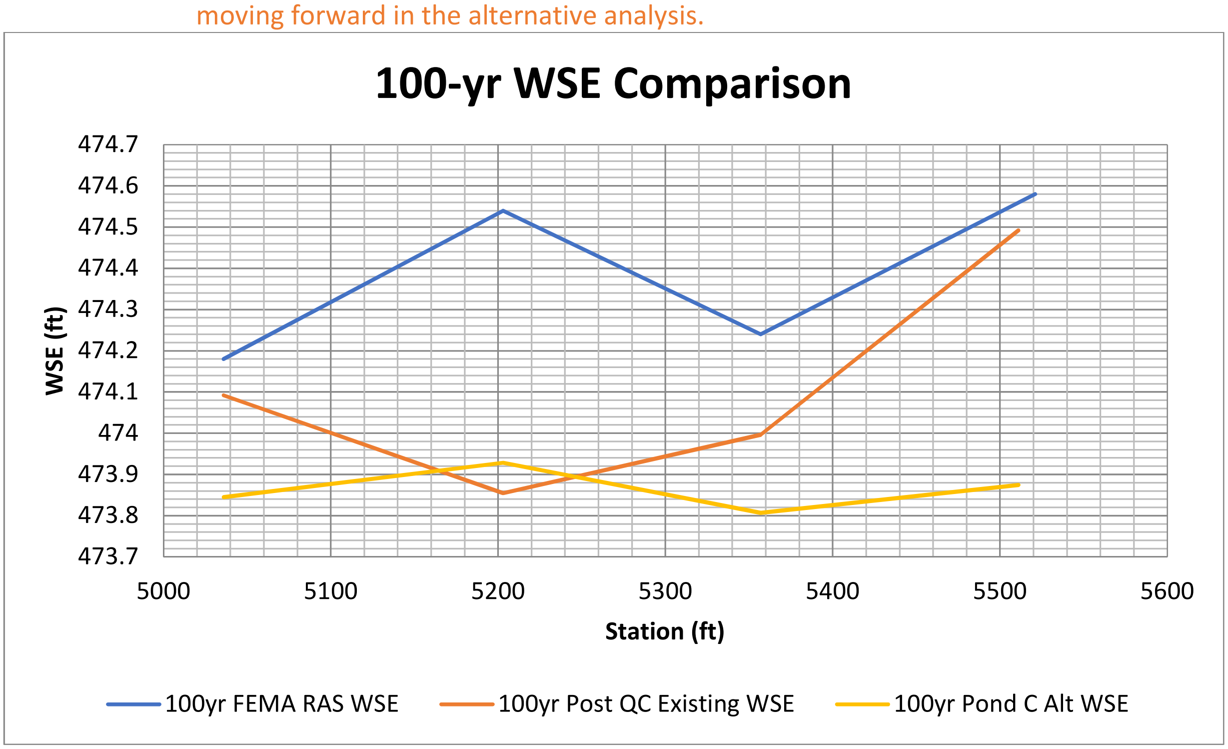
Based on the above results, Pond C is adversely impacting flooding downstream.

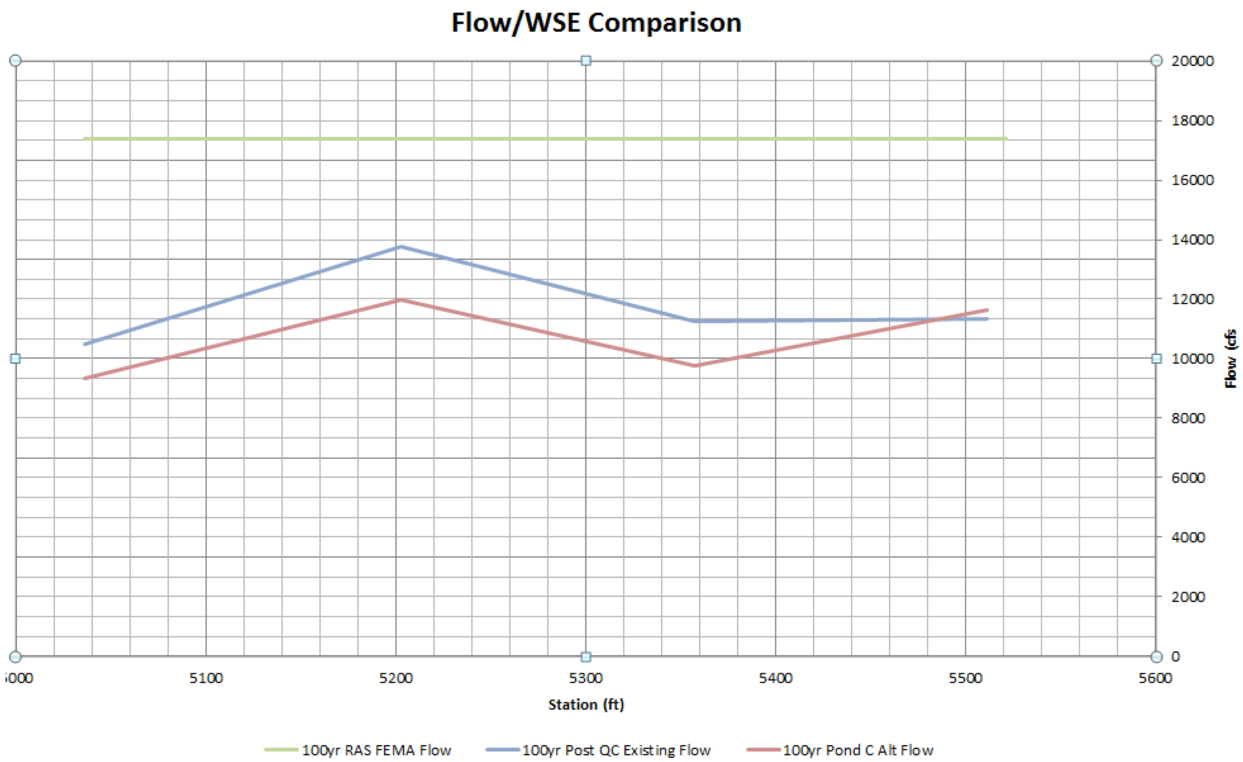
   a. HALFF RESPONSE: This was noted prior to QC. Since the pond is bounded by existing roads it does not have a designed control structure. It appears the proposed pond excavation is acting more like channel modifications, having a WSE decrease adjacent to the pond but increasing the flow downstream and causing adverse impacts. If the pond were to move forward in the alternative analysis this would need to be accounted for. However, since the pond has limited flood mitigation benefits it is not moving forward in the alternative analysis.

12. You might consider importing a permanent Results 2D Line into the mesh of the existing and proposed ICM models as shown above so that a quick comparison can be made on consistent cross sections downstream to check for adverse impacts.
   a. HALFF RESPONSE: Noted. How we assessed the flood mitigation impacts of the alternative is comparing inundated structures finished floor elevation (FFE) to the surrounding water surface elevation (using a buffer of 10'). We also looked at the linear feet of inundated roadway that was removed specifically at intersections. These shapefiles that were used will be provided in our QC response submittal to AECOM.

13. Flow/WSE comparison is shown below and in spreadsheet Pond C QC.xlsx *Tab: Shoal WSE_Flow Comp.* Comparison is done only for River Reach which is east of Pond C.
   - WSEs in alternative Pond C are generally lower for proposed than existing, but are raised above existing for a short segment.
   - Proposed flows are generally lower than existing, but are slightly higher on the upstream side of the reach.
   - Please confirm that differences in WSE and flow are acceptable.

   a. HALFF RESPONSE: The flood mitigation goal is to reduce the 100-year frequency storm event to near the 10 or 25-year event. However, this pond does not have significant flood mitigation benefits and even causes adverse impacts therefore it will not be moving forward in the alternative analysis.





Flow/WSE Comparison
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Flow (cfs
5100
5200
5300
5400
5500
5600
Station (ft)
100yr RAS FEMA Flow
100yr Post QC Existing Flow
100yr Pond C Alt Flow

Inline Detention Pond D

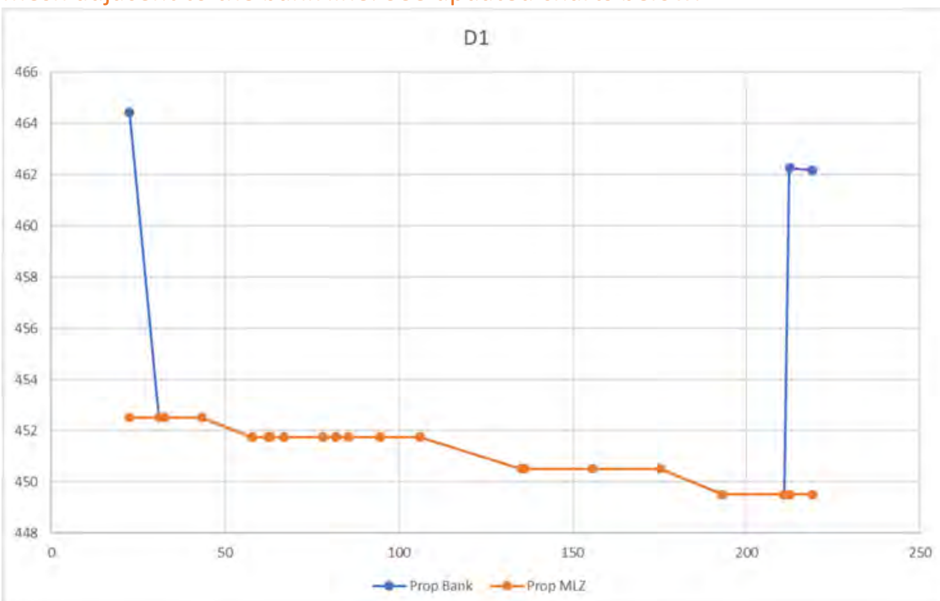
- Inline pond along Lower Shoal Creek located on the 9th Street BMX Park property between W 9th St and W 6th St
- Removed XS 4935_int33, 4935_int34, and 4935_int35 for simplification. The channel did not change significantly in this area, so it will not significantly impact the WSE.
- Lower Left and right overbanks to assumed OHWM
- Pond was modeled as mesh level zone. Bottom of pond was set to approximate OHWM elevations of adjacent
- Assumed ordinary high-water mark elevations:
    - XS 4935_int9 – 452.5'
    - XS 4935_int19 – 451.74'
    - XS 4841 – 451.74'
    - XS 4800 – 450.5'
    - At downstream end of reach (near XS 4729!) – 449.5'
- Kept inline weir ID4729!.1 that is located DS of the pond
- Lowered n-values within the pond to 0.04
- Adjusted to XS to represent bottom of pond above assume OHWM

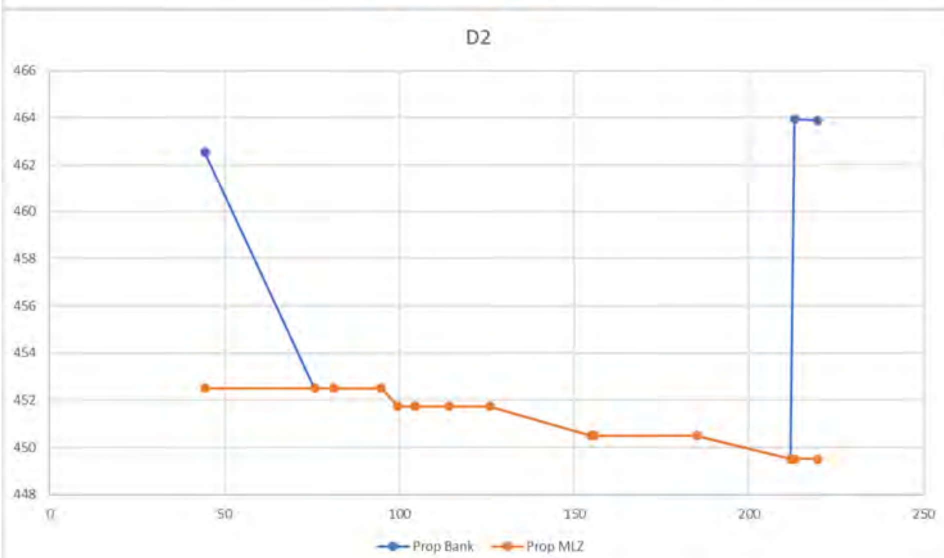
AECOM- Detail Check Comments

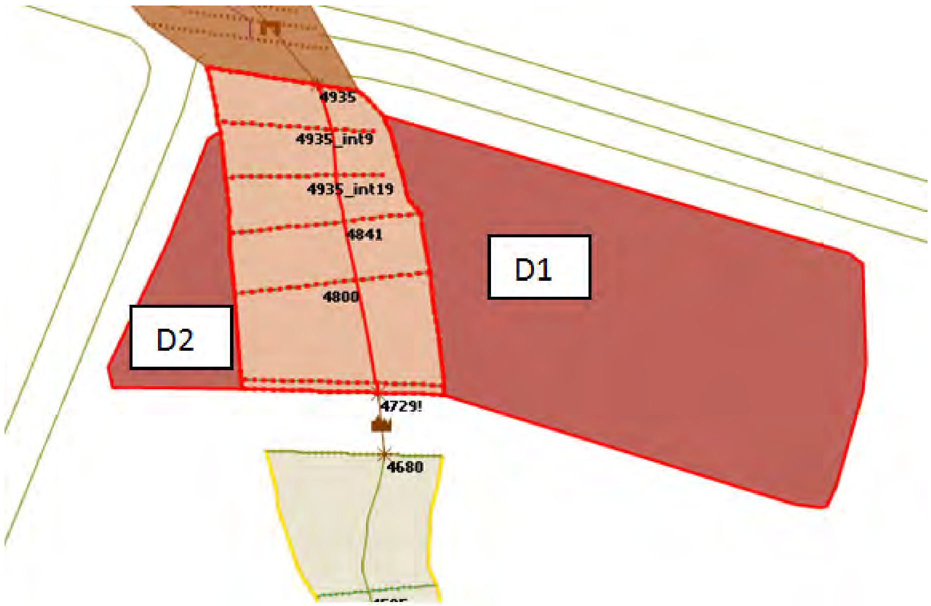
1. All Existing Post QC Comments are implemented in the Alternative Pond D.
    a. HALFF RESPONSE: Noted
2. Compared Existing and Alternatives Inflows. No Issues. (Spreadsheet: Pond D QC.xlsx, *Tab: 10yr_Flow_Inputs, 25yr_Flow_Inputs, 50yr_Flow_Inputs, 100yr_Flow_inputs and 500yr_Flow_inputs*)
    a. HALFF RESPONSE: Noted
3. Compared DS boundary condition for all alternatives. No issues. (Spreadsheet: Pond D QC.xlsx, *Tab: DS BC_All Alternatives*)
    a. HALFF RESPONSE: Noted
4. Please provide the design criteria for Pond D (e.g. 50-yr flood does not overtop).
    a. HALFF RESPONSE: We did not have a set design criterion. This model was an exercise to see if increasing storage of Shoal Creek in the available area would have any impact on flood mitigation downstream. This would be considered if the pond was moved into further evaluation.
5. Mesh Level Zone for Pond D: Elevation of vertices are modified and entered in ICM using Type "Specify":
    (i) What was the method used to choose the elevations of vertices included in the proposed mesh level zone?
        a. HALFF RESPONSE: The bottom elevations of the pond were based on the assumed OHWM of the XS within the reach. We wanted to remain above that elevation.
    (ii) Was the intention to make vertical walls in the pond?
        a. HALFF RESPONSE: Since this was a high-level exercise and we were trying to maximize the volume available, we assumed vertical walls.
6. The difference between raster elevation and vertices' elevation can be found in the Pond D QC.xlsx Spreadsheet (*Tab: Mesh Level Zone*). In the plot below, three elevation profiles are shown from alignments on the left (eastern) bank of Shoal Creek and the western border of the proposed Pond D-1. Similarly, for Pond D-2 three elevations profiles are shown from alignments on the right

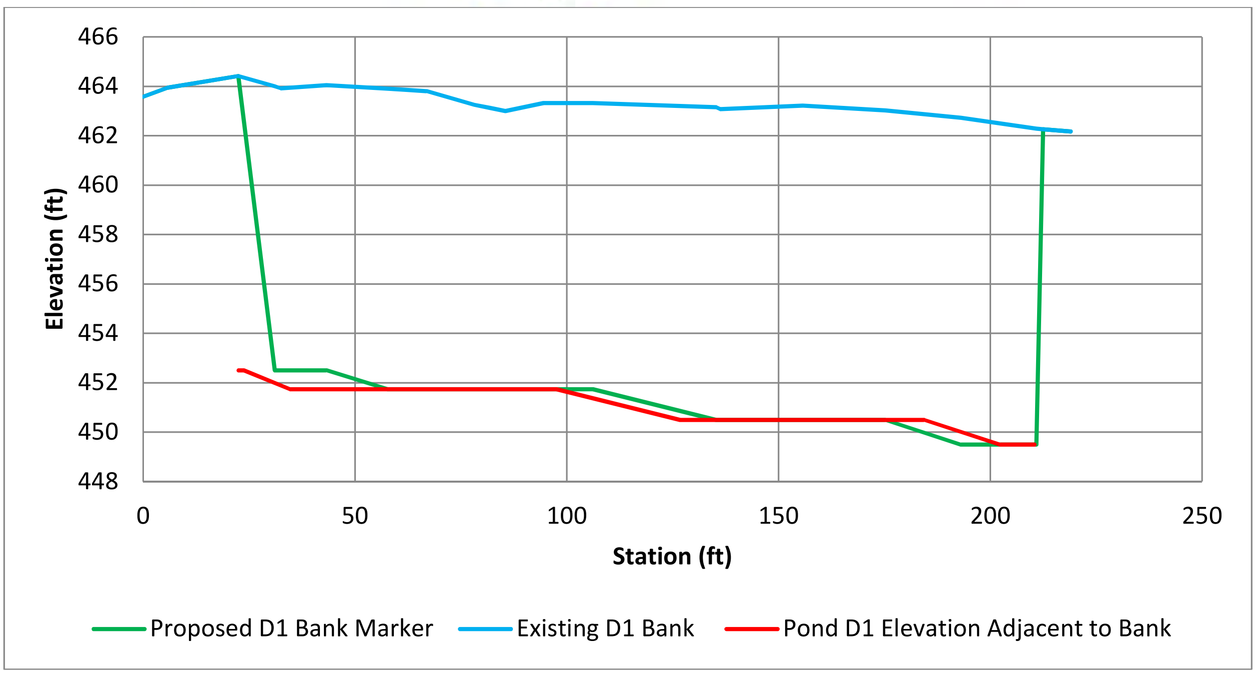
(western) bank of Shoal Creek and the Eastern border of the proposed Pond D-2. See corresponding bank and pond profile alignments highlighted in red in plan view below). The proposed profile elevations associated with the western border of Pond D1 and eastern border of Pond D2 do not match with the corresponding River Reach bank profiles. If the bottom elevation of the pond is intended to connect to the left and right bank of Shoal Creek, red and green profile elevations plotted below should line up on top of each other, but they do not. (*Spreadsheet:* Pond D QC.xlsx, *Tab: MeshLevelZone*)

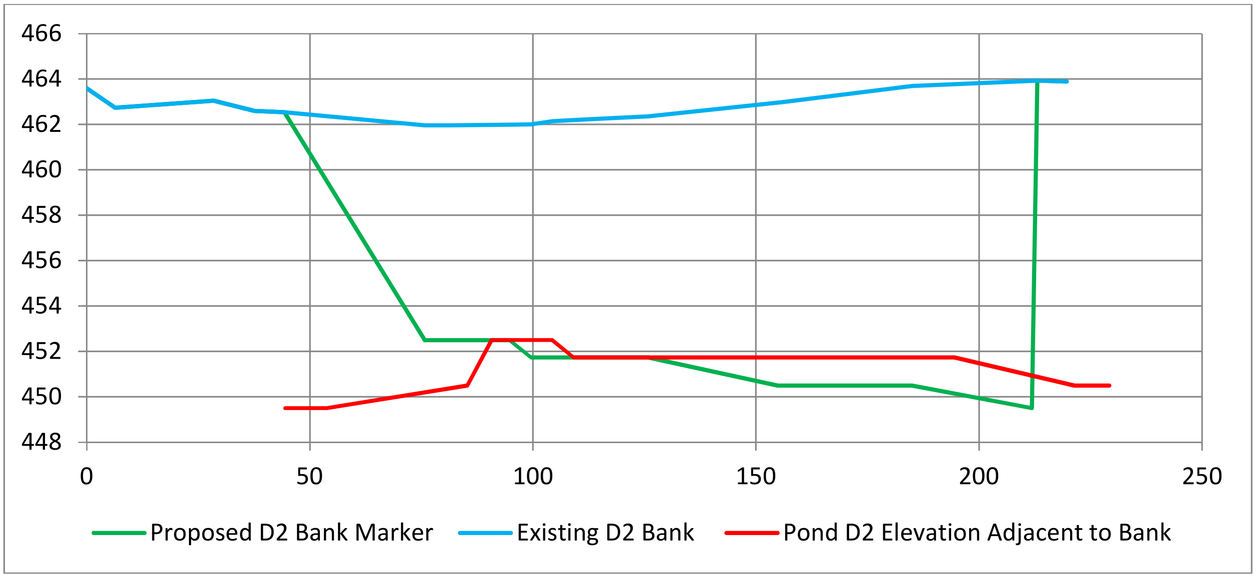
a. HALFF RESPONSE: The bank line and mesh level zone elevations were revised to be consistent with each other. The mesh level zone represents the proposed pond in the mesh adjacent to the bank line. See updated charts below.

b. 

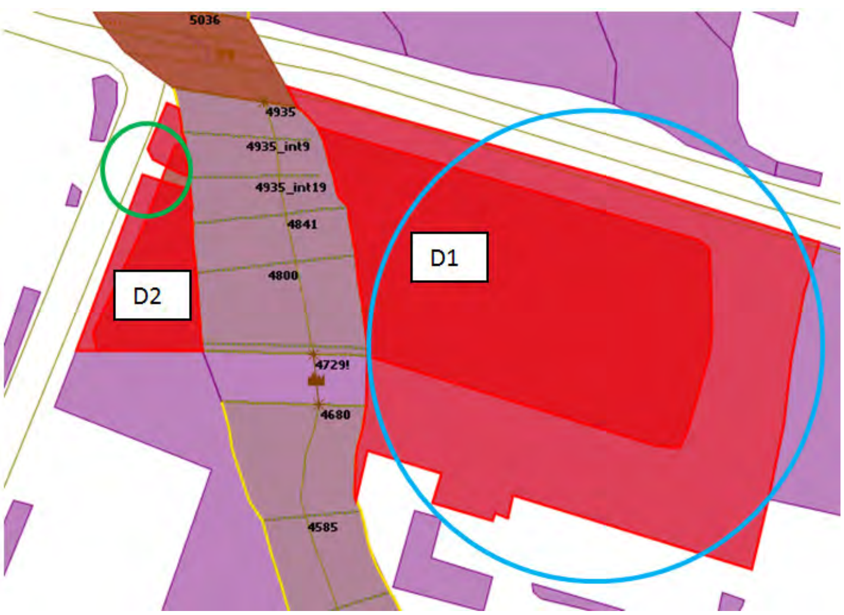
c. 


4935
4935_int9
4935_int19
4841
4800
D1
D2
4729!
4680


466
464
462
460
458
456
454
452
450
448
Elevation (ft)
0
50
100
150
200
250
Station (ft)
Proposed D1 Bank Marker
Existing D1 Bank
Pond D1 Elevation Adjacent to Bank



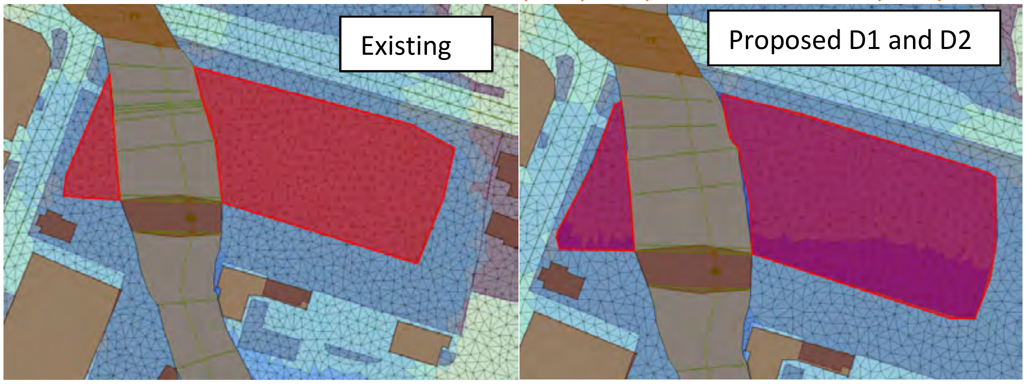
7. Discharge coefficients are not changed between existing conditions and the lowered Shoal Creek banks. Please confirm this is intentional (Spreadsheet: Pond D QC.xlsx, *Tab Pond D Bank Elevations*).
    a. HALFF RESPONSE: This was intentional.
8. When reviewing existing vs. proposed roughness polygons, Roughness Coefficient (0.4) extends outside of Pond D(Blue Circle). Also, some part of Pond D (D2) is using default roughness value of 0.025 (Green Circle). Was it intentional to change roughness outside of proposed pond and to have varying roughness within the proposed pond?
    a. HALFF RESPONSE: This was done intentional, n-values were modified for minimal areas adjacent to the pond near ROW. This is deemed appropriate for this high-level analysis.



9. As a test, a results 2D polygon was drawn around the proposed pond (red boundary in the figure below) in both the existing and proposed ICM models. The approximate existing and proposed peak volumes enclosed by the polygon are:
    (i) Max 100yr Existing storage is approximately= ~526,816 ft^3
    (ii) Max 100yr Pond D Alternative storage is approximately= ~1,320,817ft^3

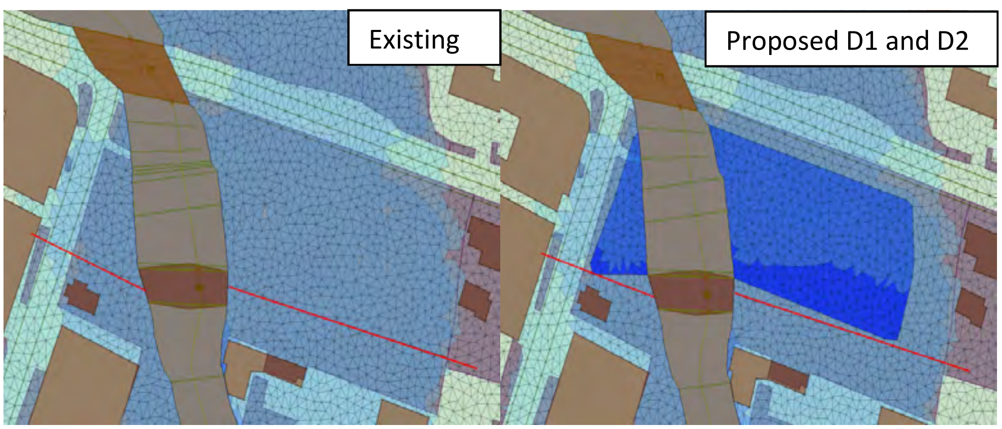
Storage in Alternative Pond D (D1+D2) > Storage in Existing Condition. Pond D is able to store ~17.2 ac-ft of volume. Is this roughly what the pond was designed to store?

a. HALFF RESPONSE: The pond is expected to hold around 30 acre-feet based on the estimate excavation. However, the pond is bounded by existing roads it does not have a designed control structure this most likely why the pond has limited capacity.



10. Results 2D line (Red line in the figure below) was drawn downstream of the pond in 100yr Existing and 100yr Pond D Alternative.

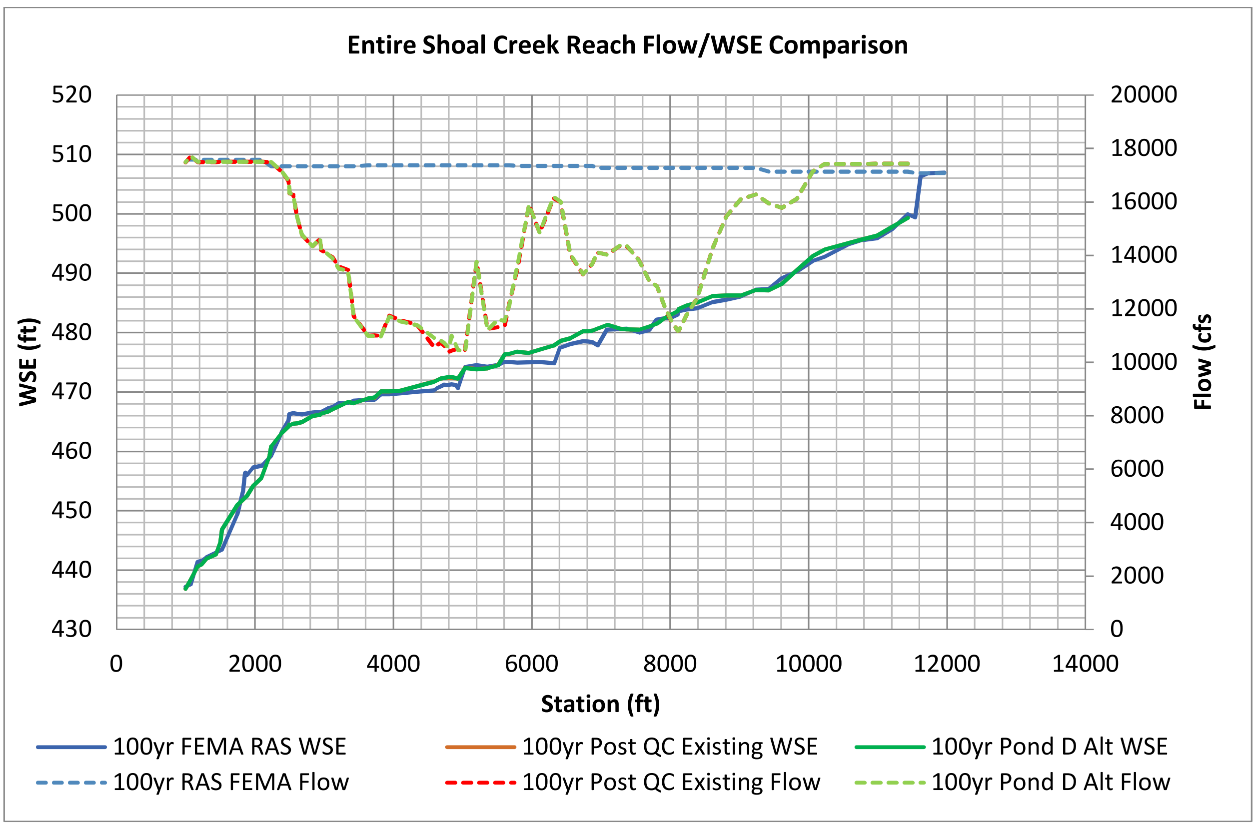
	100yr Existing D1 (cfs)	100yr Pond D1 Alt (cfs)	100yr Existing D2 (cfs)	100yr Pond D2 Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~4,891	~4,891	~1,863	~2,147
Max Depth (ft)	~11.59	~11.59	~8.6	~22.78
Max Speed (ft/s)	~2.15	~2.35	~2.62	~3.00

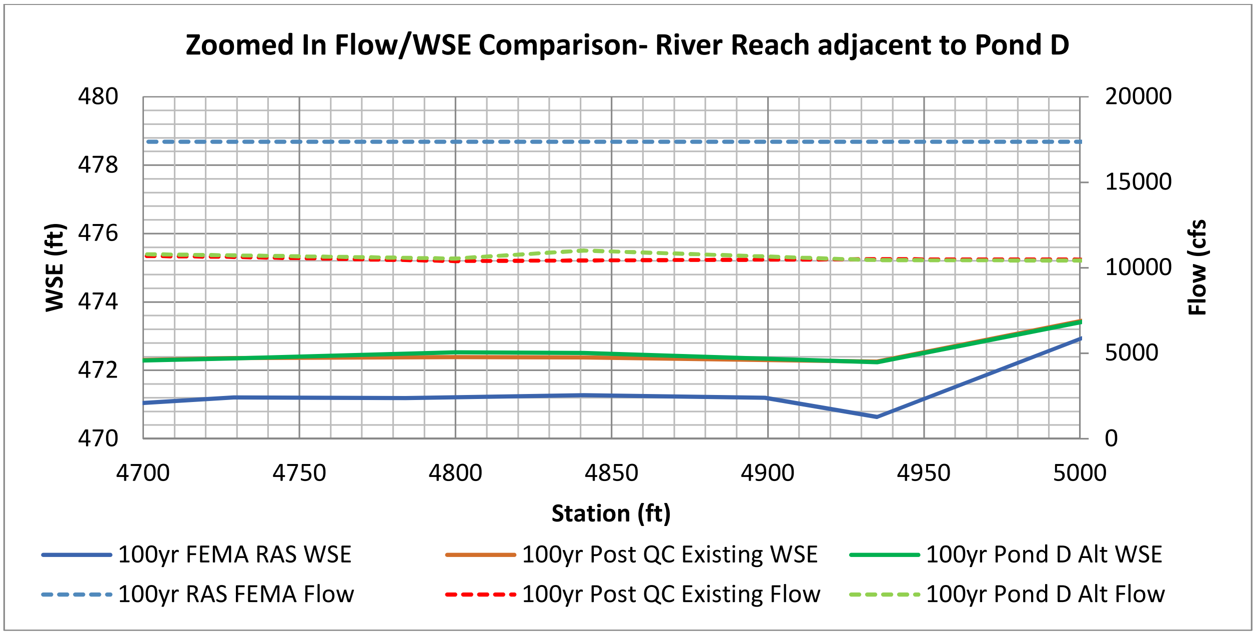


Based on the above results: There are no changes on the east of Shoal Creek (Pond D1). Pond D2 (west of Shoal Creek) is adversely affecting flooding.

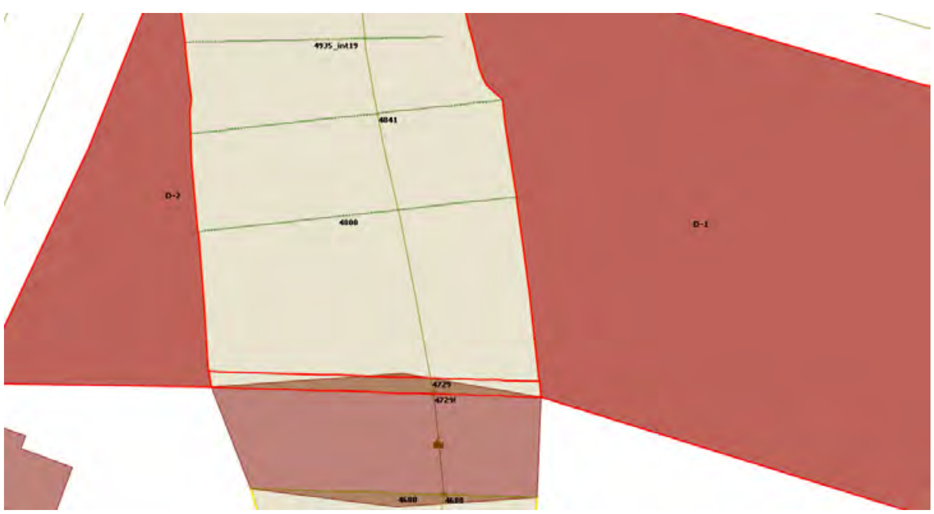
a. HALFF RESPONSE: This was noted prior to QC. Since the pond is bounded by existing roads it does not have a designed control structure. It appears the proposed pond excavation is acting more like channel modifications, having a WSE decrease adjacent to the pond but increasing the flow downstream and causing adverse impacts. If the pond were to move forward in the alternative analysis this would need to be accounted for. However, since the pond has limited flood mitigation benefits it is not moving forward in the alternative analysis.

11. You might consider importing a permanent Results 2D Line into the mesh of the existing and proposed ICM models as shown above so that a quick comparison can be made on consistent cross sections downstream to check for adverse impacts.
    a. HALFF RESPONSE: Noted. How we assessed the flood mitigation impacts of the alternative is comparing inundated structures finished floor elevation (FFE) to the surrounding water surface elevation (using a buffer of 10'). We also looked at the linear feet of inundated roadway that was removed specifically at intersections. These shapefiles that were used will be provided in our QC response submittal to AECOM.
12. Flow/WSE comparison is shown below and in spreadsheet [Pond D QC.xlsx] *Tab: Shoal_100yr_PondD_WSE_Flow_Comp.* Comparison is done only for entire Shoal Creek.
    a. WSEs in alternative Pond D are higher than the existing conditions in the river reach adjacent to Pond D. At all other river reaches WSEs match in Alternative Pond D and Existing Conditions.
    b. Proposed Flows are generally higher in the River Reach adjacent to Pond D.
    c. Please confirm that isolated differences in WSE and Flows are acceptable.
    d. HALFF RESPONSE: The flood mitigation goal is to reduce the 100-year frequency storm event to near the 10 or 25-year event. However, this pond does not have significant flood mitigation benefits and even causes adverse impacts therefore it will not be moving forward in the alternative analysis.





13. Lowered XS to match OHWMs.
    a. XS 4935_int9 – 452.5'- Match on Left side of XS (Pond D1) but do not match on Right Side (Pond D2).
    b. XS 4935_int19 – 451.74'- Yes
    c. XS 4841 – 451.74' -Yes
    d. XS 4800 – 450.5' – Yes
    e. At the downstream end of reach (near XS 4729!) – 449.5'- Pond D-1 elevation lowered. Please review that elevation of XS 4729 and XS 4729! are lowered to match 449.5 ft. Both of these XSs are within the River Reach connected to the pond.
    f. HALFF RESPONSE: The XS were revised to make sure they were consistent with the proposed pond elevation/OHWM



West Avenue Bridge Removal

- Deleted bridge 2552.1 (SHL_800 West Avenue), bridge opening SHL_800 West Avenue_O1, cross section line SHL_800 West Avenue, bank lines 2500.1 left bank line and 2500.1 right bank line, nodes 2552 and 2500, and river reach 2500.1.
- Extended bank lines 2942.1 left bank line and 2942.1 right bank line, hitting the ends of cross sections SHL_800 West Avenue _US, SHL_800 West Avenue_DS, and 2500, then continuing along the exact paths as bank lines 2500.1 left bank line and 2500.1 right bank line.
  - Updated these extended bank lines from ground model
- Extended river reach line 2941.1 to node 2493, with a vertex at node 2500 location.
- Updated river reach 2942.1 with extended reach, bank lines, and incorporating cross sections SHL_800 West Avenue _US, SHL_800 West Avenue_DS, 2500, 2497, and 2493.

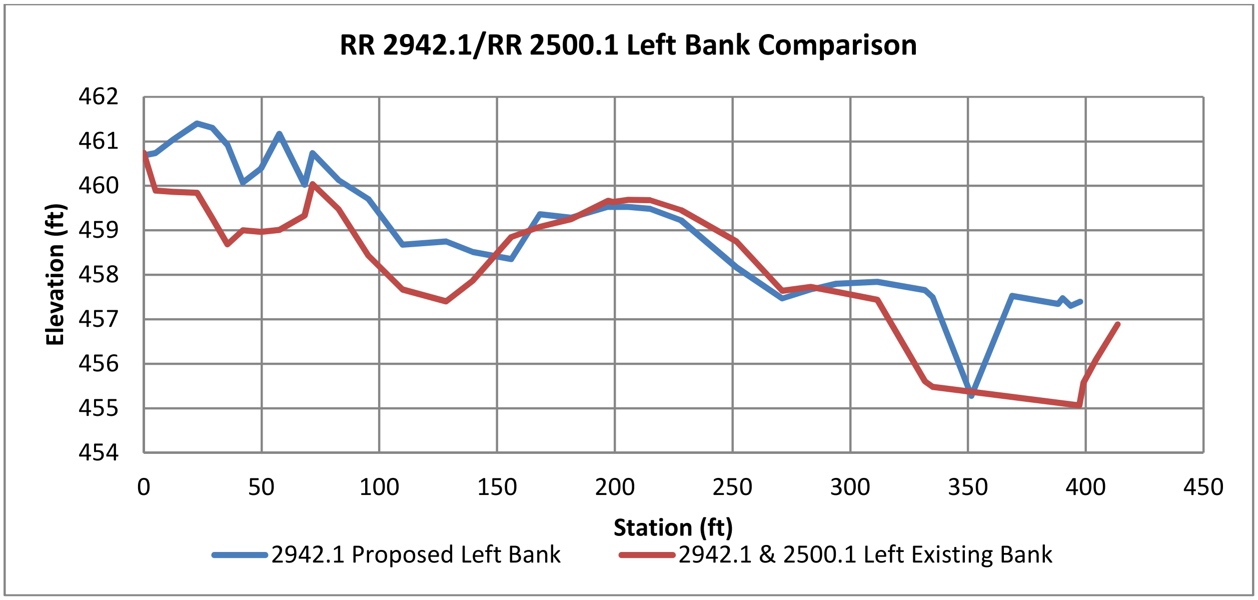
Highlighted text (yellow) above was assumed are typos and corrected by AECOM.

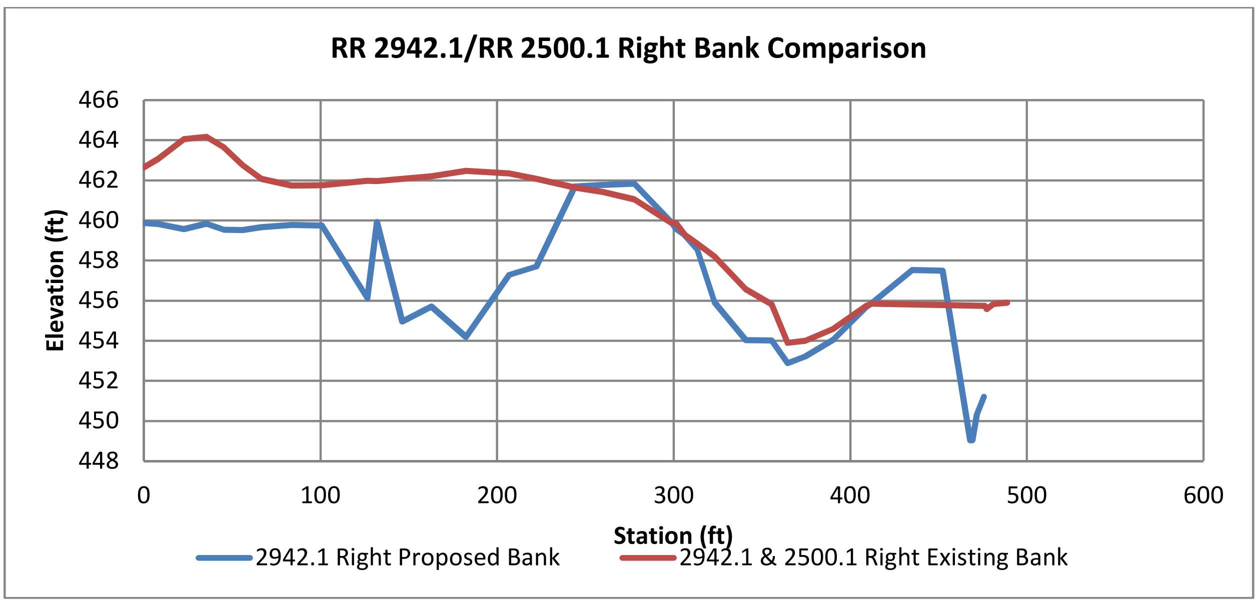
AECOM- Detail Check Comments

1. All Existing Post QC Comments are implemented in the Alternative West Avenue Bridge Removal.
    a. HALFF RESPONSE: Noted
2. Compared Existing and Alternatives Inflows. No Issues. (Spreadsheet: West Ave Removal QC.xlsx, Tab: 10yr_Flow_Inputs, 25yr_Flow_Inputs, 50yr_Flow_Inputs, 100yr_Flow_inputs and 500yr_Flow_inputs)
    a. HALFF RESPONSE: Noted
3. Compared DS boundary condition for all alternatives. No issues. (Spreadsheet: West Ave Removal QC.xlsx, *Tab: DS BC_All Alternatives*)
    a. HALFF RESPONSE: Noted
4. On comparing right and left bank of river reach 2942.1 for existing and proposed conditions, some differences are observed as shown in two figures below. Please review and confirm if they are acceptable.

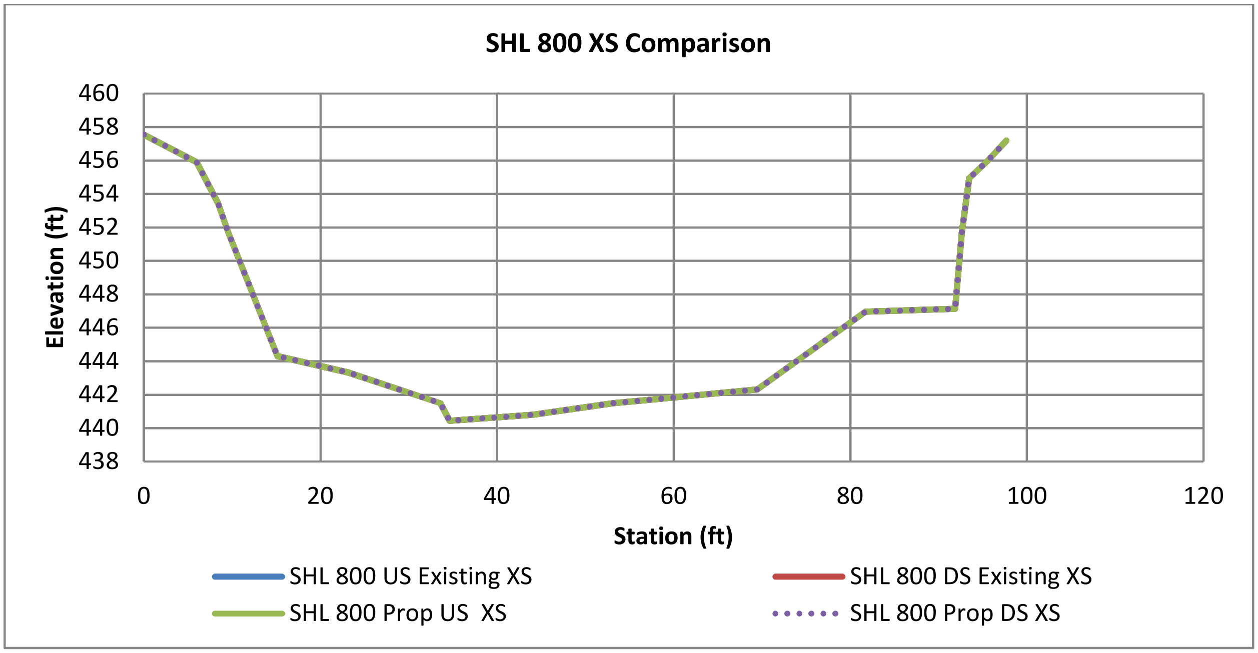
   Please note, the comparison in the figures below and in the spreadsheet, West Ave Removal QC.xlsx (*Tab: Bank Elevation*), include existing bank stations and elevations developed from River reach 2942.1 and extended by adding the distance along the banks between XSs 2552 and 2500 and incorporating stations/elevations from the downstream river reach markers (bank lines) associated with Reach 2500.1.

   Differences between existing and proposed river reach marker stations/elevations are significant (although there is no change in plan view location, when compared in GIS). Was it intended to change the bank geometry between existing and proposed conditions?
    a. HALFF RESPONSE: This was fixed to make sure the banks were consistent between existing and proposed conditions.

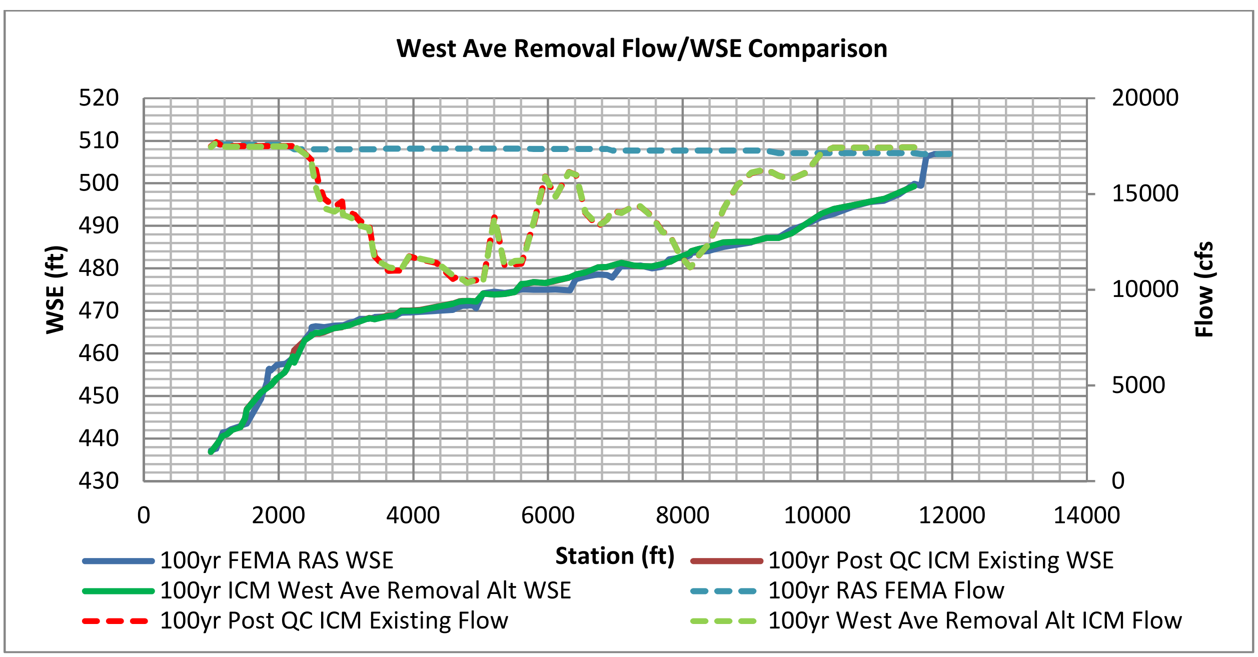


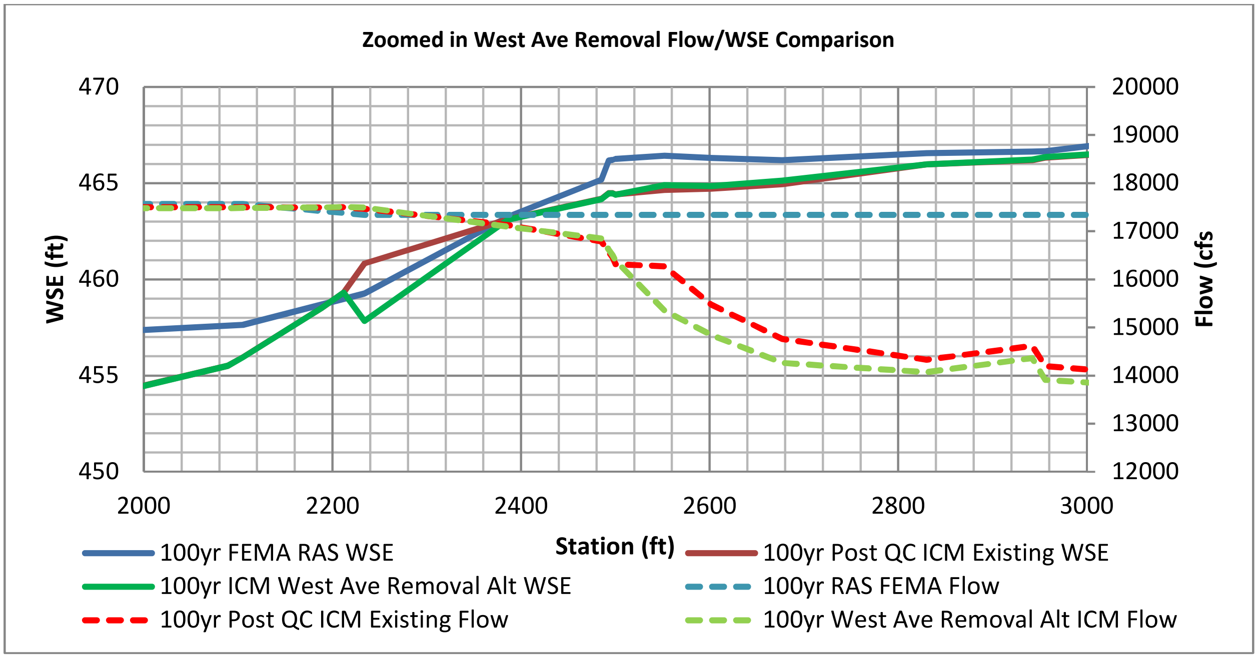


5. SHL_800 West Avenue US and SHL_800 West Avenue DS XS are replicated from existing conditions. (Spreadsheet: West Ave Removal QC.xlsx, *Tab: Crosssection*)
   a. HALFF RESPONSE **to comments 5-7**: The adverse impacts were noted prior to QC. From the bridge removal the WSE decrease is only in the immediate vicinity of the removal and also causes increased flow downstream and causing adverse impacts. If this alternative were to move forward in the alternative analysis this would need to be accounted for. However, the flood mitigation goal is to reduce the 100-year frequency storm event to near the 10 or 25-year event since the bridge removal has limited flood mitigation benefits and even causes adverse impacts it will not be moving forward in the alternative analysis.



6. River Reach WSE/Flow Figure (Spreadsheet: [West Ave Removal QC.xlsx](), *Tab: 100yr_WestAve_WSE_Flow*)
    a. Minor difference is observed in Flow and WSE close to West Ave bridge location as shown in the graph below.
    b. At zoomed in location of profile, the proposed WSE is slightly higher than the existing WSE from STA 2520 – 2800.
    c. Please confirm that differences in WSE and flow are acceptable.

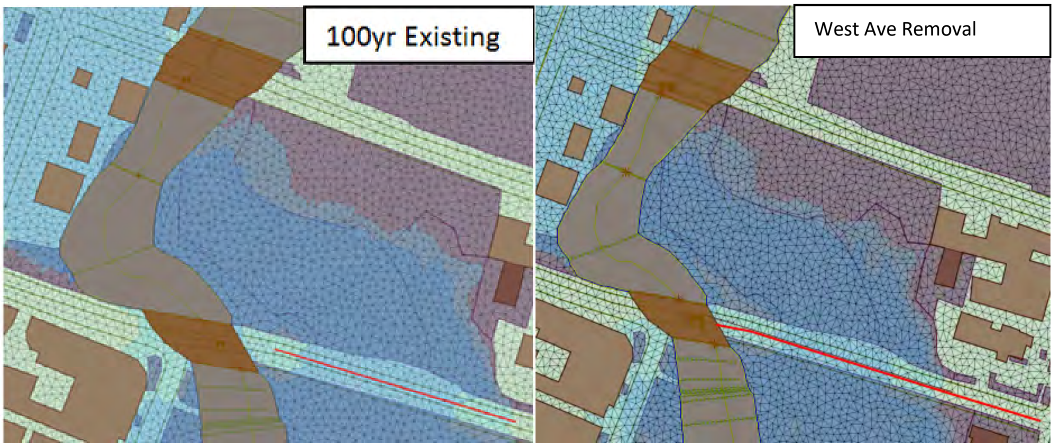




7. Flood Mitigation:
   a. North of Shoal Blvd and W 12th St

	100yr Existing (cfs)	100yr West Ave Removal Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~3,062	~3,096
Max Depth (ft)	~10.17	~10.13
Max Speed (ft/s)	~2.27	~2.28

   b. Duncan Park



	100yr Existing (cfs)	100yr West Ave Removal Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~6,350	~6,577
Max Depth (ft)	~8.4	~8.33
Max Speed (ft/s)	~3.25	~3.26

c. Along Left Bank of Shoal Creek and West Avenue

	100yr Existing (cfs)	100yr West Ave Removal Alt (cfs)
Peak Flow through the Results 2D Line (cfs)	~2,872	~3,169
Max Depth (ft)	~10.7	~10.22
Max Speed (ft/s)	~8.84	~8.38

No significant improvements are seen in this alternative at the above shown comparison, although other areas were not tested. Flow through results lines show increases (adverse impacts) when comparing existing to proposed conditions. You might consider importing a permanent Results 2D Line into the mesh of the existing and proposed ICM models as shown above so that a quick comparison can be made in specific areas to check for adverse impacts.

APPENDIX D: Evaluation Criteria

Criteria	Criteria Weight	Score Range	DETENTION Gilbert Davis Tract	CHANNEL CLEARING	BUYOUTS	BYPASS Lamar A Bypass 4	COMMUNITY RESILIENCE PLAN
Structural Flood Risk Reduction (Accounts for the amount of buildings mitigated from structural flooding during 1% ACE)	20	**5:** Structures no long at risk > 20 **4:** 14 - 20 structures no long at risk **3:** 8 - 14 structures no long at risk **2: 2** - 8 structures no long at risk **1:** Structures no long at risk < 2	2	2	4	5	1
Mobility Flood Risk Reduction (Amount of restricted drivers during time of 1% ACE inundation based on TxDOT AADT traffic counts. Important for emergency access and social impact)	10	**5:** Drivers no longer restricted > 8,000 **4:** 5,400 - 8,000drivers no longer restricted **3:** 2,800 - 5,400 drivers no longer restricted **2:** 200 - 2,800 drivers no longer restricted **1:** Drivers no longer restricted < 200	2	1	1	5	1
Length of Inundated Roadway (Length of inundated roadway removed from existing to proposed conditions for the 1% ACE. Important for emergency access and social impact)	10	**5:** Mitigated Roadway Length ≥ 6,000 feet **4:** Mitigated Roadway Length between 4,500 feet - 6,000 feet **3:** Mitigated Roadway Length between 3,000 feet - 4,500 feet **2:** Mitigated Roadway Length between 1,500 - 3,000 feet **1:** Mitigated Roadway Length ≤ 1,500 feet	1	1	1	5	1
Environmental Impact (Impact to natural creek environment, water quality)	15	**5:** Limited to no environmental impact **4:** Short term, moderate impact during construction **3:** Short term, significant impact during construction **2:** Long term, moderate impact in perpetuity **1:** Long term, significant impact in perpetuity	2	1	5	2	5
Land / Easement Acquisition (Requirement of land and/or easement acquisition to implement the project)	15	**5:** No additional land/easement acquisition needed in order to implement project **3:** Possible/Minimal land/easement acquisition needed **1:** Significant land/easement acquisition needed in order to implement project	1	5	1	3	5
Public Input (Considers - public opinion expressed at March 2017 and November 2018 public meetings, including the public survey in 2017)	10	**5:** Most favorable **3:** Neutral results **1:** Least favorable	5	3	3	1	5
Time of Implementation	5	**5:** 0-2 years, once funding is available **4:** 2-5 years, once funding is available **3:** 5-7 years, once funding is available **2:** 7-10 years, once funding is available **1:** > 10 years, once funding is available	1	4	5	1	5
Funding Constraints	5	**5:** Project can be implemented incrementally as funding is available **3:** Project is comprised of multiple smaller projects which can be implemented separately as funding is available for each **1:** Full project funding required prior to implementation	1	3	5	1	5
Complexity of Permitting	10	**5:** Limited local permits **4:** Local site plan permit **3:** Local permit with variances/Nationwide **2:** Multi-jurisdiction less permits **1:** Multi-jurisdiction more permits	3	3	5	3	5
		Weighted Score	205	245	320	325	340
		Ranking	7	4	3	2	1

Quick Facts

Number of structures no longer at risk of structural flooding in 100-year floodplain*	4	4	16	30	0
Length of roadway no longer inundated in 100-year floodplain**	1100	900	0	6700	0
Number of drivers no longer restricted during 100-year event***	1130	160	0	8220	0

* In existing conditions 61 buildings are flooded in 100-year event.
** In existing conditions 12,300 feet of roadway is inundated / flooded in 100-year event.
*** In existing conditions 15,670drivers are restricted during 100-year event.

Criteria	Criteria Weight	Score Range	Lamar A Bypass 1	Lamar A Bypass 2	Lamar A Bypass 3	Lamar A Bypass 4	Lamar B Bypass 1	Lamar B Bypass 2	Lorrain-Pressler Bypass 1	Lorrain-Pressler Bypass 2
Cost Effectiveness (Cost of construction, number of impacted structures, removed, size of tunnel, type of construction, complexity of intake/outfall structure, contingency/feasibility of construction)	20	**5:** BCA ≥ 0.750 **4:** Between 0.65 - 0.75 BCA **3:** Between 0.55 - 0.65 BCA **2:** Between 0.45 - 0.55 BCA **1:** BCA ≤ 0.45	2	2	4	5	2	4	2	1
Mobility (Amount of restricted drivers during time of 1% ACE inundation based on TxDOT AADT traffic counts. Important for emergency access and social impact)	10	**5:** Drivers no longer restricted > 8,000 **4:** 5,400 - 8,000drivers no longer restricted **3:** 2,800 - 5,400 drivers no longer restricted **2:** 200 - 2,800 drivers no longer restricted **1:** Drivers no longer restricted < 200	2	2	2	5	2	2	2	2
Length of Inundated Roadway (Length of inundated roadway removed from existing to proposed conditions for the 1% ACE. Important for emergency access and social impact)	10	**5:** Mitigated Roadway Length ≥ 6,000 feet **4:** Mitigated Roadway Length between 4,500 feet - 6,000 feet **3:** Mitigated Roadway Length between 3,000 feet - 4,500 feet **2:** Mitigated Roadway Length between 1,500 - 3,000 feet **1:** Mitigated Roadway Length ≤ 1,500 feet	1	2	3	5	1	1	2	2
Environmental Impact (Impact to natural creek environment, water quality, depth of intake structure)	15	**5:** Limited to no environmental impact **4:** Short term, moderate impact during construction **3:** Short term, significant impact during construction **2:** Long term, moderate impact in perpetuity **1:** Long term, significant impact in perpetuity	3	3	2	2	2	2	3	2
Land / Easement Acquisition (Requirement of land and/or easement acquisition to implement the project)	15	**5:** No additional land/easement acquisition needed in order to implement project **3:** Possible/Minimal land/easement acquisition needed **1:** Significant land/easement acquisition needed in order to implement project	3	3	3	3	1	1	3	3
Public Input (Considers - public opinion expressed at March 2017 and November 2018 public meetings, including the public survey in 2017)	10	**5:** Most favorable **3:** Neutral results **1:** Least favorable	1	1	1	1	3	3	1	1
Time of Implementation	5	5: 0-2 years, once funding is available 4: 2-5 years, once funding is available 3: 5-7 years, once funding is available 2: 7-10 years, once funding is available 1: > 10 years, once funding is available	1	1	1	1	1	1	1	1
Funding Constraints	5	5: Project can be implemented incrementally as funding is available 3: Project is comprised of multiple smaller projects which can be implemented separately as funding is available for each 1: Full project funding required prior to implementation	1	1	1	1	1	1	1	1
Complexity of Permitting	10	5: Limited local permits 4: Local site plan permit 3: Local permit with variances/Nationwide 2: Multi-jurisdiction less permits 1: Multi-jurisdiction more permits	3	3	3	3	3	3	3	3
		Weighted Score	**170**	**180**	**215**	**285**	**145**	**185**	**180**	**145**
		Ranking	**6**	**4**	**2**	**1**	**7**	**3**	**4**	**7**

Quick Facts

	Lamar A Bypass 1	Lamar A Bypass 2	Lamar A Bypass 3	Lamar A Bypass 4	Lamar B Bypass 1	Lamar B Bypass 2	Lorrain-Pressler Bypass 1	Lorrain-Pressler Bypass 2
Project Cost + Present Worth 50-year O&M Cost	$ 94,890,500	$ 111,403,000	$ 125,126,500	$ 166,437,500	$ 84,763,500	$ 97,862,500	$ 92,830,500	$ 146,598,500
Number of structures no longer at risk of structural flooding in 100-year floodplain*	4	13	19	30	4	7	11	12
Length of roadway no longer inundated in 100-year floodplain**	1,000	2,500	4,200	6,700	1,100	1,400	2,100	2,400
Number of drivers no longer restricted during 100-year event***	740	770	2,670	8,220	970	1,830	850	1,590
Bypass Diameter / Length	11 ft / 6,600 ft	22 ft / 6,800 ft	22-23 ft / 7,000 ft	26-28 ft / 8,000 ft	11 ft / 4,900 ft	11-13 ft / 5,000 ft	22 ft / 6,400 ft	22-26 ft / 9,600 ft

* In existing conditions 61 buildings are flooded in 100-year event.
** In existing conditions 12,300 feet of roadway is inundated / flooded in 100-year event.
*** In existing conditions 15,670 drivers are restricted during 100-year event.

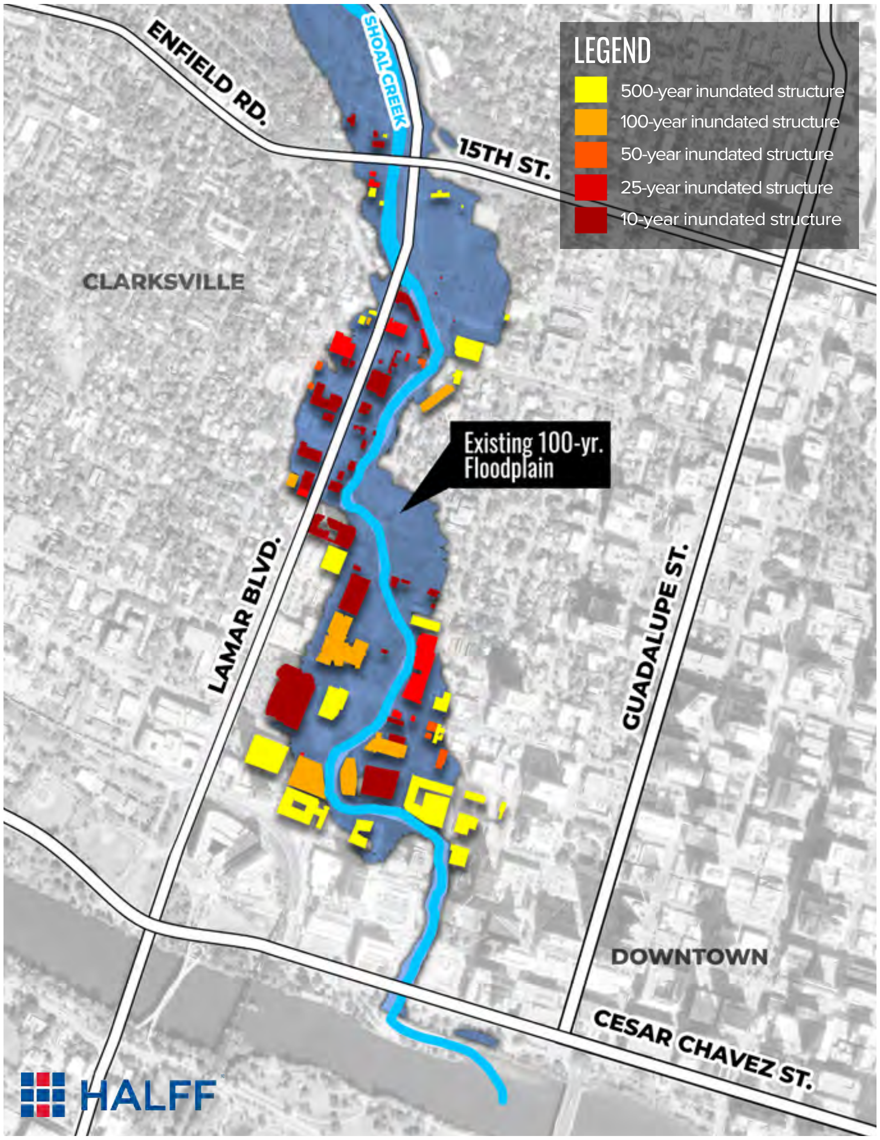
APPENDIX E: Fact Sheets

Lower Shoal Creek Flood Risk Reduction Alternatives

EXISTING CONDITIONS

WATERSHED DESCRIPTION:

Approximately 8,000 acres drain to Shoal Creek, making it one of Austin's most flood-prone creeks. There has been severe flooding along Shoal Creek throughout Austin's history. Shoal Creek experienced significant flooding on Memorial Day 1981 and, more recently on Memorial Day 2015. Recent studies show more extensive flooding is possible along Shoal Creek. Study results indicate there are many buildings, both commercial and residential, vulnerable to flooding in the study area. In addition, many roadways can become dangerous and impassible with severe rainfall. To validate the hydrologic and hydraulic analysis, the study team simulated the Memorial Day 2015 historical event using City provided gage-adjusted radar rainfall and gage records. Once validated, the updated analysis was used to redefine computed water surface elevations along Lower Shoal Creek between 15th Street and Lady Bird Lake. Based on this study, the City was able to evaluate flood risk along Lower Shoal Creek and evaluate potential flood risk reduction alternatives.



QUICK FACTS

10-year (10% chance) Flood Conditions

Number of Buildings Inundated: 36 structures

Length of Inundated Roadway: 7,400 linear feet

25-year (4% chance) Flood Conditions

Number of Buildings Inundated: 48 structures

Length of Inundated Roadway: 9,700 linear feet

50-year (2% chance) Flood Conditions

Number of Buildings Inundated: 54 structures

Length of Inundated Roadway: 10,900 linear feet

100-year (1% chance) Flood Conditions

Number of Buildings Inundated: 61 structures

Length of Inundated Roadway: 12,300 linear feet

500-year (0.2% chance) Flood Conditions

Number of Buildings Inundated: 85 structures

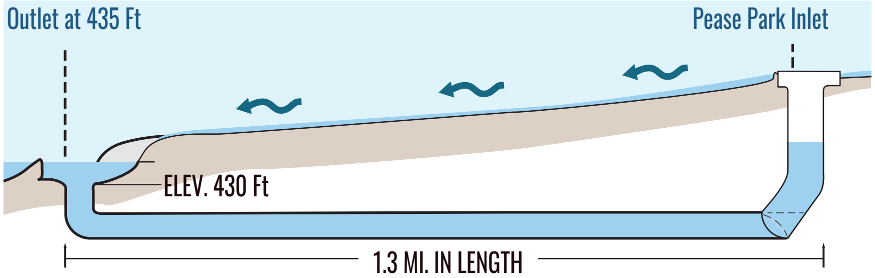
Length of Inundated Roadway: 19,400 linear feet

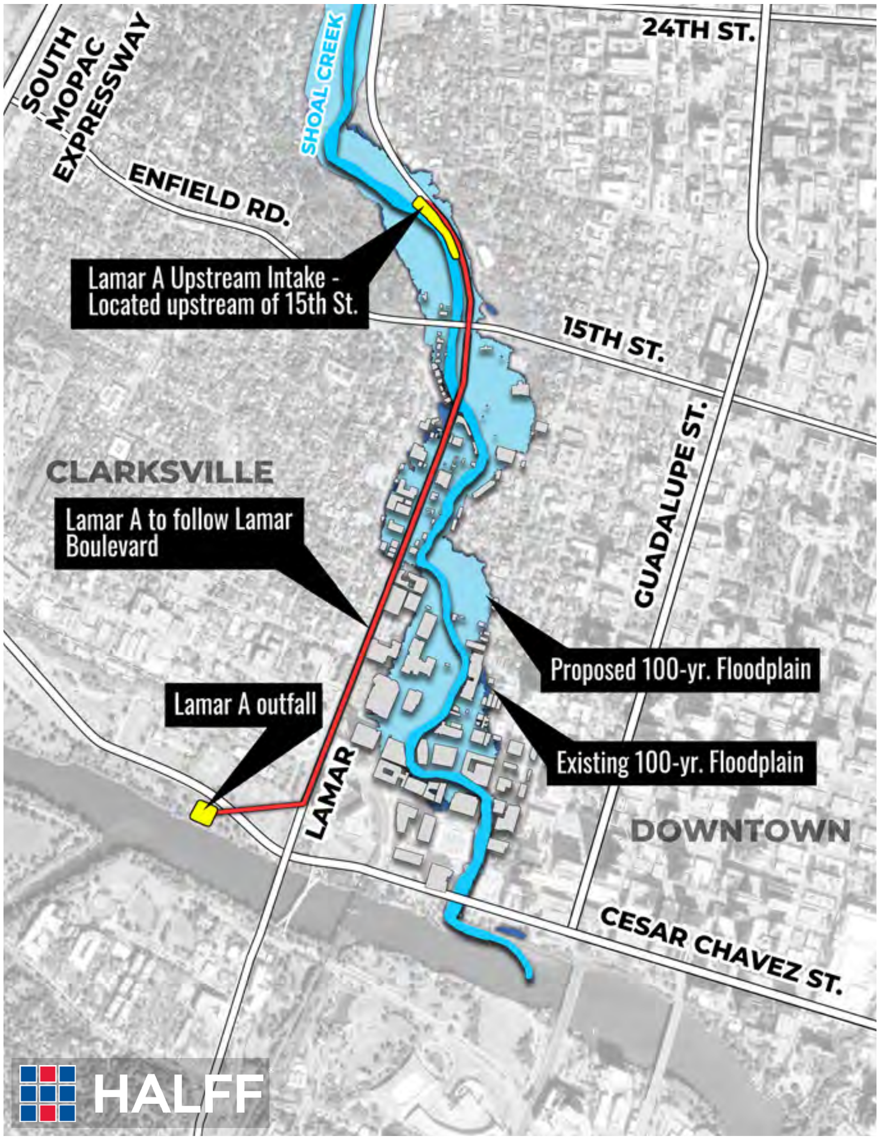
Lower Shoal Creek Flood Risk Reduction Alternatives

LAMAR A BYPASS 1

PROJECT DESCRIPTION:

Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Lamar A bypass includes underground conveyance along Lamar Boulevard with an intake structure along the east bank of Shoal Creek in Pease Park ultimately discharging into Lady Bird Lake near Lamar Boulevard. To minimize permitting requirements and environmental impacts, floodwaters would be diverted into the bypass at an elevation above the 2-year event. This allows for smaller events to remain in the creek but provides flood protection for the larger events.





QUICK FACTS

- Level of Service:
  Between 50-year and 100-year
- Bypass Dimension:
  6,630 feet long
  11-feet Diameter
- Project Cost Estimate:
  $94,890,500

100-YR. FLOOD MITIGATION BENEFITS

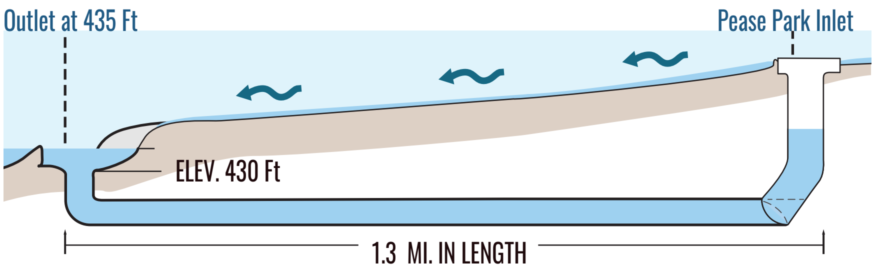
- Number of Buildings Protected:
  4 out of 61
- Length of Mitigated Inundated Roadway:
  1,000 out of 12,300 linear feet
- Increase in Mobility Based on Annual Average Daily Traffic:
  740 out of 15,670 drivers

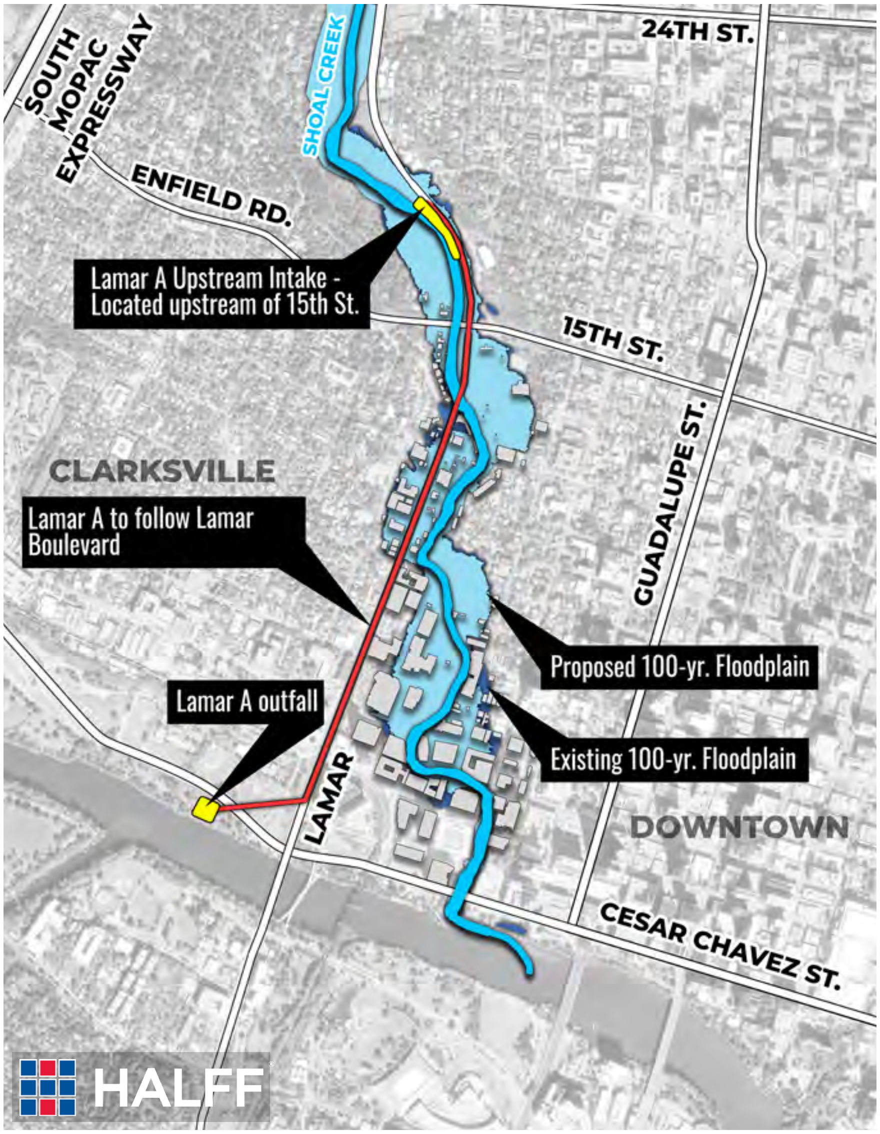
Lower Shoal Creek Flood Risk Reduction Alternatives

LAMAR A BYPASS 2

PROJECT DESCRIPTION:

Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Lamar A bypass includes underground conveyance along Lamar Boulevard with an intake structure along the east bank of Shoal Creek in Pease Park ultimately discharging into Lady Bird Lake near Lamar Boulevard. To minimize permitting requirements and environmental impacts, floodwaters would be diverted into the bypass at an elevation above the 2-year event. This allows for smaller events to remain in the creek but provides flood protection for the larger events. Lamar A Bypass 2 has a larger intake area in Pease Park than Lamar Bypass 1. A larger intake area allows for more water to enter the bypass, requiring a larger bypass, but providing more flood mitigation benefits and a higher level of service.





QUICK FACTS

Level of Service:
25-year

Bypass Dimension:
6,840 feet long
22-feet Diameter

Project Cost Estimate:
$111,403,000

100-YR. FLOOD MITIGATION BENEFITS

Number of Buildings Protected:
13 out of 61

Length of Mitigated Inundated Roadway:
2,500 out of 12,300 linear feet

Increase in Mobility Based on Annual Average Daily Traffic:
770 out of 15,670 drivers

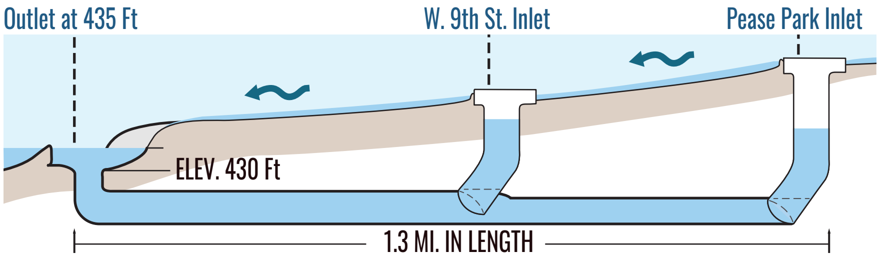
ATX FLOOD SAFETY

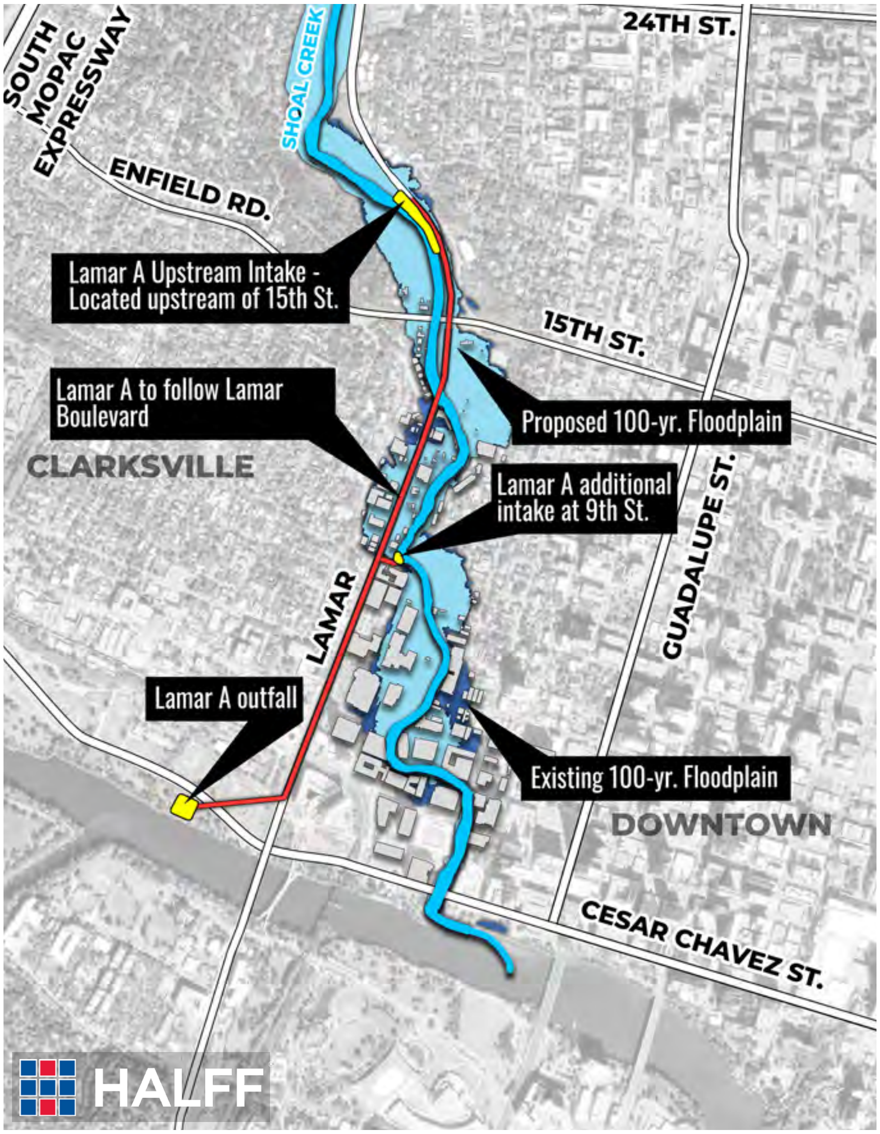
Lower Shoal Creek Flood Risk Reduction Alternatives

LAMAR A BYPASS 3

PROJECT DESCRIPTION:

Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Lamar A bypass includes underground conveyance along Lamar Boulevard with an intake structure along the east bank of Shoal Creek in Pease Park ultimately discharging into Lady Bird Lake near Lamar Boulevard. To minimize permitting requirements and environmental impacts, floodwaters would be diverted into the bypass at an elevation above the 2-year event. This allows for smaller events to remain in the creek but provides flood protection for the larger events. With the addition of an intake at 9th Street, this allows for more water to enter the bypass, requiring a larger bypass downstream of the intake, but providing more flood mitigation benefits and a higher level of service.





QUICK FACTS

Level of Service:
Between 10-year and 25-year

Bypass Dimension:
7,020 feet long
22-feet to 23-feet Diameter

Project Cost Estimate:
$125,126,500

100-YR. FLOOD MITIGATION BENEFITS

Number of Buildings Protected:
19 out of 61

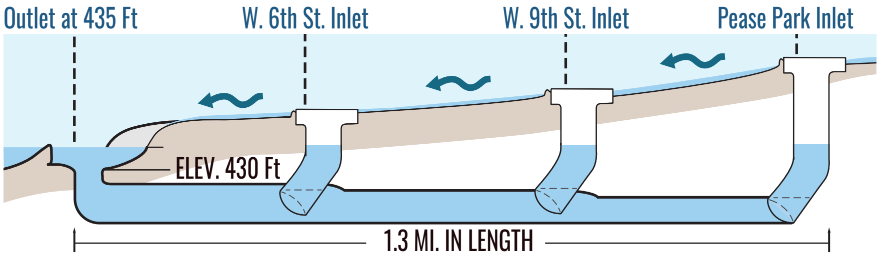
Length of Mitigated Inundated Roadway:
4,200 out of 12,300 linear feet

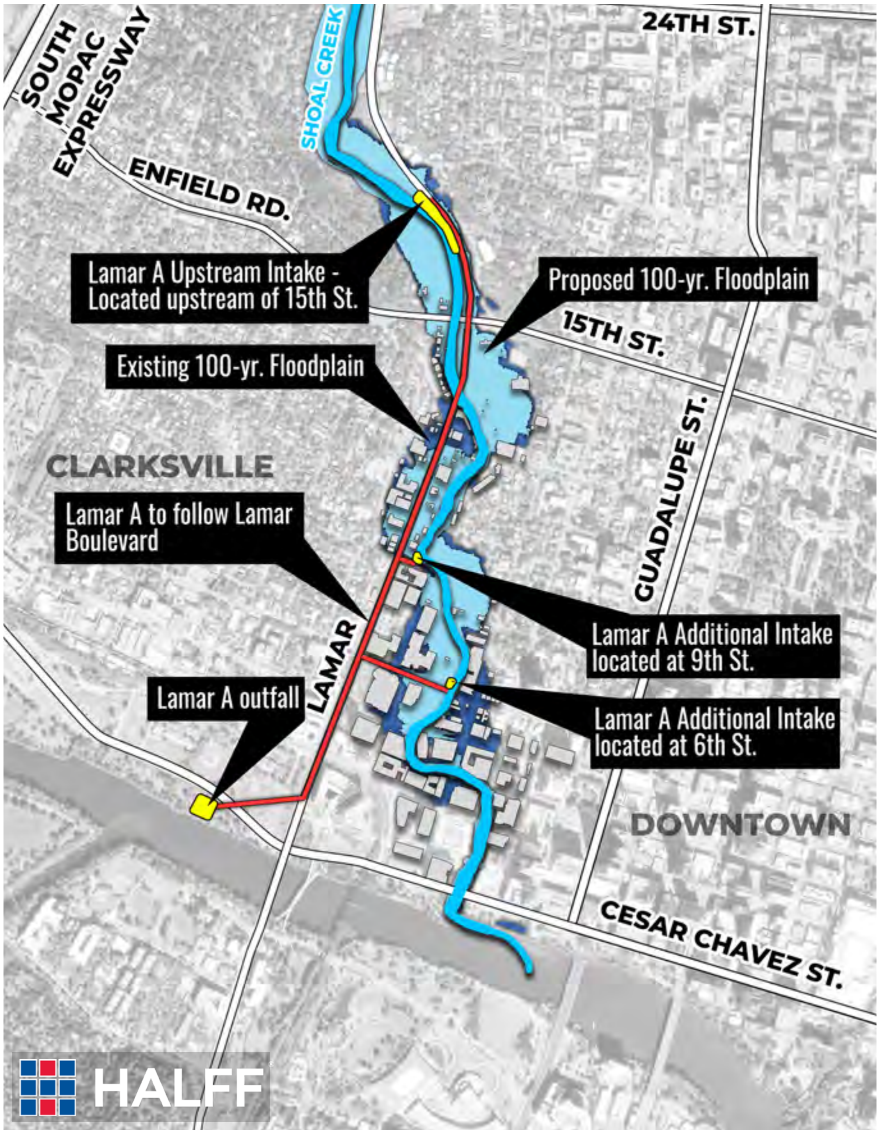
Increase in Mobility Based on Annual Average Daily Traffic:
2,670 out of 15,670 drivers

Lower Shoal Creek Flood Risk Reduction Alternatives

LAMAR A BYPASS 4

PROJECT DESCRIPTION:
Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Lamar A bypass includes underground conveyance along Lamar Boulevard with an intake structure along the east bank of Shoal Creek in Pease Park ultimately discharging into Lady Bird Lake near Lamar Boulevard. With the addition of multiple intakes at 6th and 9th Street, this allows for more water to enter the bypass, requiring a larger bypass downstream of each intake, but providing more flood mitigation benefits and a higher level of service.





QUICK FACTS

- Level of Service:
  Less than 10-year
- Bypass Dimension:
  7,970 feet long
  26-feet to 28-feet Diameter
- Project Cost Estimate:
  $166,437,500

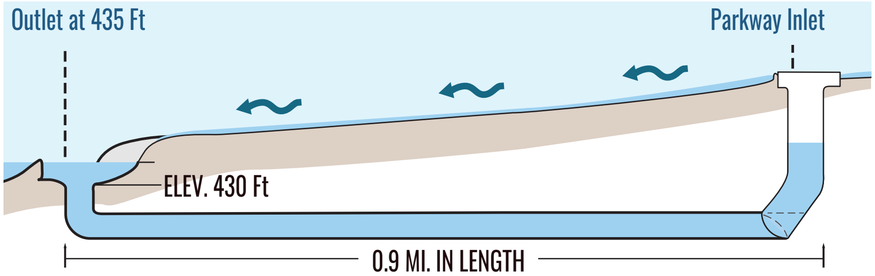
100-YR. FLOOD MITIGATION BENEFITS

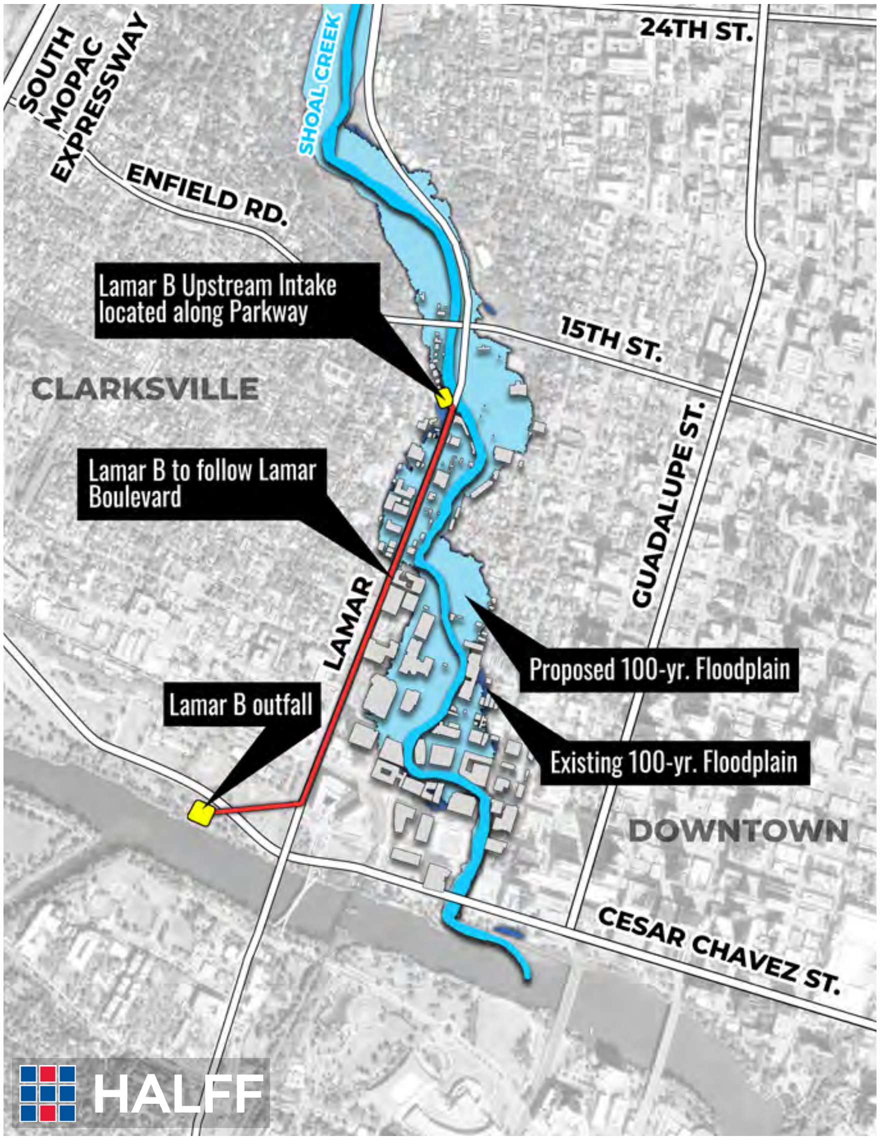
- Number of Buildings Protected:
  30 out of 61
- Length of Mitigated Inundated Roadway:
  6,700 out of 12,300 linear feet
- Increase in Mobility Based on Annual Average Daily Traffic:
  8,220 out of 15,670 drivers

Lower Shoal Creek Flood Risk Reduction Alternatives

LAMAR B BYPASS I

PROJECT DESCRIPTION:
Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Lamar B bypass includes underground conveyance along Lamar Boulevard with an intake structure near the Lamar Boulevard crossing of Shoal Creek ultimately discharging into Lady Bird Lake near Lamar Boulevard.





QUICK FACTS

- Level of Service:
  Between 50-year and 100-year
- Bypass Dimension:
  4,850 feet long
  11-feet Diameter
- Project Cost Estimate:
  $84,763,500

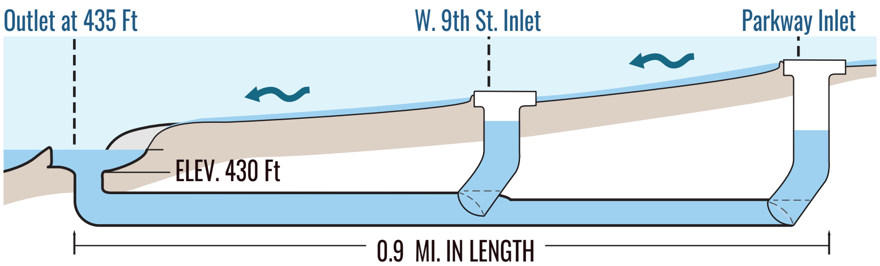
100-YR. FLOOD MITIGATION BENEFITS

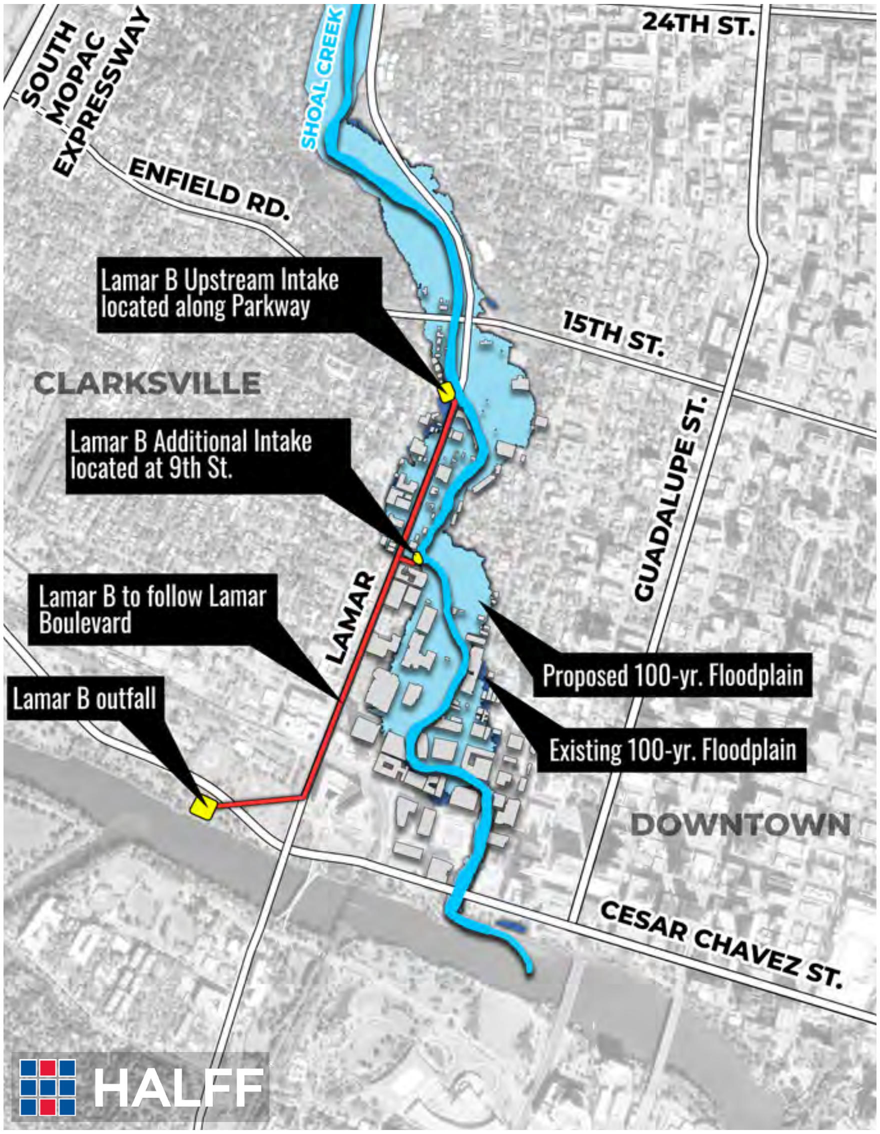
- Number of Buildings Protected:
  4 out of 61
- Length of Mitigated Inundated Roadway:
  1,100 out of 12,300 linear feet
- Increase in Mobility Based on Annual Average Daily Traffic:
  970 out of 15,670 drivers

Lower Shoal Creek Flood Risk Reduction Alternatives

LAMAR B BYPASS 2

PROJECT DESCRIPTION:
Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Lamar B bypass includes underground conveyance along Lamar Boulevard with an intake structure near the Lamar Boulevard crossing of Shoal Creek ultimately discharging into Lady Bird Lake near Lamar Boulevard. With the addition of an intake at 9th Street, this allows for more water to enter the bypass, requiring a larger bypass downstream of the intake, but providing more flood mitigation benefits and a higher level of service.





QUICK FACTS

- Level of Service: 50-year
- Bypass Dimension: 5,030 feet long; 11-feet to 13-feet Diameter
- Project Cost Estimate: $97,862,500

100-YR. FLOOD MITIGATION BENEFITS

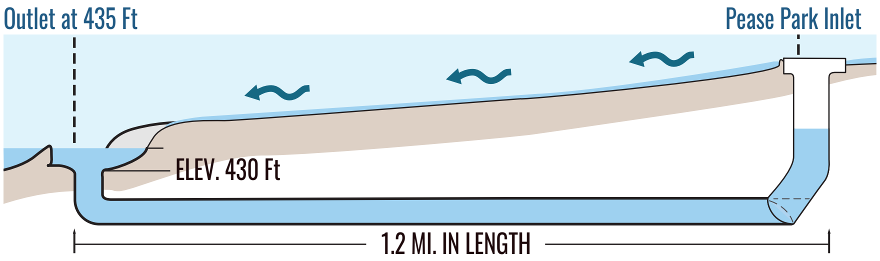
- Number of Buildings Protected: 7 out of 61
- Length of Mitigated Inundated Roadway: 1,400 out of 12,300 linear feet
- Increase in Mobility Based on Annual Average Daily Traffic: 1,830 out of 15,670 drivers

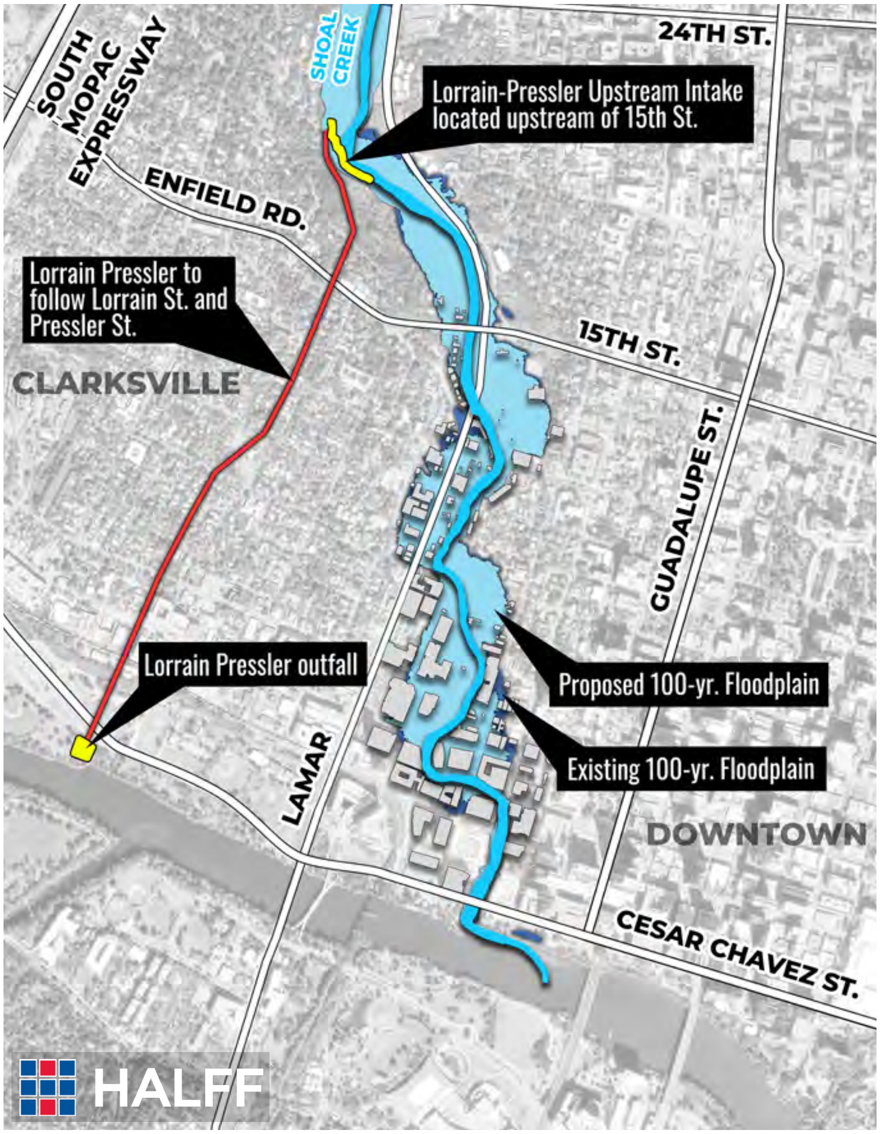
Lower Shoal Creek Flood Risk Reduction Alternatives

LORRAIN-PRESSLER BYPASS I

PROJECT DESCRIPTION:

Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Pressler-Lorain bypass includes underground conveyance along Lorrain Street and Pressler Street with an intake structure in along the west bank of Shoal Creek in Pease Park ultimately discharging into Lady Bird Lake near Stephen F Austin Boulevard. To minimize permitting requirements and environmental impacts, floodwaters would be diverted into the bypass at an elevation above the 2-year event. This allows for smaller events to remain in the creek but provides flood protection for the larger events.





QUICK FACTS

- Level of Service:
  Between 25-year and 50-year
- Bypass Dimension:
  6,440 feet long
  22-feet Diameter
- Project Cost Estimate:
  $92,830,500

100-YR. FLOOD MITIGATION BENEFITS

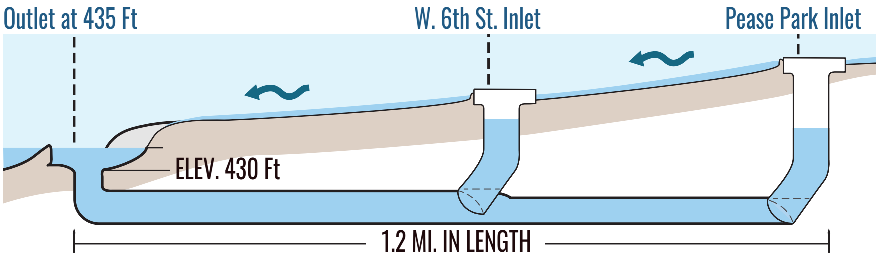
- Number of Buildings Protected:
  11 out of 61
- Length of Mitigated Inundated Roadway:
  2,100 out of 12,300 linear feet
- Increase in Mobility Based on Annual Average Daily Traffic:
  850 out of 15,670 drivers

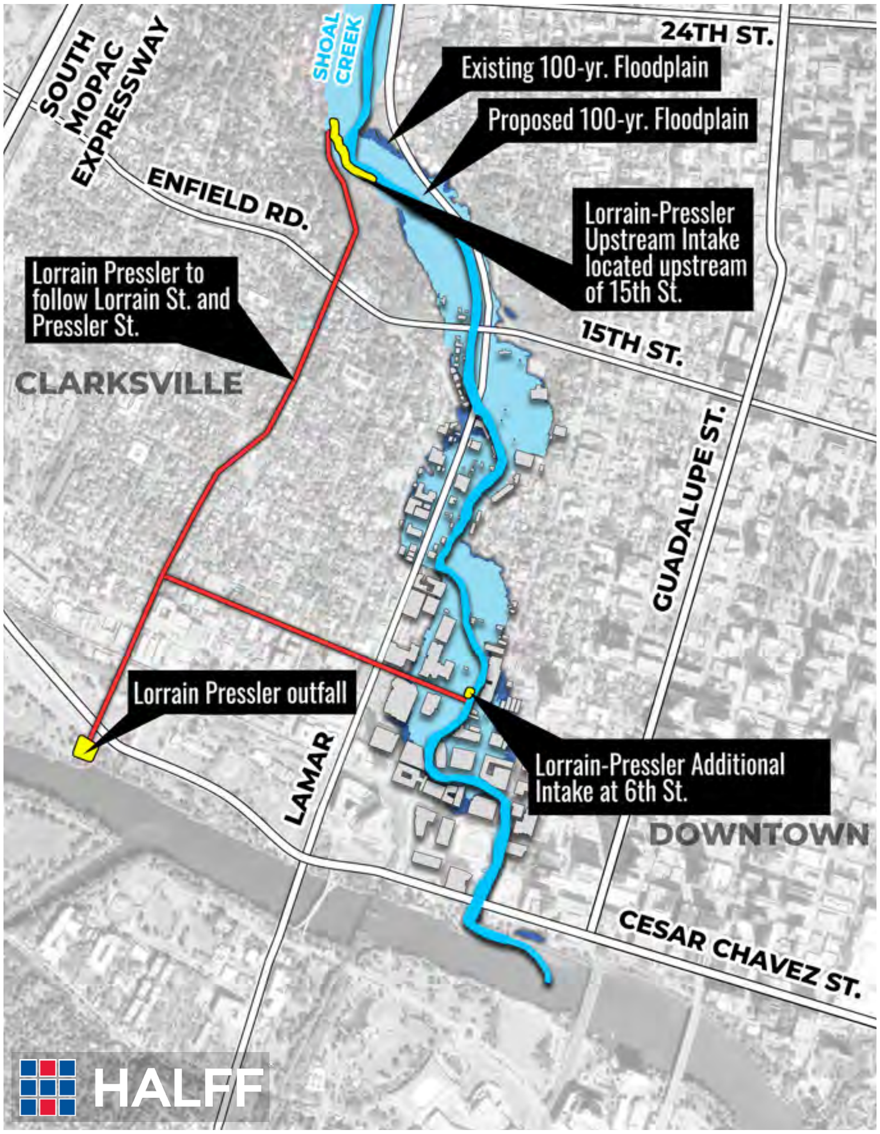
Lower Shoal Creek Flood Risk Reduction Alternatives

LORRAIN-PRESSLER BYPASS 2

PROJECT DESCRIPTION:

Providing additional conveyance along Lower Shoal Creek is an effective alternative to reduce flood elevations. The proposed Pressler-Lorain bypass includes underground conveyance along Lorrain Street and Pressler Street with an intake structure in along the west bank of Shoal Creek in Pease Park ultimately discharging into Lady Bird Lake near Stephen F Austin Boulevard. To minimize permitting requirements and environmental impacts, floodwaters would be diverted into the bypass at an elevation above the 2-year event. This allows for smaller events to remain in the creek but provides flood protection for the larger events. With the addition of an intake at 6th Street, this allows for more water to enter the bypass, requiring a larger bypass downstream of the intake, but providing more flood mitigation benefits and higher level of service.





QUICK FACTS

- Level of Service:
  25-year
- Bypass Dimension:
  9,550 feet long
  22-feet to 26-feet Diameter
- Project Cost Estimate:
  $146,598,500

100-YR. FLOOD MITIGATION BENEFITS

- Number of Buildings Protected:
  12 out of 61
- Length of Mitigated Inundated Roadway:
  2,400 out of 12,300 linear feet
- Increase in Mobility Based on Annual Average Daily Traffic:
  1,590 out of 15,670 drivers

Lower Shoal Creek Flood Risk Reduction Alternatives

COMMUNITY RESILIENCE PLAN

PROJECT DESCRIPTION:

Many high-value buildings are anticipated to flood at events even as low as the 50% annual chance event (2-year). Consequently, it is not cost efficient to mitigate or acquire all at-risk buildings. In these cases, it may be more cost effective and prudent to evaluate opportunities for improving the resilience of individual buildings and structures in the area. In this regard, a community resilience plan could be implemented to increase standards for new development, incentivize safe redevelopment and retrofits, inform citizens to increase flood preparedness, and implement better warning systems. Some combination of mitigation and improved resilience may be the most viable option for moving forward. These plans typically involve many moving parts and all potential ideas may involve individuals, groups, or entities beyond the City of Austin.

COMMUNITY RESILIENCE

Flood Resilient:
- -Require flood response plan for new development
- -Design improvements for new development (e.g. flood gates)

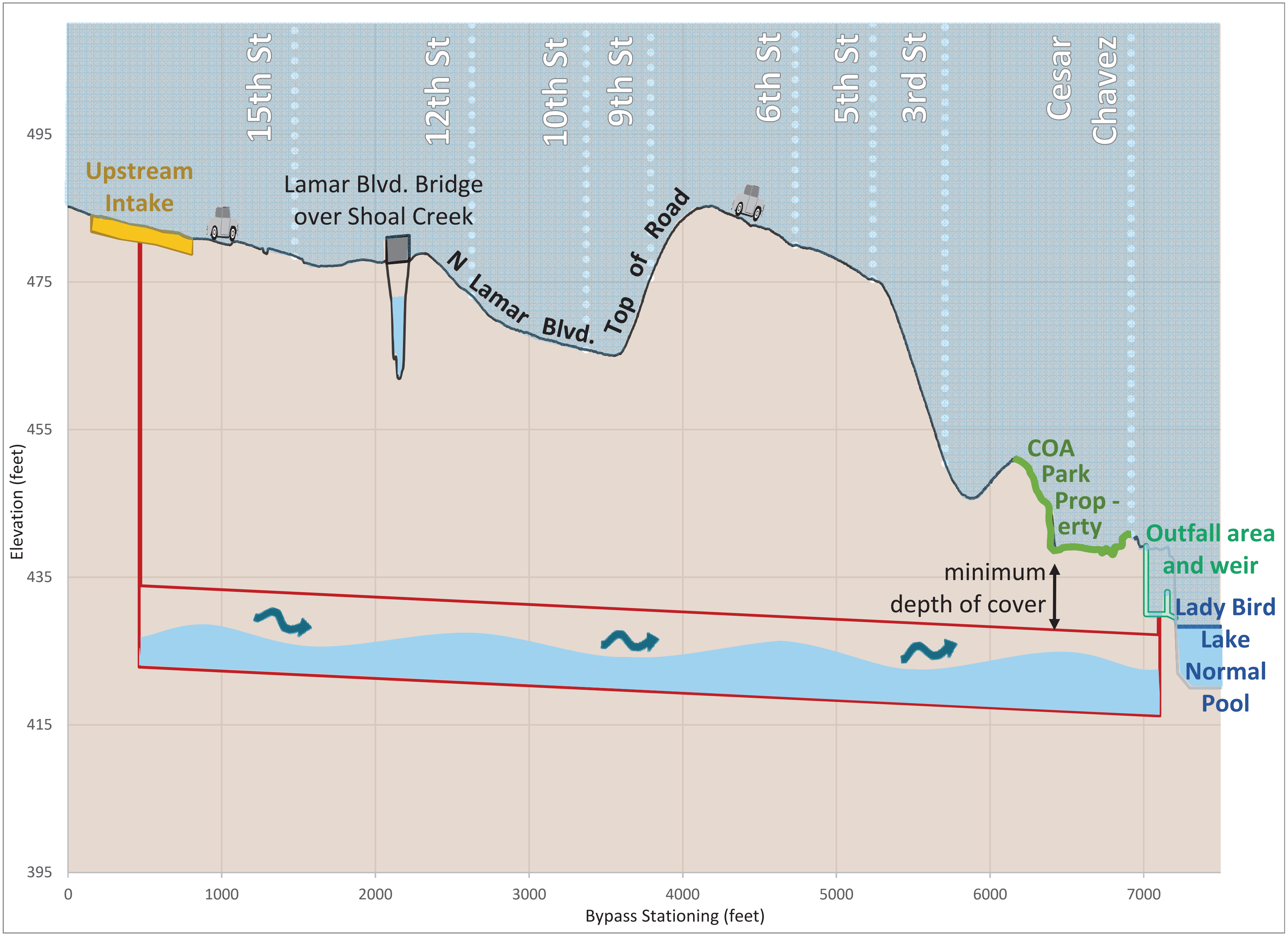
Redevelopment:
- -Incentivize redevelopment or retrofits for existing structures
- -Elevate critical infrastructure above 1% ACE (100-yr) water surface
- -Design improvements for existing development (e.g. flood gates)
- -Coordination with Code Compliance to monitor remodeling in the area
- -Consider grants for flood assistance/flood proofing

People:
- -Develop a Lower Shoal Creek Area Flood Plan
- -Yearly community outreach program, hosting informational and training sessions regarding:
  - Preparing for a flood event
  - Remaining safe during a flood event
  - How to decrease turnaround time for business after a flood
- -AISD (House Park) education/outreach, evacuation plan, and flood plan

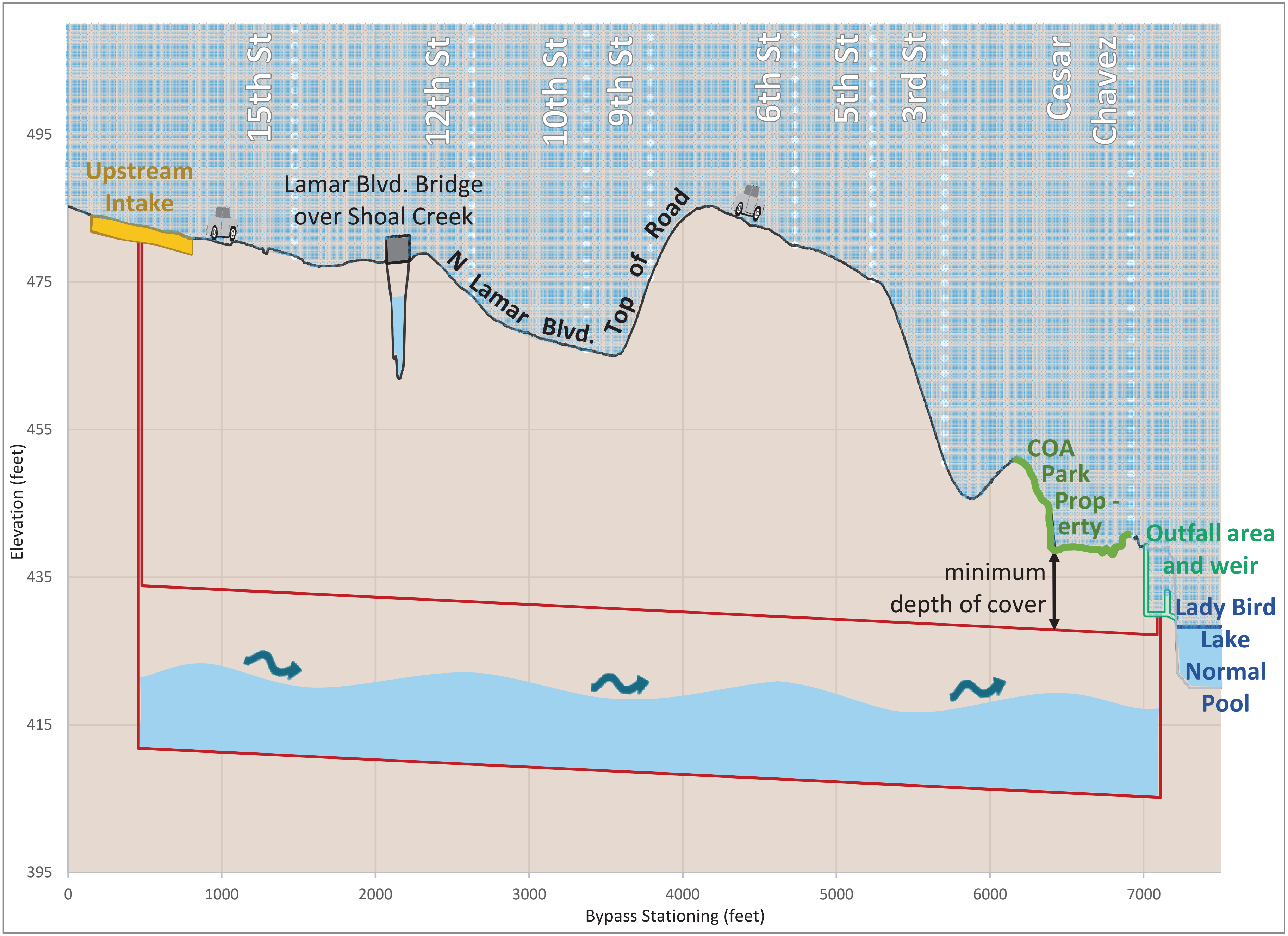
Access:
- -Improving control of access (e.g. installing flood gates at access points to roadways that consistently flood)
- -Provide better warning signage and notification
- -Excavation and detour routes
- -Incentives to create elevated access paths where feasible

APPENDIX F: Conceptual Underground Bypass Profiles

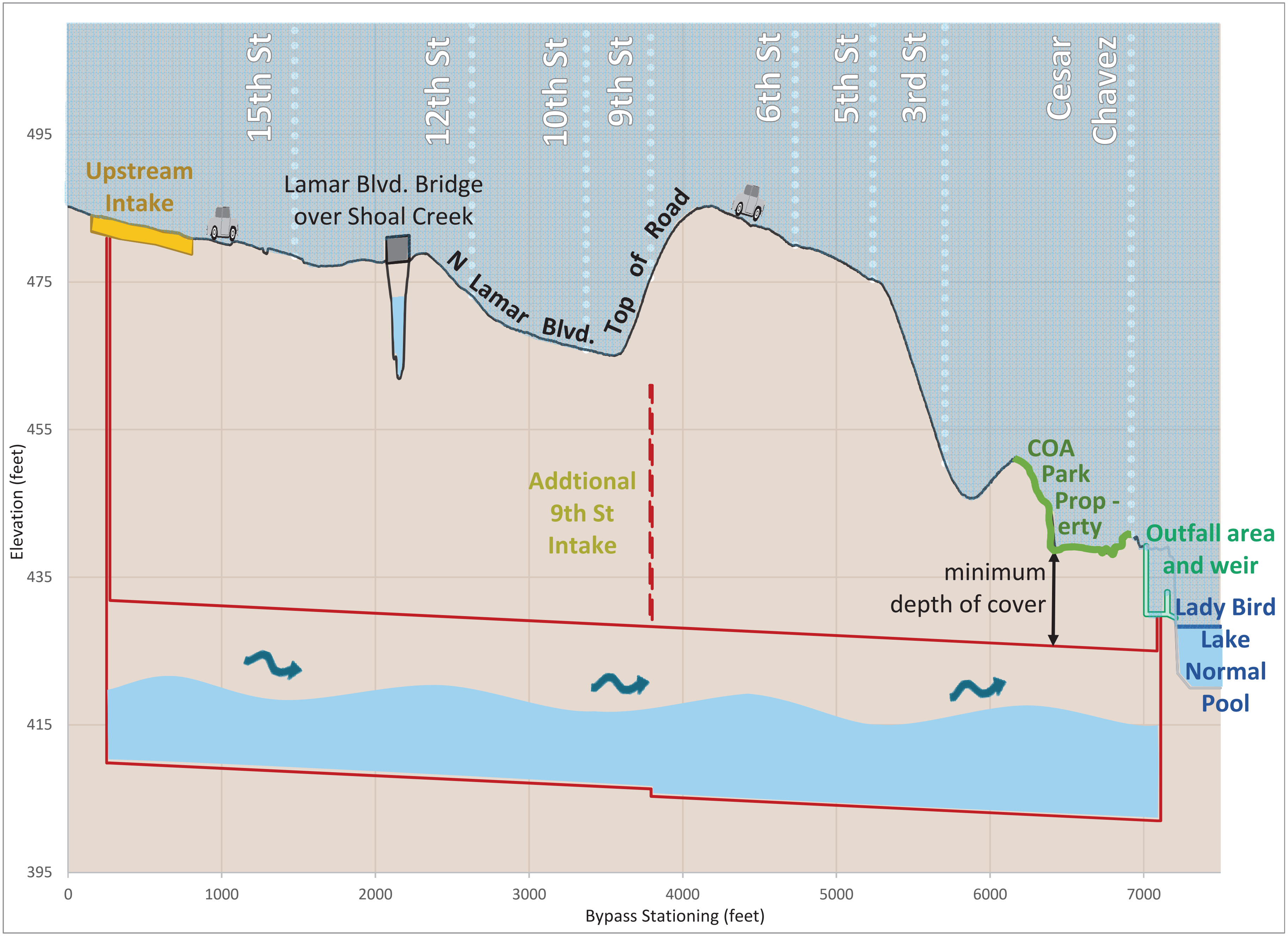
Lamar A Bypass 1 Conceptual Profile



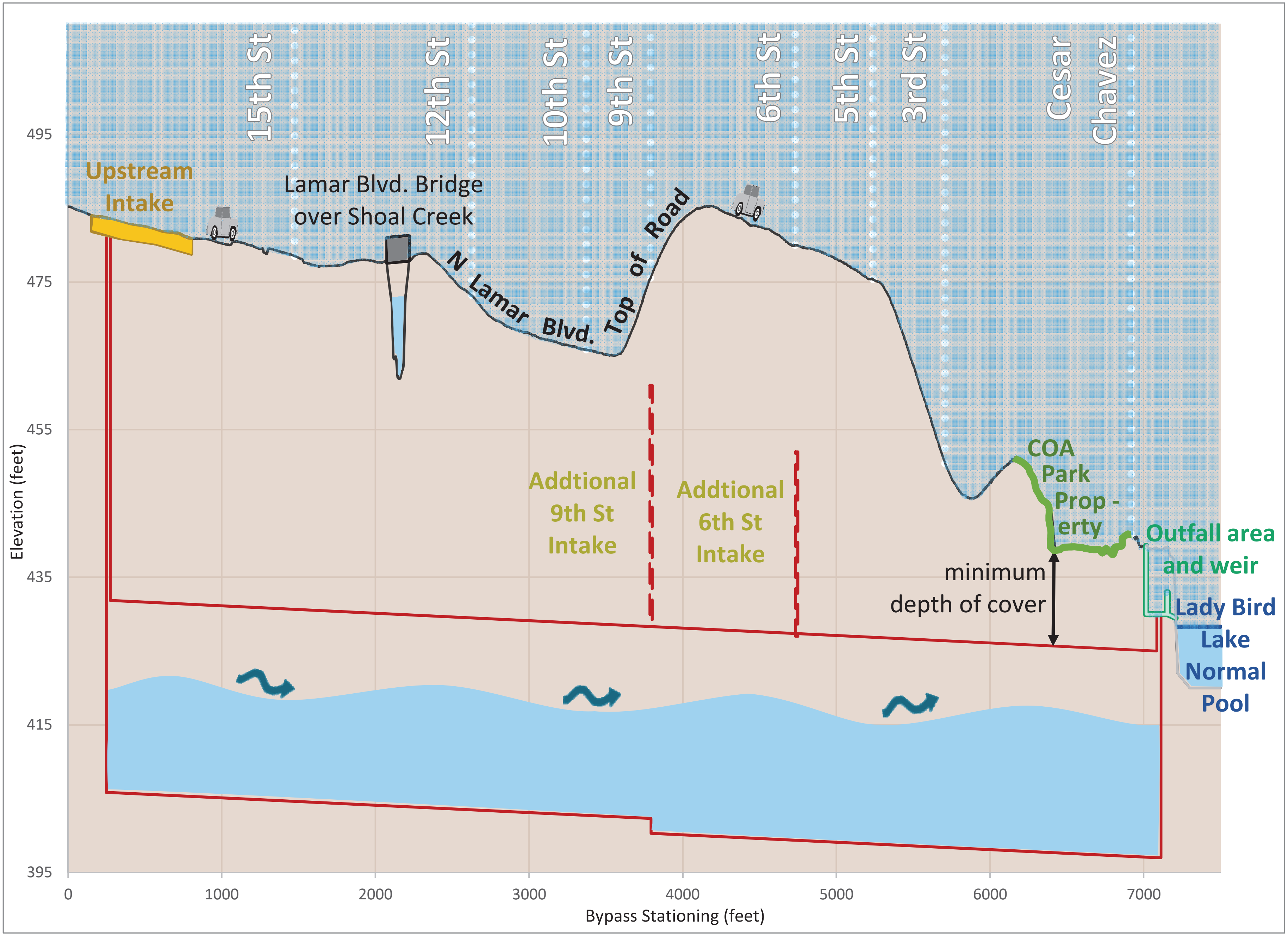
Lamar A Bypass 2 Conceptual Profile



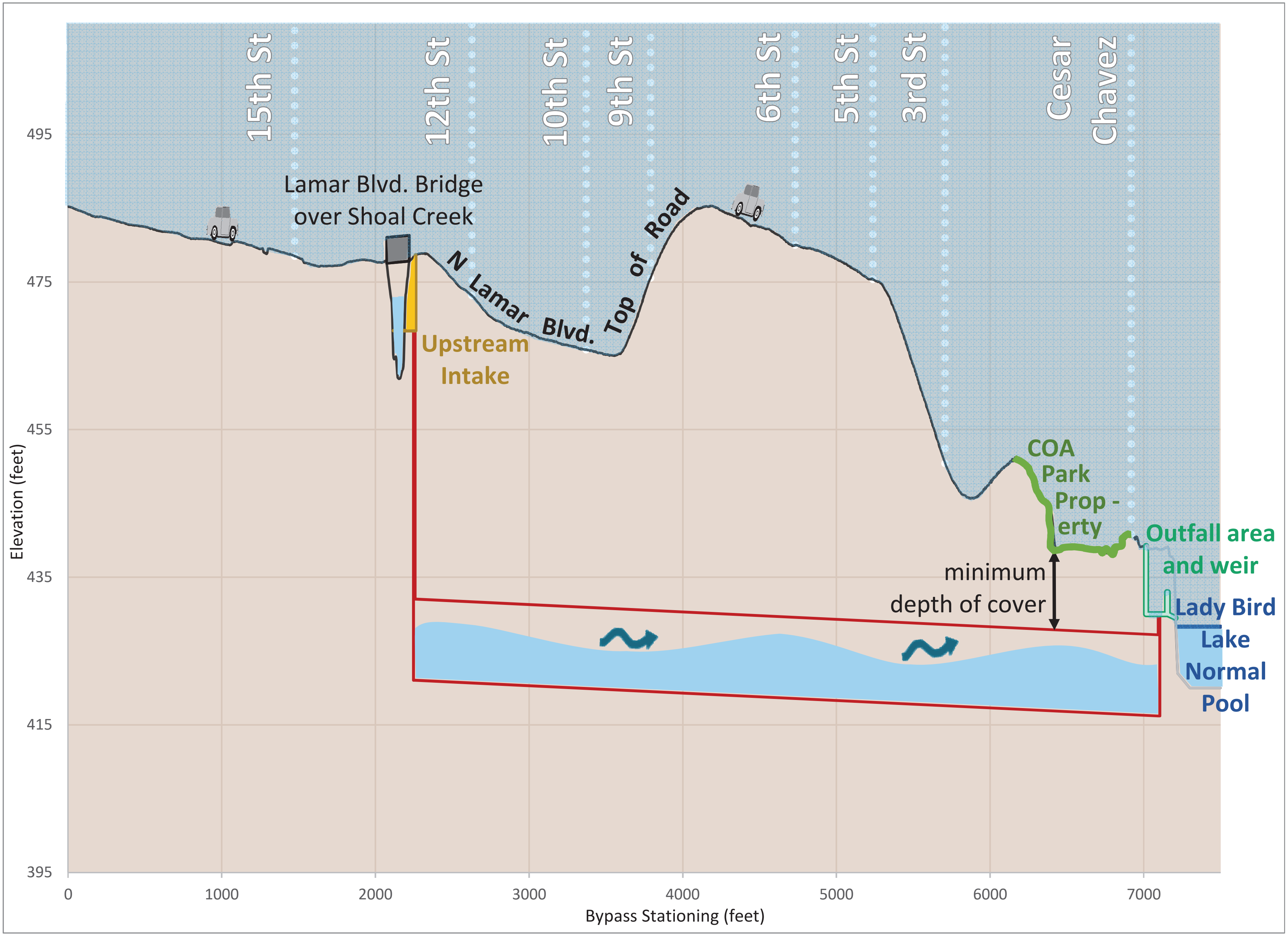
Lamar A Bypass 3 Conceptual Profile



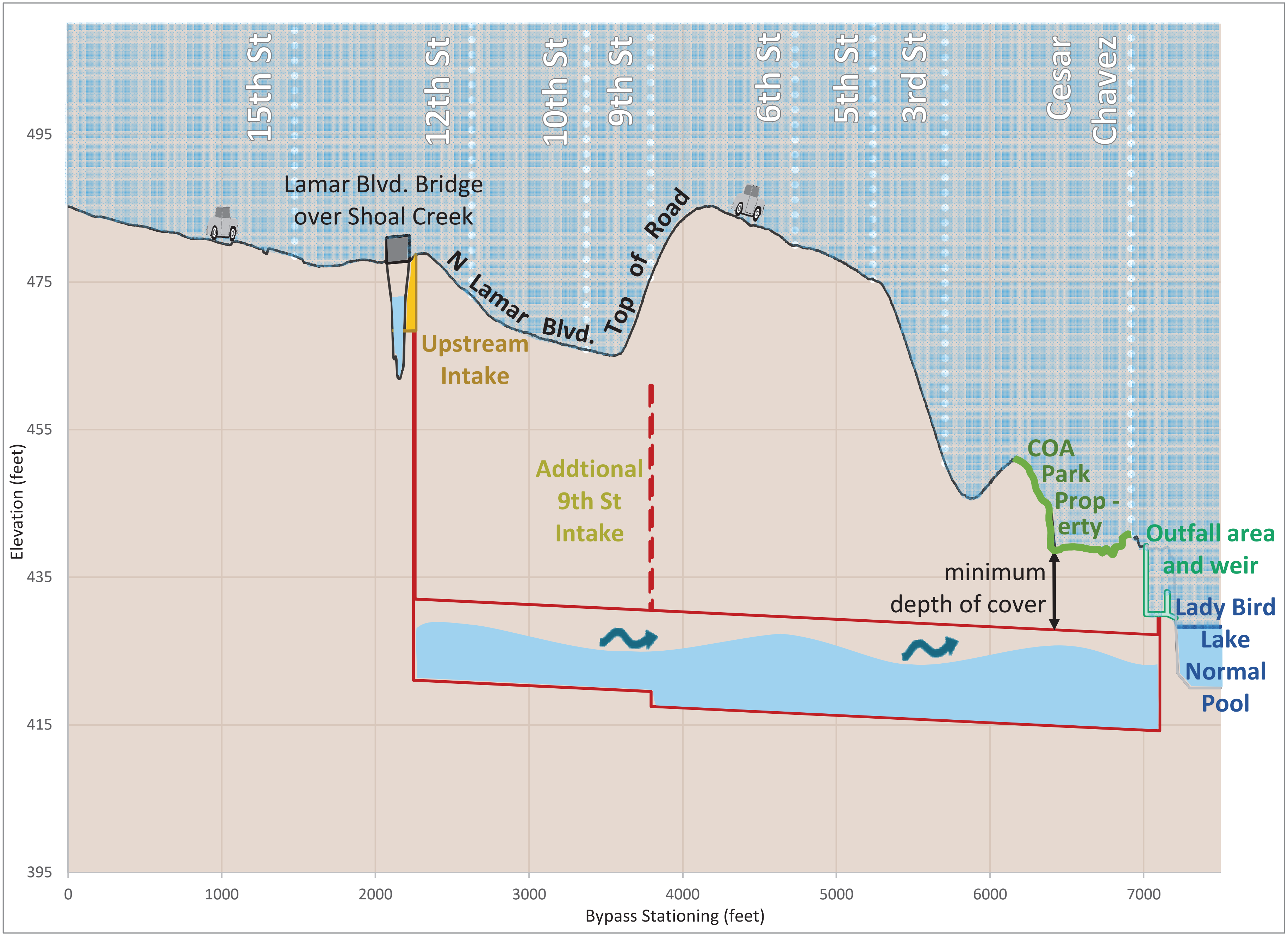
Lamar A Bypass 4 Conceptual Profile

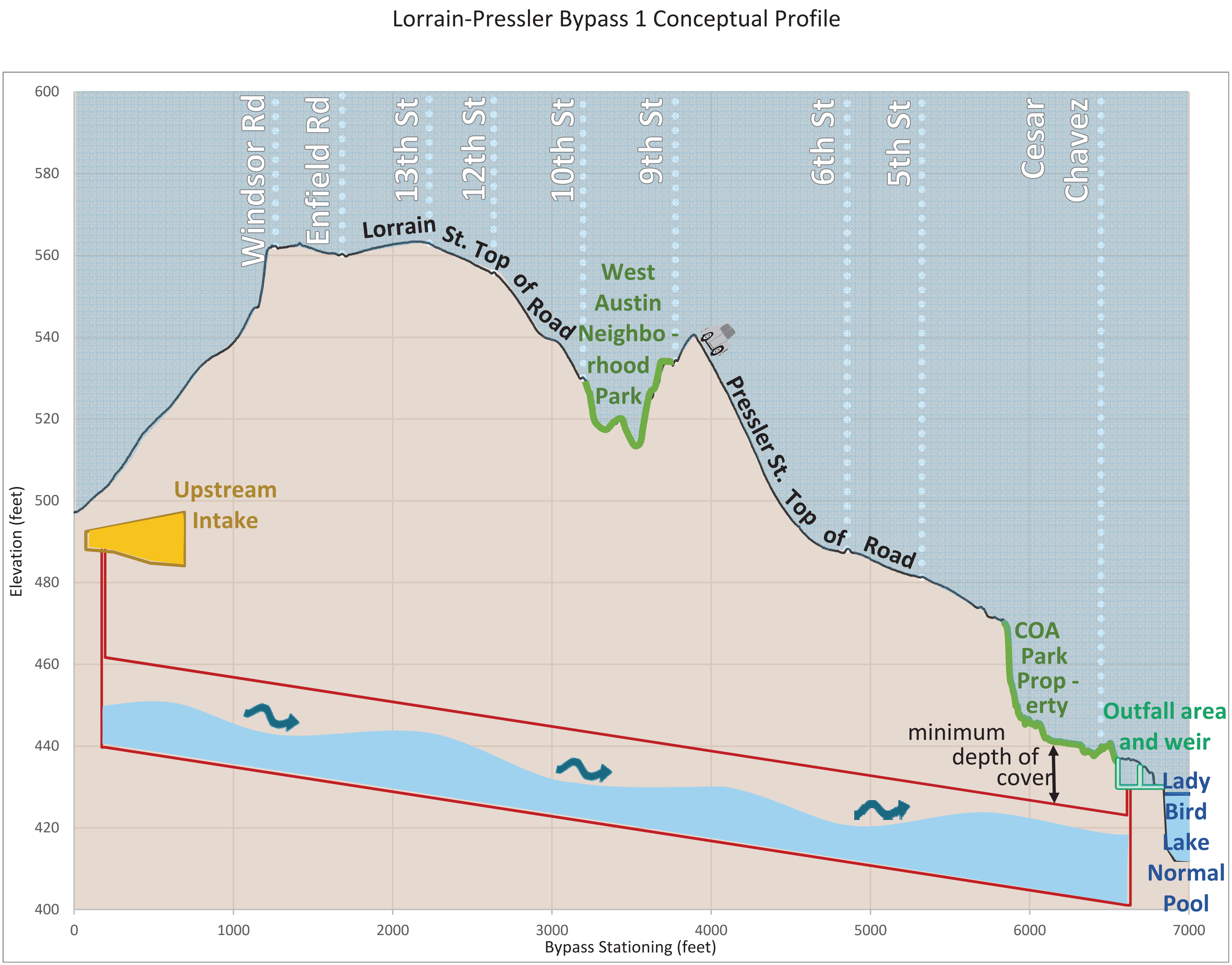


Lamar B Bypass 1 Conceptual Profile



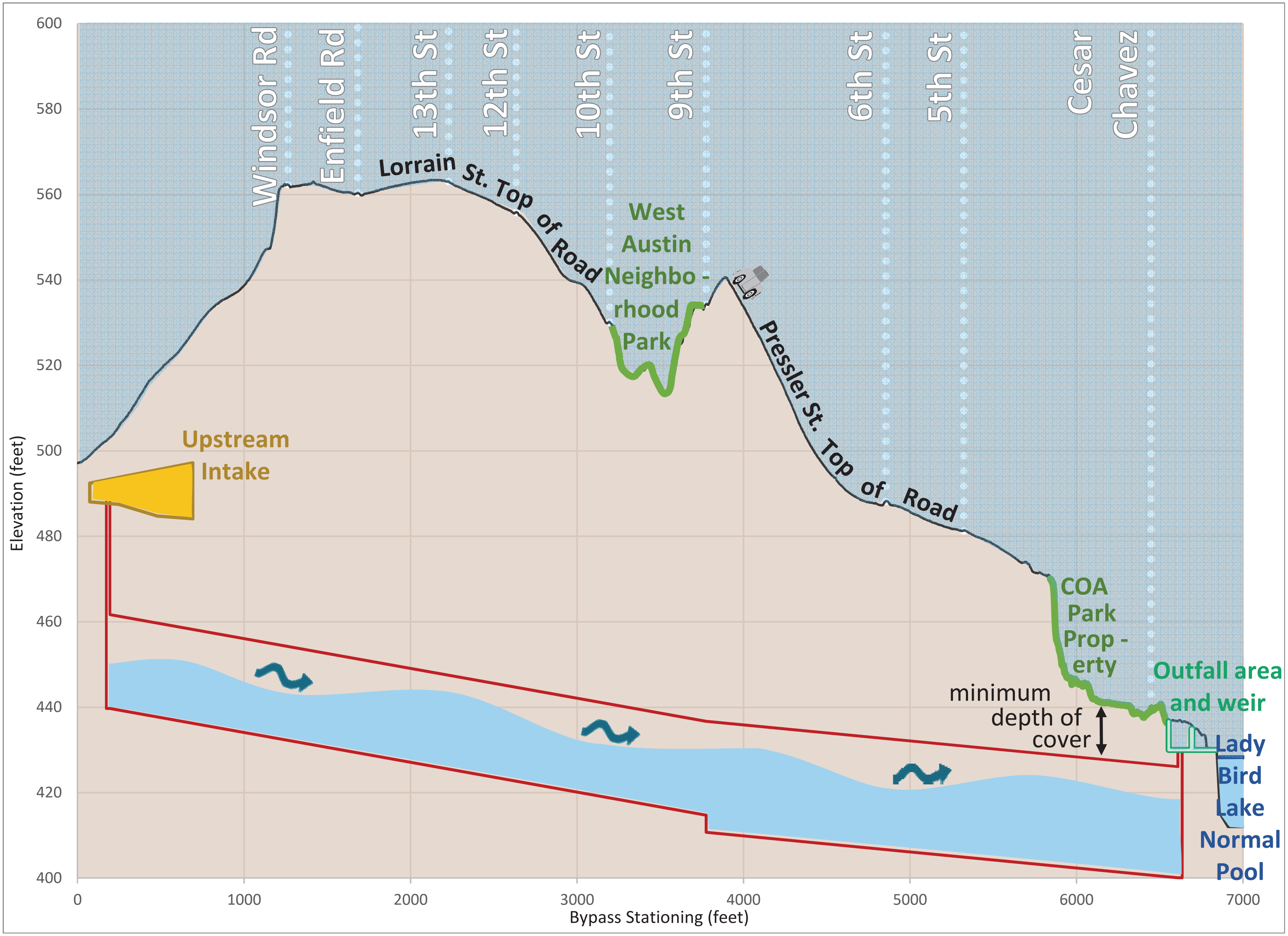
Lamar B Bypass 2 Conceptual Profile



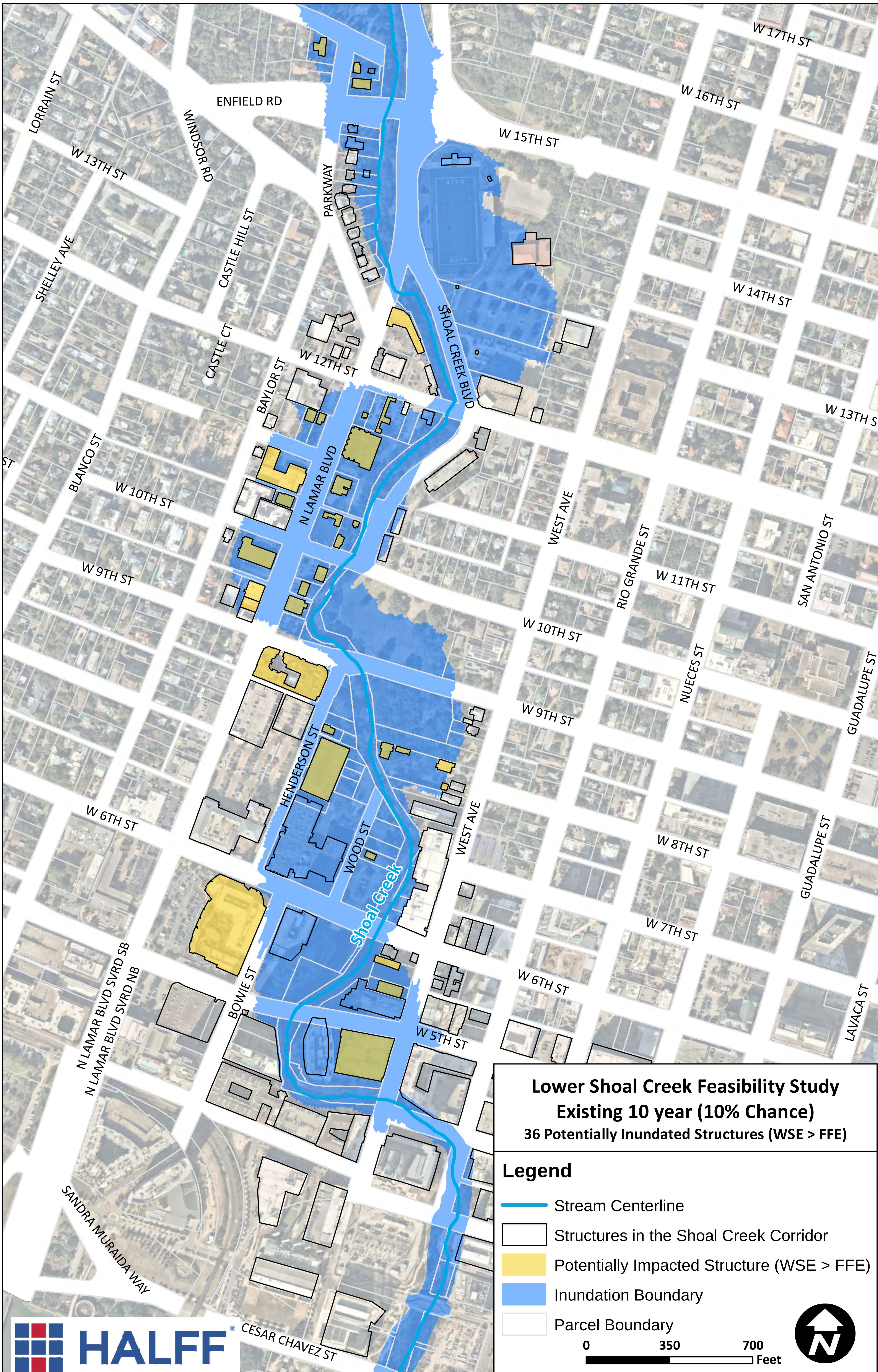


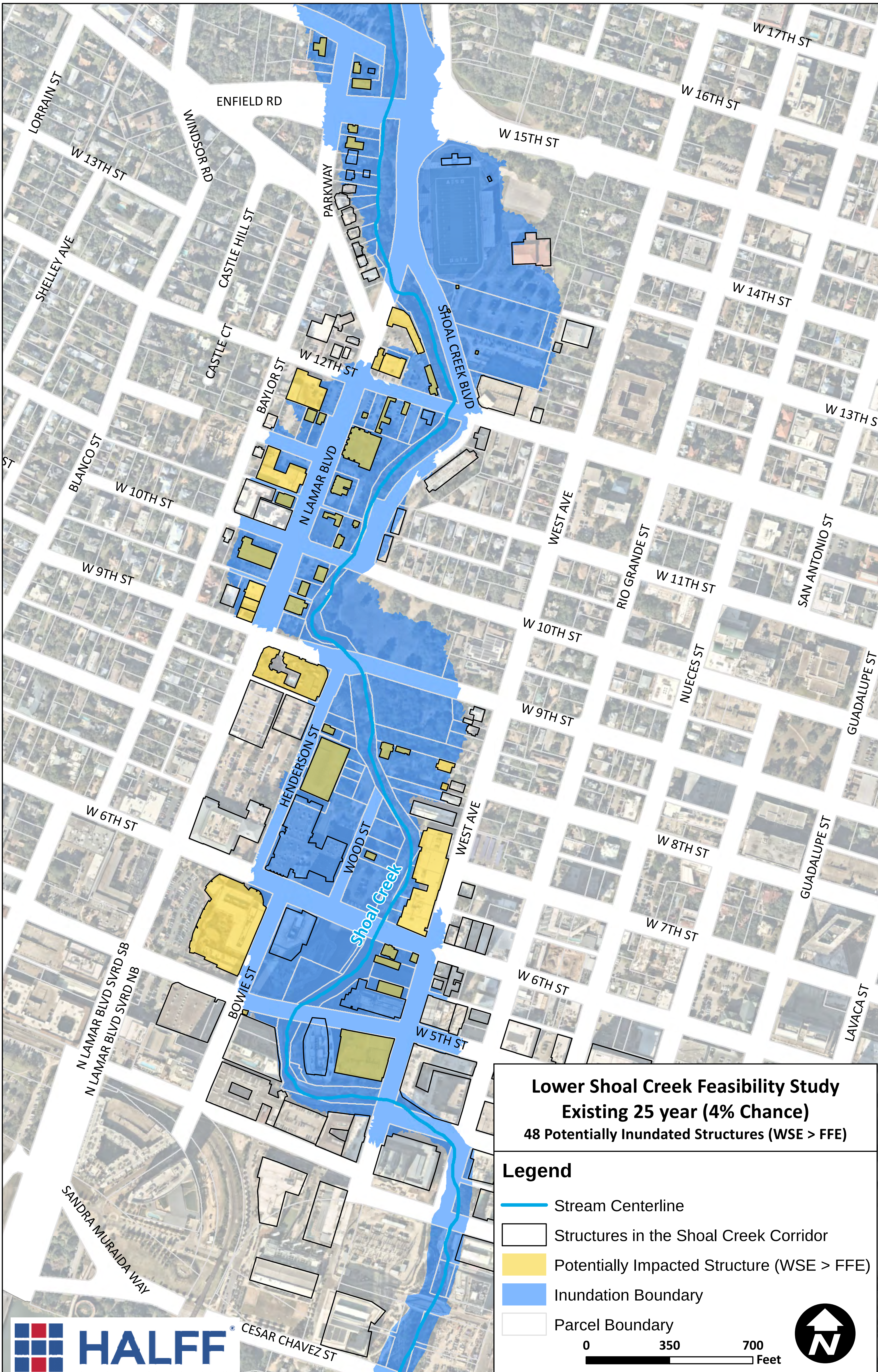
Lorrain-Pressler Bypass 1 Conceptual Profile
Windsor Rd
Enfield Rd
13th St
12th St
10th St
9th St
6th St
5th St
Cesar Chavez
Lorrain St. Top of Road
West Austin Neighbo - rhood Park
Pressler St. Top of Road
Upstream Intake
COA Park Prop - erty
Outfall area and weir
minimum depth of cover
Lady Bird Lake Normal Pool
Elevation (feet)
Bypass Stationing (feet)
600
580
560
540
520
500
480
460
440
420
400
0
1000
2000
3000
4000
5000
6000
7000

Lorrain-Pressler Bypass 2 Conceptual Profile

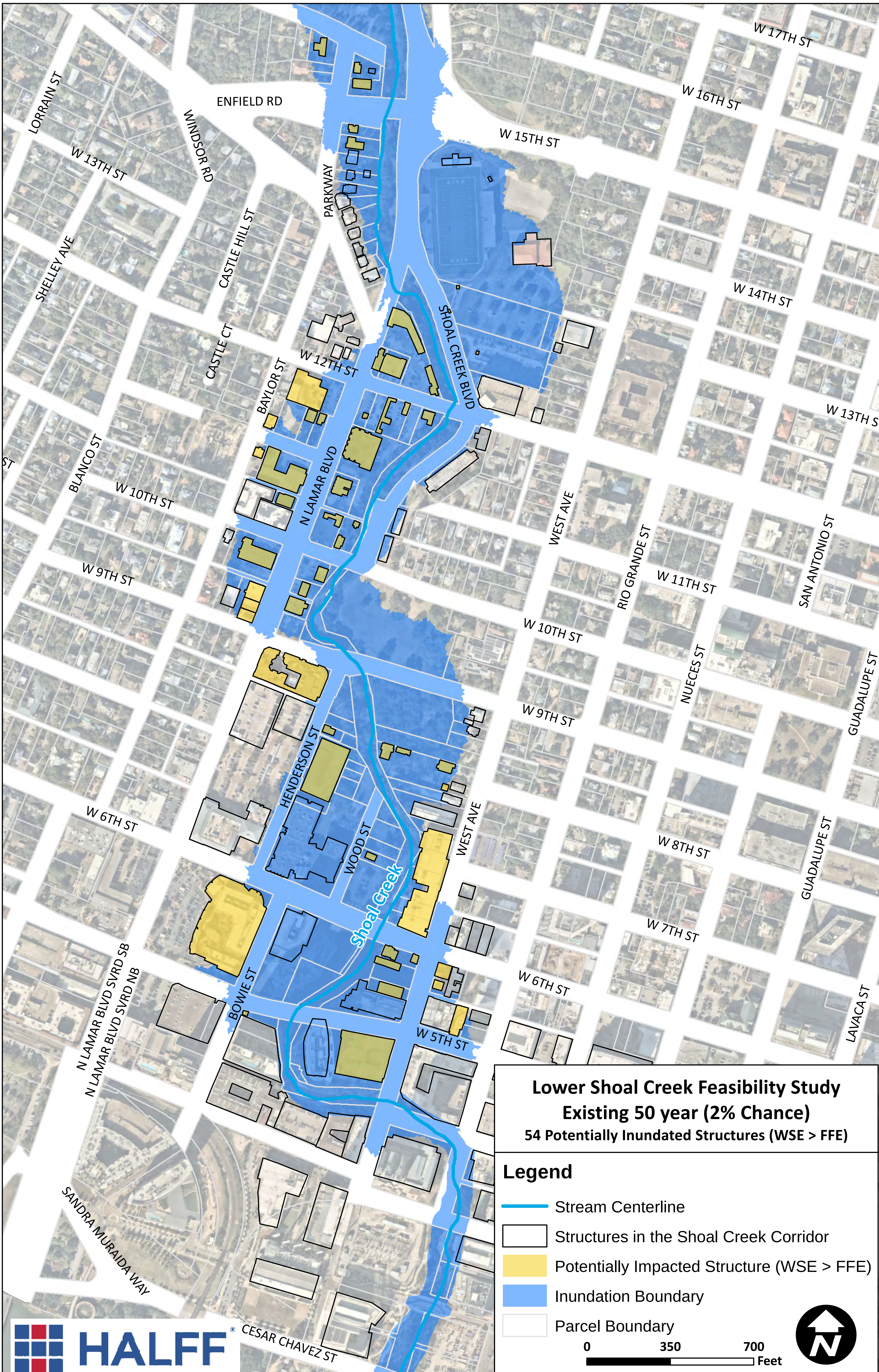


APPENDIX G: Floodplain Comparisons


Lower Shoal Creek Feasibility Study
Existing 10 year (10% Chance)
36 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
W 13TH ST
W 12TH ST
W 11TH ST
W 10TH ST
W 9TH ST
W 8TH ST
W 7TH ST
W 6TH ST
W 5TH ST
CESAR CHAVEZ ST
ENFIELD RD
LORRAIN ST
WINDSOR RD
PARKWAY
CASTLE HILL ST
SHELLEY AVE
CASTLE CT
BAYLOR ST
BLANCO ST
N LAMAR BLVD
SHOAL CREEK BLVD
WEST AVE
RIO GRANDE ST
NUECES ST
SAN ANTONIO ST
GUADALUPE ST
LAVACA ST
HENDERSON ST
WOOD ST
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
SANDRA MURAIDA WAY



Lower Shoal Creek Feasibility Study
Existing 25 year (4% Chance)
48 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
W 17TH ST
W 16TH ST
W 15TH ST
ENFIELD RD
LORRAIN ST
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
SHELLEY AVE
W 14TH ST
SHOAL CREEK BLVD
CASTLE CT
W 12TH ST
BAYLOR ST
N LAMAR BLVD
BLANCO ST
W 10TH ST
WEST AVE
RIO GRANDE ST
W 11TH ST
SAN ANTONIO ST
W 9TH ST
NUECES ST
GUADALUPE ST
HENDERSON ST
W 6TH ST
WOOD ST
W 8TH ST
W 7TH ST
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
W 5TH ST
LAVACA ST
SANDRA MURAIDA WAY
CESAR CHAVEZ ST

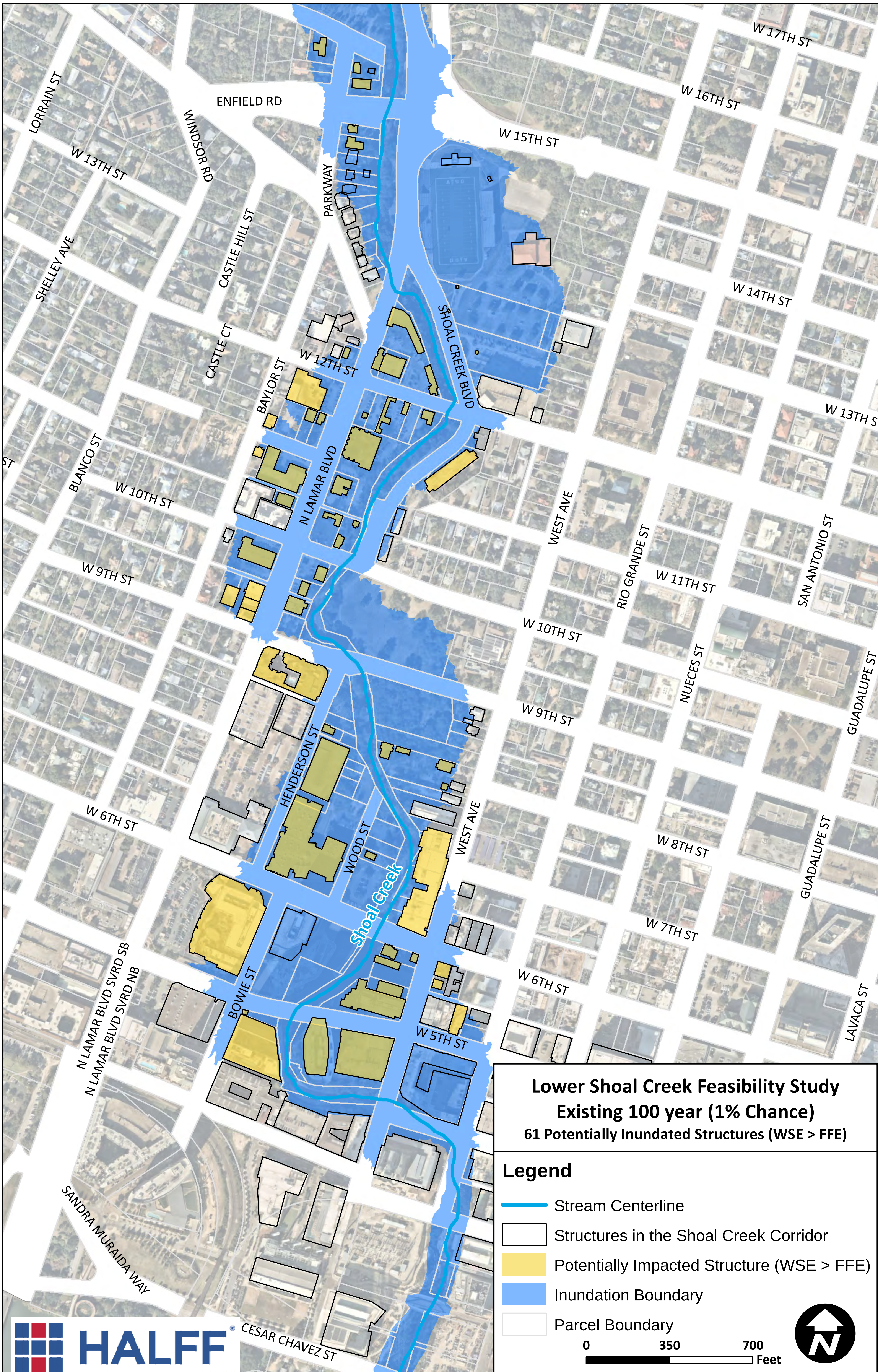


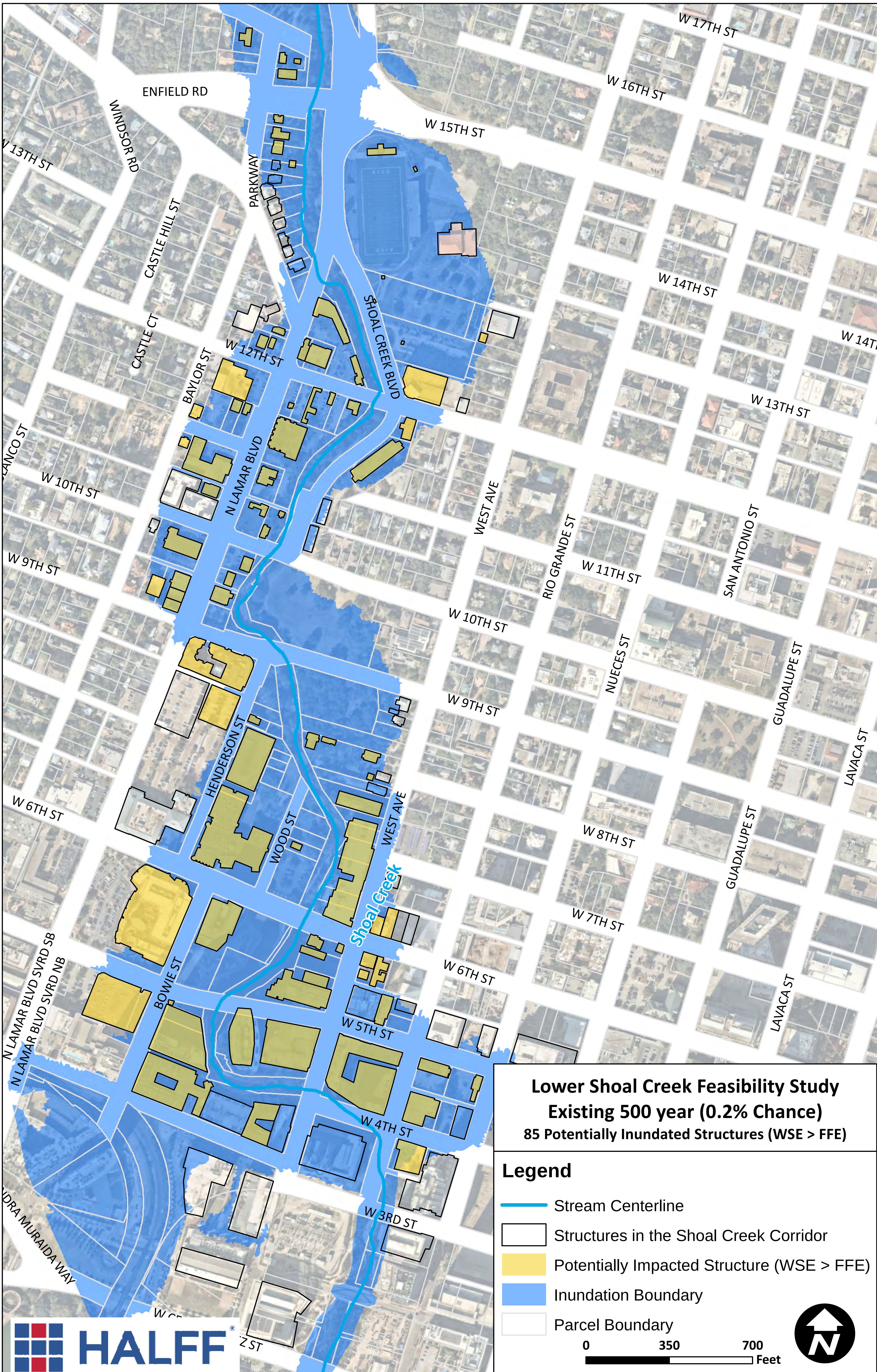
Lower Shoal Creek Feasibility Study
Existing 50 year (2% Chance)
54 Potentially Inundated Structures (WSE > FFE)

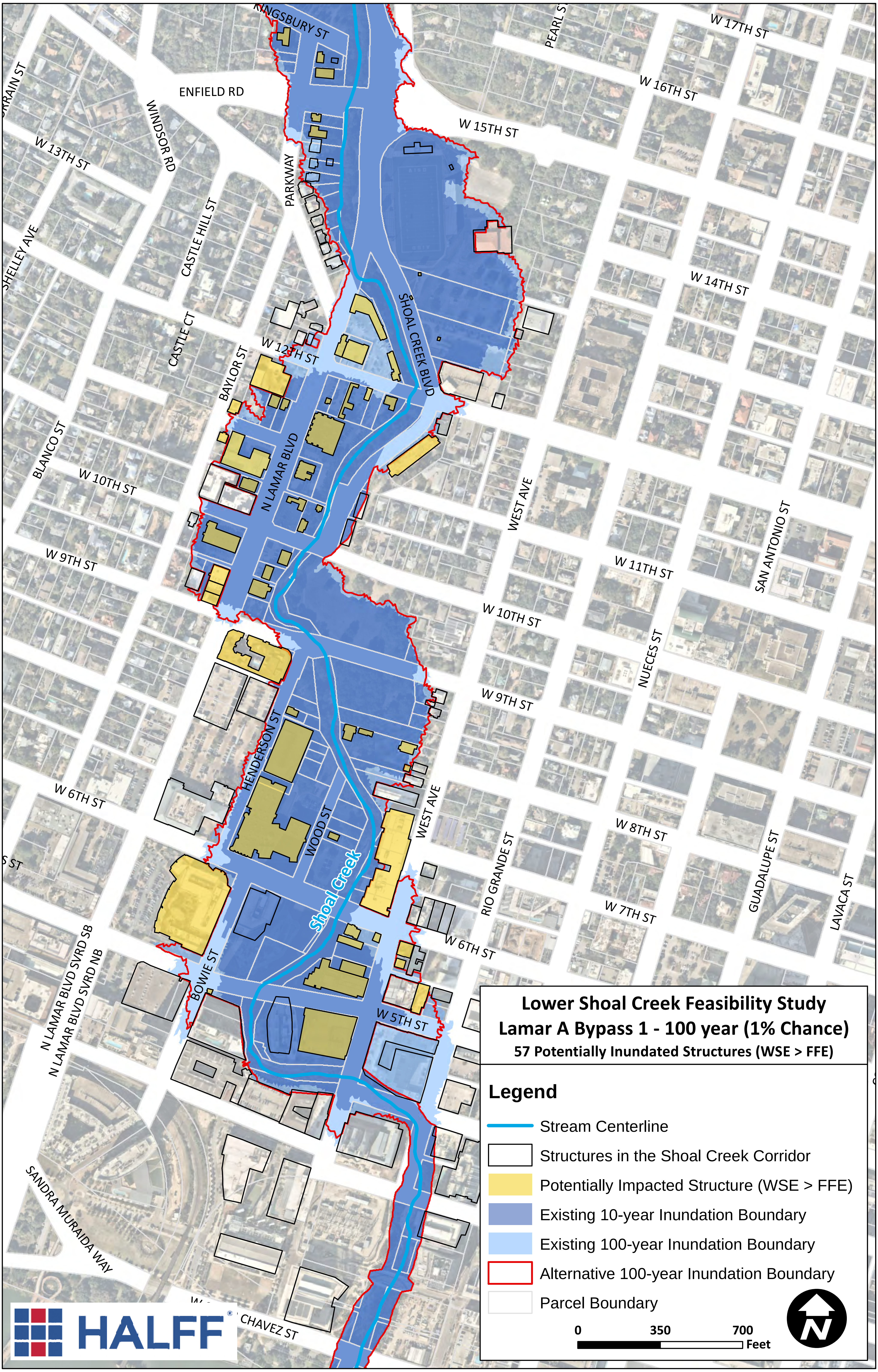
Legend

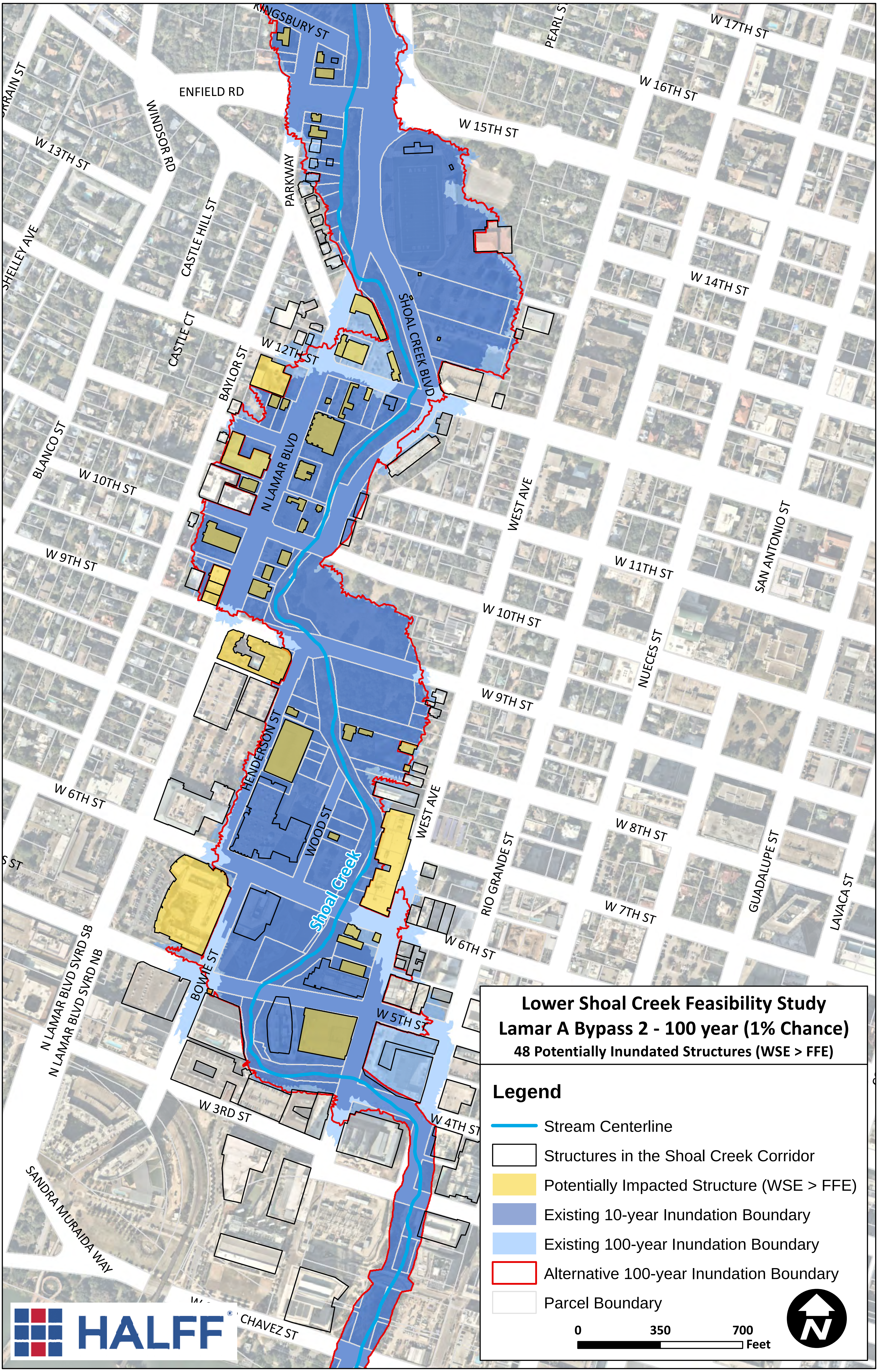
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Inundation Boundary
Parcel Boundary

0 350 700 Feet

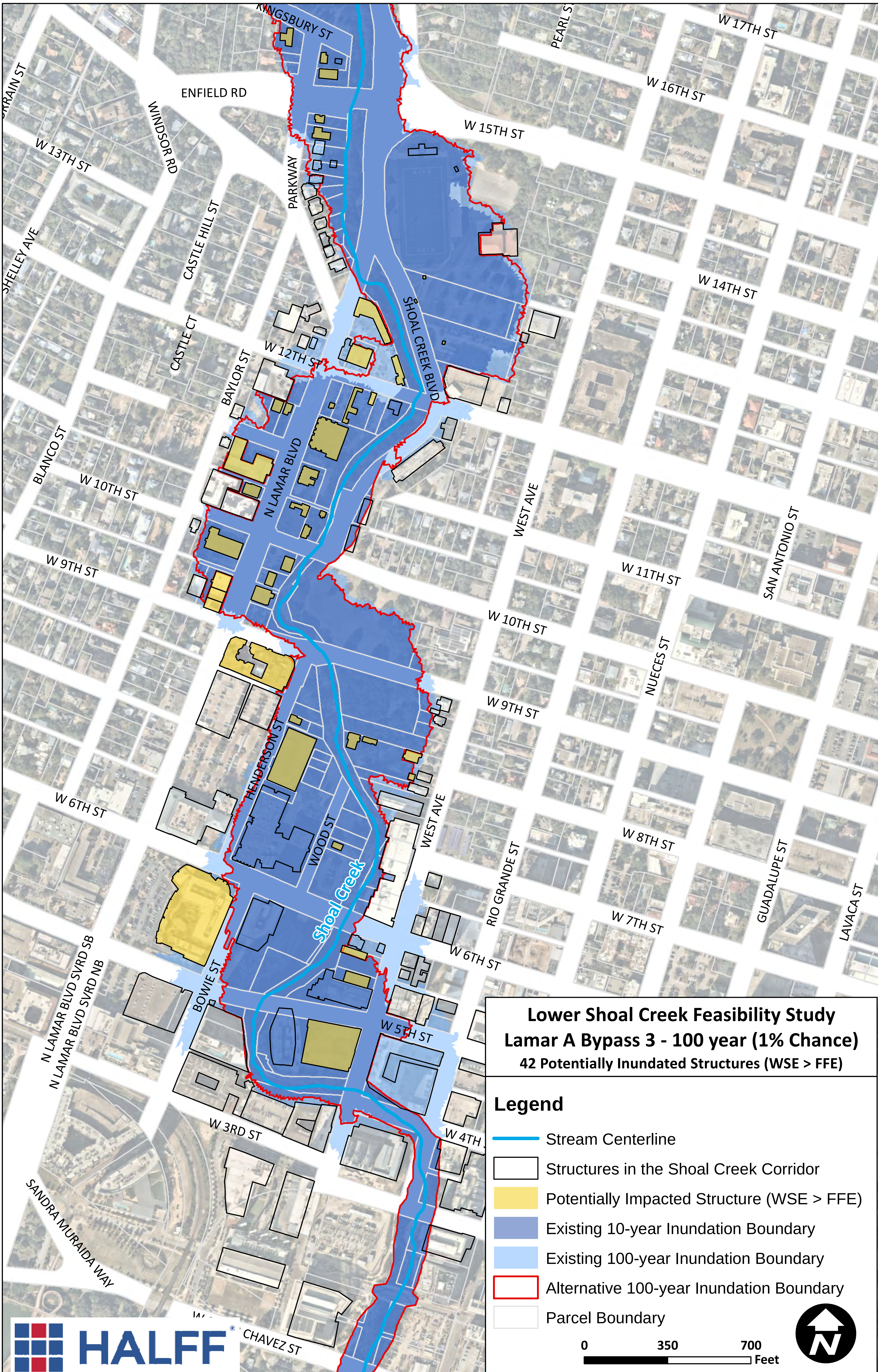

Lower Shoal Creek Feasibility Study
Existing 100 year (1% Chance)
61 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Inundation Boundary
Parcel Boundary
0
350
700
Feet
HALFF
Shoal Creek
W 17TH ST
W 16TH ST
W 15TH ST
ENFIELD RD
LORRAIN ST
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
SHELLEY AVE
W 14TH ST
SHOAL CREEK BLVD
CASTLE CT
W 12TH ST
BAYLOR ST
W 13TH ST
BLANCO ST
N LAMAR BLVD
W 10TH ST
WEST AVE
RIO GRANDE ST
SAN ANTONIO ST
W 11TH ST
W 9TH ST
W 10TH ST
NUECES ST
GUADALUPE ST
W 9TH ST
HENDERSON ST
W 6TH ST
WEST AVE
WOOD ST
W 8TH ST
GUADALUPE ST
W 7TH ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
BOWIE ST
W 6TH ST
LAVACA ST
W 5TH ST
SANDRA MURAIDA WAY
CESAR CHAVEZ ST

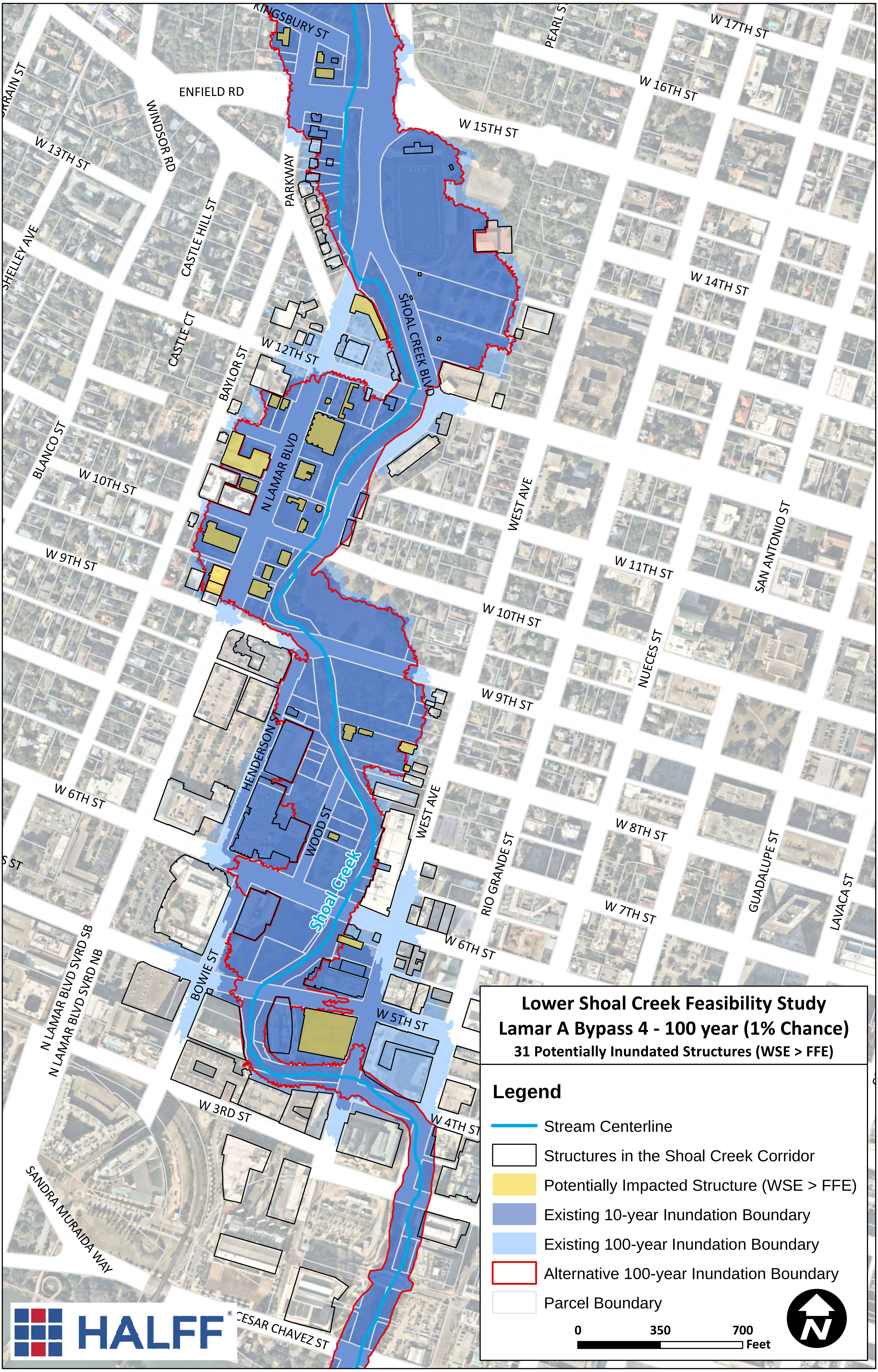

Lower Shoal Creek Feasibility Study
Existing 500 year (0.2% Chance)
85 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Inundation Boundary
Parcel Boundary
0
350
700
Feet
HALFF
W 17TH ST
W 16TH ST
W 15TH ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
CASTLE CT
W 14TH ST
W 12TH ST
BAYLOR ST
SHOAL CREEK BLVD
W 13TH ST
N LAMAR BLVD
W 10TH ST
WEST AVE
RIO GRANDE ST
W 11TH ST
SAN ANTONIO ST
W 9TH ST
W 10TH ST
NUECES ST
GUADALUPE ST
W 9TH ST
LAVACA ST
HENDERSON ST
W 6TH ST
WOOD ST
WEST AVE
W 8TH ST
GUADALUPE ST
Shoal Creek
W 7TH ST
W 6TH ST
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
W 5TH ST
LAVACA ST
W 4TH ST
W 3RD ST

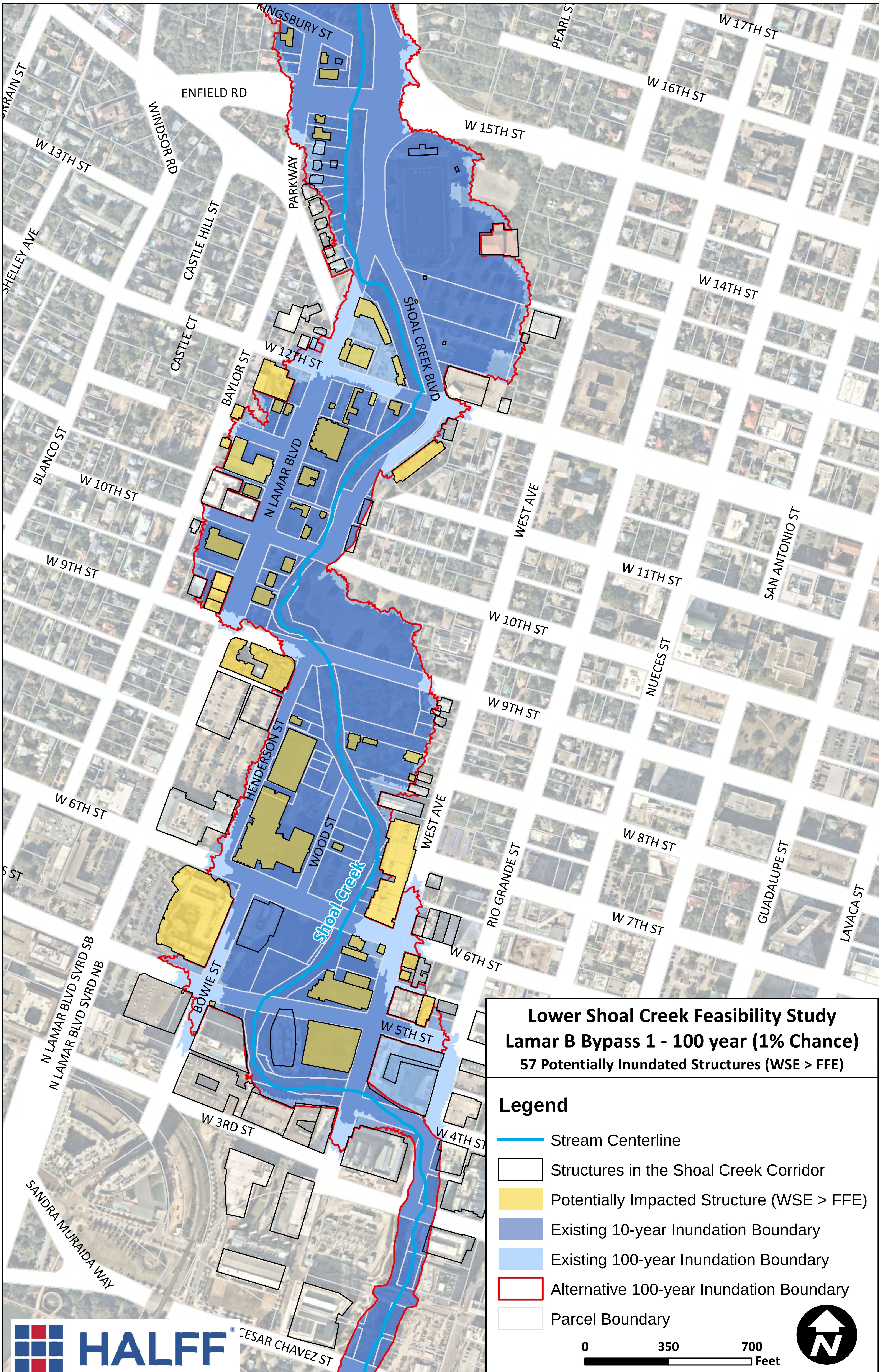

Lower Shoal Creek Feasibility Study
Lamar A Bypass 1 - 100 year (1% Chance)
57 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
SHELLEY AVE
CASTLE CT
W 12TH ST
BAYLOR ST
SHOAL CREEK BLVD
N LAMAR BLVD
BLANCO ST
W 10TH ST
W 9TH ST
W 6TH ST
HENDERSON ST
WOOD ST
WEST AVE
BOWIE ST
W 5TH ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
SANDRA MURAIDA WAY
CHAVEZ ST
PEARL ST
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
W 11TH ST
NUECES ST
SAN ANTONIO ST
W 8TH ST
W 7TH ST
RIO GRANDE ST
GUADALUPE ST
LAVACA ST



Lower Shoal Creek Feasibility Study
Lamar A Bypass 2 - 100 year (1% Chance)
48 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
SHELLEY AVE
CASTLE CT
BAYLOR ST
W 12TH ST
SHOAL CREEK BLVD
N LAMAR BLVD
BLANCO ST
W 10TH ST
W 9TH ST
HENDERSON ST
W 6TH ST
WOOD ST
WEST AVE
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
W 5TH ST
W 4TH ST
W 3RD ST
SANDRA MURAIDA WAY
CHAVEZ ST
PEARL ST
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
W 11TH ST
SAN ANTONIO ST
NUECES ST
RIO GRANDE ST
W 8TH ST
W 7TH ST
GUADALUPE ST
LAVACA ST


Lower Shoal Creek Feasibility Study
Lamar A Bypass 3 - 100 year (1% Chance)
42 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
SHELLEY AVE
CASTLE CT
BAYLOR ST
W 12TH ST
SHOAL CREEK BLVD
PEARL ST
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
BLANCO ST
W 10TH ST
N LAMAR BLVD
W 9TH ST
WEST AVE
W 11TH ST
SAN ANTONIO ST
NUECES ST
W 10TH ST
W 9TH ST
HENDERSON ST
W 6TH ST
WOOD ST
WEST AVE
RIO GRANDE ST
W 8TH ST
GUADALUPE ST
LAVACA ST
W 7TH ST
W 6TH ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
BOWIE ST
W 5TH ST
W 4TH
W 3RD ST
SANDRA MURAIDA WAY
CHAVEZ ST


Lower Shoal Creek Feasibility Study
Lamar A Bypass 4 - 100 year (1% Chance)
31 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
SHELLEY AVE
CASTLE CT
BAYLOR ST
W 12TH ST
SHOAL CREEK BLVD
N LAMAR BLVD
BLANCO ST
W 10TH ST
W 9TH ST
HENDERSON ST
W 6TH ST
WOOD ST
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
W 3RD ST
SANDRA MURAIDA WAY
CESAR CHAVEZ ST
PEARL ST
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
WEST AVE
W 11TH ST
SAN ANTONIO ST
NUECES ST
W 10TH ST
W 9TH ST
W 8TH ST
RIO GRANDE ST
GUADALUPE ST
LAVACA ST
W 7TH ST
W 6TH ST
W 5TH ST
W 4TH ST



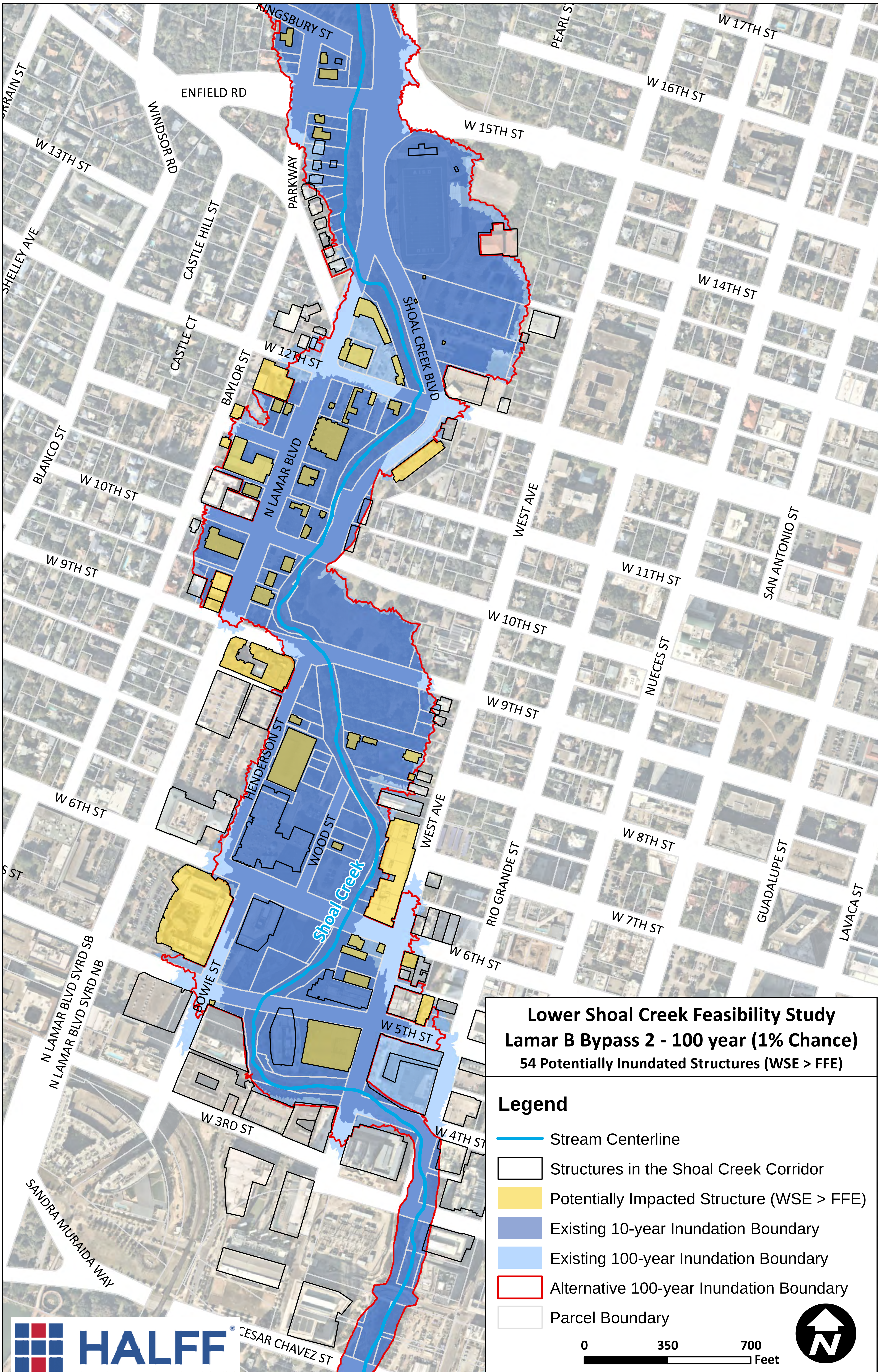
Lower Shoal Creek Feasibility Study
Lamar B Bypass 1 - 100 year (1% Chance)
57 Potentially Inundated Structures (WSE > FFE)

Legend

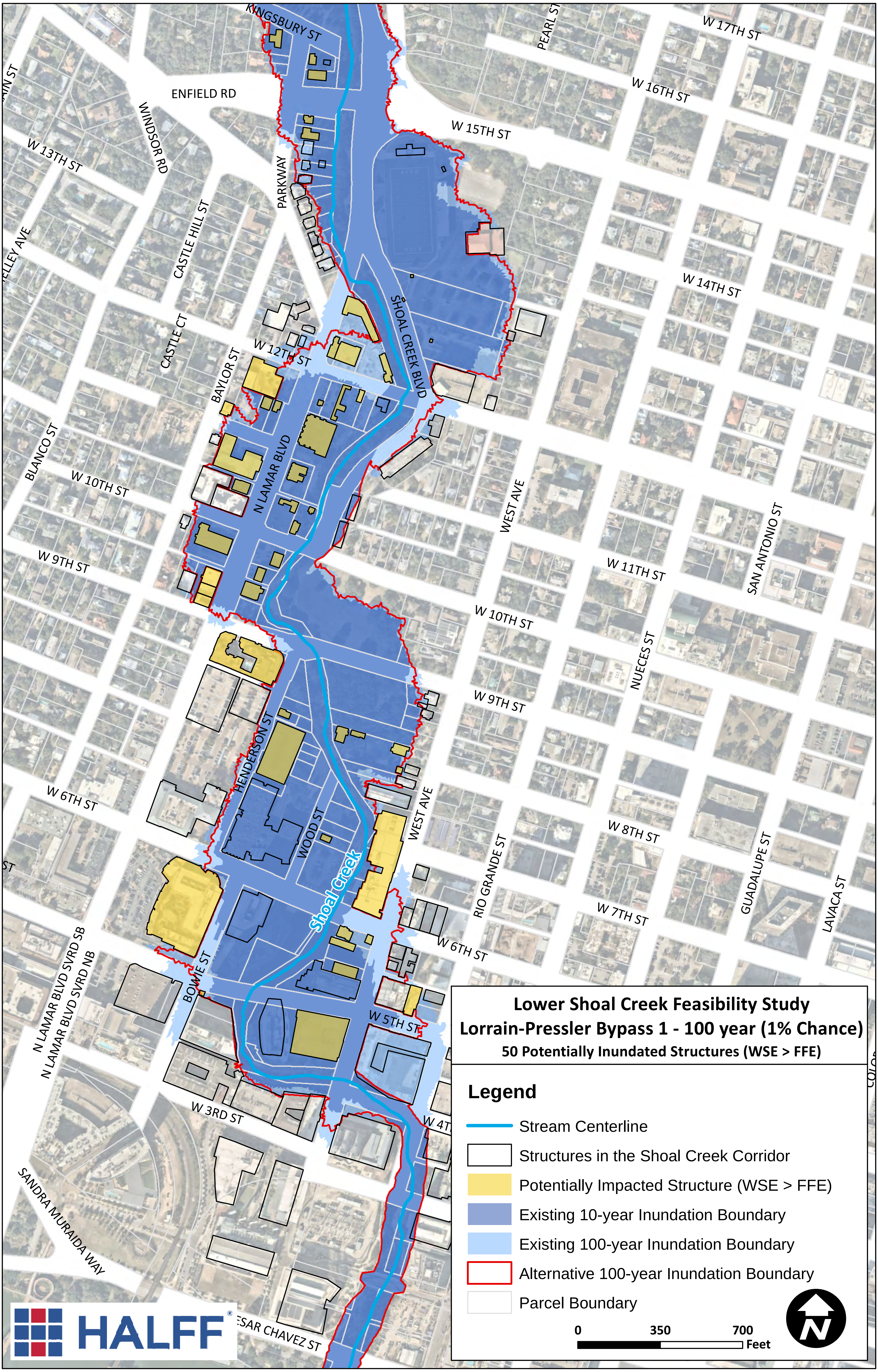
- Stream Centerline
- Structures in the Shoal Creek Corridor
- Potentially Impacted Structure (WSE > FFE)
- Existing 10-year Inundation Boundary
- Existing 100-year Inundation Boundary
- Alternative 100-year Inundation Boundary
- Parcel Boundary

0 350 700 Feet

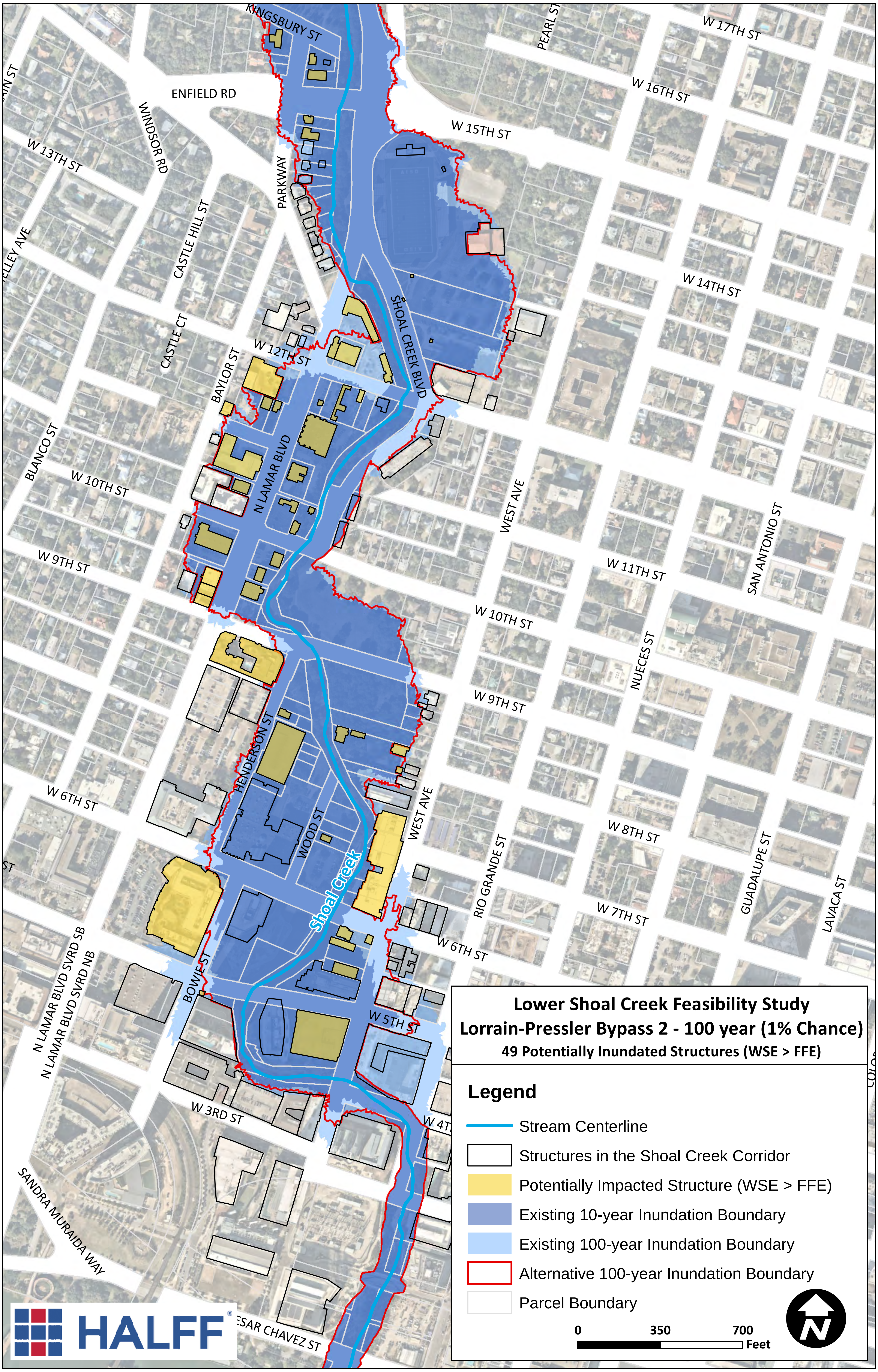
HALFF



Lower Shoal Creek Feasibility Study
Lamar B Bypass 2 - 100 year (1% Chance)
54 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
W 13TH ST
W 12TH ST
W 11TH ST
W 10TH ST
W 9TH ST
W 8TH ST
W 7TH ST
W 6TH ST
W 5TH ST
W 4TH ST
W 3RD ST
CESAR CHAVEZ ST
PEARL ST
WINDSOR RD
PARKWAY
CASTLE HILL ST
CASTLE CT
SHELLEY AVE
BAYLOR ST
BLANCO ST
N LAMAR BLVD
SHOAL CREEK BLVD
WEST AVE
SAN ANTONIO ST
NUECES ST
HENDERSON ST
WOOD ST
RIO GRANDE ST
GUADALUPE ST
LAVACA ST
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
SANDRA MURAIDA WAY



Lower Shoal Creek Feasibility Study
Lorrain-Pressler Bypass 1 - 100 year (1% Chance)
50 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
CASTLE CT
BAYLOR ST
W 12TH ST
SHOAL CREEK BLVD
N LAMAR BLVD
BLANCO ST
W 10TH ST
W 9TH ST
W 6TH ST
HENDERSON ST
WOOD ST
WEST AVE
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
W 3RD ST
SANDRA MURAIDA WAY
PEARL ST
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
W 11TH ST
W 10TH ST
W 9TH ST
W 8TH ST
W 7TH ST
W 6TH ST
W 5TH ST
NUECES ST
SAN ANTONIO ST
RIO GRANDE ST
GUADALUPE ST
LAVACA ST



Lower Shoal Creek Feasibility Study
Lorrain-Pressler Bypass 2 - 100 year (1% Chance)
49 Potentially Inundated Structures (WSE > FFE)
Legend
Stream Centerline
Structures in the Shoal Creek Corridor
Potentially Impacted Structure (WSE > FFE)
Existing 10-year Inundation Boundary
Existing 100-year Inundation Boundary
Alternative 100-year Inundation Boundary
Parcel Boundary
0
350
700
Feet
N
HALFF
Shoal Creek
KINGSBURY ST
ENFIELD RD
WINDSOR RD
W 13TH ST
PARKWAY
CASTLE HILL ST
CASTLE CT
BAYLOR ST
W 12TH ST
SHOAL CREEK BLVD
N LAMAR BLVD
BLANCO ST
W 10TH ST
W 9TH ST
W 6TH ST
HENDERSON ST
WOOD ST
BOWIE ST
N LAMAR BLVD SVRD SB
N LAMAR BLVD SVRD NB
W 3RD ST
SANDRA MURAIDA WAY
W 5TH ST
W 4T
PEARL ST
W 17TH ST
W 16TH ST
W 15TH ST
W 14TH ST
WEST AVE
W 11TH ST
SAN ANTONIO ST
W 10TH ST
NUECES ST
W 9TH ST
W 8TH ST
RIO GRANDE ST
W 7TH ST
GUADALUPE ST
LAVACA ST
W 6TH ST

APPENDIX H: Benefit-Cost Analysis (BCA)

Halff ID	Parcel ID	Address	DDF Used	# of Units for Multi-family	FFE	FFE Source	SQFT_Live	Building Sq Ft	Stories	CAD Improvement Value	CAD Land Value	CAD Appraised Value	Benefits by Alternative							
													Lamar A Bypass 1	Lamar A Bypass 2	Lamar A Bypass 3	Lamar A Bypass 4	Lamar B Bypass 1	Lamar B Bypass 2	Lorrain-Pressler Bypass 1	Lorrain-Pressler Bypass 2
1	199584	1518 PARKWAY TX 78703	Residential	6	480.58	Estimated	5536	2834.53	2	118252	725460	843712	$ 869,193	$ 877,348	$ 877,556	$ 1,321,023	$ 212	$ (331)	$ 872,768	$ 872,802
2	199678 (Bldg 1 of 2)	1005 KINGSBURY ST TX 78703	Residential	0	478.57	Estimated	1026	1282.16	1	191209	409500	600709	$ 29,162	$ 31,243	$ 1,105,086	$ 694,992	$ 766	$ 314	$ 22,325	$ 22,164
4	199677	1517 PARKWAY TX 78703	Residential	0	478.18	Estimated	3126	3150.66	2	370465	365750	736215	$ 37,868	$ 37,220	$ 148,992	$ 1,239,968	$ 442	$ 271	$ 27,158	$ 26,996
5	199603	1509 PARKWAY TX 78703	Residential	0	481.34	Surveyed	2256	1276.41	2	92433	327250	419683	$ 85,825	$ 87,760	$ 62,779	$ 1,701,499	$ 403	$ 449	$ 87,163	$ 87,158
6	199602	1507 PARKWAY TX 78703	Residential	0	481.32	Surveyed	2357	2833.64	2	152250	386750	539000	$ 188,185	$ 375,308	$ 368,496	$ 472,469	$ 789	$ 910	$ 191,040	$ 191,040
21	199661	1200 N LAMAR BLVD TX 78703	Convenience Store	0	476.10	Estimated	1391.5	1099.06	1	54239	542400	596639	$ 11,434	$ 24,955	$ 27,699	$ 29,283	$ 11,572	$ 9,626	$ 23,217	$ 24,156
22	199675 (Bldg 1 of 2)	908 W 12 ST A AUSTIN, TX 78703	Grocery	0	477.61	Surveyed	9635.0	9978.55	1	34712	3015288	3050000	$ 1,579,096	$ 1,659,913	$ 1,668,933	$ 3,577,995	$ 1,489,549	$ 332,883	$ 1,619,316	$ 1,596,374
23	199675 (Bldg 2 of 2)	908 W 12 ST A AUSTIN, TX 78703	Grocery	0	476.77	Surveyed	3025	3537.49	1	34712	3015288	3050000	$ 115,014	$ 218,578	$ 866,932	$ 303,022	$ 119,559	$ 120,382	$ 182,893	$ 183,663
24	199674	922 W 12 ST TX 78703	Non-Fast Food	0	476.39	Surveyed	4926	2727.51	2	827240	272760	1100000	$ 31,864	$ 79,245	$ 5,585,473	$ 112,224	$ 31,753	$ 32,772	$ 64,837	$ 72,939
25	199673	918 W 12 ST AUSTIN, TX 78703	Grocery	0	476.24	Surveyed	7664	7511.46	1	671717	781320	1453037	$ 216,974	$ 406,384	$ 31,440	$ 546,697	$ 212,665	$ 219,754	$ 398,774	$ 400,553
29	199618 (Bldg 1 of 2)	SHOAL CREEK BLVD TX 78701	Recreation	0	473.37	Surveyed	135	169.33	1	0	5431200	5431200	$ 32,315	$ 24,455	$ 26,412	$ 76,956	$ 17,722	$ 18,124	$ 12,984	$ 12,575
30	199618 (Bldg 2 of 2)	SHOAL CREEK BLVD TX 78701	Recreation	0	471.57	Surveyed	112	139.44	1	0	5431200	5431200	$ 28,880	$ 10,283	$ 1,697,126	$ 83,129	$ 12,344	$ 12,538	$ 2,902	$ 1,663
31	199617	SHOAL CREEK BLVD TX 78701	Recreation	0	471.17	Surveyed	1	164.04	1	350318	4882400	5232718	$ 37,027	$ 16,754	$ 221,717	$ 108,817	$ 17,677	$ 18,042	$ 6,243	$ 5,506
36	107090	1112 N LAMAR BLVD TX 78703	Grocery	0	473.76	Surveyed	20276	18387.57	2	444542	3268240	3712782	$ (456,317)	$ 185,319	$ 104,407	$ 1,047,843	$ 312,971	$ (400,528)	$ 103,900	$ 143,849
37	107089	1004 W 11 ST TX 78703	Warehouse, Non-Refrig	0	469.97	Surveyed	2200	2060.78	1	11952	450000	461952	$ 472,280	$ 475,182	$ 418,762	$ 450,840	$ 325,365	$ 503,812	$ 325,219	$ 366,356
38	107088	1104 N LAMAR BLVD TX 78703	Convenience Store	0	470.19	Surveyed	866	1328.04	1	6237	598400	604637	$ 195,719	$ 215,804	$ 24,692	$ 319,621	$ 149,901	$ 204,422	$ 165,906	$ 208,626
39	107092	1101 BAYLOR ST TX 78703 / 1018 W 11TH ST	Office One-Story	0	474.25	Surveyed	4550	2424.83	2	893898	562500	1456398	$ 22,128	$ 108,790	$ 9,265	$ 172,082	$ 22,146	$ 23,633	$ 81,668	$ 81,908
40	196571	927 W 12 ST TX 78703	Industrial Light	0	471.21	Surveyed	340	500.13	1	5299	306154	311453	$ 73,189	$ 56,262	$ 15,345	$ (5,391)	$ 59,438	$ 68,891	$ 52,220	$ 51,662
41	196573 (Bldg 1 of 2)	919 / 921 W 12 ST TX 78703	Non-Fast Food	0	473.53	Surveyed	3628	3518.87	1	673191	765000	1438191	$ 261,888	$ 354,842	$ 945,127	$ 512,187	$ 231,255	$ 260,724	$ 313,301	$ 319,849
42	196573 (Bldg 2 of 2)	921 W 12 ST TX 78703	Non-Fast Food	0	474.34	Surveyed	1176	1177.93	1	673191	765000	1438191	$ 76,533	$ 84,023	$ 632,968	$ 139,780	$ 71,767	$ 78,565	$ 83,625	$ 83,832
43	196576	1105 N LAMAR BLVD TX 78703	Office One-Story	0	470.28	Surveyed	33252	18376.95	2	4469329	3581487	8050816	$ 1,571,952	$ 1,767,309	$ 308,897	$ 5,453,195	$ 789,461	$ 2,612,826	$ 1,174,730	$ 1,189,889
44	196575	903 W 12 ST TX 78703	Fast Food	0	476.13	Surveyed	1344	2242.34	1	86395	459000	545395	$ 25,101	$ 59,740	$ 126,761	$ 71,234	$ 25,341	$ 32,527	$ 59,631	$ 59,671
46	Multiple IDs	1101 - 1301 Shoal Creek Blvd	Residential	28	477.79	Estimated	22623	14139.66	2	0	0	0	$ 143,589	$ 445,727	$ 38,166	$ 478,969	$ 143,999	$ 145,315	$ 351,308	$ 376,725
47	107083	1011 W 11 ST TX 78703	Office One-Story	0	475.25	Surveyed	1462	1563.56	1	0	0	0	$ 18,378	$ 58,695	$ 69,264	$ 66,896	$ 18,498	$ 35,772	$ 47,239	$ 49,882
48	107084	1014 N LAMAR BLVD TX 78703	Non-Fast Food	0	469.26	Surveyed	18827	19763.72	1	101875	2400000	2501875	$ 3,861,026	$ 4,040,686	$ 359,048	$ 7,716,415	$ 2,577,337	$ 3,960,691	$ 3,352,866	$ 3,702,910
50	107078	1010 N LAMAR BLVD TX 78703	Non-Fast Food	0	468.08	Surveyed	3334	3349.62	1	282489	530000	812489	$ 927,893	$ 1,016,556	$ 85,347	$ 1,670,057	$ 639,537	$ 1,001,726	$ 726,931	$ 801,690
52	196577	1011 N LAMAR BLVD AUSTIN, TX 78703	Office One-Story	0	470.80	Surveyed	4779	4798.50	2	313830	1136170	1450000	$ 128,004	$ 121,655	$ 1,850,956	$ 1,104,269	$ 110,821	$ 127,369	$ 104,255	$ 107,234
53	196578	1001 N LAMAR BLVD TX 78703	Industrial Light	0	469.56	Surveyed	528	2342.46	1	30443	1319200	1349643	$ 444,345	$ 206,209	$ 64,536	$ 1,288,617	$ 222,966	$ 387,062	$ 67,170	$ 109,183
54	196579 (Bldg 1 of 2)	900 W 10 ST TX 78703	Hotel	0	470.47	Surveyed	1494	1588.35	1	177690	692310	870000	$ 163,203	$ 171,276	$ 452,550	$ 389,288	$ 14,855	$ 167,166	$ 167,000	$ 168,013
55	196579 (Bldg 2 of 2)	900 W 10 ST TX 78703	Warehouse, Non-Refrig	0	468.40	Surveyed	506	641.13	2	177690	692310	870000	$ 198,219	$ 143,457	$ 59,151	$ 470,918	$ 147,471	$ 216,278	$ 114,441	$ 55,504
59	107071	914 N LAMAR BLVD TX	Retail-Clothing	0	466.72	Surveyed	12132	11607.58	2	115431	2380000	2495431	$ 770,140	$ 846,675	$ 5,942,175	$ 8,206,203	$ 394,333	$ 841,925	$ 519,895	$ 603,657
60	107073	1008 W 9 ST TX	Warehouse, Non-Refrig	0	476.01	Estimated	4756	4910.89	1	50000	669375	719375	$ 1,188	$ 24,831	$ 87,762	$ 30,988	$ 2,202	$ 13,285	$ 26,802	$ 26,635
61	107075 (Bldg 1 of 3)	900 N LAMAR BLVD TX 78703	Convenience Store	0	471.69	Surveyed	3079	3079.97	1	1102413	1190000	2292413	$ 295,343	$ 345,497	$ 1,375,382	$ 443,053	$ 216,704	$ 338,038	$ 341,480	$ 343,833
62	107075 (Bldg 2 of 3)	900 N LAMAR BLVD TX 78703	Convenience Store	0	469.00	Surveyed	3260	3260.12	1	1102413	1190000	2292413	$ 140,201	$ 481,190	$ 131,415	$ 1,027,247	$ 93,240	$ 459,867	$ 145,678	$ 164,453
63	107075 (Bldg 3 of 3)	900 N LAMAR BLVD TX 78703	Convenience Store	0	466.20	Surveyed	5062	5062.42	1	1102413	1190000	2292413	$ 588,209	$ 567,467	$ 307,964	$ 4,094,213	$ 318,378	$ 656,882	$ 356,370	$ 407,961
64	196570	917 N LAMAR BLVD TX 78703	Convenience Store	0	468.19	Surveyed	2460	2609.07	1	60645	925540	986185	$ 87,011	$ 128,852	$ 230,086	$ 815,537	$ 68,029	$ 126,893	$ 74,171	$ 87,184
65	196568	915 N LAMAR BLVD TX 78703	Non-Fast Food	0	467.93	Surveyed	2091	2079.52	2	17841	601020	618861	$ 558,211	$ 624,567	$ 181,604	$ 1,466,471	$ 165,351	$ 595,968	$ 178,813	$ 463,042
66	196567	907/909 N LAMAR BLVD TX 78703	Non-Fast Food	0	467.30	Surveyed	3900	4994.49	1	281356	490000	771356	$ 1,420,503	$ 1,407,235	$ 5,571,805	$ 3,740,080	$ 680,255	$ 1,482,430	$ 709,595	$ 718,159
67	499524	901/907 W 9TH ST	Residential	99	468.50	Surveyed	191861	33367.23	11	0	0	0	$ 106,889	$ 177,994	$ 375,330	$ 3,936,735	$ 96,281	$ 1,017,605	$ (2,355,962)	$ 187,308
71	196581	709 HENDERSON ST A TX 78703	Residential	0	467.68	Surveyed	1105	1497.19	1	56313	77440	133753	$ 14,642	$ 20,074	$ 31,900	$ 324,295	$ 11,613	$ 21,900	$ 16,376	$ 20,689
72	105313 (Bldg 1 of 2)	830 W 6 ST TX 78703	Industrial Light	0	467.36	Surveyed	0	30736.56	6	10874160	30332873	41207033	$ 1,279,766	$ 3,403,161	$ 395,174	$ 5,402,603	$ 248,352	$ 3,368,847	$ 1,367,951	$ 3,419,339
73	105313 (Bldg 2 of 2), 105303	828/830 W 6TH ST, 605 HENDERSON	Office One-Story	0	470.03	Surveyed	131465	63905.57	3	10874160	31436873	42311033	$ 1,430,388	$ 2,371,712	$ 648,038	$ 2,800,183	$ 1,432,203	$ 1,784,659	$ 2,373,124	$ 2,371,910
79	196591 (Bldg 1 of 5)	800 WEST AVE TX 78701	Office One-Story	0	463.17	Surveyed	4472	2881.52	2	237866	3005291	3243157	$ 1,683,722	$ 1,135,921	$ 2,719,911	$ 3,568,516	$ 1,358,692	$ 2,066,250	$ 1,168,163	$ 1,171,124
80	196591 (Bldg 2 of 5)	800 WEST AVE TX 78701	Office One-Story	0	463.05	Surveyed	924	1339.68	1	237866	3005291	3243157	$ 430,523	$ 296,274	$ 442,235	$ 1,235,143	$ 245,325	$ 543,314	$ 170,408	$ 256,775
81	196591 (Bldg 3 of 5)	800 WEST AVE TX 78701	Office One-Story	0	464.90	Surveyed	5463	2815.43	3	237866	3005291	3243157	$ 777,153	$ 771,175	$ 974,583	$ 1,788,288	$ 585,512	$ 1,072,709	$ 574,883	$ 756,281
83	196591 (Bldg 5 of 5)	716/800 WEST AVE TX 78701	Office One-Story	0	465.30	Surveyed	540	720.33	2	237866	3005291	3243157	$ 130,168	$ 137,254	$ 2,234,450	$ 341,305	$ 91,033	$ 173,585	$ 87,349	$ 134,234
87	105329	609 WOOD ST TX 78703	Medical Office	0	464.97	Surveyed	2250	1185.82	2	155735	897000	1052735	$ 125,792	$ 142,639	$ 2,820,514	$ 362,289	$ 92,756	$ 181,026	$ 100,770	$ 179,034
88	105335	800 W 6 ST TX 78701	Industrial Light	0	470.50	Surveyed	142225	50196.62	5	39842751	14598667	54441418	$ (115,163)	$ 2,726,346	$ 153,735	$ 3,642,819	$ 1,264,273	$ 2,515,973	$ (258,730)	$ 2,947,323
94	105379	525 N LAMAR BLVD TX 78703 or 835 W 6th St	Grocery	0	466.00	Surveyed	291822	85603.22	5	72279646	31785499	104065145	$ 9,914,803	$ 10,646,225	$ 4,569,760	$ 17,310,680	$ 9,879,171	$ 13,847,526	$ 10,392,475	$ 14,994,504
96	105381 (Bldg 1 of 2)	807 W 6 ST TX 78701	Fast Food	0	466.28	Surveyed	2541	2770.74	1	10000	1572211	1582211	$ 61,897	$ 124,274	$ 2,735,962	$ 184,701	$ 61,912	$ 121,315	$ 94,497	$ 140,682
97	105381 (Bldg 2 of 2)	807 W 6 ST TX 78701	Convenience Store	0	465.73	Surveyed	1092	1025.61	1	10000	1572211	1582211	$ 37,135	$ 50,655	$ 1,411,619	$ 74,667	$ 37,200	$ 48,138	$ 49,606	$ 57,287
98	105382	508 WEST AVE TX 78701	Non-Fast Food	0	463.10	Surveyed	2250	3243.63	1	10000	1853227	1863227	$ 2,399,891	$ 2,558,204	$ 500,369	$ 3,019,062	$ 2,230,480	$ 2,177,697	$ 2,456,218	$ 2,584,427
99	105383	506 WEST AVE TX 78701	Non-Fast Food	0	464.27	Surveyed	4800	4998.02	2	10000	1486738	1496738	$ 454,581	$ 567,719	$ 1,129,861	$ 886,591	$ 243,510	$ 561,876	$ 560,706	$ 679,162
100	563553	800 W 5th ST	Residential	82	467.40	Surveyed	166302	23097.55	12	0	0	0	$ 569,113	$ 762,865	$ 250,921	$ 1,196,015	$ 570,772	$ 734,112	$ 760,653	$ 859,648
101	105390	717 W 6 ST TX 78701	Non-Fast Food	0	466.77	Surveyed	3386	3595.89	1	45158	662400	707558	$ 70,478	$ 107,946	$ 277,666	$ 160,185	$ 65,946	$ 92,052	$ 101,733	$ 134,153
102	105396	507 WEST AVE TX 78701	Office One-Story	0	466.89	Surveyed	2952	1540.25	2	589298	800702	1390000	$ 30,309	$ 55,379	$ 3,561,694	$ 67,185	$ 28,652	$ 38,924	$ 42,592	$ 56,823
106	105397 (Bldg 1 of 2)	710 W 5 ST TX 78701	Medical Office	0	465.50	Surveyed	12240	6154.80	2	923033	2306077	3229110	$ 150,192	$ 295,702	$ 15,993,157	$ 395,489	$ 188,599	$ 252,777	$ 261,376	$ 327,973
112	105428	817 W 5 ST TX 78701	Non-Fast Food	0	465.50	Surveyed	304	436.67	1	47962	275065	323027	$ 10,129	$ 15,816	$ 168,676	$ 30,080	$ 9,209	$ 14,943	$ 15,369	$ 22,089
113	824754	311 Bowie St	Residential	358	469.28	Surveyed	1218969	42325.30	36	0	0	0	$ 557,874	$ 1,330,332	$ 70,404	$ 1,768,095	$ 577,770	$ 919,720	$ 1,349,722	$ 1,454,460
118	772659 (Bldg 1 of 2)	801 W 5th St	Residential	310	468.00	Surveyed	475671	22021.82	27	0	0	0	$ 360,923	$ 691,837	$ 2,464,200	$ 910,778	$ 373,502	$ 429,074	$ 686,815	$ 712,306
119	772659 (Bldg 2 of 2)	801 W 5th St	Industrial Light	0	460.52	Surveyed	7938	39692.42	3	0	0	0	$ 654,548	$ 953,132	$ 791,495	$ 12,105,228	$ 484,107	$ 4,901,336	$ 726,767	$ 5,144,803
												Total	$ 36,386,526	$ 47,129,928	$ 76,803,730	$ 112,949,618	$ 29,893,944	$ 51,592,631	$ 33,898,695	$ 52,801,630

APPENDIX I: Digital Data (CD Only)