Leon River Watershed Study

Hydrologic and Hydraulic Analysis

City of Eastland

Eastland, Eastland County, Texas
December 29, 2023

FINAL SUBMITTAL

Prepared for**: City of Eastland**

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Contents

Tables

Figures

Appendices

1 Executive summary

The City of Eastland is in Eastland County on Interstate-20 approximately 100 miles west of the Dallas-Fort Worth Metroplex and 55 miles east of Abilene. This is a Flood Infrastructure Fund (FIF) Watershed Study sponsored by the Texas Water Development Board (TWDB). The City of Eastland (City) sub-contracted HDR Engineering, Inc (HDR) to develop this evaluation formally identified as "The Leon River Watershed Study" to guide the City in recommending flood risk mitigation efforts. A list of Capital Improvement Projects (CIPs) has been developed in connection with the study, including conceptual design and cost estimates of recommended mitigation alternatives.

Key stakeholders in the project are the City of Eastland (City) and TWDB. The Federal Emergency Management Agency (FEMA), the United States Army Corps of Engineers (USACE), Texas Department of Transportation (TxDOT), the Texas Commission on Environmental Quality (TCEQ), and the State Flood Plan's (SFP) Region 8 Regional Flood Planning Group (RFPG) are recognized as secondary stakeholders.

The scope of work is to develop updated hydrology for the entirety of the South Fork Leon River-Leon River (1207020101) HUC-10 watershed along with hydraulic models to support analysis of flood mitigation alternatives for the following detailed study reaches: North Fork Leon River, Tributary 1 (Weaver Creek), Tributary 2, Tributary 3, and Tributary 5.

The scope of work also includes updated modeling and dam breach analysis of Lake Eastland and Ringling Lake, which are situated upstream of the City of Eastland and feed into the North Fork of the Leon River. Using the hydrologic and hydraulic models of the North Fork Watershed, an updated dam breach analysis of each lake has been performed, and updated spillway recommendations have been developed for each lake.

Hydrologic modeling was performed using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) Version 4.9. Gage adjusted rainfall data for two historical events (**September 2020 and May 2021)** in the area was used to validate the Snyder peaking coefficients for the watersheds of the North and South Forks. The gage adjusted rainfall data for each of the two historical events was determined to represent approximately a 25-year storm event. The routing of flood flows through Ringling Lake and Lake Eastland was performed using HEC-HMS Elevation-Storage-Discharge curves. The 10-, 25-, 50-, 100-, and 500-year events were evaluated.

USACE HEC-RAS Version 6.2 with two dimensional (2D) computations was used to define the hydraulic characteristics and extents of flood-prone regions within the study area. The hydraulic model was validated by varying HEC-HMS runoff hydrographs and hydraulic modeling parameters until the observed high-water marks were within a tolerance of the gauged storms.

Four structural and two non-structural flood mitigation alternatives were analyzed in connection with the study. The four structural alternatives are:

- **Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements**
- **Tributary 3 Culvert and Grading Improvements**
- **Lake Eastland Spillway Reconstruction**

- **Structural Buyouts and Raising of Finished Floor Elevations**

Cost estimates were developed for each of the CIPs to perform a benefit-cost analysis (BCA). The BCA was then used to help rank the CIPs to explore which flood mitigation solutions are the most cost-effective for the City of Eastland. The benefit-cost analysis results will assist the City in prioritizing capital improvement projects to pursue. The 100-year flood event BCA ratio for each structural mitigation alternatives is as follows in **Table 1-1**:

Table 1-1. Benefit Cost and Ratios for the 100-year event.

Project	Cost	Benefit	Ratio
CIP 01 – Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements	$6.85M	$724K	0.1
CIP 02 – Tributary 3 Culvert and Grading Improvements	$2.91M	$691K	0.3
CIP 03 – Lake Eastland Spillway Reconstruction	$15.70M	$901K	0.2
CIP 04 – Structural Buyouts and Raising of Finished Floor Elevations	$3.56M	$7.42M	2.5

These ratios are low due to the high cost of each alternative and relative low impact during the 100-year event. Lower frequency events, such as the 10-year storm event, result in a benefit increase in most CIP projects evaluated due to greater reductions in water surface elevations.

The two non-structural flood mitigation alternatives analyzed were:

- **Stream Gauge Additions**
- **Flood Management Practices Recommendations and Education Outreach.**

The stream gauge additions are an effective and relatively economical way of detecting high water danger in critical flood prone areas as well as sources for potential flooding such as Lake Eastland water levels. Floodplain management practices improve protection of life and property. HDR proposes an opportunity to obtain funding to strengthen Eastland’s ability to regulate and adopt consistent minimum floodplain management standards and land use practices. An effective education program about flooding and issues related to flooding can help people make more informed decisions so that they can take steps to protect themselves from flooding.

A public hearing was held early in the project (May 2022) with stakeholders and the community to inform them of the project progress and to gather public information and flooding concerns. A second public hearing was held in May 2023. This hearing informed the public of the Study results and recommendations and was an opportunity to gather feedback and prioritize flood mitigation alternatives. Based on the BCA analysis, discussions with the City, and public outreach, HDR proposes to prioritize the alternatives as follows in **Table 1-2**:

Table 1-2. Capital Improvement Project Rankings.

Ranking	Project
1	CIP 01 – Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements
2	CIP 04 – Structural Buyouts and Raising of Finished Floor Elevations
3	CIP 05 – Stream or Rain Gauge Addition
4	CIP 06 – Evaluation and Recommendations on Floodplain Management Practices
5	CIP 03 – Lake Eastland Spillway Reconstruction
6	CIP 02 – Tributary 3 Culvert and Grading Improvements

Potential funding sources identified to implement and execute these projects are listed as: TWDB FIF or State Flood Plan, FEMA’s Flood Mitigation Assistance Program, TxDOT Assistance, USGS assistance, UPRR assistance.

For the TWDB’s State Flood Plan, the formulated CIPs or Flood Management Projects (FMPs) were submitted to the State Flood Plan in Region 8 (Lower Brazos) on May 19, 2023. This included the associated modeling, cost-benefit analysis, and floodplain maps proving a no-negative impact. Submitting the CIP projects to the State Flood Plan qualifies them for future funding from the Texas Water Development Board. The following CIP (FMP) projects were submitted:

- CIP 01 - Weaver Creek and Main Street Culvert Improvements (FMP ID 83001303)
- CIP 02 – Tributary 3 and UPPR Culvert Improvements (FMP ID 83001304)
- CIP 03 – Reconstruction of primary Lake Eastland spillway (FMP ID 83001305)

2 Introduction

The City of Eastland is in Eastland County on Interstate-20 (IH-20) approximately 100 miles west of the Dallas-Fort Worth Metroplex and 55 miles east of Abilene. The City of Eastland (City) is developing the Leon River Watershed Study to guide the City in future flood risk mitigation efforts. This study is sponsored by the TWDB as part of its ongoing efforts to reduce flooding statewide.

Most of the Leon River watershed is rural, except for reaches running through the City of Eastland. The study focuses on riverine flooding at the exclusion of enclosed storm sewer system analysis. The extents of the riverine flooding area analyzed are shown in **Figure 2-1**, and in **Exhibit A-1** of **Appendix A**.

Figure 2-1. Project Location

The scope of work includes the development of updated hydrology for the entirety of the South Fork Leon River-Leon River (1207020101) HUC-10 watershed and hydraulic models to support analysis of flood mitigation alternatives for the following detailed study reaches:

- North Leon River from downstream of Lake Eastland to below IH-20
- South Leon River from IH-20 to the confluence with the North Leon River
- Tributary 1 (known locally as Weaver Creek) from the Union Pacific Railroad (UPRR) running on the north side of the City to the confluence with the North Leon River
- Tributary 2 from CR 328 to the confluence with the North Leon River
- Tributary 3 from West Main Street to the confluence with the North Leon River (crossing under the UPRR)
- Tributary 5 from Foxhollow Road to the confluence with the South Leon River

Dam Risk Assessments - The project scope also includes analysis of two lakes in the City: **Lake Eastland and Ringling Lake.** The series of tasks includes an updated breach analysis of each lake, along with updated structural recommendations for each lake. A breach analysis , emergency action plan (EAP), is provided for each lake. The hydrologic and hydraulic models developed for the North Fork of the Leon River will be used for the breach analysis. The EAP will be based on the breach analysis to update per TCEQ criteria including incorporating the updated inundation mapping downstream. Ringling Lake has been repeatedly cited as non-compliant with TCEQ regulations. Lake Eastland is cited in a similar condition as Ringling Lake as “the structure appears to be in overall very poor condition. Due to the TCEQ reports, the City is taking steps, via separate contract, to repair the Spillway on Lake Eastland. Updated structural recommendations for Lake Eastland's primary spillway and recommendations for future action for each Lake will be provided in an attempt to comply with state and federal agency regulations.

The content included in this report is correct to the best of our knowledge and has been developed in accordance with the standard of care that is customarily followed by a practitioner in this industry. The standard of care was followed for collection and analysis of data, and for calculations or modeling performed in support of this report. Naming convention from the FEMA Flood Insurance Rate Map (FIRM) Panel was maintained for all streams and tributaries with the exception of Tributary 1, known as Weaver Creek locally.

2.1 Key stakeholders

This study is sponsored by the TWDB under the Flood Infrastructure Fund (FIF) Grant Program. Passed by the Legislature and approved by Texas voters through a constitutional amendment, the FIF program provides financial assistance in the form of loans and grants for flood control, flood mitigation, and drainage projects. HDR is serving as a consultant to the City of Eastland (City) in assisting with execution of the grant process. The City and the TWDB are recognized as primary stakeholders. The Federal Emergency Management Agency (FEMA), the United States Army Corps of Engineers (USACE), Texas Department of Transportation (TxDOT), the Texas Commission on Environmental Quality (TCEQ), and the SFP's Region 8 RFPG are recognized as secondary stakeholders. Mainstreet, also known as SH112, is a TxDOT road and any culvert replacement will require coordination with TxDOT. Lake Eastland and Ringling Lake are both regulated by TCEQ. The Federal Emergency Management Agency (FEMA) is also considered a secondary stakeholder on this project because existing and proposed modeling will change the effective mapping. Future State funding for flood projects will only be available to projects in the Regional Flood Plans. The City of Eastland is located in Region 8, making the Region 8 Regional Flood Planning Group (RFPG) is a secondary stakeholder in the project.

3 Project background

The City does not currently have comprehensive hydraulic modeling of local waterways, and the FEMA's Flood Insurance Rate Maps (FIRMs) do not accurately reflect flooding observations by City staff and citizens. The 2-dimensional (2D) hydraulic modeling (as part of this watershed study) will update the City's flood risk data. Updated hydrologic and hydraulic models provide valuable information, especially when validated using local observances and high-water marks. Up-to-date HEC-RAS (2D) modeling data will allow the City to establish revised existing conditions and floodplain extents. The intent of this study is to provide a good base analysis for flood planning for the City and to provide recommendations for flood risk reduction Capital Improvement Projects (CIPs).

Ringling Lake has been repeatedly cited as non-compliant with TCEQ regulations. A 2003 TCEQ inspection report indicates that "the structure appears to be in overall very poor condition. Due to lack of maintenance, the dam is in a very advanced state of deterioration that could result in serious structural problems." The City and TCEQ therefore proposed decommissioning of the Lake, a step which has been opposed by USACE; both entities are considered secondary stakeholders.

Lake Eastland is cited in a similar condition as Ringling Lake as "the structure appears to be in overall very poor condition. Due to lack of maintenance, the dam is in a very advanced state of deterioration that could result in serious structural problems" in a 2003 TCEQ inspection report. Due to the TCEQ reports, the City is taking steps, via separate contract, to repair the Spillway on Lake Eastland.

3.1 Purpose of the study

The City of Eastland (City) is developing the Leon River Watershed Study to provide guidance regarding future flood mitigation efforts. The City currently experiences repeated flooding on Main Street where an important business district sits at the confluence of Weaver Creek and Main Street.

Chapter 7 of this Study provides a list of CIP flood mitigation recommendations (projects) developed as part of this Study. This included conceptual designs and cost estimates of recommended flood mitigation alternatives to be considered by City Staff. Additionally, due to future State funding being available through the Regional Flood Planning process, this Study provides the necessary qualifications for the CIPs listed to become Flood Mitigation Projects (FMPs).

> The City has two lakes upstream: Lake Eastland and Ringling Lake. Both lakes are currently regulated by TCEQ and as such require regular breach analyses. Using the hydrologic and hydraulic models of the North Fork Watershed, an updated breach analysis of each lake has been performed, and updated spillway recommendations have been developed for each lake. A dam breach hydraulic model will be developed using unsteady two-dimensional (2D) HEC-RAS (Version 6.2) for each lake. The hydraulic models will be used to evaluate the different dam breach scenarios and corresponding breach inundation mapping. This information will be used to update the Emergency Action Plan (EAP). Major structures, such as roads, culverts and bridges will be modeled in connection with the breach analysis to better understand the depth of overtopping and the impact of backwater flooding from undersized drainage structures. Further explanation can be found in Chapter 6 of this Report.

3.2 Previous studies

Previous H&H Studies, inspection reports, constructions plans, and survey data were provided to HDR by the City and TxDOT. Data and noteworthy information were incorporated into the modeling.

Lake Eastland Dam received a Phase I Inspection performed by Freese and Nichols in 1978 for USACE (1978 study). A more recent assessment of Lake Eastland is available; therefore, the 1978 study was used for historical background information only.

The FEMA Map Service Center shows the City of Eastland and its surrounding unincorporated areas as "no digital data available". The available Flood Insurance Rate Map (FIRM) panels are 4807930002N (effective 9-1-2007), 4802040005C (effective on 8-5-1997), and 4807930006B (effective 9-1-2007). A physical copy of the FIS study dated August 5, 1997 was obtained from City records. An index of the FIRM panel numbers is shown in **Figure 3-1** below. The physical FIRM panel dated August 5, 1997 was also received from the City, and is provided in **Appendix A**.

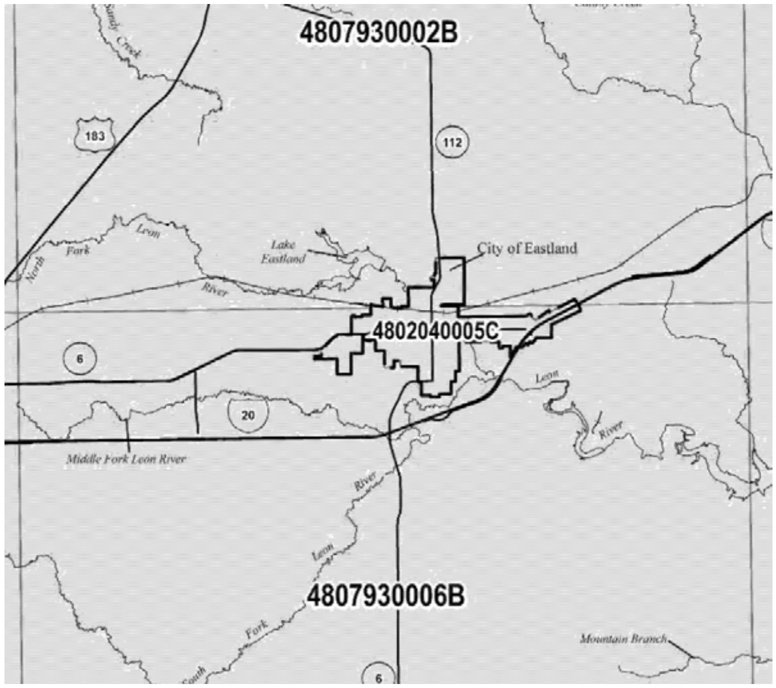

Figure 3-1. FEMA FIRM Panel Index

A report titled *Hydrologic and Hydraulic Study for Eastland and Ringling Lakes* dated July 1988 was performed by Jacob and Martin, Inc. (Jacob & Martin, Inc, 1988).

In keeping with the Dam Safety Program administered by TCEQ, in 2003 Lake Eastland and Ringling Lake were evaluated (TCEQ 2003). A memorandum is provided detailing the status of each structure. These memoranda provide pictures of both dams and sketches of the Ringling Lake outfall. These memoranda contribute to the overall historical narrative of the dams.

A Probable Maximum Flood (PMF) study, titled *Review of Lake Eastland Dam* and dated September 2009, was completed by Freese and Nichols, Inc. The elevation-storage and elevation-discharge relationships provided in this study were utilized in the hydrologic modeling (FNI 09 Study).

A draft Emergency Action Plan dated December 21, 2010 was received from the City. HDR has been contracted to update the Emergency Action Plan under separate cover.

Table 3-1. Summary of Previous Studies Utilized.

Date	Name	Source	Information	Abbreviation
1976	Phase 1 Inspection Report for Ringling Lake Dam	Freese and Nichols	Confirmed structural instability of the embankment and compared PMF data.	FNI 1976
1978	Phase I Inspection Report for Lake Eastland Dam	Freese and Nichols	Historical information on the condition of the dam and its appurtenant structures.	FNI 1978
1984	Inspection Report on Existing Dam (Ringling Lake Dam)	Texas Department of Water Resources	Confirmed structural instability of the embankment and compared PMF Data. Referenced sketches.	TDWS 1984
1988	H&H Study for Eastland and Ringling Lakes	Jacob and Martin, Inc.	Elevation-area-discharge rating curves for Lake Eastland and Ringling Lake.	J&M 1988
2009	Review of Lake Eastland Dam	Freese and Nichols	Elevation-storage-discharge rating curves for Lake Eastland and detailed hydrologic analysis highlighting the methods used for the study area.	FNI 2009
2020	Lake Leon Dam Hazard Mitigation project	HDR	Detailed H&H report detailing runoff calculation method, Initial and Constant Loss, used in nearby study area.	HDR 2020

4 Hydrologic analysis

As previously developed FEMA stormwater models were unavailable, HDR performed hydrologic and hydraulic (H&H) evaluations to provide data on existing flooding conditions in the study watershed. Updated modeling was used to evaluate the existing conditions.

The following sections discuss the assumptions, methodologies, and results for the H&H analysis.

4.1 Data collection

HDR gathered and compiled readily available geospatial data, FEMA data, National Inventory of Dams data, previous studies, and as-built plans, and also performed site reconnaissance to help characterize existing conditions with the study area. These activities were completed in addition to a field survey performed by Enprotec, Hibbs, and Todd (eHT) to support the study. All data were obtained as digital files in geographic information system (GIS), AutoCAD, or PDF format.

4.1.1 Geospatial data

Available geospatial data was compiled from local, regional, and state sources for the study area. A complete list of geospatial data collected, and their sources, are included in **Table 4-1.**

Table 4-1. Collected Geospatial Data.

Dataset	Source	Description	Date
SSURGO Soil Data	USDA	Hydrologic soils groups for the state of Texas	2019
1-Meter DEM	USGS	Brazos River Basin LiDAR	2018
HUC Boundaries	USGS	Hydrologic Unit watersheds	2017
Stream Centerlines	USGS	Centerlines of major streams	2017

4.1.2 Additional background

Research was conducted for Lake Eastland using the National Inventory of Dams (NID). Lake Eastland's National Inventory number is TX01411. The NID height is 32.5 ft and NID storage is shown as 7,561 acre-feet. This height and storage value put the dam under TCEQ regulation. NID records indicate that the dam was constructed in 1922 for the primary purpose of recreation and water supply.

Ringling Lake's National Inventory number is TX01410. The NID height is 18.0 ft and NID storage is shown as 272 acre-feet. NID records indicate that the dam was construction in 1922 for the primary purpose of recreation and water-supply. In 1922, the Normal pool of Ringling Lake was 10-feet lower; the NID records conflict with field measured data. Field measured data took precedence.

4.1.3 Site reconnaissance

A field investigation was performed on March 23, 2022, to collect site conditions data for the existing structures, complete a stream condition assessment, and collect high water marks. Additional reconnaissance around the lakes was completed to observe conditions of the outlet structures. Photos were taken of high interest structures and stream crossings in the study area. A photo log was developed, shown in **Appendix H**, and was used as a reference when delineating drainage areas and creating the hydraulic models.

A second field investigation was performed on January 12, 2023 for a more detailed assessment of the dams. The existing embankments, outlets structures and auxiliary spillways are described in **Section 6.3 – Lake Eastland – spillway structural analysis.**

4.2 Hydrologic methodology

Hydrologic modeling was performed using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) Version 4.9 software. This was the latest available software at the start of the hydrologic modeling effort. This project encompasses the entirety of the South Fork Leon River-Leon River (1207020101) HUC-10 watershed, as shown in **Exhibit B-1** of **Appendix B.**

4.2.1 Watershed delineation

Using the available watershed boundaries for USGS Hydrologic Unit Code 10 (HUC10) watershed boundaries and 2-ft contours from LiDAR data provided from TNRIS (as discussed in **Section 4.1 Data Collection**), the drainage areas for the North and South Forks were delineated. Major roadways and railroads were used as boundaries, and major storm drain outfalls were considered when delineating the more urban subbasins as shown in **Exhibit B-2** of **Appendix B**. **Table 4-2** summarizes each of the major watershed subbasins and their contributing areas. The total area contributing to the study was found to be 323 square miles as shown in **Exhibit B-1** of **Appendix B**.

Table 4-2. Drainage Area Summary.

Reach	Drainage Area ID	Area (acres)	Area (sq. miles)
Lakes	Lake Eastland	21,542	33.66
	Ringling Lake	2,200	3.44
Tributary 1: Weaver Creek	T1WC-1	2,198	3.43
	T1WC-2	354	0.55
	T1WC-3	213	0.33
Tributary 2	T2-1	414	0.65
	T2-1a	359	0.56
	T2-2	40	0.06
Tributary 3	T3-1	161	0.25
	T3-1a	26	0.04
	T3-2	38	0.06
	T3-3	46	0.07
North Fork Leon River	LRNF-1	567	0.89
	LRNF-2	120	0.19
	LRNF-3	185	0.29
	LRNF-4	224	0.35
	LRNF-4a	74	0.12
	LRNF-4b	24	0.04
	LRNF-5	314	0.49
	LRNF-6	468	0.73
South Fork Leon River	LRSF-1	39	0.06
	LRSF-2	71	0.11
	LRSF-3	523	0.82
	LRSF-3a	243	0.38
	LRSF-4	33	0.05
	LRSF-5	208	0.32
	LRSF-5a	1,050	1.64
	LRSF-5b	277	0.43
Tributary 5	T5-1	9,268	14.48
	T5-1a	89,371	139.64
	T5-2	86	0.13
Additional HUC-10 areas	LR Main	34,551	53.99
	Lake Leon	41,422	64.72
	Total	**206,709**	**322.98**

4.2.2 Runoff loss method

The Texas Initial and Constant-Rate Loss Model was used for modeling soil infiltration losses for this study. The method was developed by Texas Department of Transportation (TxDOT) from recent research (TxDOT 0-4193-7) developed from four computational approaches for estimating initial abstraction (*Equation 1*) and constant loss (*Equation 2*) for watersheds specifically in Texas. The four approaches utilized the 92 gauged watersheds in Texas and their corresponding rainfall and runoff data.

$$I_A = 2.045 - 0.5497(L)^{-0.9041} - 0.1943(D) + 0.2414(R) - 0.01354(CN) \qquad \textit{Equation 1}$$

$$C_L = 2.535 - 0.4820(L)^{0.2312} + 0.2271(R) - 0.01676(CN) \qquad \textit{Equation 2}$$

Where:

$I_A = intial\ abstraction\ (in)$

$C_L = constant\ loss\ rate\ \left(\frac{in}{hr}\right)$

$L = main\ channel\ length\ (mi)$

$D = 0\ for\ undeveloped\ watersheds, 1\ for\ developed\ watersheds$

$R = 0\ for\ non-rocky\ watersheds, 1\ for\ rocky\ watersheds$

$CN = NRCS\ curve\ number$

Previous reports in the same study area utilized the initial and constant loss method; therefore, it was deemed appropriate for continued use.

This method assumes that the maximum potential rate of precipitation loss from infiltration is constant throughout a rainfall event. The initial loss component represents interception and depression storage. The Texas Initial and Constant-Rate Loss Model was implemented and is detailed in the current TxDOT Hydraulic Design Manual, which is dated September 2019. This method uses an NRCS curve number and watershed characteristics to develop its two parameters: initial abstraction (in) and constant loss rate (in/hr). Exhibits displaying both the landcover and hydrologic soils group used when calculating the curve numbers for each drainage area can be found in **Appendix B**. The percent impervious was calculated by assigning an impervious value to each landcover category, then calculating a composite value for each drainage area. The landcover categories used are from the National Land Cover Database (NLCD) Multi-Resolution Land Characteristics Consortium (MRLC), where the percent impervious applied to each category of developed area was assigned based on the descriptions found in **Figure 4-1**. **Table 4-3** summarizes the parameters and results obtained from the Texas Initial and Constant-Rate Loss Method.

Developed	
21	**Developed, Open Space**- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity**- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity**-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.

Figure 4-1. **NLCD: Impervious Landcover**

4.2.3 Transformation method

The runoff transformation method consists of simulating direct runoff resulting from excess precipitation over a watershed. The Snyder Unit Hydrograph was used for modeling runoff transformation for this study. This is typical of the area and previous studies.

Snyder developed a method that, as he stated, was "mostly empirical" for deriving unit hydrographs for ungauged areas (Wilbur L. Meier, 1964). The City of Eastland does not have any gauges, and therefore lacks historical stage or rainfall data. The Snyder method provides a means for predicting the time base, peak discharge, and lag time for a particular basin. The lag time, t_P, is a function of the length of the main channel, L, the length of the main channel to the centroid of the drainage basin, L_C, and two coefficients, the C_t and C_P. L and L_C are characteristics of the basin, leaving the two parameters for the Snyder method: the lag coefficient (c) and peaking coefficient (C_P). Lag time was calculated using *Equation 3*, found below. The drainage areas and channel length parameters can be seen on **Exhibits B-3** and **B-4** in **Appendix B.** The parameters used in *Equation 3* for each drainage area are shown in **Appendix B**.

$$t_p = CC_t(LL_c)^{0.3} \qquad \textit{Equation 3}$$

Where:

$t_p = lag\ time\ (hr)$

$C = conversion\ constant\ (0.75\ for\ SI\ and\ 1.00\ for\ foot - pound\ system)$

$C_t = basin\ coefficent\ (calibration\ parameter)$

$L = length\ of\ main\ channel\ (mi)$

$L_c = length\ of\ main\ channel\ from\ outlet\ to\ nearest\ point\ of\ the\ watershed\ centroid\ (mi)$

To develop a unit hydrograph using Snyder's method, it is necessary to evaluate C_T and C_P from known floods. Based on data developed by the US Army District, Fort Worth, Texas, the values of C_t and C_P have been found to vary from 0.6 to 6.0 and 0.48 to 0.94, respectively (Wilbur L. Meier, 1964).

Based on **Figure 4-2**, values of 0.7 and 0.78 were selected for the initial C_t and C_p values, respectively, for the Leon River.

Table 1.--Snyder's coefficients developed by U. S. Army District, Fort Worth, Texas

River Basin	Stream and description of area	C_t	$640C_p$	t†
Neches	Angelina River Watershed above McGee Bend Dam	6.0**	320	6
	Neches River Watershed above Dam B	6.0**	310*	6
Trinity	Big Fossil Creek Watershed	.9	420	1
	Elm Fork Trinity--above Lewisville Dam	1.95	508	6
	Trinity River from confluence of Elm & West Forks to mouth of East Fork	1.8	500	6
	Trinity River from East Fork to head of Tennessee Colony Res.	2.9	460	6
	Cedar Creek above head of Tennessee Colony Res.	4.5	530	6
	Richland Creek Watershed from Bardwell and Navarro Mills Dam to head of Tennessee Colony Res.	3.0	530	6
Brazos	Brazos River above Whitney Dam	1.65	397	12
	Leon River--river mile 50.0 to Belton Dam	.7	500	3
	Lampasas River--above Stillhouse Hollow Dam	1.3	515	6
	San Gabriel River--North Fork above North Fork Damsite	.8	530	6
	Yegua Creek--above Somerville Dam	3.0	500	6
	Navasota River Watershed	3.0	475	6
Colorado	Hords Creek above Hords Creek Dam	1.0	600**	1
	Remainder of Pecan Bayou Watershed above Brownwood Dam	1.5	500	3
Guadalupe	Guadalupe River Watershed above Canyon Dam	.68	400	3
San Antonio	San Antonio River and tributaries in vicinity of San Antonio	.6*	500	1

* Minimum value
** Maximum value
† t is the duration of rainfall excess

Figure 4-2. Snyder's Coeff developed by the US Army District, Fort Worth, Texas

Given that the Meier paper used 0.7 as a C_T value at Belton Dam 128 miles downstream of Eastland and that HDR has previously performed calibrations on a stream-gaged watershed at Lake Leon using a C_T value of 3.28, HDR felt a higher C_T value was justified. The hydrologic model was run using various C_T-values in addition to the 0.7 value. The varying C_T values were validated using 2020 and 2021 historic rainfall events. The validation of the C_T-values is discussed in detail in **Sections 4.3, 5.1,** and **5.2**. The final C_T values of 0.7 for the North Fork and 3.0 for the South Fork were selected and the resulting hydrology is shown below in **Table 4-3**.

Table 4-3. Hydrologic Parameters.

Reach	Drainage Area ID	Initial Loss (in)	Constant Loss Rate (in/hr)	Standard Lag (hr)
Lakes	Lake Eastland	0.994	0.46	2.52
	Ringling Lake	0.681	0.76	1.18
Tributary 1: Weaver Creek	T1WC-1	0.620	0.90	1.31
	T1WC-2	0.003	0.78	0.70
	T1WC-3	0.000	0.72	0.67
Tributary 2	T2-1	0.110	0.88	0.74
	T2-1a	0.350	0.83	0.76
	T2-2	0.000	1.03	0.56
Tributary 3	T3-1	0.00	0.79	0.43
	T3-1a	0.00	0.93	0.21
	T3-2	0.00	1.03	0.29
	T3-3	0.00	1.00	0.40
North Fork Leon River	LRNF-1	0.57	0.83	0.85
	LRNF-2	0.09	1.00	0.39
	LRNF-3	0.00	0.91	0.46
	LRNF-4	0.00	0.88	0.64
	LRNF-4a	0.00	0.92	0.25
	LRNF-4b	0.00	0.98	0.44
	LRNF-5	0.00	0.83	0.79
	LRNF-6	0.49	0.82	0.82
South Fork Leon River	LRSF-1	0.00	1.05	0.88
	LRSF-2	0.00	1.03	1.61
	LRSF-3	0.46	0.87	2.78
	LRSF-3a	0.00	0.81	2.53
	LRSF-4	0.00	1.12	1.38
	LRSF-5	0.56	0.87	2.19
	LRSF-5a	0.52	0.85	3.91
	LRSF-5b	0.67	0.82	0.75
Tributary 5	T5-1	1.02	0.52	11.33
	T5-1a	1.06	0.29	23.28
	T5-2	0.00	0.95	2.15
Other	LR Main	0.98	0.61	9.56
	Lake Leon	1.03	0.42	15.17

4.2.4 Reservoir routing

Two lakes are included in the scope of this study: Lake Eastland and Ringling Lake. The routing for these lakes was performed using HEC-HMS Elevation-Storage-Discharge curves. Lake Eastland started at the normal pool elevation of 1,457.4 feet, which was determined from the ground survey performed by eHT and supported by the FNI 2009 study. Ringling Lake started at the normal pool elevation of 1462.0 feet, which was supported by the J&M 1988 study and was confirmed using LiDAR and aerial imagery.

All modeling performed has the lakes starting at normal pool. It should be noted that if the lakes are lower than the normal pool on any given day, per a drought condition, the lakes will provide additional storage below the normal pool. If the model were adjusted to start below the normal pool and allowed water to be stored in either of the lakes, the contributing volume from either lake downstream would decrease due to the increased storage provided. Additionally, the timing of hydrographs would be impacted, by delaying the time to peak further into the simulation.

Per the Emergency Action Plan (EAP) discussed in detail in **Section 6.5**, and past supporting studies, at the normal pool level of 1,457.4 feet, Lake Eastland has an original storage capaCity of 1,740 acre-feet of water. The surveyed normal pool elevation is 1456.43'.

The surveyed normal pool of Ringling Lake is 1463.61'. The surveyed flowline at the earthen outflow (creek) of the lake is 1464.59'. Previous studies show the normal pool of Ringling Lake being almost 10' lower, indicating Ringling Lake has accumulated sediment over time likely from the earthen outfall.

Based on conversations with City staff, there have been no major changes to the elevation-storage-discharge relationships since these studies were performed for Lake Eastland. No additional survey was performed in the area, and the relationships from the 2009 Freese and Nichols study were utilized for the routing of the lake as shown in **Table 4-4**. As-builts for the Lakes can be viewed in **Appendix I.** The storage-discharge relationship was updated for Ringling Lake using FlowMaster. A cross-section taken along the embankment was used to model the spillway. By increasing the water surface elevation of the lake incrementally, the discharge passed through the spillway was determined as shown in **Table 4-5**.

Table 4-4. Lake Eastland Elevation-Storage-Discharge Relationships.

Elevation	Volume (ac-ft)	Discharge (cfs)
1457.0	0.0	0
1459.0	504.0	1,000
1461.0	1,248.0	3,270
1463.0	2,149.0	6,500
1465.0	3,225.0	10,450
1467.0	4,496.0	15,300
1469.0	5,812.0	20,560
1471.0	7,516.0	26,290

Table 4-5. Ringling Lake Elevation-Storage-Discharge Relationships.

Elevation	Volume (ac-ft)	Discharge (cfs)
1462.0	226.0	0
1464.0	237.0	48
1466.0	256.0	348
1468.0	285.0	1,248
1470.0	312.0	3,256
1472.0	335.0	6,291

4.2.5 Design storm precipitation

The HEC-HMS frequency storm method was used to define the rainfall hyetographs for the 10%, 4%, 2%, 1%, and 0.2% annual exceedance probability (AEP) events. Point precipitation depths were obtained from the National Oceanic and Atmospheric Administration (NOAA) Atlas14 data for Eastland, Texas (latitude: 32.4025°, longitude: -98.8179°) as shown in **Table 4-6**. The 24-hour 1% AEP rainfall depth is approximately 8.65" which is representative of rainfall data across the entire City of Eastland watershed. Additional rainfall data is discussed **5.1 Gage adjusted rainfall data**.

Table 4-6. Point Rainfall Depths for Frequency Storms.

Time	10-yr Depth (in)	25-yr Depth (in)	50-yr Depth (in)	100-yr Depth (in)	500-yr Depth (in)
5 min	0.67	0.80	0.89	0.99	1.23
15 min	1.33	1.58	1.76	1.95	2.43
1 hr	2.35	2.80	3.12	3.46	4.38
2 hr	2.93	3.55	4.03	4.53	5.90
3 hr	3.29	4.03	4.62	5.25	6.95
6 hr	3.92	4.86	5.63	6.46	8.70
12 hr	4.55	5.66	6.57	7.57	10.30
24 hr	5.23	6.48	7.51	8.65	11.80

4.3 Validation

Due to the lack of historical rainfall for the City of Eastland and stage data for Lake Eastland and Ringling Lake, a combination of highwater marks (HWMs) and Gauge Adjusted Radar Rainfall (GARR) were utilized in the hydraulic model to determine the basin coefficient, C_T, as shown in *Equation 3* from **Section 4.2.3**.

A detailed explanation of the process and GARR data used during this calibration method is found in **Section 5.1** and **5.2.** The basin coefficient for the drainage areas contributing to the North Fork Leon River was found to be 3.0, while a value of 0.7 was established for the drainage areas contributing to the South Fork Leon River.

Initially, a consistent C_T value was used for the North and South Fork watersheds. However, values were not converging to the GARR data, so different C_T values were selected for the North and South Fork watersheds. Differing the C_T values on the North and South Fork watersheds was anticipated due to:

- the different levels of urbanization in the two watersheds
- the size of sub-basin T5-1a (139.6 square miles) compared with the largest North Fork drainage area (Lake Eastland at 33.7 square miles).

A detailed explanation of the Validation of C_T is provided in **Section 5.3**.

To benchmark the peak discharges produced from the hydrologic model, alternative methods were used for calculating runoff for rural watersheds. The TxDOT Omega EM Regression equations for the *2019 TxDOT Hydraulic Design Manual* were used for the drainage areas greater than 1 square mile. This method produced 100-year peak discharges within approximately 10% error from the results shown in **Table 4-8**. Benchmarking values with a common methodology such as the TxDOT Regression equations can be a useful comparison tool.

4.4 Hydrologic results

The existing conditions hydrologic model was developed using the methods listed above and HEC-HMS Version 4.9. **Table 4-7** summarizes the results from the 100-year recurrence interval, or 1% AEP, storm event. The discharge hydrographs for the two lakes are found below in **Figure 4-3** and **Figure 4-4**. The results for all drainage areas for each event are found in **Appendix B**. The hydrologic model outputs can be found in the submittal in **Appendix B – Hydrologic Maps and Results** .

Table 4-7. Hydrologic Summary - 100 year.

Reach	Drainage Area ID	Peak Discharge (cfs)	Volume (ac-ft)	Time to Peak (00:00)
Lakes	Lake Eastland	12,662	7,301	15:00
	Ringling Lake	4,116	560	12:14
Tributary 1: Weaver Creek	T1WC-1	3,547	500	12:15
	T1WC-2	1,060	117	11:41
	T1WC-3	700	94	11:39
Tributary 2	T2-1	1,121	112	11:43
	T2-1a	950	89	11:44
	T2-2	130	11	11:33
Tributary 3	T3-1	692	64	11:25
	T3-1a	175	13	11:13
	T3-2	198	13	11:17
	T3-3	192	13	11:24
North Fork Leon River	LRNF-1	1,391	151	11:49
	LRNF-2	499	29	11:23
	LRNF-3	728	60	11:27
	LRNF-4	749	99	11:37
	LRNF-4a	419	21	11:15
	LRNF-4b	104	11	11:26
	LRNF-5	945	157	11:46
	LRNF-6	1,238	154	11:47
South Fork Leon River	LRSF-1	95	15	11:51
	LRSF-2	104	24	12:33
	LRSF-3	466	149	13:39
	LRSF-3a	267	88	13:25
	LRSF-4	43	6	12:19
	LRSF-5	242	65	13:05
	LRSF-5a	630	255	14:44
	LRSF-5b	223	82	14:05
Tributary 5	T5-1	2,614	3,058	21:49
	T5-1a	15,489	30,223	09:11
	T5-2	92	25	13:03
Other	LR Main	10,914	10,892	20:07
	Lake Leon	9,194	13,368	01:27*

Note: *Occurs on Day 2 of simulation

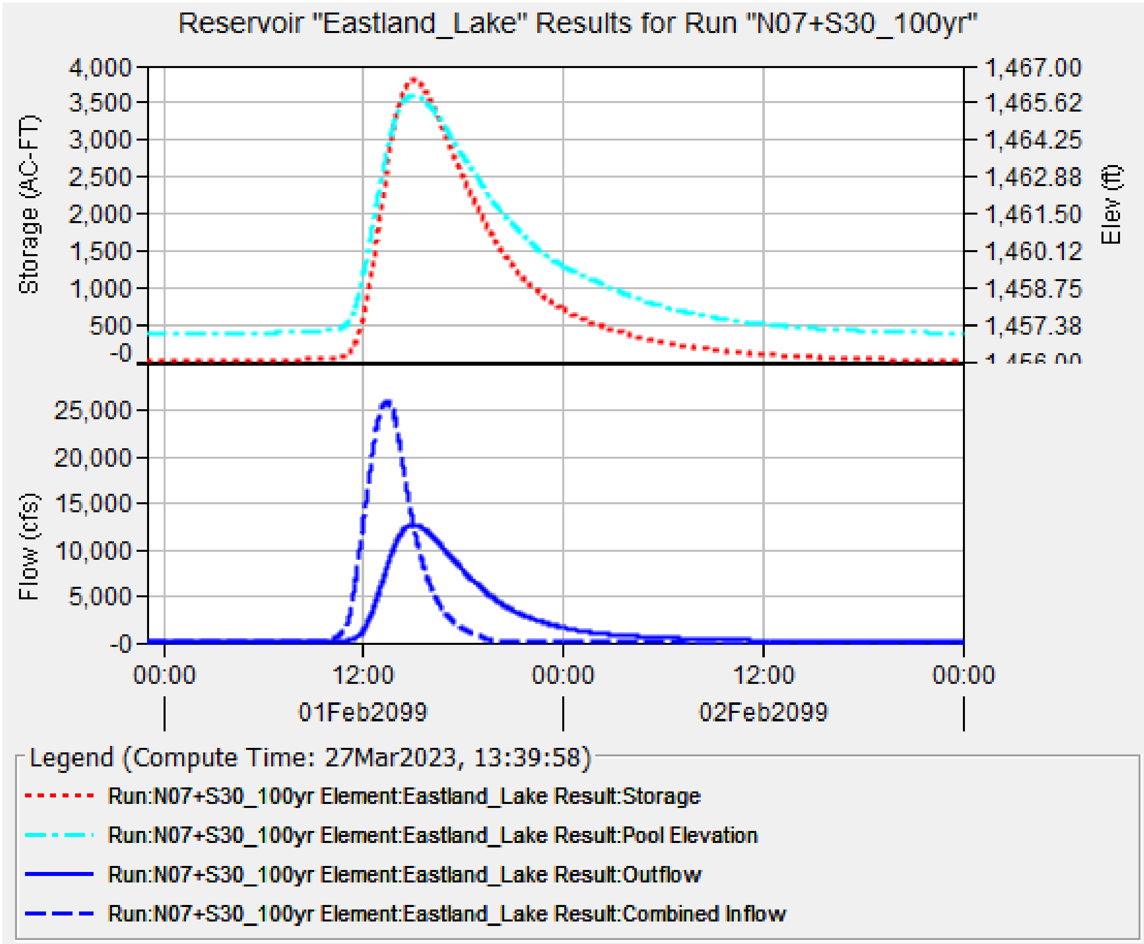

Figure 4-3. Lake Eastland 100-yr Results

As shown in **Figure 4-3,** Lake Eastland's outflow hydrograph peaks at 12,662 cfs during hour 15:00 of Day 1 in the 48-hr (100-year ACE) HEC-HMS run, producing approximately 3,804 ac-ft of storage.

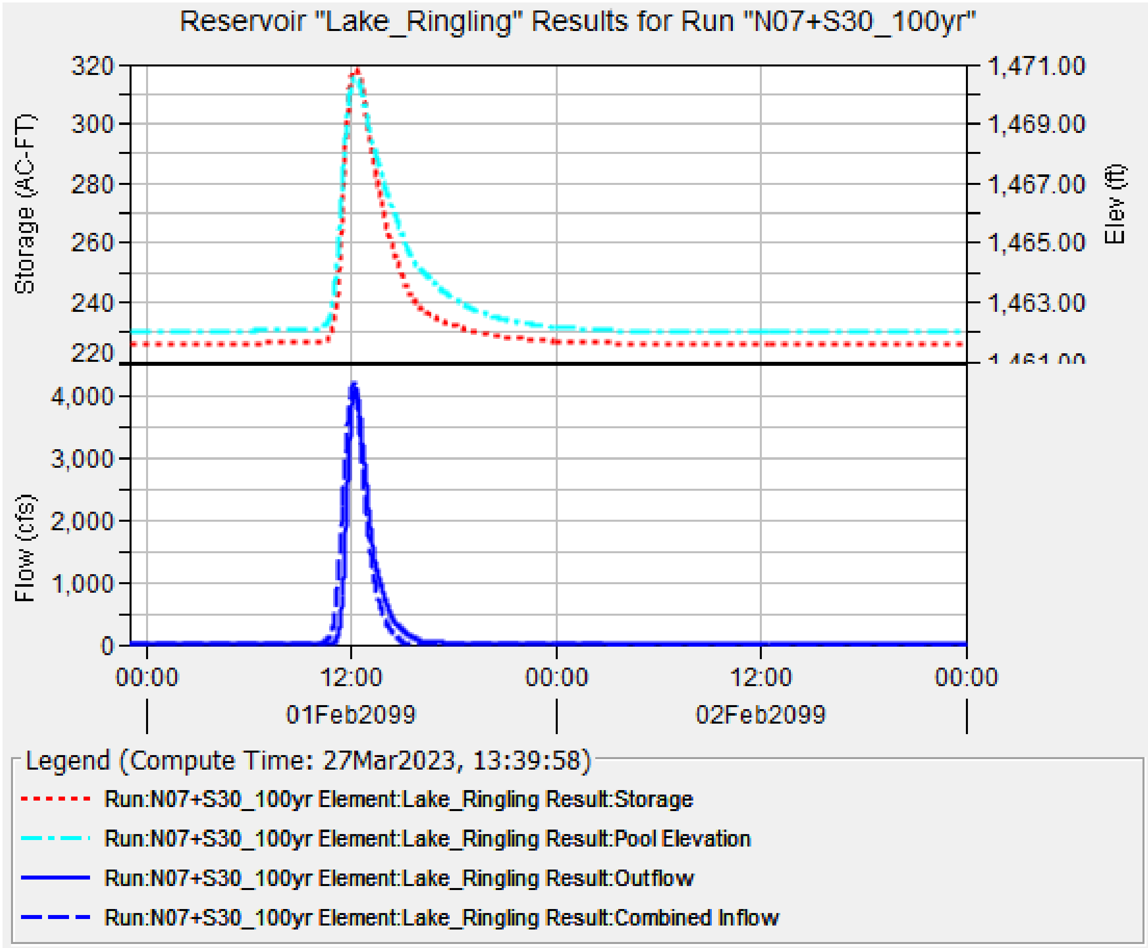

Figure 4-4. Ringling Lake 100-yr Results

As shown in **Figure 4-4**, Ringling Lake's outflow hydrograph peaks at 4,116 cfs during hour 12:00 of Day 1 of the 48-hr (100-year ACE) HEC-HMS run, producing approximately 319 ac-ft of storage. This is a relatively low level of storage given the inflows into Ringling Lake. When comparing the inflow (4,173 cfs) and outflow (4,116 cfs) hydrographs, shown in blue in **Figure 4-4** they are nearly identical.

The lake water depth levels for the different recurrence intervals are shown in **Table 4-8** below:

Table 4-8. Lake Levels.

Lake	Recurrence Interval	Level
Eastland	10	1462.9
Ringling		1469.0
Eastland	25	1464.0
Ringling		1469.7
Eastland	50	1465.0
Ringling		1470.2
Eastland	100	1465.9
Ringling		1470.6
Eastland	500	1468.5
Ringling		1471.7

5 Hydraulic analysis

The area of analysis is shown in the **Figure 2-1**. The USACE's HEC-RAS Version 6.2 was used with two dimensional (2D) computations to model the hydraulic extents. The extents were appropriately defined to include the scoped streams and the anticipated floodplain area. A normal depth downstream boundary condition was used just downstream of IH-10.

A computational 2D mesh with a general cell size of 100 by 100 feet was assigned; industry standards dictate this level of detail is appropriate for the size of the studied watershed. Manning's roughness coefficients reference Chow's 1959 Open Channel Hydraulic Manual and the HEC-RAS Reference Manual. Typical values used in this analysis were captured by aerial imagery and account for channel sinuosity, encroachments, water depths, surface obstructions. These are summarized in **Table 5-1**. The grid cells were refined in certain areas to capture finer resolution features in the underlying geometry using enforced break-lines and refinement regions. Areas of refinement were chosen in the City limits with the intention of getting the most precise results possible where residents of the City may be affected by flooding. The Full Momentum computation method was used in the 2D model. Full Momentum was selected instead of Strict Momentum equations because the Full Momentum equations are more conservative. Full Momentum equations provide more iterations than the Diffusion Wave Method in high velocity and overtopping situations both of which occur with the watershed studied.

Table 5-1. Manning's Roughness Coefficients.

Type	n-Value
Concrete	0.013
Open Water	0.03
Cultivated Crops	0.035
Barren to Grassy	0.04
Woody Pastures	0.05
Light Brush	0.06
Medium Brush	0.07
Heavy Brush/Urban Open Space	0.08
Developed, Medium Density	0.15
Developed, High Intensity	0.20
Mixed Forest	0.10

5.1 Gauge adjusted rainfall data

An approximate 30-mile radius was established around the Eastland Subbasins as the region in which to analyze GARR (gauge adjusted radar rainfall) data for the two historical storms needed for model validation. The first event was September 1-4, 2020, and the second was May 31,2021 through June 2, 2021. For these rainfall events, rainfall data was recorded at several gauges within the analysis area. HDR utilized 19 of these gauges in varying combinations for each rainfall event as per their availability and the quality of the data recorded during each event. Rainfall data was collected from various sources, including the NCEI Hourly (National Centers for Environmental Information) first order stations (i.e. Airport meteorological stations), NCEI Daily (COOP sites), NCEP (National Center for Environmental Prediction) HADS (Hydrometeorological Automated Data Systems) sites, CoCoRaHS (Community Collaborative Rain, Hail & Snow Network), City of Eastland, LCRA (Lower Colorado River Authority), APRSWXNET/CWOP (Citizen Weather Observing Program), and RAWS (Wildland Fire Remote Automated Weather Stations).

The number of gauges used for each historical event varied, but a sufficient number of geographically spaced gauges was available to produce accurate GARR data for the watershed during these events.

Radar data utilized in the production of GARR was produced by the NWS NEXRAD Dual Pol Doppler Radar system from the Fort Worth, TX (KFWS) radar station located at latitude 32.573 N, longitude -97.303 W. This radar station is located approximately 89 miles to the east of Eastland, TX.

Rainfall gauges were consistently analyzed to determine whether they were in good agreement with radar data and surrounding rain gauges. Once a bias correction value is calculated for each rainfall event, the resultant ZR ratio is used to convert the raw radar reflectivity values to rainfall values for each 5-minute radar scan. This data is turned into radar grids (1km X 1km spatial resolution) and can be used as gridded rainfall data input to HEC-RAS.

Examples of the final product from this methodology can be seen in the following **Figure 5-1, Figure 5-2, Figure 5-3** and **Figure 5-4** from the events of September 2020 and May 2021.

The rainfall data was provided as a DSS file and concentrated on the City of Eastland.

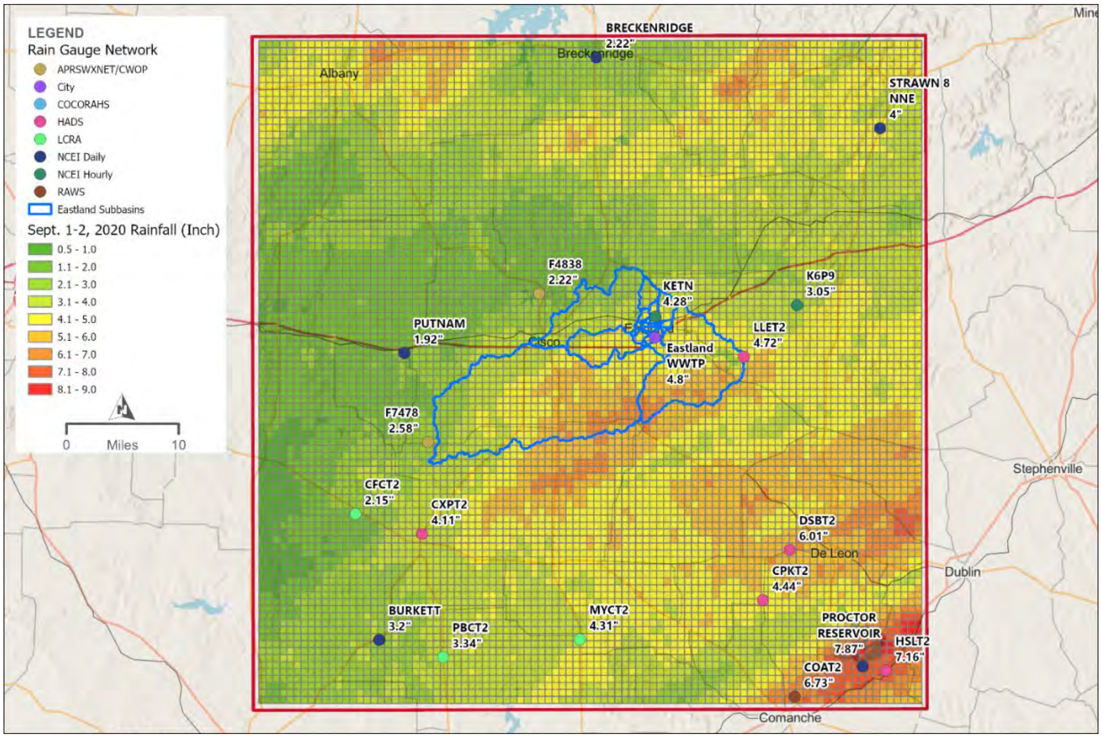

Figure 5-1. **Rainfall and Gage Data - September 1-4, 2020**

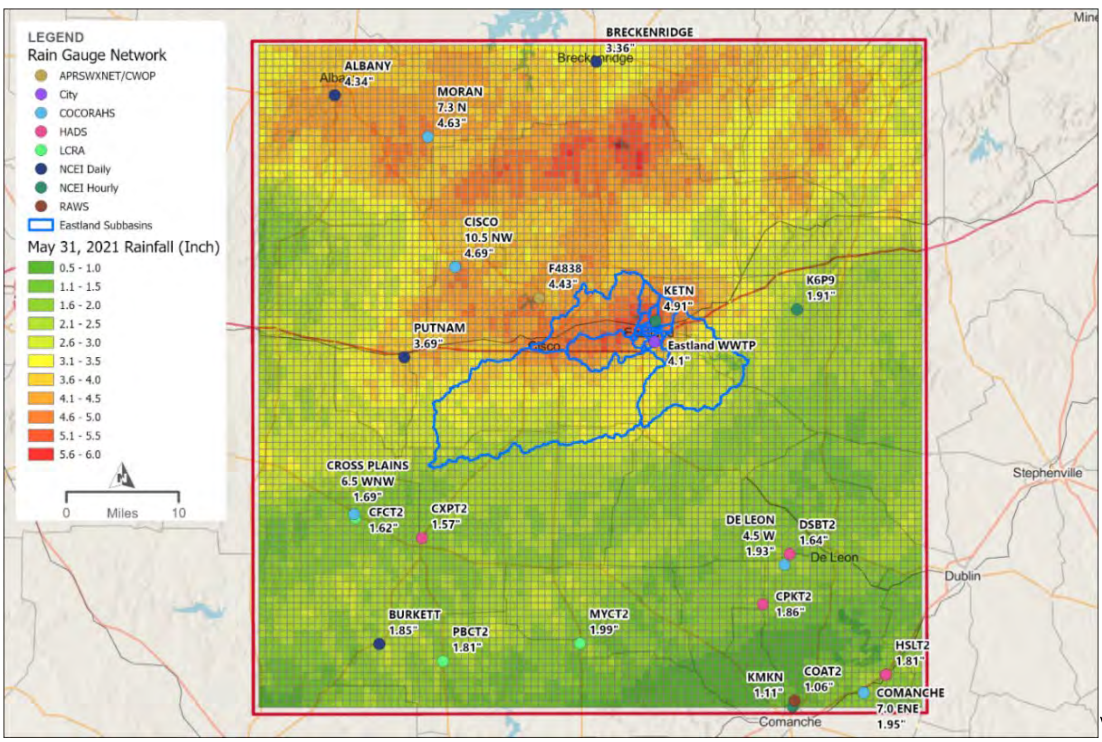

Figure 5-2. **Rainfall and Gage Data - May 31, 2021 through June 2, 2021**

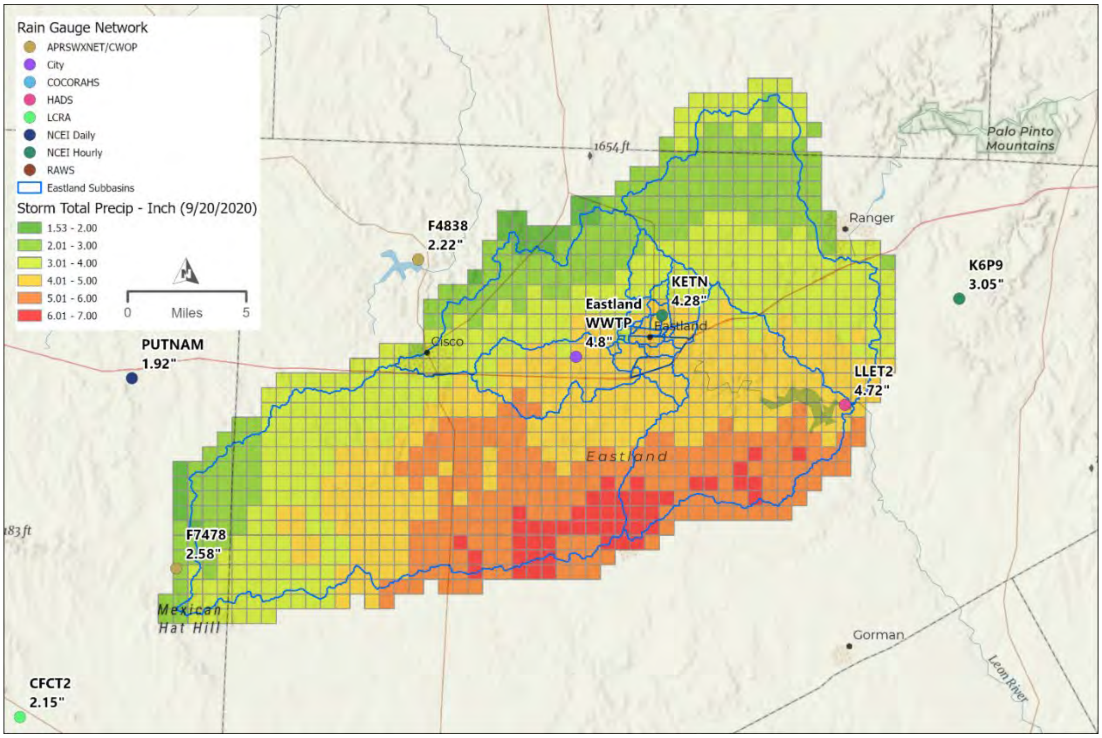

Figure 5-3. **HEC-RAS DSS Data September 2020**

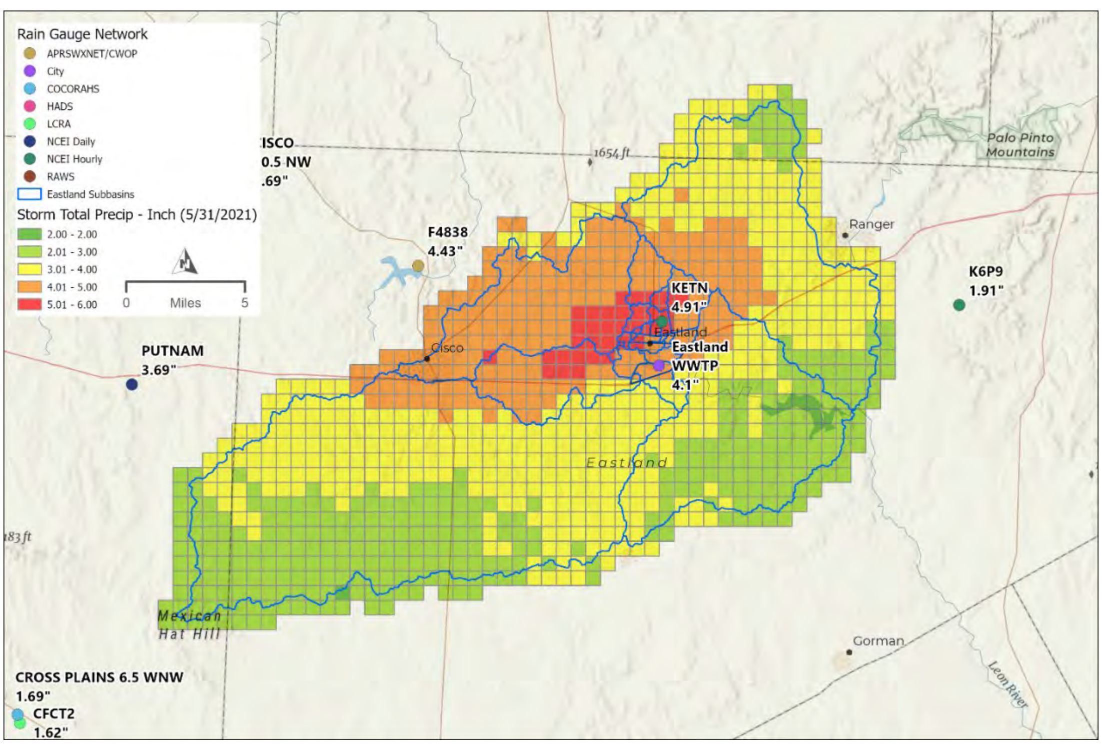

Figure 5-4. **HEC-RAS DSS Data May 2021**

5.1.1 WWTP values

The City provided rainfall depth data at the wastewater treatment plant in the form of a Microsoft Excel spreadsheet. In 2020, the WWTP depth value in the Excel data was 4.8” max on September 1. GARR data in September 2020 is 4.45” for the City. GARR data is a little lower than observed, but within an acceptable tolerance. An acceptable tolerance was defined as 1 foot for this study.

Another storm event evaluated was in June of 2021 where the City data registered 3.9” of rainfall depth. GARR data shows 4.23” for the same storm event. These values are within an acceptable range to validate the GARR data HDR developed.

Based on the GARR data, the 2020 and 2021 events were approximately 25-year events as compared with the NOAA Atlas 14 depth of 4.65” during a 24-hour period. These events will be used in validation efforts and are discussed in the next section.

5.2 Inflow locations

5.2.1 Design storms

The inflow hydrographs generated in HEC-HMS were imported into HEC-RAS by linking DSS results. Each hydrograph was input as a boundary condition to be applied at the downstream point of the watershed boundary. The Hydraulic Work Map in **Appendix C** shows location of each inflow hydrograph as a boundary condition. Flow moves through the 2D mesh cells based on the Manning’s roughness value in **Table 5-1**. The 2D Mesh boundary and Boundary Conditions for inflow hydrographs are shown in **Appendix C – Hydraulic Maps**.

5.2.2 GARR events

The HEC-RAS 2D mesh boundaries appropriately cover the limits of hydraulic study listed in the scope of work. For the 2020 and 2021 GARR events, the gridded gauge adjusted rainfall data from **Figure 5-1** and **Figure 5-2** was applied to the HEC-RAS 2D Mesh (as a DSS file), while GARR-inflow hydrographs for the remainder of the studied watershed were applied at the “edges” of the mesh. The Mesh limits are shown in the GARR hydraulic work map in **Appendix C.** The inflow hydrographs had point depths applied as individual precipitation gauges for each event using the gridded DSS data shown in **Figure 5-3** and **Figure 5-4**. The point depths were applied in HMS at the following locations.

- LRSF-5a
- T5-1
- T5-1a
- T1WC-1
- LRSF5-1
- Lake Eastland
- Ringling lake
- T2-1a

These locations are shown on the GARR Hydraulic Work Map in **Appendix C.** The hydrographs within the mesh boundaries received 0.0 inches of precipitation in the HEC-HMS Basin Model and were accounted for as a "Dummy" precipitation gauges.

The computed flood depths from the GARR events were used in the validation of the C_T values for the North and South Forks, as discussed in the next section (5.3 Validation of C_T).

5.3 Validation of C_T

The City of Eastland is not a gauged area. For validation, high water marks (HWMs) were observed and collected on the field visit performed March 23, 2022. The HWMs were taken with a depth rod, photograph, then collected as a survey point. High water marks reflect actual flood depths for the 2020 and 2021 events. **Figure 5-5** shows the locations of the HWMs. An example of the depth rod measurements at highwater marks is shown in Photo 19 of **Appendix G – Photo Log**. Points 7 and 8 were evaluated as "these areas have not flooded in City memory". This verbal anecdote from local experts served as an additional validation tool; if depths were greater than 0 at these locations, then a lower C_T value was selected to reduce flood flow rates.

Figure 5-5. High Water Marks

The addition of the survey elevation to depth-rod measurement gives the expected water-surface-elevation in the model at measured locations. **Table 5-2** shows the field survey measured value with the measured rod depth and the expected WSE at the field points shown in **Figure 5-5**.

Table 5-2. Observed High Water Mark Elevations.

Observed high water mark elevations				
ID	**Description**	**Field Survey Measurement (ft)**	**Measurement Rod Depth (ft)**	**WSE (ft)**
1	NE Flood Wall @ Weaver Creek Business	1428.70	1.88	1430.58
2	SE HWM @ Weaver Creek Business	1428.03	2.00	1430.03
3	William F Simpson Surgery	1423.67	2.00	1425.67
4	SE Flood Wall @ Weaver Creek Business	1426.38	1.96	1428.34
5	NE Flood Wall @ Weaver Creek Business	1426.31	1.75	1428.06
6	NW Flood Wall @ Weaver Creek Business	1426.28	1.63	1427.91
7	Wastewater Treatment Plant	1429.71	0.00	1429.71
8	Pump Station	1415.47	0.00	1415.47
9	I-20 Bridge Pillar	1414.06	3.08	1417.14

The goal of the validation is for the expected WSE values to GARR 2020 and 2021 values to be within 1.0’.

5.3.1 Iterations

An initial assumption of 0.70 for the C_T value was used based on a reference paper by the Fort Worth District Corps of Engineers shown in **Figure 4-1**. As mentioned in section **4.2.3 Transformation method**, based on the Lake Leon calibration performed by HDR (with a stream gauge at Lake Leon) where the C_T was 3.28, a higher C_T may be more appropriate for the City of Eastland.

To validate the model, field high water marks were compared to the 2020 and 2021 GARR model results iterated to be within 1.0’. By adjusting the C_T parameter, the 2021 and 2020 depths are within 1.0’ of the field-measured high water marks the model will be validated. A graphic of the iterative process is shown in **Figure 5-6**.

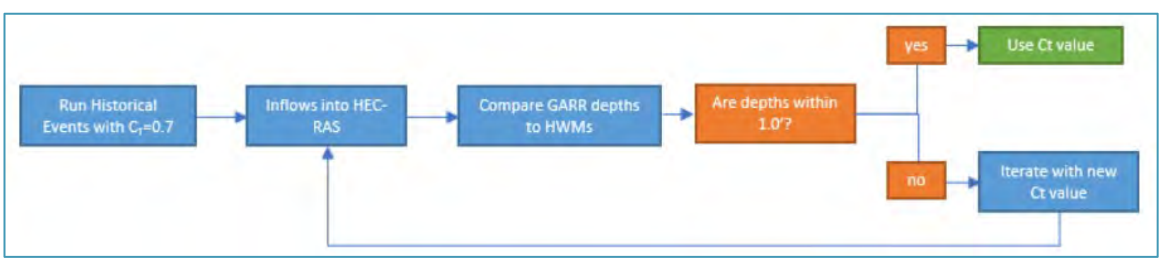

Figure 5-6. Iterative Process for C_T Values

Initially, a consistent C_T value was used for the North and South Fork watersheds. However, values were not converging to the historical events, so different C_T values were selected for the North and South Fork watersheds. Differing the C_T values on the North and South Fork watersheds was anticipated due to:

- the different levels of urbanization in the two watersheds
- the size of sub-basin T5-1a (139.6 square miles) compared with the largest North Fork drainage area (Lake Eastland at 33.7 square miles).

As seen in **Figure 5-2** and **Figure 5-3** the 2020 rainfall event centers in the South Fork, while the 2021 rainfall event centers in the North Fork. Therefore, the 2020 event was favored in the South Fork validation and the 2021 event was favored in the North Fork Validation.

A value of C_T=0.7 was selected for the North Fork and a value of C_T=3.0 was selected for the South Fork. A summary table of the computed flood depths at high water mark locations can be seen below in **Table 5-3**:

Table 5-3. Comparison of GARR Depths and High Water Mark Comparison.

HEC-RAS RESULTS						
North Fork Ct=0.7						
South Fork Ct = 3.0						
ID	Description	Depth (ft)			Delta (ft)	
		1	2	3	1-3	2-3
		2020	2021	HWM	2020-HWM	2021-HWM
1	NE Flood Wall @ Weaver Creek Business	0.35	1.54	1.83	-1.48	-0.29
2	SE HWM @ Weaver Creek Business	0.78	1.28	2.00	-1.22	-0.72
3	William F Simpson Surgery	0.00	1.72	2.00	-2.00	-0.28
4	SE Flood Wall @ Weaver Creek Business	0.33	1.07	1.96	-1.63	-0.89
5	NE Flood Wall @ Weaver Creek Business	0.43	1.27	1.75	-1.32	-0.48
6	NW Flood Wall @ Weaver Creek Business	0.00	0.64	1.63	-1.63	-0.99
7	Wastewater Treatment Plant	0.00	0.00	0.00	-	-
8	Pump Station	0.00	0.00	0.00	-	-
9	I-20 Bridge Pillar	2.77	3.25	3.08	-0.31	0.17

Our analysis and hydraulic results have a high confidence level because of the validation method described. However, we highly recommend that the City add stream gauges on strategic locations within the North and South Fork. This will aid in monitoring flood levels and further enhance the confidence interval.

It is known that the City has rain gauge data at the Wastewater Treatment Plant and the airport. Additionally, readily available meteorologic data from the National Oceanic and Atmospheric Administration is easily obtained. If a rain gauge can be placed in the watershed draining to Lake Eastland, rain data and lake-level-elevation data can be calibrated to greater specificity.

5.4 Hydraulic results

5.4.1 No-impact analysis

All projects to be funded by TWDB in the future must be constructable, permittable, and have no impact. No impact is generally defined as not increasing flows from pre- to post-project. This definition is used for CIP 04, 05, and 06. For CIPs 01 and 02, the purpose of the projects is the remove flow obstructions to increase conveyance and reduce flooding upstream. Increasing of conveyance naturally increases flow downstream, so the projects also include downstream channelization to contain increased flows. No-impact for CIPs 01, 02, 03 is defined as, no additional structures flooded, as well as no additional top width added to the floodplain. See Section 7 for determination of no impact on each of the CIPs.

5.4.2 FIS comparison

Resulting depth maps are provided for each AEP event in **Appendix C – Hydraulic Maps**. **Figure 5-7** shows the inundation depths for the 100-year event. When compared to the boundary of the existing FIRM panel in **Appendix A** the boundaries are similar. **Table 5-4** shows a comparison of the Base Flood Elevations from the FIS study and compares them to the HEC-RAS model results for the existing conditions 100-year event.

Table 5-4. FIS Comparison.

Flooding Source		**Base Flood Water-Surface Elevation**		
Cross Section	**Distance[1]**	**Regulatory (FIS)**	**Existing**	**Delta**
Tributary 1				
A	3745	1438.80	1437.60	1.20
Tributary 2				
A	3084	1434.90	1432.32	2.58
B	5394	1444.40	1445.80	-1.40
C	8254	1461.70	1462.50	-0.80
Tributary 3				
A	2565	1452.90	1452.85	0.05
B	3381	1459.30	1459.66	-0.36
C	4631	1464.30	1466.32	-2.02

[1] Feet above confluence with North Fork Leon River

Figure 5-8 shows flooding depths ranging from 3 to 6 feet in the core of the City of Eastland around Main Street.

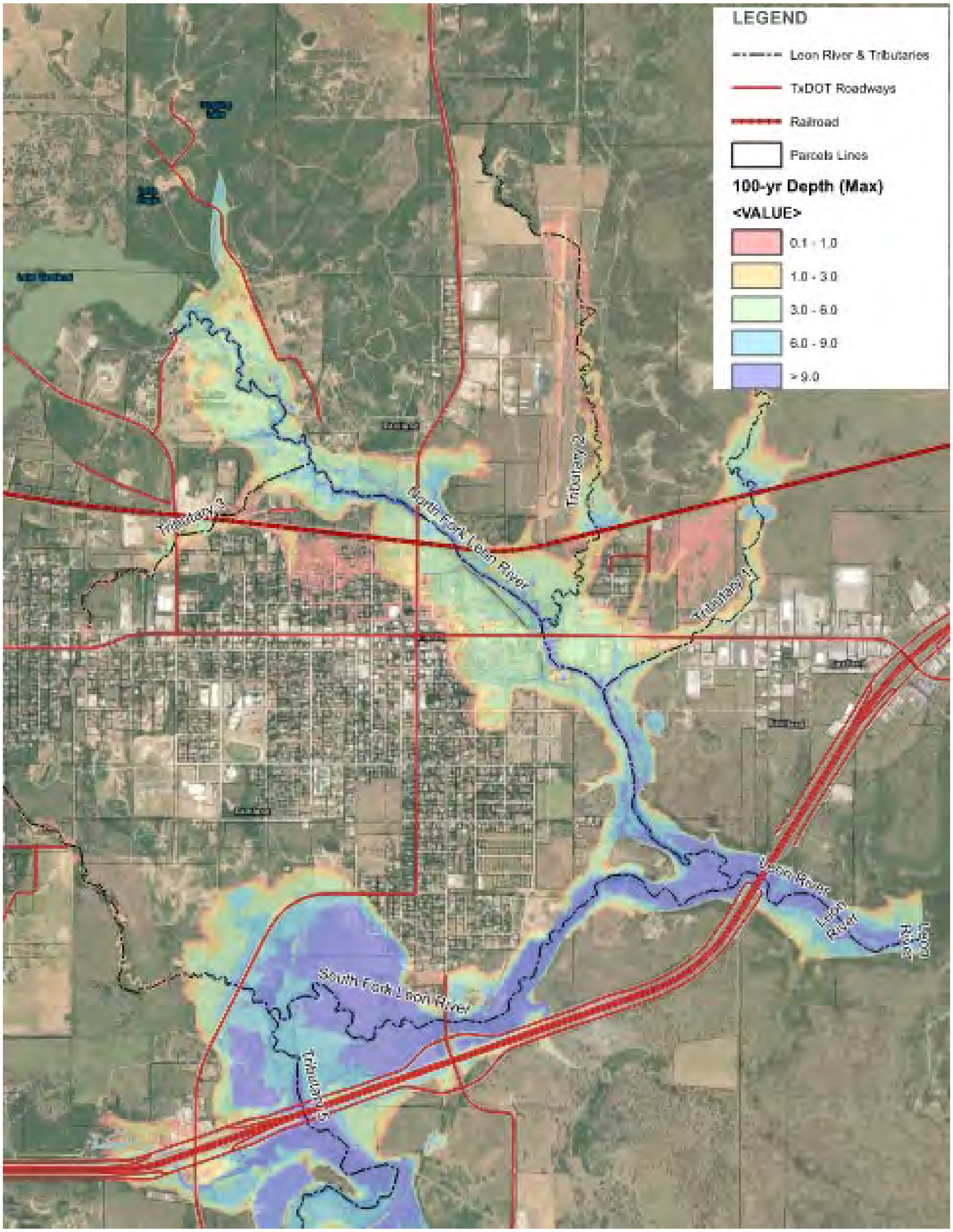

Figure 5-7. 100-year Depth Inundation Map

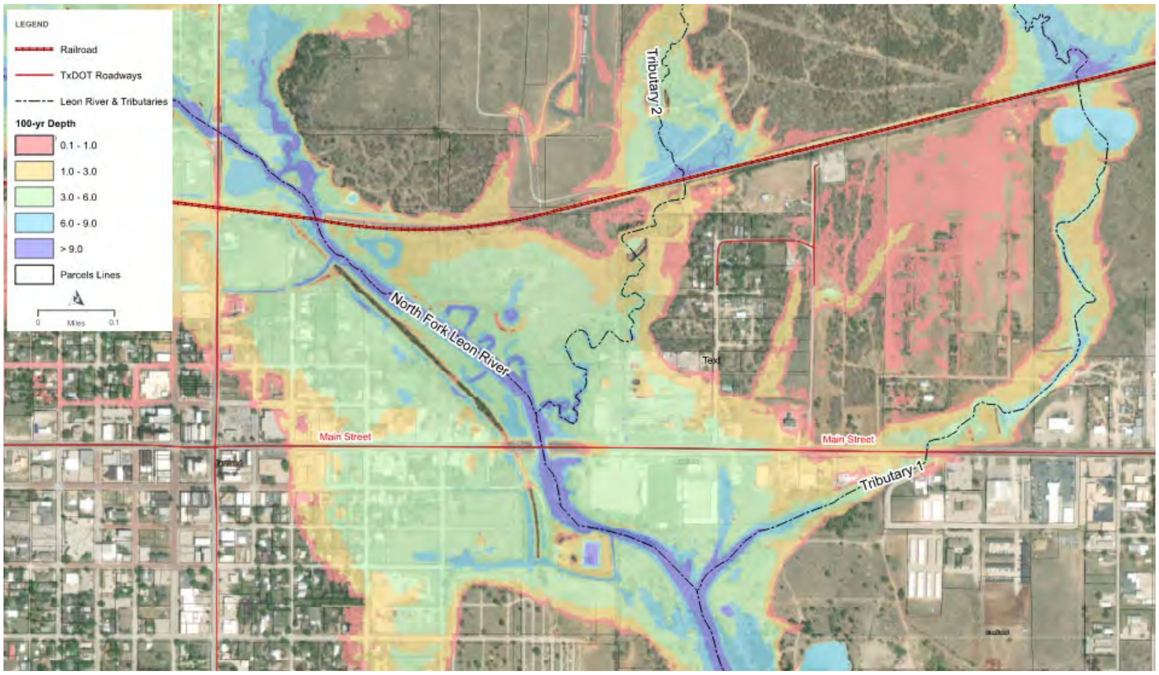

Figure 5-8. 100-year Depth Inundation Map of Main Street Area

Based on the inundation from the existing conditions models, Capital Improvement Projects are proposed for the City and discussed in **Section 7.1-Structural mitigation alternatives**.

5.4.3 At risk structures

In the Inundation Maps in **Appendix C – Hydraulic Maps** high-risk structures (hospitals, jails, schools, water/wastewater treatment plants) are mapped. The wastewater treatment plant remains non-inundated during all storm events. The Wastewater Lift Station at the North Fork is also non-inundated in all events. At-risk structures should be prioritized for flood risk reduction as a matter of public safety. CIP 01 – Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements reduces flood levels from a flood prone section of Main Street, a TxDOT Area office, and other important businesses. CIP 02 – Tributary 3 Culvert and Grading Improvements seek to reduce flood levels of critical railroad infrastructure. Refer to **Section 7 Alternatives analysis** for further discussion and recommendations on flooding improvements.

5.4.4 North and south fork interaction

The North Fork peaks around Hour 16:55 on Feb 01, while the South Fork peaks around hour 13:00 on Feb 02. These results reflect almost a 24-hour difference between the time that it takes each stream to peak. As the North Fork peaks, velocities in excess of 6 fps are shown in yellow in **Figure 5-9**. When the South Fork begins to peak, the North Fork it loses velocity around the meander, spills out of its banks, and sheet flows to the downstream side of I-20 as shown in **Figure 5-9**. Low velocities near the confluence indicate inefficient flow. The ineffective confluence angle of the North and South Fork shown in **Figure 5-10** cause a turbulence in flow that has resulted in the erosion of the embankment of I-20. The erosion of the embankment is evident in the topography and from google street view.

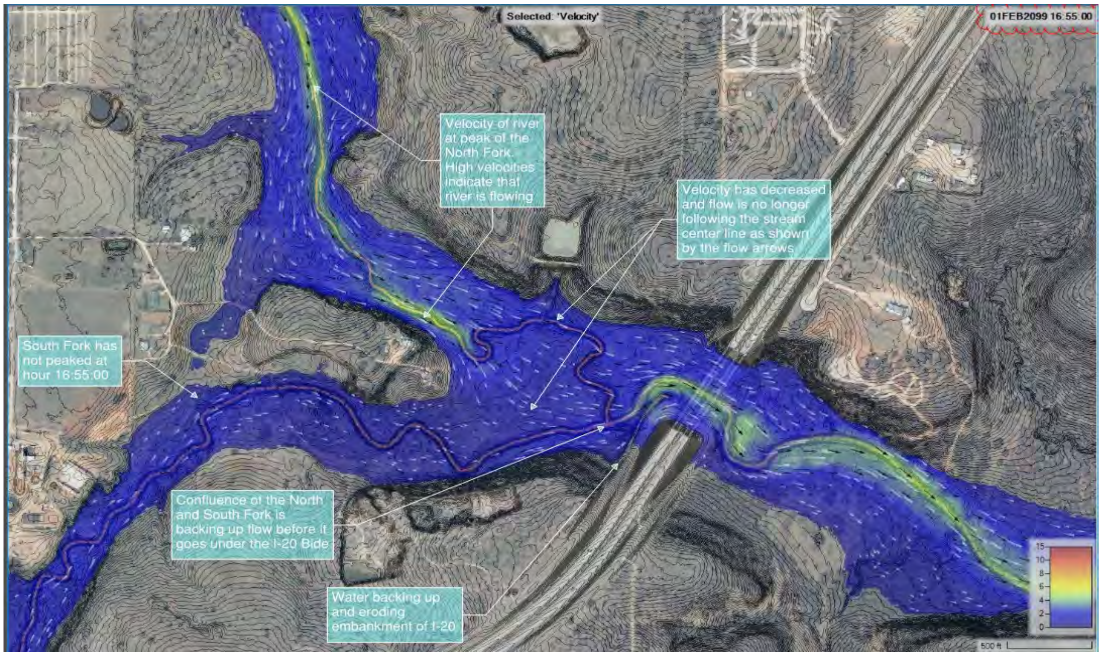

Figure 5-9. **Velocity Vectors at North Fork Peak**

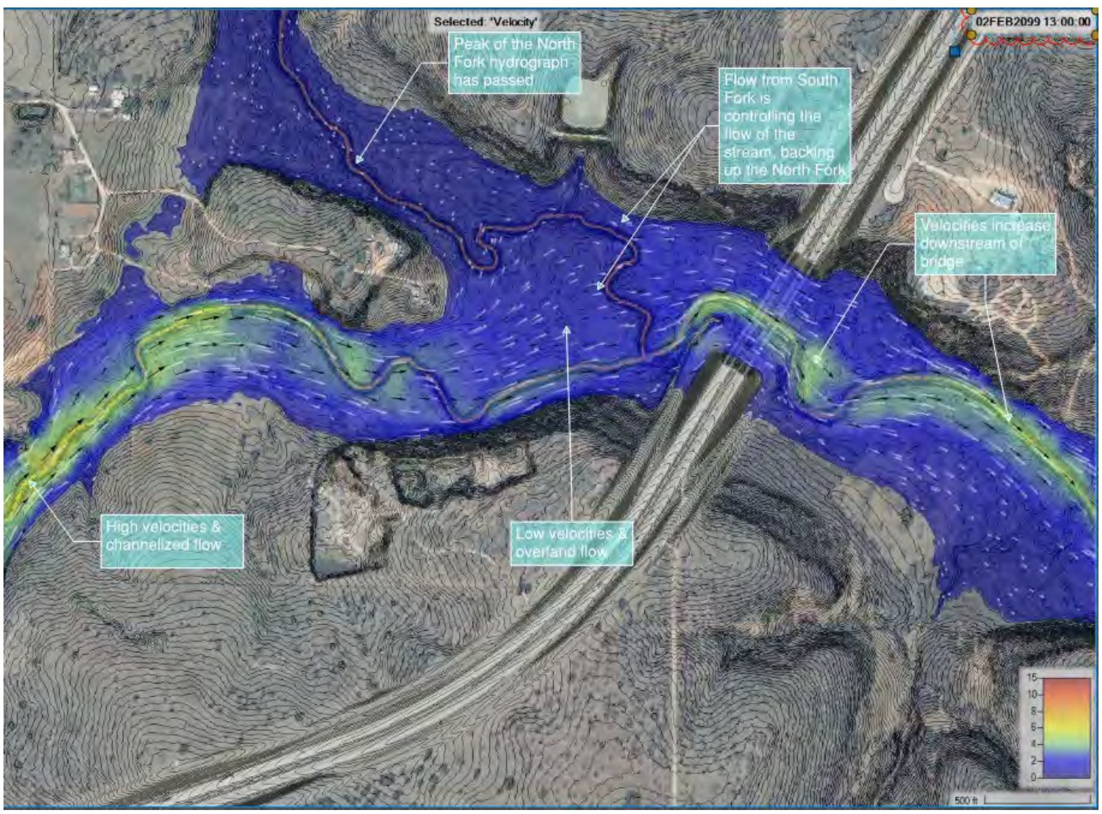

Figure 5-10. **Velocity Vectors at South Fork Peak**

Figure 5-9 shows the North Fork at its peak hour while **Figure 5-10** is the South Fork at its peak. The low velocities in the North Fork and high velocities of the South Fork at its peak indicates that when the South Fork is peaking, it creates a backwater effect on the North Fork.

The approach angle of the North Fork is in a negative direction in relation to the flow of the South Fork. See **Section 7.1.6**

6 Dam breach analysis

A dam breach hydraulic model was developed using unsteady two-dimensional (2D) HEC-RAS (Version 6.2) for both Eastland and Ringling Lake. The hydraulic models are used to evaluate the different dam breach scenarios and corresponding breach inundation mapping that was eventually used to update the EAP. Terrain data used for the computational mesh is the same terrain used for modeling the design storms. The terrain represents 2018 TNRIS LiDAR that is complemented by ground survey completed by eHT.

Dam breach cross section are shown in **Figure 6-1** and **Figure 6-2** for Lake Eastland and Lake Ringling, respectively. The breach models assumes that Lake Eastland Dam breaches at the concrete spillway due to its poor condition and evidence of water seeping through cracks of the spillway. Typically, a breach would occur at the center of the dam, but no evidence of seepage was observed at the downstream toe of the earthen embankment. However, that is not the case for Ringling Lake. The 1978 TCEQ dam inspection report state that Ringling dam shows signs of seeping through the embankment. Seepage leads to internal erosion of the embankment causing piping failure. Therefore, the embankment was chosen as the breach location for all the Ringling Dam breach scenarios instead of the spillway.

Typically for a dam breach modeling, downstream structures like bridges and culverts can be excluded under the assumption that the structure would be overtopped and washed away, or that the structure does not represent a significant obstruction to the flow. However, for the City of Eastland study, all major structures were modeled in connection with the breach analysis to better understand the depth of overtopping and the impact of backwater flooding from undersized drainage structures.

Figure 6-1. **Aerial View of Eastland Lake Dam**

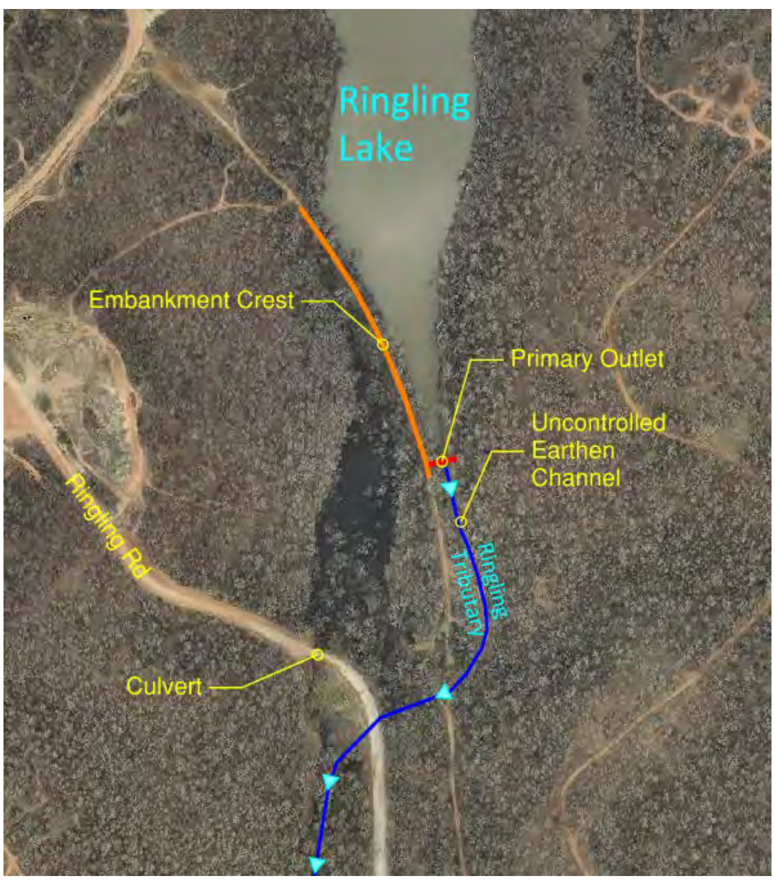

Figure 6-2. **Aerial View of Lake Ringling Dam**

6.1 Probable maximum flood hydrology

Part of the dam breach evaluation is to perform a Probable Maximum Flood (PMF) analysis on Lake Eastland and Ringling Lake based on the updated Probable Maximum Precipitation (PMP) rainfall values provided by TCEQ in their 2016 PMP Study. The PMP rainfall values are produced from the Maximum Probable Storm (PMS) centered over the watershed of interest. The PMS that produces the most critical conditions on a dam are dependent on the location of storm center, size of storm area, storm orientation, and temporal arrangement of precipitation values.

A hydrologic model for each dam was developed using HEC-HMS (version 4.9) and the PMP values from the TCEQ PMP Evaluation Tool were used to determine the critical storm duration that resulted in the maximum reservoir level. The critical storm event was determined based on TCEQ (2007) guidance (*TCEQ H&H Guidelines for Dams*). The storm event durations were increased in the model until a longer duration storm produced a lower peak reservoir WSEL. The storm event that produced the highest WSEL is the critical storm duration.

The TCEQ PMP Evaluation Tool produces area average PMP depths for three different types of storm scenarios: local, general, and tropical. The maximum value for each drainage area was then selected to calculate an area weighted PMP value based on the basin's respective area within the overlain isohyets shown on **Exhibits F-5** and **F-6** in **Appendix F**. A temporal distribution was applied to these PMP values to develop hyetographs used in the hydrologic model to produce outflow hydrographs that are then utilized in the hydraulic model.

6.1.1 Lake eastland probable maximum flood hydrology

To perform a PMF analysis on Lake Eastland, PMP values were obtained using the 2016 TCEQ PMP Evaluation Tool for storm durations of 3, 6, 12, 24, and 48-hour. Under TCEQ (2007) Guidance, the suggested minimum storm duration based on Lake Eastland's contributing drainage area size is the 3-hour storm. A hydrologic model was developed for Lake Eastland, and a spatial distribution was applied to the PMP values from **Table 6-1** to develop hyetographs implemented in the model to determine the critical storm duration that resulted in the maximum reservoir WSEL.

Table 6-1. 2016 TCEQ PMP Values for Lake Eastland.

Storm Type	PMP 3-hr (in)	PMP 6-hr (in)	PMP 12-hr (in)	PMP 24-hr (in)	PMP 48-hr (in)
Local	16.56	22.97	27.58	33.24	42.49
General	10.21	17.38	20.44	23.49	27.92
Tropical	16.38	20.09	27.64	33.24	43.80
Maximum	**16.56**	**22.97**	**27.64**	**33.24**	**43.80**

The model results indicated that the 24-hour storm was the critical storm duration, which differs from the previous PMF analysis performed in the 2009 FNI study. However, the maximum WSE of Lake Eastland only differs by 0.03 feet when compared to this same study. The 24-hour event produced the highest peak WSE, 1,477.8 feet, as shown in **Table 6-2**, along with the rest of the results from the critical storm analysis.

Table 6-2. Summary of Critical PMP Analysis for Lake Eastland.

Results	PMP 3-hr (in)	PMP 6-hr (in)	PMP 12-hr (in)	PMP 24-hr (in)	PMP 48-hr (in)
Peak Inflow (cfs)	77622	87367	83753	**63172**	41449
Peak Elevation (ft-msl)	1469.8	1477.3	1477.7	**1477.8**	1475.2
Peak Storage (ac-ft)	7958	16406	17086	**17150**	13646

To account for the contributing drainage areas downstream of Lake Eastland in the PMF analysis, a combined approach was applied using the previous HMR-52 PMP isohyets and the updated PMP values from the 2016 TCEQ PMP Evaluation Tool. The subbasins were grouped according to their intervening tributary and a theoretical storm positioned on the centroid of the Lake Eastland drainage area was developed using HMR-52 data to produce elliptical isohyets. The isohyets are used to determine the PMP values applied to the downstream contributing drainage areas, as shown in **Exhibit F-5**, to produce the values found in **Table 6-3.**

Table 6-3. Lake Eastland PMP Rainfall Depths for Tributaries to the North and South Forks of the Leon River.

Drainage Area	Area (sq mi)	PMP Depth (in)
LRNF-1	0.83	22.35
LRNF-2	0.53	20.08
LRNF-3	0.73	18.36
Trib_1	4.43	21.16
Trib_2	1.27	23.71
Trib_3	0.42	22.58
Ringling Lake	3.44	30.55
D/S_Ringling_Lake	0.89	26.58
LRSF-1	1.42	19.91
LRSF-2	2.40	15.81
Trib_5	154.24	15.02

6.1.2 Ringling lake probable maximum flood hydrology

The PMF analysis on Ringling Lake used the same methodology to obtain the PMP values as Lake Eastland (previous description). Under TCEQ (2007) Guidance, the suggested minimum storm duration based on Ringling Lake’s contributing drainage area size is the 1-hour storm. A similar methodology as Lake Eastland was performed on Ringling Lake in order to develop hyetographs from the PMP values shown in **Table 6-4**.

Table 6-4. 2016 TCEQ PMP Values for Ringling Lake.

Storm Type	PMP 1-hr (in)	PMP 2-hr (in)	PMP 3-hr (in)
Local	9.8	19.62	21.37
General	6.62	9.67	14.12
Tropical	12.67	16.77	18.82
Maximum	**12.67**	**19.62**	**21.37**

The model results indicated that the 2-hour storm was the critical storm duration. The 2-hour event produced the highest peak WSE, 1,476.7 feet, as shown in **Table 6-5** along with the rest of the results from the critical storm analysis.

Table 6-5. Summary of Critical PMP Analysis for Ringling Lake.

	PMP 1-hr (in)	PMP 2-hr (in)	PMP 3-hr (in)
Peak Inflow (cfs)	8875	**17766**	14924
Peak Elevation (ft-msl)	1472.5	**1476.7**	1475.8
Peak Storage (ac-ft)	342	**404**	391

Similar to the Lake Eastland procedure, the contributing drainage areas downstream of Ringling Lake had to be accounted for in the PMF analysis. The same combined approach was applied using HMR-52 PMP isohyets and the updated PMP values from the 2016 TCEQ PMP Evaluation Tool, as shown in **Exhibit F-6** of **Appendix F**. The results from this process are found in **Table 6-6**.

Table 6-6. Ringling Lake PMP Rainfall Depths for Tributaries to the North and South Forks of the Leon River.

Drainage Area	Area (sq mi)	PMP Depth (in)
LRNF-1	0.83	15.54
LRNF-2	0.53	12.66
LRNF-3	0.73	10.56
Trib_1	4.43	10.18
Trib_2	1.27	16.46
Trib_3	0.42	16.96
Lake Eastland	33.68	7.60
D/S_Ringling_Lake	0.89	19.62
LRSF-1	1.42	12.59
LRSF-2	2.40	8.86
Trib_5	154.24	3.48

6.2 Dam breach scenarios

A dam can breach differently depending on its environment. TCEQ guidelines require evaluation of a

1. Sunny-day breach, a
2. % PMF passing, for dams that cannot pass the full design flood (barely overtopping breach), and a
3. Design-flood breach (75% PMF).

A sunny day breach condition assumes the dam fails at the normal pool elevation. A % PMF passing condition assumes a breach when the reservoir reaches the crest of the dam (barely overtopping). The 75% PMF condition assumes a breach when the reservoir reaches the WSE of 75% of the full PMF storm. A separate breach scenario was done for the 75% PMF condition that assumes the dam does not breach.

The full PMF (100% PMF) conditions determined the maximum water surface elevation and the time for the Lake to peak. These parameters were then used for breach initiation conditions in the design flood breach scenario. The full PMF is a theoretical storm that uses statistical analysis to predict the worst-case rainfall depths that could occur during a storm event. WSE elevation table for each event found in **Table 6-7**.

Table 6-7. Eastland and Ringling Dam Inflow and WSE Summary.

Dam	Full PMF		75% PMF		% PMF Passing		Sunny Day	
	Inflow (cfs)	WSE (ft)	Inflow (cfs)	WSE (ft)	Inflow (cfs)	WSE (ft)	Volume (ac-ft)	WSE (ft)
Eastland	63,172	1477.8	47,379	1474.6	25,269	1,469.2	1,740	1457
Ringling	24,766	1481.1	13,310	1475.2	3,198	1469.8	54.2	1461

TCEQ classifies dams according to size and hazard. The Lake Eastland dam falls into the intermediate size category due to having a max height and storage capacity of 33-ft and 7,561 ac-ft respectively. The Ringling Lake dam is a small size dam, having a max height of 13-ft and storage capacity of 144 ac-ft. Eastland and Ringling are both high hazard dams due to their proximity to the City and the potential for life loss and property damage if the dams were to fail..

Based on the Texas administrative code rule 299.155 passed in 2009, all existing high hazard dams are required to safely pass a design flood equal to 75% of PMF. The spillways are hydraulically inadequate to convey the 75% PMF, thus a barely overtopping breach analysis was required. . Lake Eastland and Ringling Lake only pass the 40% and 18% PMF respectively. Information is summarized in **Table 6-7**.

Lake Eastland dam has an earthen embankment with a primary 104-ft wide concrete spillway at south end of the embankment and a 73-foot-wide earthen trapezoidal channel with a concrete overflow auxiliary spillway located on the north end. **Figure 6-3** is a field sketch from the 1984 TCEQ dam inspection report that shows the geometry of Lake Eastland dam. Pertinent data for Lake Eastland Dam is included in **Table 6-8.** Ringling Lake Dam does not have a controlled service spillway as it was never designed nor engineered as a dam. It was constructed in the 1920's by the Ringling Brothers to provide water supply to their steam generated trains and later inherited by the City of Eastland. There is an uncontrolled earthen channel that acts as the primary spillway to the left (south) of the dam embankment. The overflow channel parallels the dam for about 600 feet and then turns right and continues under an old railroad trestle as a natural creek. **Figure 6-4** is a field sketch from the 1984 TCEQ dam inspection report that shows the geometry of Ringling Lake dam. Pertinent data for Ringling Dam is included in **Table 6-9.**

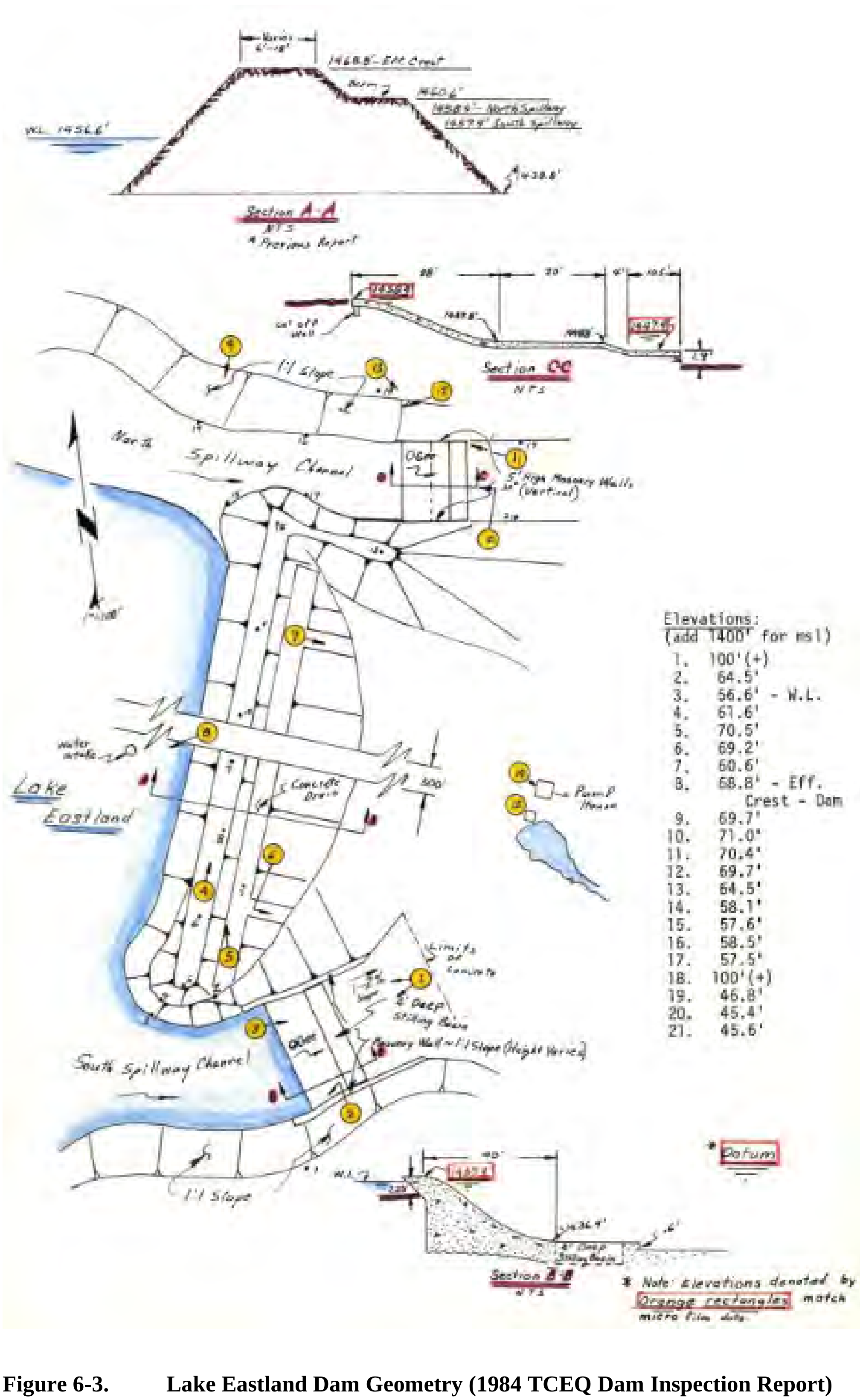

Figure 6-3. Lake Eastland Dam Geometry (1984 TCEQ Dam Inspection Report)

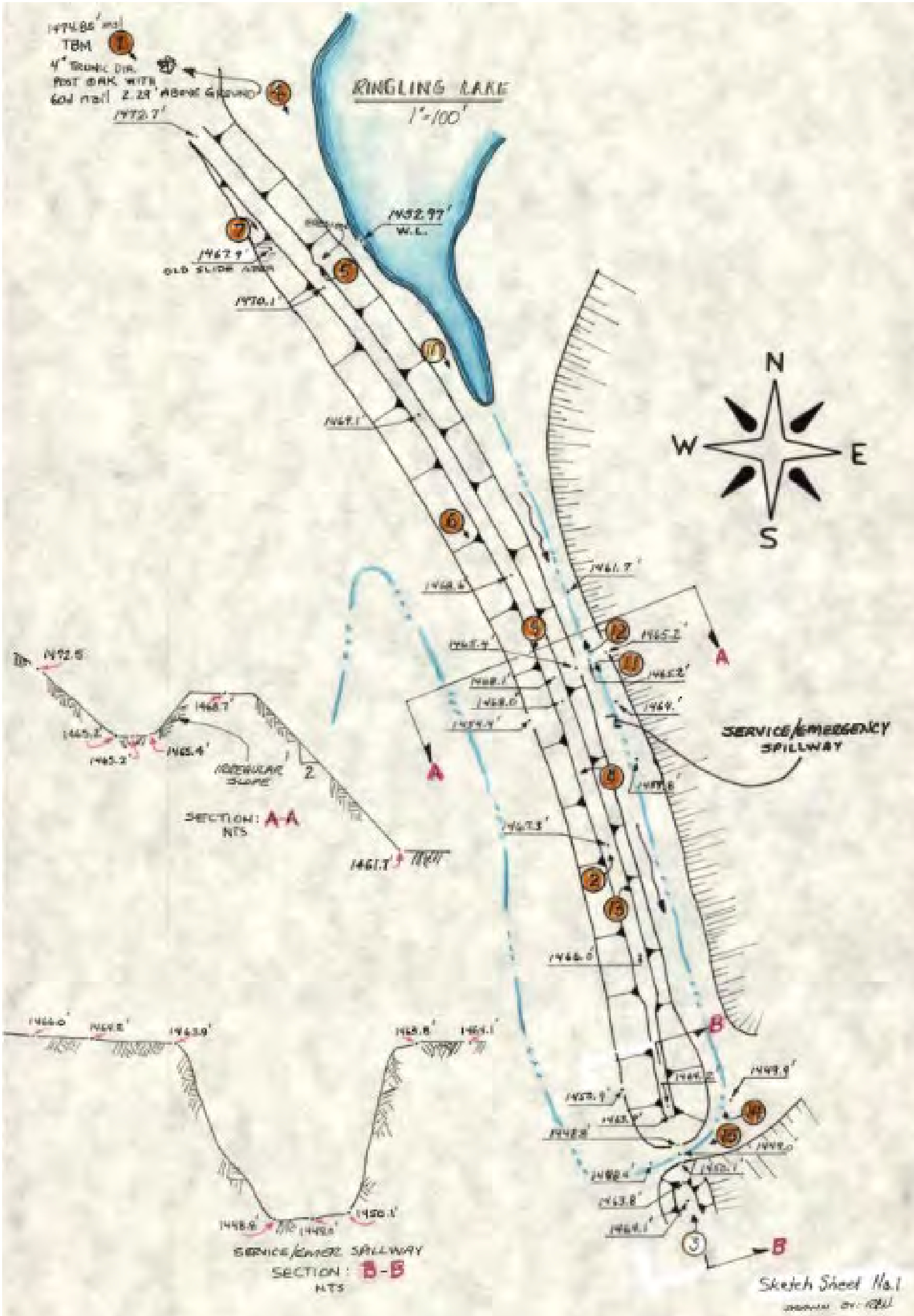

Figure 6-4. Ringling Lake Dam Geometry (1984 TCEQ Dam Inspection Report)

Table 6-8. **Eastland Dam Geometry Summary.**

Official Dam Name:	Lake Eastland TCEQ ID (TX01411)			
Stream:	Leon River			
Type of Dam:	Compacted Earthfill			
Crest Width (ft):	12 feet		**Dam Designer:**	H.P Brelsford
Built:	1923		**Drainage Area (sqmi):**	33.69
Height (ft):	33		**Hazard Classification:**	High
Length (ft):	945		**Principal Spillway CapaCity[1] (cfs):**	58
Principal Spillway:	104-ft wide Concrete Ogee		**Auxiliary Spillway CapaCity[1] cfs):**	12,015
Auxiliary Spillway:	73-ft wide Concrete Ogee		**Auxiliary Spillway PMF Discharge (cfs):**	3,428
Latitude:	32.417352		**Normal Storage Volume (ac-ft)**	1,740
Longitude:	-98.832807		**Maximum Storage Volume (ac-ft)**	7,561
Elevations (ft-msl)	**Normal Pool**	**Principal Spillway**	**Auxiliary Spillway**	**Top of Dam**
	1456.43 (2022 field survey)	1457.07 (2022 field survey)	1458.4 (1988 as-builts)	1468.23 – 1469.90 (2022 field survey)
Dam Upgrades:	**Year**		**Description:**	**Designer:**
	-		-	-

Table 6-9. **Ringling Dam Geometry Summary.**

Official Dam Name:	Ringling Lake TCEQ ID (TX01410)			
Stream:	Leon River			
Type of Dam:	Compacted Earthfill			
Crest Width (ft):	15 feet		**Dam Designer:**	H & TC Railway Co.t
Built:	1922		**Drainage Area (sqmi):**	3.44
Height (ft):	33		**Hazard Classification:**	High
Length (ft):	1,000		**Principal Spillway CapaCity[1] (cfs):**	575
Principal Spillway:	14-ft wide discharge channel		**Auxiliary Spillway CapaCity[1] (cfs):**	N/A
Auxiliary Spillway:	N/A		**Auxiliary Spillway PMF Discharge (cfs):**	N/A
Latitude:	32.484722		**Normal Storage Volume (ac-ft)**	54.2
Longitude:	-98.818611		**Maximum Storage Volume (ac-ft)**	144
Elevations (ft-msl)	**Normal Pool**	**Principal Spillway**	**Auxiliary Spillway**	**Top of Dam**
	1463.61 (2022 field survey)	1464.59 (2022 field survey)	N/A	1467.94 – 1472.76 (2022 field survey)
Dam Upgrades:	**Year**		**Description:**	**Designer:**
	-		-	-

6.2.1 Sunny day

For the sunny-day breach scenario, the reservoir level in each lake was assumed to be at the normal pool elevation at the time of breach without any rainfall inflow to any of the Leon River drainage areas. The breach bottom elevation was set to the lake's lowest elevation, simulating a worst-case scenario, and allowing the entire lake to drain during the simulation. Sunny-day breach parameters were calculated using the Froehlich (2008) Method within HEC-RAS and are presented in **Table 6-10** and **Table 6-11** for Lake Eastland and Ringling, respectively. Dam breach cross section are shown in **Figure 6-5** and **Figure 6-6** for Lake Eastland and Lake Ringling, respectively. The principal and auxiliary spillways are not engaged in this scenario.

The dams were modeled as storage areas that are connected to the 2D domain via a 2D storage area connection, centered along the dam embankment. A storage elevation curve for the volume of water below the normal pool elevation was not available. An elevation storage relationship was created by offsetting the normal pool elevation contour at a 4H:1V slope to the bottom of lake elevation. The area of the offset contours was then summed to determine the cumulative volume of the lake below normal pool. This methodology was repeated for Eastland and Ringling Lake storage elevation curves.

The failure mechanism is assumed to be internal erosion (piping) with a sunny day breach. Breach parameters were computed using the breach parameter calculator in HEC-RAS and cross checked by spreadsheets. The parameter calculator in HEC-RAS evaluates and compares five different breach erosion calculation methodologies to compute breach bottom width, breach side slopes and breach development time based on the geometry properties of the embankment and storage area behind the dam.

Per TCEQ H&H guidelines, it was assumed that the breaches occur at the maximum dam section. Sunny day breaches occur at the embankment of the dam. Historical imagery and site visits at Ringling Lake show standing water at the downstream toe of the Ringling dam embankment that fluctuates with the level in the lake and with the season. The dam shows signs of seeping through the embankment, which coincide with the 1978 TCEQ dam inspection report.

The dam breach inundation maps attached to this report show the sunny-day breach inundation limits for areas downstream, as shown in **Exhibits F-1** and **F-2** of **Appendix F**.

Figure 6-5. Lake Eastland Dam Embankment - Storage Area 2D Connection

Table 6-10. Lake Eastland Sunny Day Breach Parameters.

Center Station (ft)	12+95
Breach Bottom Width (ft)	83
Breach Bottom Elevation (ft)	1442
Breach Side Slopes (H:1V)	0.7
Failure Mode	Piping
Full Formation Time (hrs)	0.96
Initial Piping Elevation (ft-msl)	1447
Peak Breach Discharge at Dam (cfs)	10,040

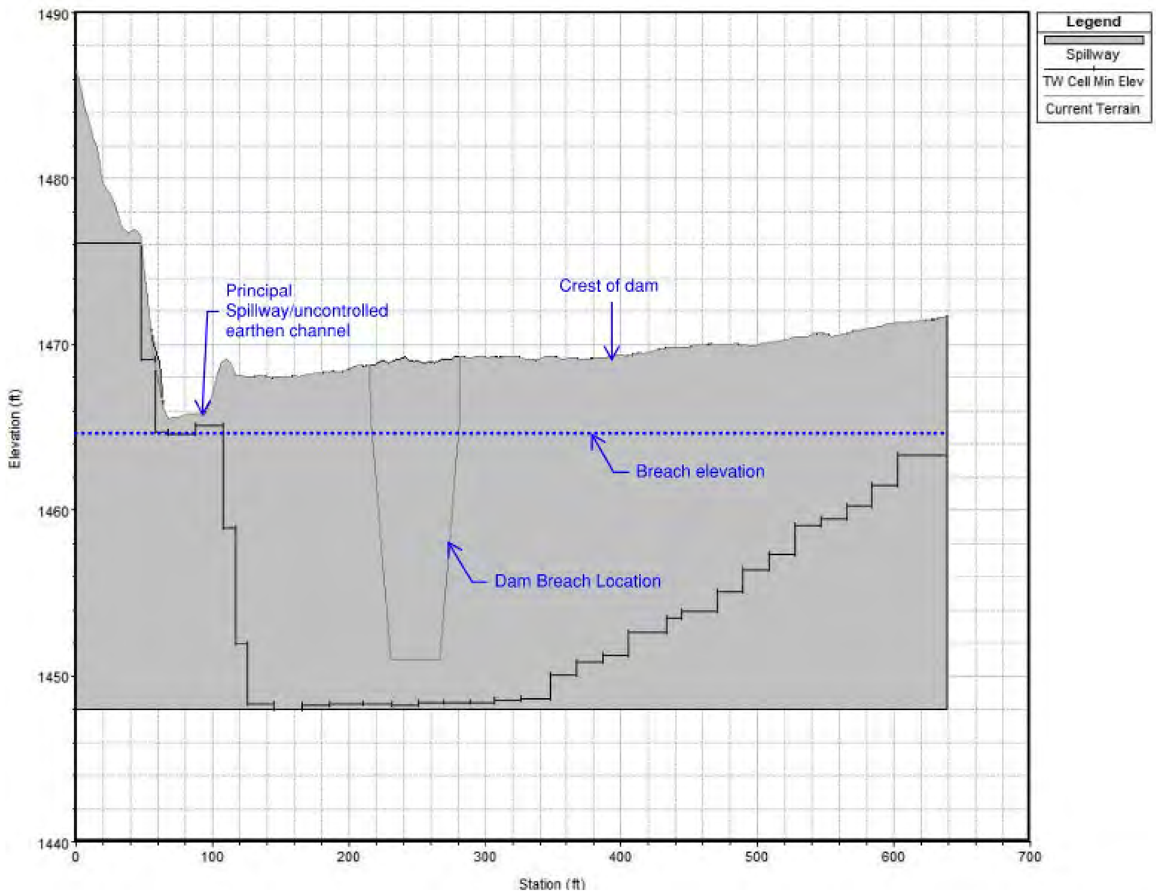

Figure 6-6. Ringling Lake Dam Embankment - Storage Area 2D Connection

Table 6-11. Lake Ringling Sunny Day Breach Parameters.

Center Station (ft)	1+50
Breach Bottom Width (ft)	14
Breach Bottom Elevation (ft)	1451
Breach Side Slopes (H:1V)	1
Failure Mode	Piping
Full Formation Time (hrs)	0.96
Initial Piping Elevation (ft-msl)	1455
Peak Breach Discharge at Dam (cfs)	1,905

6.2.2 Design flood breach

The design flood scenario (75% PMF) in the HEC-RAS model utilizes a very similar domain/mesh as the design storm model. One of the differences between the dam breach and design storm geometries is that the lakes are modeled as storage areas in the breach model instead of inflow boundary conditions. Modeling the lakes as storage areas allows the user to input a storage elevation relationship and normal pool elevation of each of the lakes. Another benefit is that the storage area can continue to accumulate flow and keep routing it though the outlet, even after the dam breaches, which is the case in the Lake Eastland model. The PMF inflow hydrographs from HMS were routed though the storage areas and from the storage areas into the 2D mesh. The dam embankment is modeled as a 2D connection that transfers flow from the storge area to the downstream 2D mesh. Elevation, storage, and discharge relationship for the dam and spillways were updated using the merged terrain data and results of HEC-RAS model. The updated elevation, storage, and discharge relationship is shown on Table 6-12 and Table 6-13.

Table 6-12. Lake Eastland elevation, storage, and discharge relationship.

Lake Eastland			
Elevation (ft)	**Surface Area (acres)**	**Cumulative Vol (acre*ft)**	**Spillways Discharge (cfs)**
1457	222.64	222.636	0
1459	264.56	751.748	10703.89
1461	325.79	1403.332	14668.57
1463	395.13	2193.586	16005.04
1465	464.96	3123.504	21211.82
1467	584.54	4292.592	25613.69
1469	719.16	5730.914	30079.49
1471	860.75	7452.418	34545.29

Table 6-13. Ringling Lake elevation, storage, and discharge relationship.

Ringling Lake			
Elevation (ft)	**Surface Area (acres)**	**Cumulative Vol (acre*ft)**	**Spillways Discharge (cfs)**
1462	20.20	106.20	0.00
1464	32.27	164.03	4944.52
1466	45.68	248.68	6955.72
1468	59.09	360.14	8860.28
1470	72.50	498.43	11611.64
1472	85.91	663.54	14410.06

This scenario assumes that the dam will breach at the time the water level in the reservoir reaches its maximum state storage during the design flood (75% PMF). The design inflow hydrograph was added as a lateral inflow hydrograph and routed though HEC-RAS. If the dam is overtopped by the design flood inflow, then the failure mechanism of this breach is set to overtopping. The breach parameters for each of the dams were determined directly in the breach parameter tool in HEC-RAS. The time of failure was set to begin once the maximum water surface elevation within the reservoir was reached.

The PMF breach modeled assumes that the breach occurs at the maximum section of the dam per TCEQ guidelines, which would result in the maximum loss of reservoir volume and produce the maximum inundation downstream. However, a breach could occur at virtually any location along each dam embankment and inundate areas immediately downstream. The breach inundation maps shown in the **Exhibits F-3** and **F-4** of **Appendix F** show the limits and depths of flooding that could occur during different 75% PMF breach scenarios. A critical infrastructure GIS layer was created and is shown in the inundation maps to illustrate what could be impacted by the dam breach flooding. These exhibits are documented as part of the Emergency Action Plan reports (Section 6.5)

As shown in **Table 6-14**, both dams are hydraulically inadequate by TCEQ standards since the spillway cannot pass the design storm without overtopping of the dam. Lake Eastland and Ringling Lake do not pass the 75% PMF with each lake only passing 40% and 18% respectively.

Table 6-14. 75% PMF Event Conditions – Eastland and Ringling Lake.

Dam	Peak Inflow	Peak Outflow	Max WSEL	Top of Dam	Depth of Overtopping
	(cfs)	(cfs)	(ft. MSL)	(ft. MSL)	(ft)
Eastland	47,377	37,803	1474.6	1468.2	6.4
Ringling	13,325	13,267	1475.2	1468.1	7.1

6.3 Lake Eastland - spillway structural analysis

6.3.1 Inspection

A structural inspection of the Lake Eastland ogee spillway was performed by HDR, inc. on January 12, 2023. The structural inspection was conducted on foot and detailed notable defects were documented through written notes and photographs. See **Appendix G – Eastland Photo Log** for photographs. The inspection was broken down into three main parts of the spillway, which included the ogee section, the side training walls and the exit channel slab (including the stilling basin). The notable defects present on the ogee spillway include large cracks across the downstream and upstream faces of the spillway, varying from 1/4 inch to almost 1-1/2 inches in width. Significant vegetation was also present in a majority of the cracks. The downstream face of the ogee spillway was measured to have settled close to three inches, and the top cap of the ogee was cracked and separated with a large 1-inch crack and void with a 2-inch offset across the entire width of the spillway. The most notable defects of the side training walls were large cracks with voids in the soil behind the walls. The soil behind the walls was also eroded away due to overflows from the upstream channel. The exit channel slab had major cracks, erosion, and vegetation present. These must be addressed and are considered very serious. The cracks in the training walls and the voids behind them are signs of internal erosion. Flood video from site inspections also shows water flowing out of these voids. The settlement of the spillway near the center of the structure indicates internal erosion and voids progressing over time. The full inspection report can be found in **Appendix I** of this document.

6.3.2 Stability analysis

A preliminary stability analysis was performed on the Factor of Safety for Sliding, Overturning, and Bearing for a normal loading. The analysis references the specifications of the Texas Commission on Environmental Quality (TCEQ) “Design and Construction for Dams in Texas” and the U.S. Army Corps of Engineer’s EM 1100-2-2100 “Stability Analysis of Concrete Structures.” The analysis was conducted on the stand-alone ogee structure and does not include the downstream stilling basin or apron. The calculations indicate that the existing structure is at risk of sliding failure with factors of safety that are much lower than typical modern design standards. On the other hand, the overturning analysis indicates the structure is stable with regard to that particular failure mode. Without geotechnical information on soil properties, only the maximum and minimum bearing is recorded, along with the required allowable bearing capacity. The calculations for this analysis can be found in **Appendix I** of this document.

6.3.3 Cost estimate

An AACE Class V Feasibility Level Construction Cost Estimate was developed for replacing the existing spillway structure in-kind. The cost estimate was developed using quantity takeoffs from the existing structure and unit price data from the Texas Department of Transportation and RSMeans. Contingencies are based on scope definition and are subject to change as the project progresses. The current cost estimate provides a range between $10.8M and $16.2M. A summary of the cost estimate can be found in **Appendix D – Cost Estimates** of this document.

6.3.4 Recommendations

Based on the inspection and stability analysis of the existing ogee spillway at Lake Eastland, removal and replacement of the spillway is recommended. The inspection indicates dam safety concerns and damage to the structure beyond what may be remedied via reasonable repairs, and those concerns must be addressed. While not unstable for normal loading condition (water to top of ogee), the spillway ogee does not appear to meet the stability criteria defined by the TCEQ Design and Construction for Dams in Texas. The sliding stability factors of safety are well below standard criteria. American Association of Cost Estimating (AACE) Class V feasibility level cost estimations indicate a replacement in kind could range between $10.8M and $16.2M.

6.4 Ringling Lake – evaluation and discussion

The owner of Ringling Lake Dam is the City of Eastland. The track embankment was originally constructed by the Ringling Brothers Circus Group to impound the lake and provide supply of water for their steam engine trains. For cost saving purposes, the abandoned railroad embankment was repurposed as the dam embankment.

The dam is a 1000-foot-long earthen embankment with a maximum height above the stream bed of approximately 18 feet. The compacted earth fill embankment has varying upstream and downstream slopes, averaging to approximately 2.5H:1V and a crest width of 15 feet. Both the upstream and downstream slopes are covered with dense native grasses, brush, and trees. There is no engineered structural spillway and just an uncontrolled earthen channel located at the southeast end of the dam embankment. There is significant vegetation and numerous boulders that have broken off the side slopes, partially blocking the conveyance and forming a training wall on the north side of the channel. The dam is classified as a small dam for having an embankment height greater than 6-ft and impounding greater than 50 ac-ft of water. The dam is currently classified as a high hazard dam by TCEQ.

Modeling results reveal that if a sunny day breach were to occur, no structures would be inundated downstream of the dam and only Ringling Road would be overtopped. The incremental consequences of a dam breach during the 75% PMF compared to the 75% PMF without a dam breach are estimated to be minimal when compared to the outflow of the Lake Eastland dam (which is the main contributor to the flooding occurring at the North Fork of the Leon River. **Figure 6-7** reflects the minimal impact due to a sunny day breach. Refer to **Appendix H – Emergency Action Plans** for the full Ringling Lake Emergency Action Plan and Dam Breach Inundation Maps.

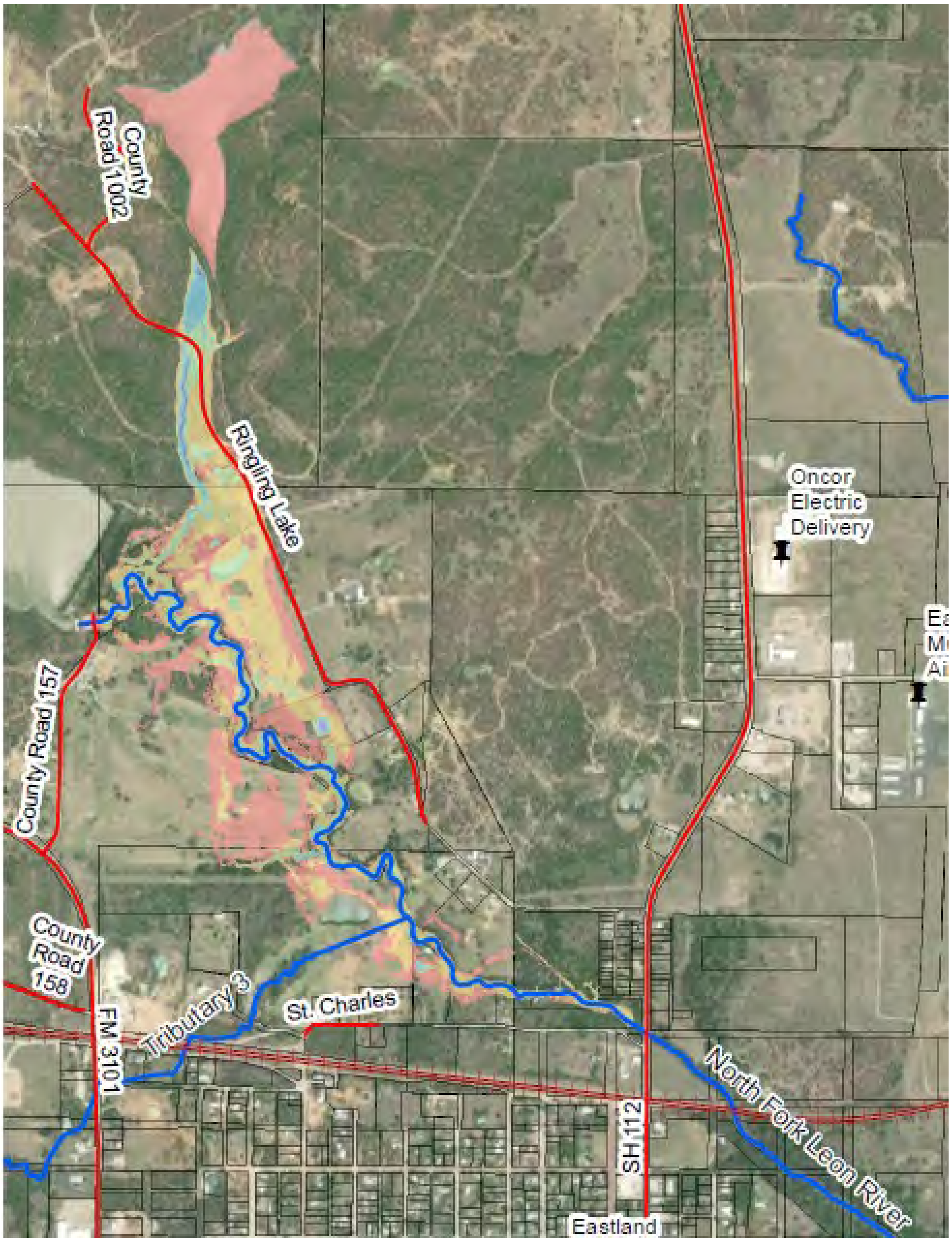

Figure 6-7. Ringling Lake Sunny Day Breach Inundation Limits

The future effort for Ringling Lake may include an attempt to obtain approval from applicable agencies for a partial breach of Ringling Lake dam (potential decommission). This would eliminate TCEQ's dam safety regulatory authority of the dam while maintaining some degree of wetland upstream of the dam to potentially satisfy environmental concerns.

A future funding source is required to continue with this evaluation. If funding is approved, a new scope of work will be required to evaluate decommissioning the dam (or removal of dam).

If partial breach of Ringling Lake dam is not approved, then the facility will be left in its existing condition except for removing brush and trees on the embankment and removing vegetation and rocks obstructing the service spillways at the entrance.

If further funding is approved to attempt to breach the dam and remove it from a high hazard classification, an environmental evaluation will be required. The USACE previously stated during a preapplication meeting that **compensatory wetland mitigation** would be required to do any water level lowering, regardless of method. It is estimated that at least 14 acres of mitigation is needed. There is the option of creating wetlands, but permittee-responsible mitigation requires long-term maintenance, monitoring, reporting, and potentially additional site protection. Long term maintenance with vegetation replacement does not seem to be a viable option if dam maintenance is beyond the scope of the City's interest.

The future scope would require the consultant and City of Eastland to perform an evaluation and coordination meetings to understand USACE, TCEQ, and Texas Parks and Wildlife Department required permits for compliance.

6.5 Emergency action plans for Lake Eastland and Ringling Lake

HDR received drafts of Emergency Action Plans (EAPs) developed in 2010 for Lake Eastland and Ringling Lake from the City of Eastland. The EAPs were updated with the results of the dam breach analysis, as noted in **Section 6**. The analysis produces flood inundation mapping for two different breach scenarios that allow the City to gain a better understanding of downstream consequences. Additionally, the TCEQ document *Guidelines for Developing Emergency Action Plans for Dams in Texas* was last updated in 2019. This revised document was used alongside TCEQ's updated EAP template for intermediate or small dams, to update the EAPs for Lake Eastland and Ringling Lake. TCEQ requires a tabletop review of the EAP every 5 years. Updating the document to TCEQ's standards allows the City to better plan for potential dam breaches, promptly alert the public, and determine which areas are most in danger during emergency situations that could pose a threat to the integrity of either dam. The updated EAPs for each dam are found in **Appendix H**.

6.6 At risk structures sunny day

A primary purpose for performing a Sunny Day breach analysis is to update the City's EAP and communicate the risk to emergency responders in an attempt to evacuate people and save lives. Shown below in **Table 6-15** and **Table 6-16** show top of road versus breach maximum WSE at the major road crossings located downstream of Lake Eastland and Ringling Lake. The time between the dam failure and the initiation of flooding in downstream areas should be used for warning and evacuation notices. Citizens should be warned of road closures before the peak stage of a breach event. During a sunny day breach scenario, Lake Eastland and Ringling Lake Dams do not inundate any habitable structures and do not overtop any downstream roads. However, there is the potential for bridge abutments and piers to be damaged due to the high flow velocities associated with the breach. The flow from a Ringling dam breach is contained within the channel banks before it reaches the first bridge at North Seaman Street. Refer to **Appendix H – Emergency Actions Plans.**

Table 6-15. Eastland Dam Sunny Day Breach Max Depth and Time to Peak at Road Crossings.

Road Crossing	Time to Peak Stage (h:m)	Top of Road (ft)	Breach Max WSE (ft)	Depth of Overtopping (ft)
N. Seaman St	1:15	1437.41	1435.88	None
NLR & Railroad	2:05	1435.53	1431.26	None
NLR & Main St	2:25	1429.82	1428.63	None

Table 6-16. Ringling Dam Sunny Day Breach Max Depth and Time to Peak at Road Crossings.

Road Crossing	Time to Peak Stage (h:m)	Top of Road (ft)	Breach Max WSE (ft)	Depth of Overtopping (ft)
Ringling Rd	0:05	1450.05	1454.63	4.58
N. Seaman St	1:21	1437.41	1427.30	None

7 Alternatives analysis

Many alternatives were explored for reduction in flood risks in the City. Alternatives should be constructable, permittable, and result in no adverse impact. Section 7.3 shows a Measles chart of the alternatives investigated. The most beneficial were selected as Capital Improvement Projects for the City to pursue, while the remainder are classified as Flood Mitigation Evaluations (FMEs). The FMEs can be pursued if additional funding becomes available to the City. FMP 01, 02, and 03 were submitted and selected by Regional Flood Planning Group Region 8 to be in the Regional Flood Plan.

7.1 Structural mitigation alternatives

7.1.1 CIP01 Weaver Creek and Main Street Culvert upsizing, channel, and grading Improvements

The culverts on Main Street on Weaver Creek are currently (3)-8.25’x6’RCBs. The City has expressed that this is a high visibility area and therefore high priority. Main Street’s frequent use as a major thoroughfare through town also makes it a priority from a safety standpoint. Some site and model observations keeping the culverts from performing optimally are as follows.

- On the site visit, a small wall was observed just upstream of the culvert that consistently impounds water (Photo 15). On each subsequent site visit, water has been observed impounded behind the wall at weaver creek (Photo 16).
- In the lowest frequency event studied (the 10-year return period), flows either overtop Main Street at Weaver Creek or travel along the north side of Main Street to a low point approximately 1250 LF to the west (near the football stadium). Also observed is the fact that the culverts approach the road at a 90-degree angle, while Weaver Creek downstream is at a 38-degree skew. From a hydraulic standpoint, minimizing the change in direction flow takes will result in better conveyance than outfalling to a stream at a 90-degree angle.
- There is 2’ of silt and heavy vegetation (manning’s n=0.08) at the downstream end of the Weaver creek culverts. (Photo 17)

Figure 7-1 shows the existing observations. To mitigate these factors, CIP 01 involves adding upstream detention, removing the wall upstream of the culverts, adding capacity to the culverts by increasing barrel number and size, and clearing the downstream channel of vegetation.

Figure 7-1. **CIP 01 Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements**

CIP 01 improvements

To promote conveyance, the wall is proposed to be removed, the culverts to be skewed to align with the stream, and the stream to be cleared and regraded. Currently a flow of about 2,500 cubic feet per second (cfs) makes it way to the Weaver Creek culverts in a 100-year event (1,800 cfs in the 25-year event). To pass this flow without overtopping main street, and to maintain 1-foot of freeboard from the top of road, seven (7) 12’ x 6’ RCBs are proposed. In addition, detention is proposed upstream of Main Street. Stream clearing and regrading to convey the 100-year event is shown in **Figure 7-2**. Adjacent to the business district and Lago Vista Boulevard a 50-ft bottom with and 4H:1V side slopes are proposed. When more right of way becomes available, a 100-ft bottom with and 4H:1V side slopes are proposed. The detention pond upstream is proposed with a Top of Bank at 1430.0’, a 0.75% bottom slope, and 4H:1V side slopes. The detention pond contains flows, so they do not travel parallel to Main Street.

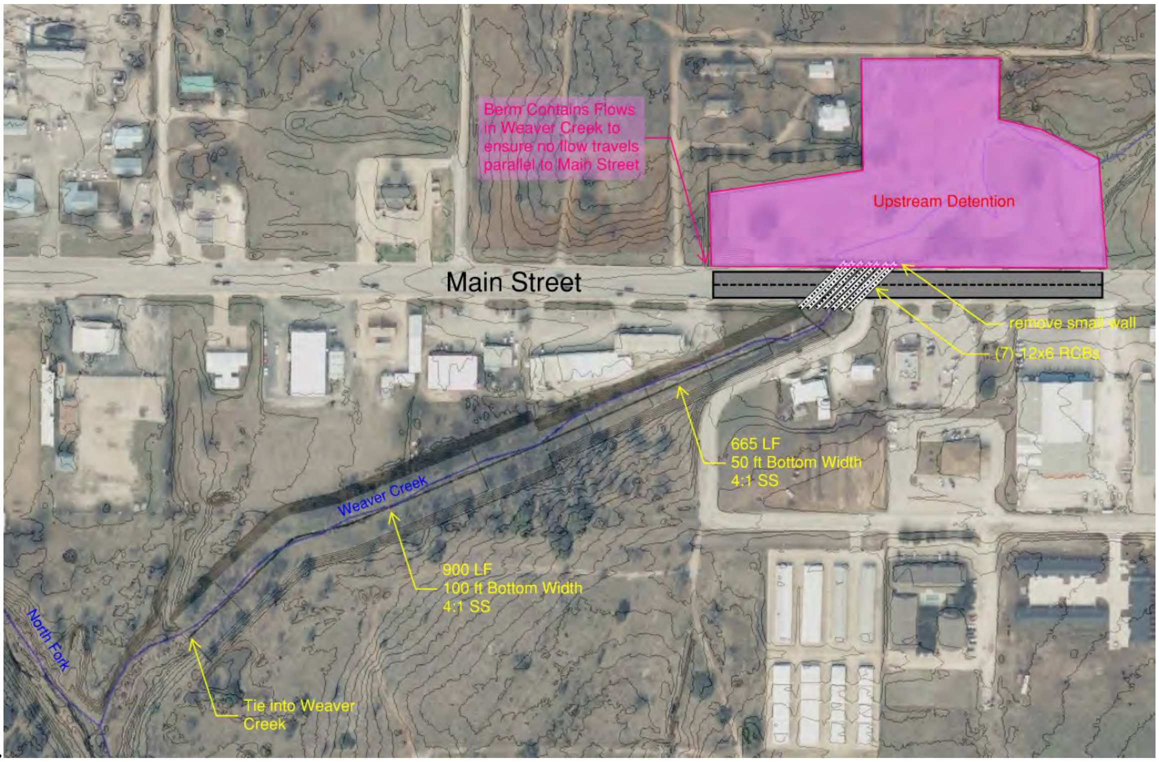

Figure 7-2. CIP 01 Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements

To implement the improvements at Weaver Creek, drainage easements affecting six parcels are required, as shown in **Figure 7-3**. The total cost estimate for acquiring these drainage easements is approximately $820,000 and is further discussed in Section 8.1.1.

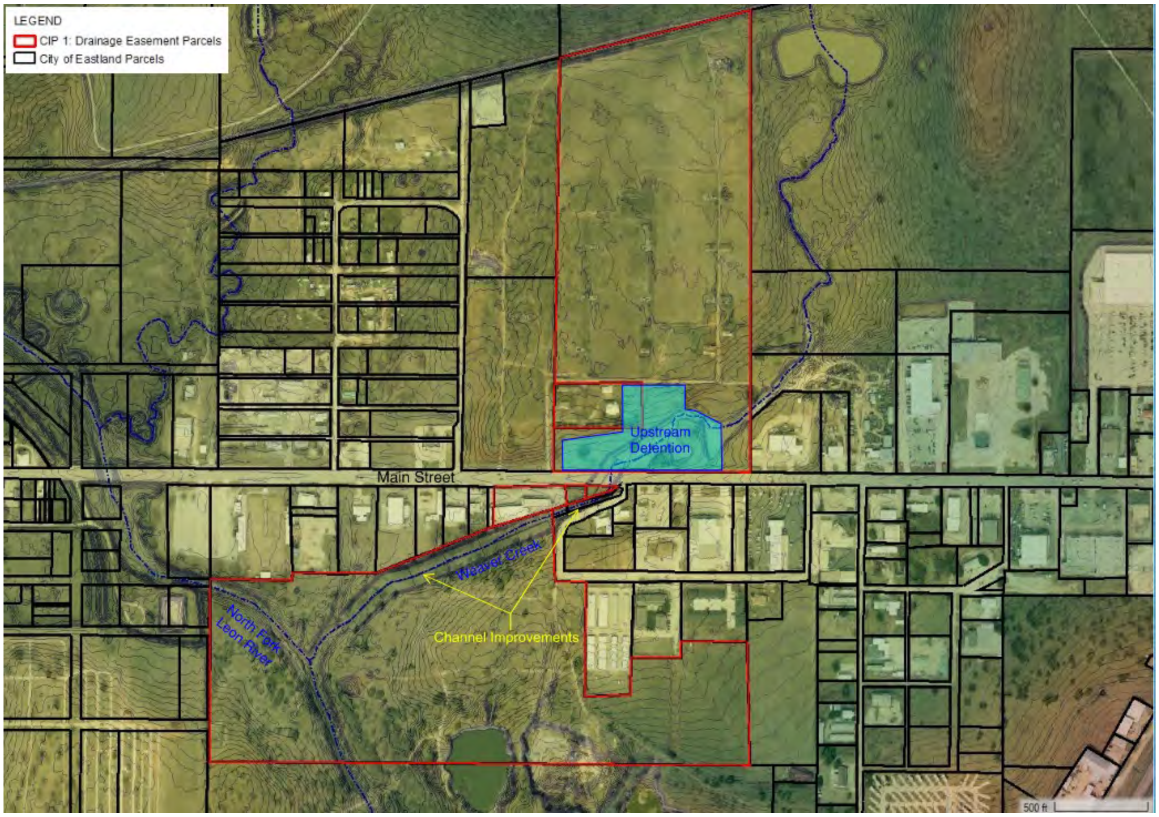

Figure 7-3. CIP 01 Weaver Creek Drainage Easements

CIP 01 results

With these improvements, 0 structures are removed in the 100-year event, but there are important flood level reductions. **Table 7-1** below summarizes the model results.

Table 7-1. Summary of CIP 01 Model Results.

Event	Existing	CIP01	DELTA
10	233	232	-1
25	267	265	-2
50	288	290	+2
100	305	305	0
500	347	347	0

These improvements do produce significant benefits. Main Street is not over-topped in the 100-year event (**Figure 7-5**). Flow does not travel parallel to Main Street from Weaver Creek overtopping (Main Street remains inundated with the releases from Lake Eastland, not Weaver Creek). A little over 1,000 linear feet of Main Street are no longer inundated in the 100-year event. Flood depths along Main Street are reduced by up to 1.4 feet. The benefit-cost for the project is discussed in Section 9.

For flood insurance purposes, any reduction in flood elevations for the 1% ACE (100-year) event is desirable. From a citizen standpoint however, benefits realized during the more frequently occurring events are very noticeable. **Figure 7-4** illustrates model results for the 10-year event.

Weaver Creek (Tributary 1) is entirely contained within the proposed channel improvements, and the business district adjacent to Weaver Creek is either removed from the 10-year floodplain, or depths of flooding are decreased.

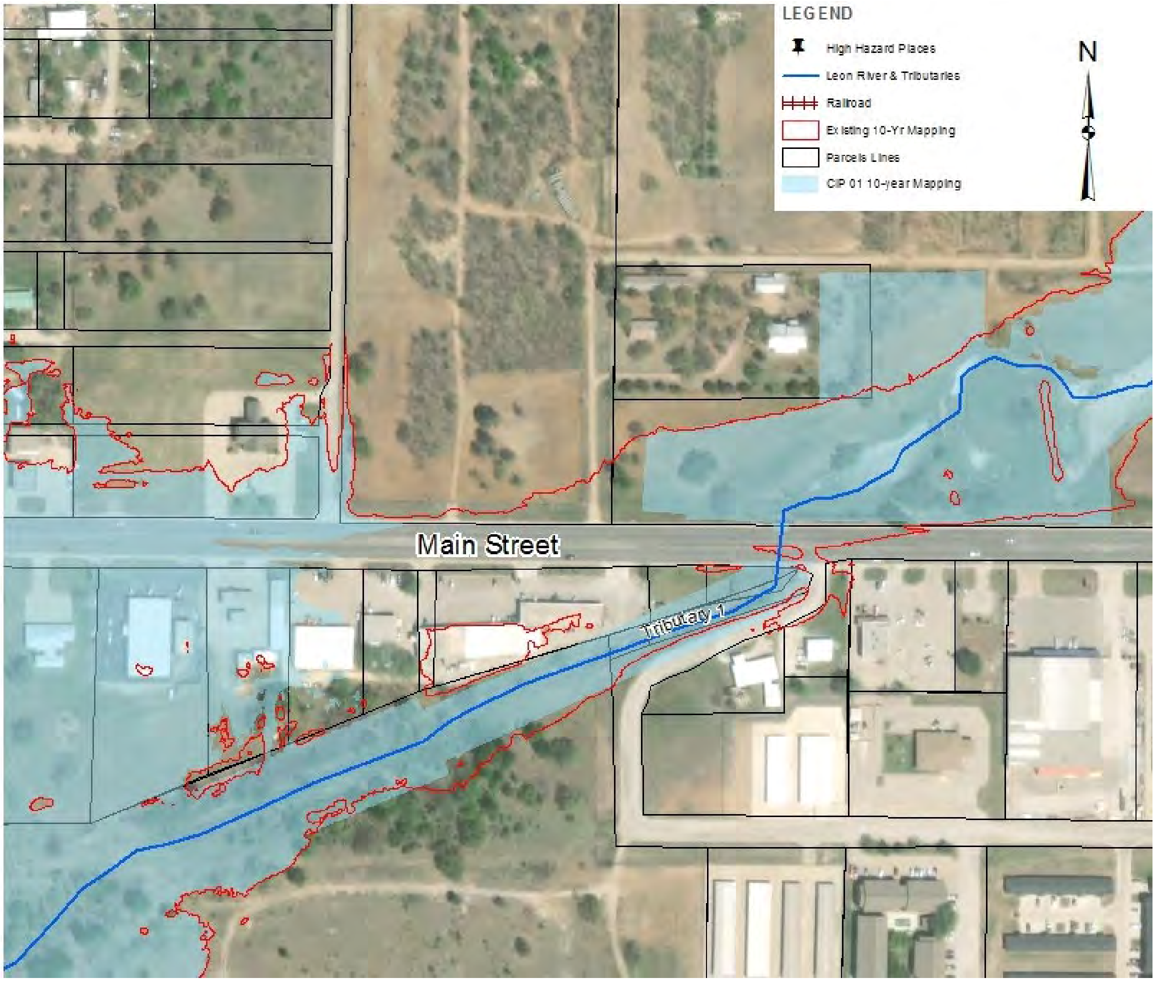

Figure 7-4. **CIP 01 10-year Inundation Limits**

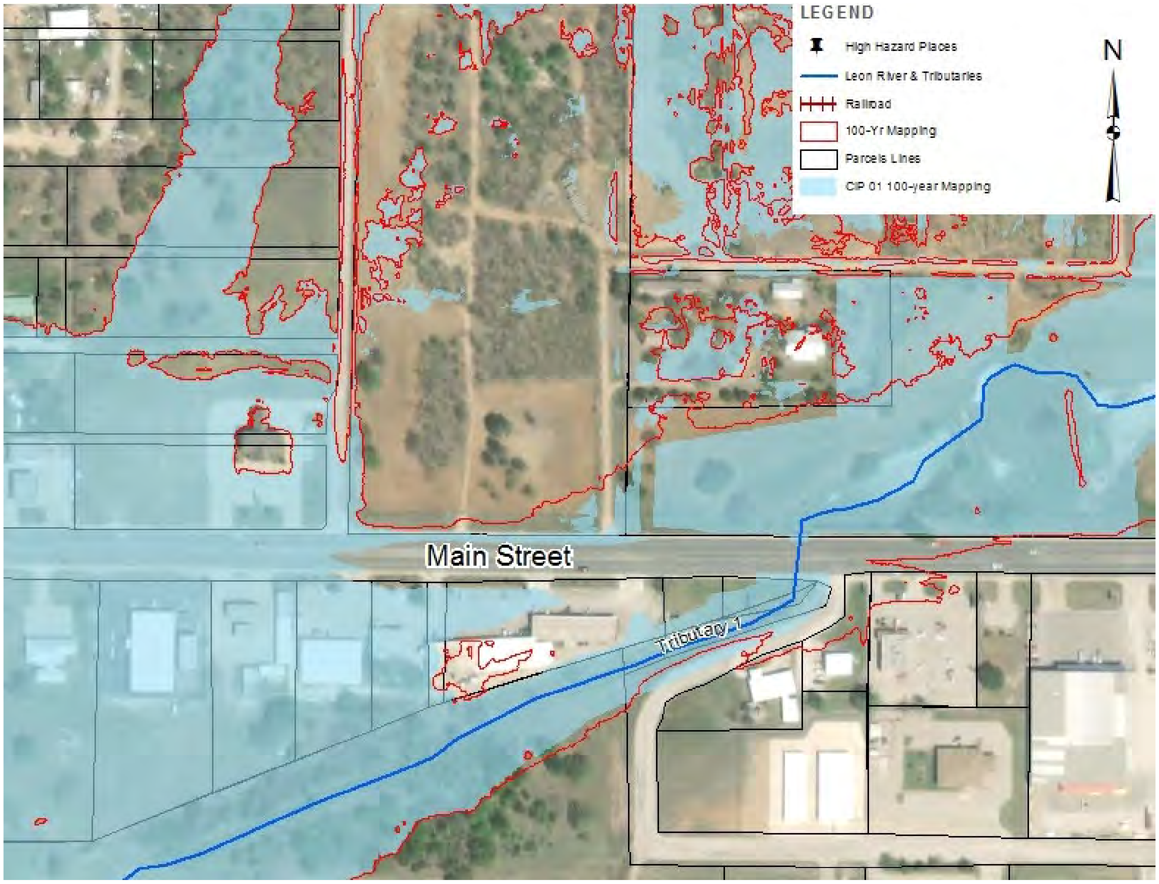

Figure 7-5. CIP 01 100-year Inundation Limits

CIP 01 no adverse impacts

No adverse impact for CIP 01 is defined as meeting the specifications of Table 21 and Section 3.6A of the "Exhibit C: Technical Guidelines for Regional Flood Planning Section 3.6." Refer to the No Negative Impact Determination Table in Appendix C. The hydraulic model was used as a basis of determination as well as engineering judgement. Furthermore, the model does not reveal an increase in water surface elevations of more than 0.3 feet and no additional top width in the flood plain downstream, and no additional structures flooded as reflected in **Figure 7-5. It** shows the proposed inundation mapping top width (in blue) is less than the existing inundation mapping top width (in red), therefore showing no increases in inundation for storm drainage networks, channels, roadways and private property or easements. **Table 7-1** shows no additional structures are flooded in the 100-year event, confirming CIP causes no adverse impact. The proposed project does not include any unusual structures, construction techniques, or site conditions, therefore it is deemed generally constructable for planning purposes. A desktop and in-person review of site conditions did not reveal any non-permittable circumstances, therefore it is deemed generally permittable for planning purposes.

CIP 01 considerations

- Drainage easements required from 6 landowners
- USACE Section 404 Permitting (schedule and budget impacts)

This CIP (Flood Management Project (FMP)) was submitted to the State Flood Plan's Region 8 (Lower Brazos) on May 19, 2023. This included the associated modeling, cost-benefit analysis, and floodplain maps proving a no-negative impact. Submitting the CIP project to the State Flood Plan may qualify it for future funding from the Texas Water Development Board.

7.1.2 CIP 02 Tributary 3 culvert and grading improvements

Flows in Tributary 3 cross the railroad (owned by Union Pacific – UPRR) via a single 48" RCP. Currently during the 10-year event, 231 structures are flooded. This area is on the north side of town, a residential area. 751 cfs is approaching the existing culvert. As flow accumulates behind the 48", backwater spreads along the railroad embankment and through the neighborhood (**Figure 7-6**). Additionally, overtopping of the banks of the North Fork results in flood waters spilling over the railroad and embankment and into the neighborhood (**Figure 7-7**).

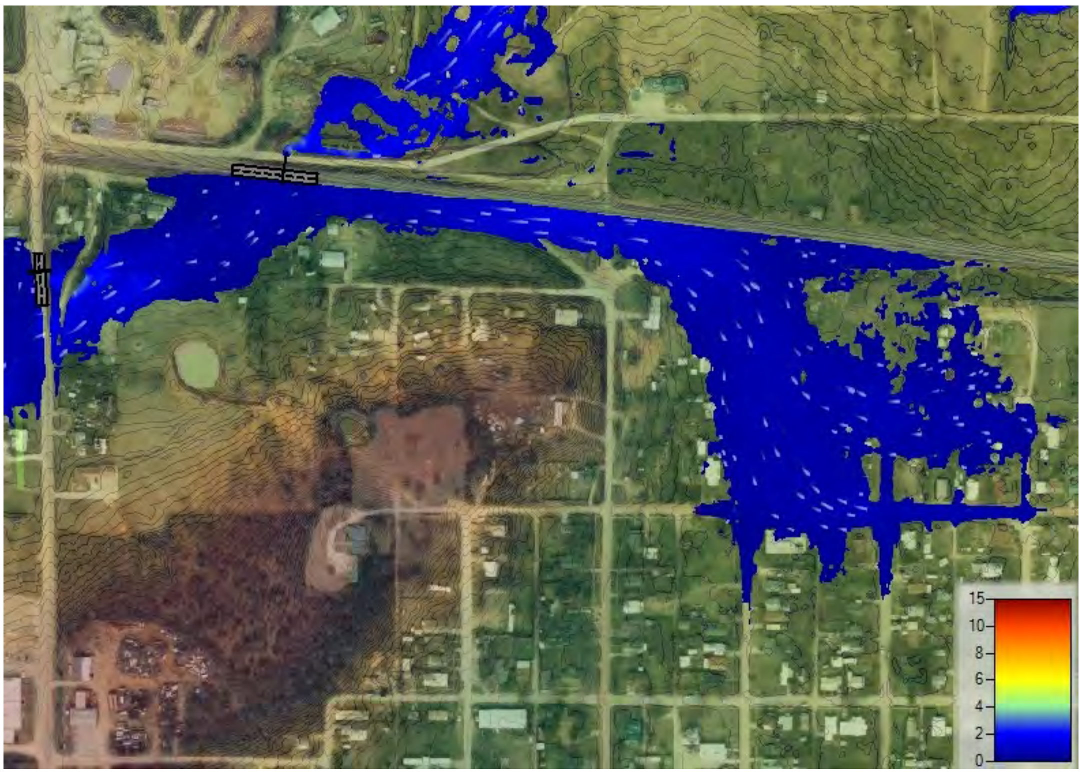

Figure 7-6. CIP 02 Velocity and Direction of Flow (10-year) in Tributary 3

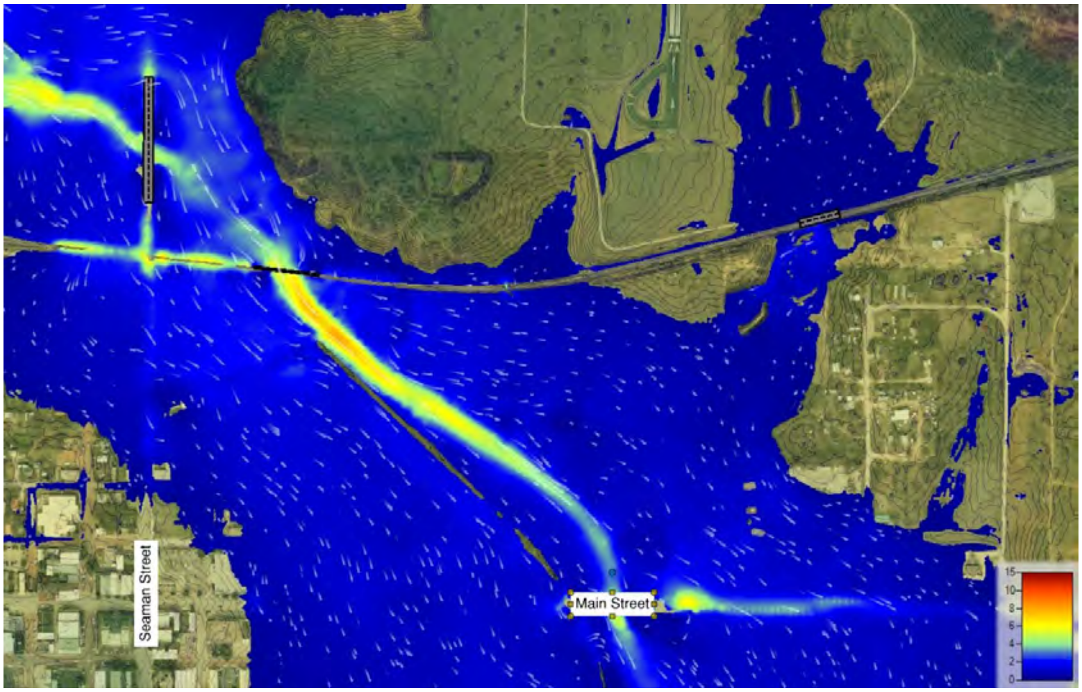

Figure 7-7. CIP 02 Velocity and Direction of Flow (100-Year) In North Fork

CIP 02 improvements

Four 60” RCPs are proposed to cross the railroad tracks with grading upstream and downstream of the tracks to contain the flows and avoid backwater spilling into the neighborhood. Furthermore, channel and swale grading upstream are necessary to improve the approach to the culverts; a 20 bottom-width natural trapezoidal channel with 4H:1V side slopes at about 2.5 feet of depth is proposed. The grading downstream of the proposed UPRR culverts is proposed as a 40 bottom-width natural trapezoidal channel with 4H:1V side slopes at about 3.5 feet of depth. Additionally, a very small area of fill is proposed adjacent to the tracks to “plug” the flow and keep it from spreading into the neighborhood. This small fill area is helpful in the lower frequency storm events.

Figure 7-8. CIP 02 Proposed Tributary 3 Culvert and Grading Improvements

In the 100-year event 305 structures are flooded. With the 4-60” RCPs, the number of structures flooded decreases to 248.

Table 7-2. Summary of CIP 02 Model Results.

Event	Existing	CIP02	DELTA
10	233	144	-89
25	267	188	-79
50	288	223	-65
100	305	248	-57
500	347	310	-37

CIP 02 results

As previously mentioned, the more frequent the return interval of an event, the more noticeable the benefit to the public. With the proposed improvements, the neighborhood no longer floods from Tributary 3 overflows in the 10-year event (**Figure 7-9**), and flooding is reduced in the 100-year event (**Figure 7-10**).

Figure 7-9. **CIP 02 10-year Inundation Limits**

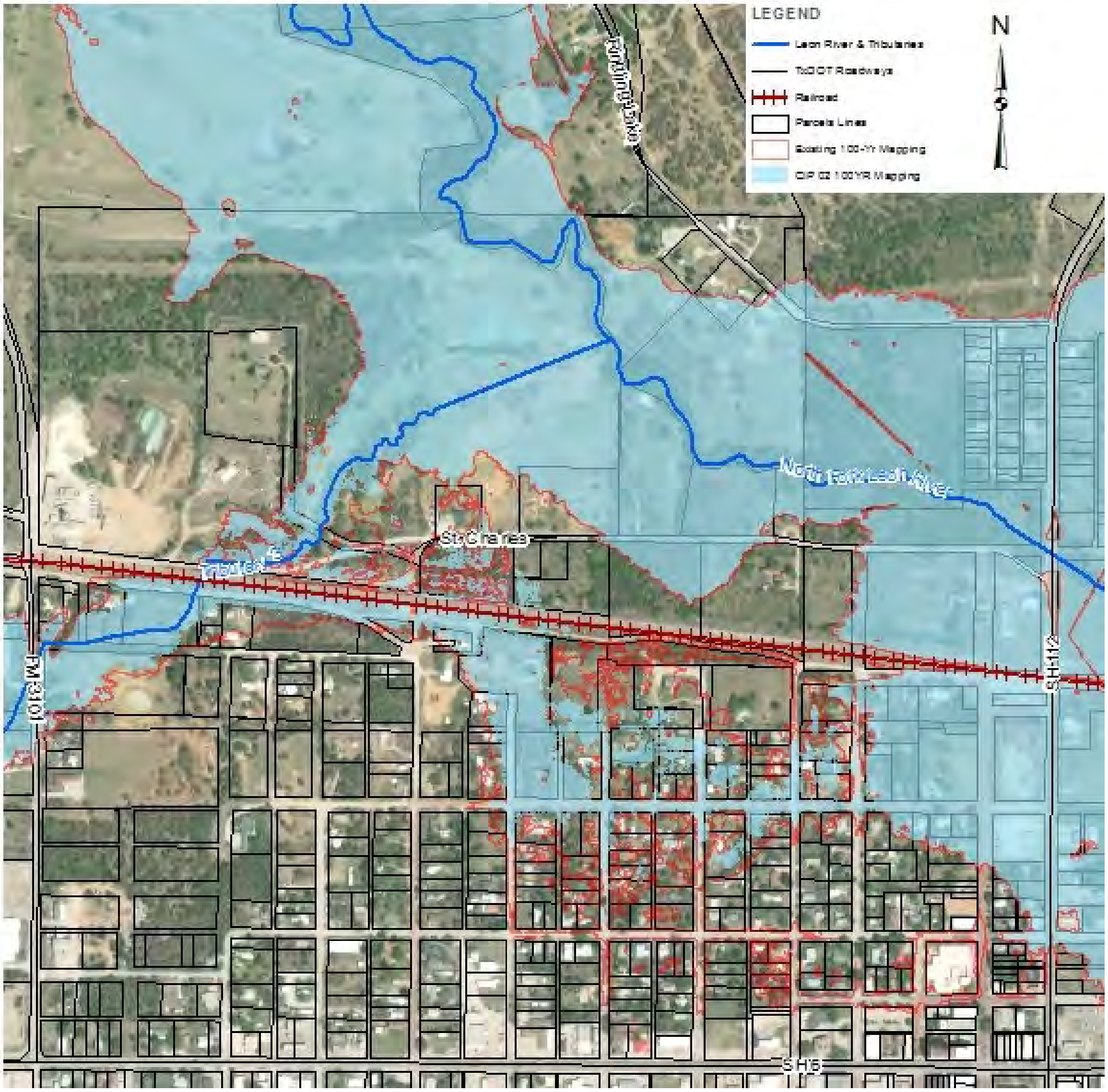

Figure 7-10. **CIP 02 100-year Inundation Limits**

CIP 02 no adverse impacts

No adverse impact for CIP 02 is defined as meeting the specifications of Table 21 and Section 3.6A of the “Exhibit C: Technical Guidelines for Regional Flood Planning Section 3.6”. Refer to the No Negative Impact Determination Table in Appendix C. The hydraulic model was used as a basis of determination as well as engineering judgement. Furthermore, the model does not reveal an increase in water surface elevations of more than 0.3 feet and no additional top width in the flood plain downstream, and no additional structures flooded as reflected in **Figure 7-10.** The figure shows the proposed inundation mapping top width (in blue) is less than the existing inundation mapping top width (in red), therefore showing no adverse impact. **Table 7-2** shows no additional structures, roadways and channels are flooded in the 100-year event, confirming CIP causes no adverse impact. The proposed project does not include any unusual structures, construction techniques, or site conditions, therefore it is deemed generally constructable for planning purposes. A desktop and in-person review of site conditions did not reveal any non-permittable circumstances; therefore, it is deemed generally permittable for planning purposes. While permitting is possible, permitting for this project could add additional time to the project. Permitting considerations are discussed in the next section.

CIP 02 considerations

- For the railroad to remain in service, jack and bore (as opposed to open cut) needs to be the construction method.
- The drainage easements proposed are from a single landowner upstream of the railroad. Downstream, an easement from Breckenridge Ready-mix company will need to be requested. The remainder of the downstream channel improvements are proposed on City of Eastland property as shown in **Figure 7-11**. The total cost estimate for acquiring these drainage easements is approximately $166,000 and is further discussed in Section 8.1.2
- Time delays of up to a year are expected for coordination with the railroad.
- USACE Section 404 permitting (schedule and budget impacts)

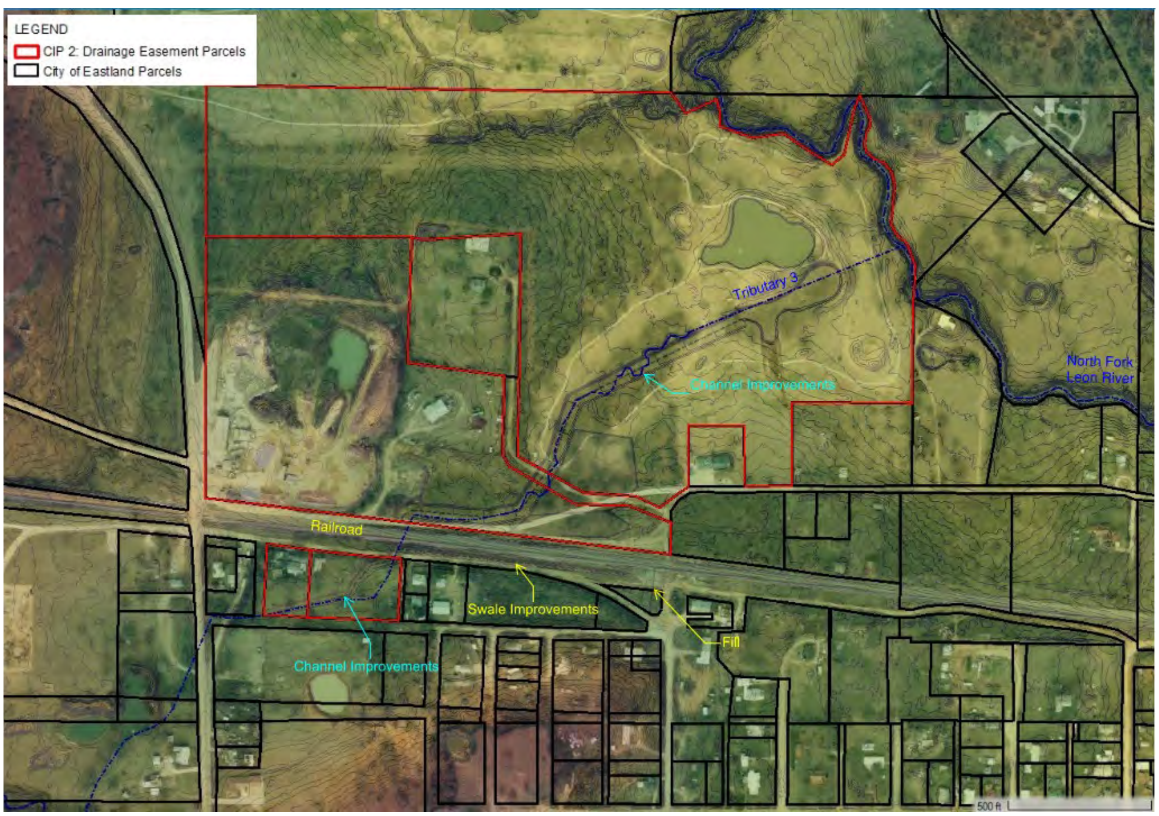

Figure 7-11. CIP 02 Tributary 3 Drainage Easements

This CIP (Flood Management Project (FMP)) was submitted to the State Flood Plan's Region 8 (Lower Brazos) on May 19, 2023. This included the associated modeling, cost-benefit analysis, and floodplain maps proving a no-negative impact. Submitting the CIP project to the State Flood Plan may qualify it for future funding from the Texas Water Development Board.

7.1.3 CIP 03 Lake Eastland spillway reconstruction

The drainage area upstream of Lake Eastland is 33.6 square miles It is the largest contributing area to the North Fork of the Leon River. Lake Eastland's purpose is for flood mitigation. Modifying it to provide more storage with a different outflow curve could further mitigate flooding.

CIP 03 improvements

A new 200-foot spillway design (as recommended in Section 6.3) is proposed to incorporate a V-notch weir. The current ogee spillway has a flowline elevation of 1457 feet. By lowering the V-notch weir's elevation to 1455 feet, two additional feet of storage are provided in the lake; using interpolation, this amounts to an additional 1548.3 ac-ft of storage. The V-notch side slope is set at 135 degrees, or 12:1 H:V and continues to elevation 1461 feet; at an elevation of 1461 feet it transitions to a 200-ft ogee spillway.

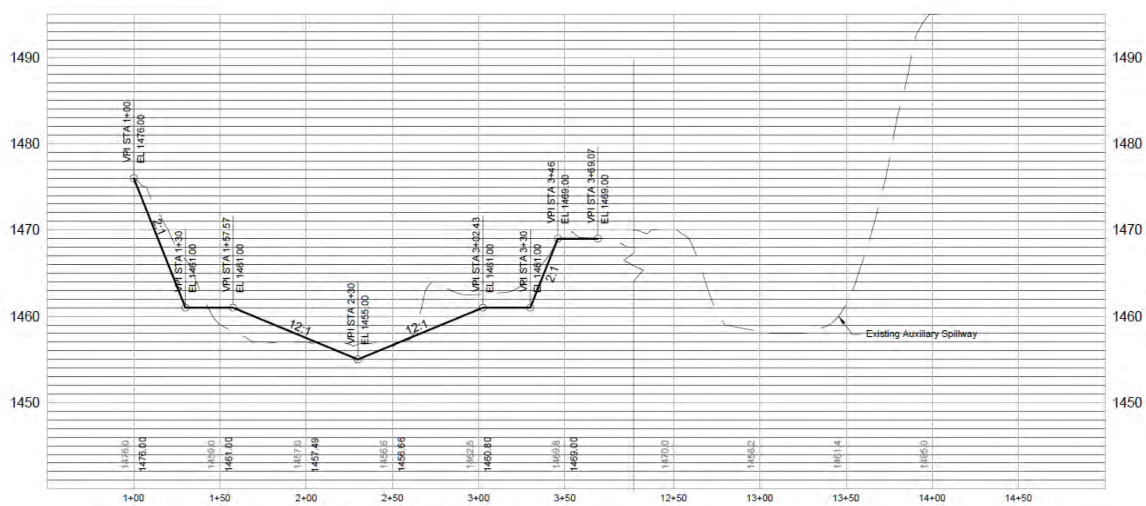

Figure 7-12. CIP 03 Proposed Spillway Geometry

CIP 03 results

With the modifications to the spillway, a significant number of structures are removed from the "flooded" category, and a significant area is removed from the floodplain. The spillway modification allows less flow from the lake during the more frequent storm events, which results in the reduction of flooded structures in the lower storm events.

Table 7-3. Summary of CIP 03 Model Results.

Event	Existing	CIP02	DELTA
10	233	188	-45
25	267	221	-46
50	288	288	-0
100	305	301	-4
500	347	342	-5

See **Appendix C – Hydraulic Maps** for flood reclamation. **Figure 7-13** shows the 10-year reductions along the North Fork. As with the other CIPs, the improvements focus on higher frequency storm events for greater resident benefit while maintaining lesser benefits in lower frequency events. **Figure 7-13** shows the reductions in inundation in the neighborhood as well as all along the North Fork. **Figure 7-14** shows that the improvements cause no adverse impact in the 100-year; the reduction in inundation is along the edges of the floodplain.

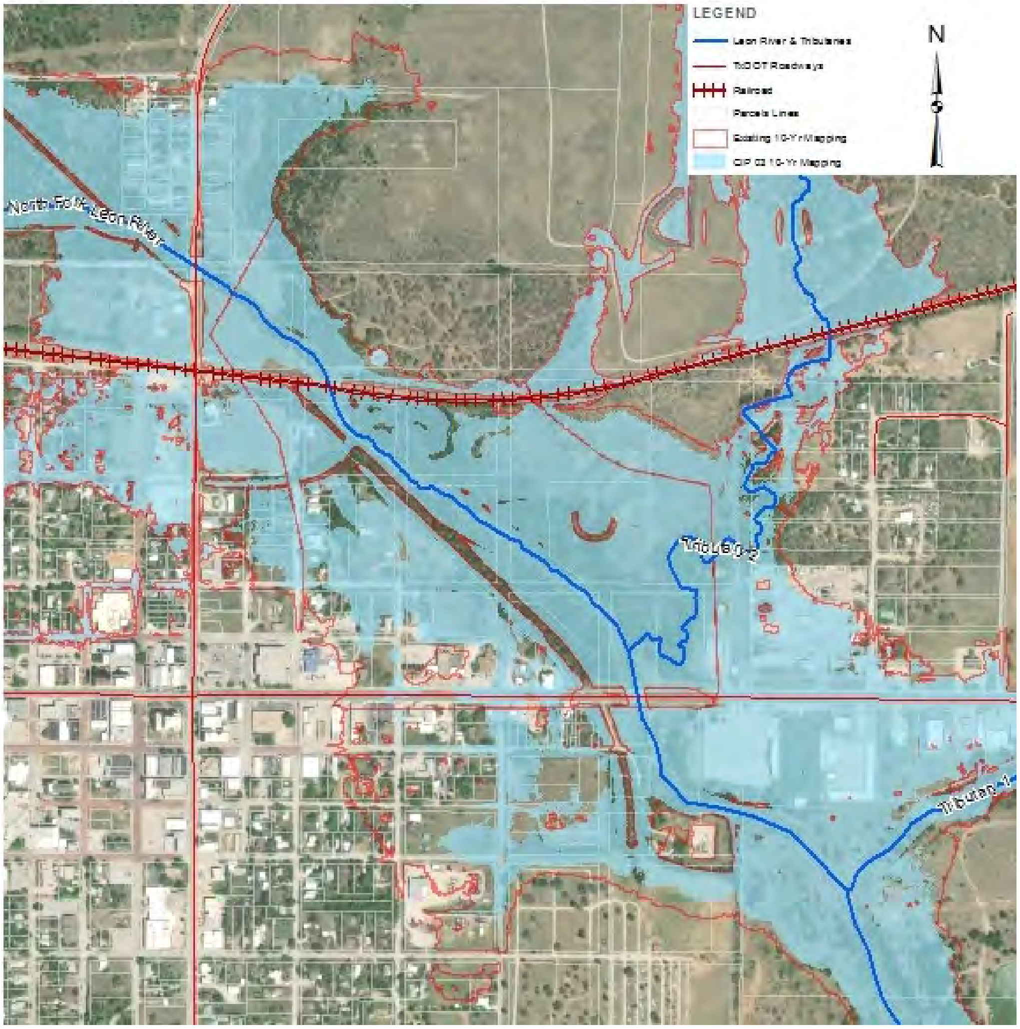

Figure 7-13. CIP 03 10-Year Inundation Limits

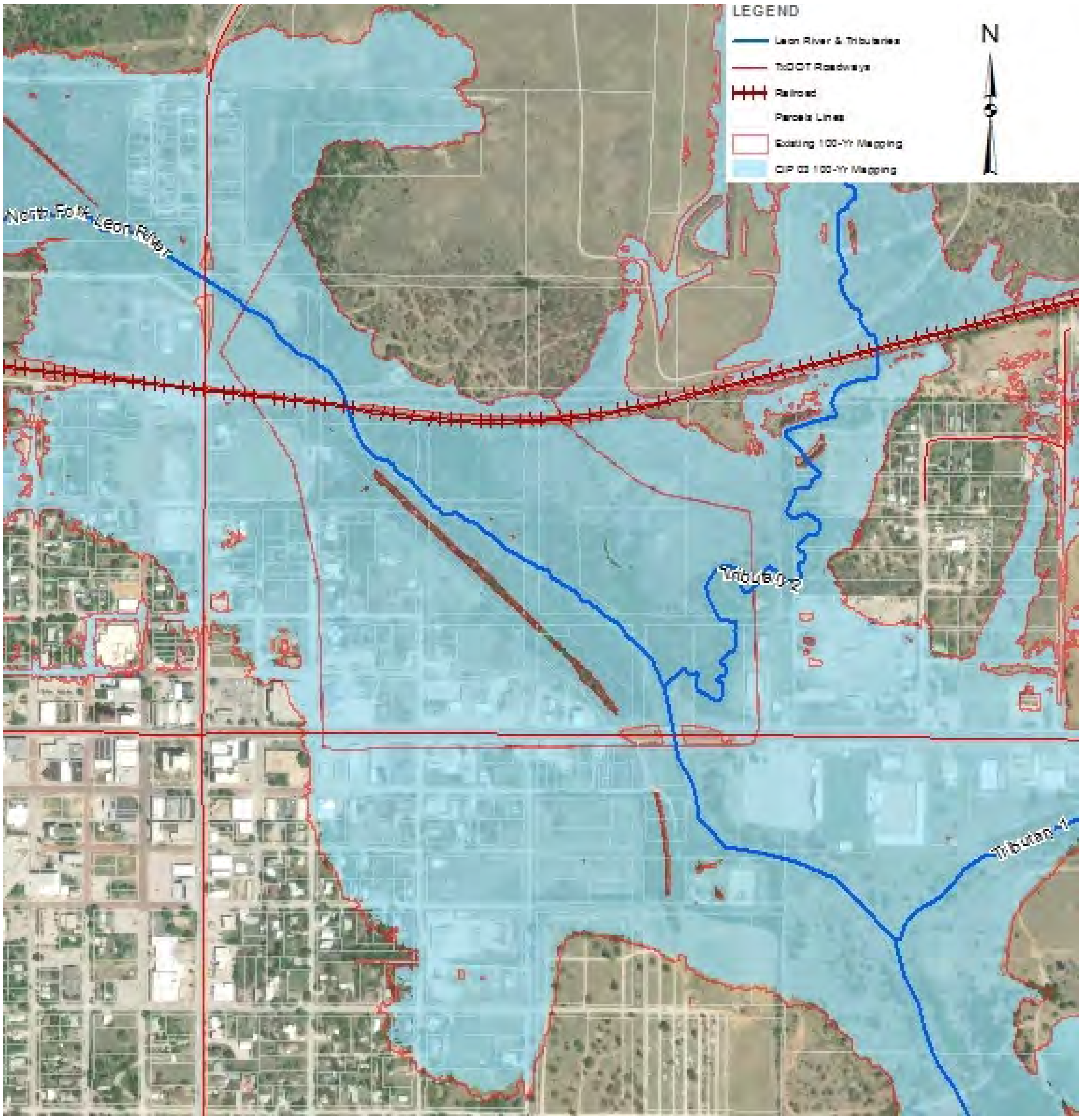

Figure 7-14. CIP 03 100-year Inundation Limits

CIP 03 no adverse impacts

No adverse impact for CIP 03 is defined as meeting the specifications of Table 21 and Section 3.6A of the “Exhibit C: Technical Guidelines for Regional Flood Planning Section 3.6”. Refer to the No Negative Impact Determination Table in Appendix C. The hydraulic model was used as a basis of determination as well as engineering judgement. Furthermore, the model does not reveal an increase in water surface elevations of more than 0.3 feet and no additional top width in the flood plain downstream, and no additional structures flooded as reflected in **Figure 7-14. It** shows the proposed inundation mapping top width (in blue) is less than the existing inundation mapping top width (in red), therefore showing no adverse impact. **Table 7-3** shows no additional structures, roadways and channels are flooded in the 100-year event, confirming CIP causes no adverse impact. The proposed project does not include any unusual structures, construction techniques, or site conditions, therefore it is deemed generally constructable for planning purposes. A desktop and in-person review of site conditions did not reveal any non-permittable circumstances; therefore, it is deemed generally permittable for planning purposes. While permitting is possible, the permitting for this project could add additional time to the project. Permitting considerations are discussed in the next section.

CIP 03 considerations

- Lowering the normal pool elevation of Lake Eastland introduces considerable Waters of the United States regulation with the USACE via the Section 404 permitting process. This due to the amount of wetlands sitting across the lake's perimeter that could be impacted.
- If this option is not viable, another potential alternative to evaluate would be to add flood storage by increasing the height of the embankment. This option would require a full geotechnical evaluation of the embankment to determine if reinforcements to the existing one are needed prior to adding height to it. The existing embankment did not show signs of seepage but did reflect heavy tree and vegetation overgrowth due to lack of maintenance.
- The Lake Eastland Dam ultimately needs to be in compliance with the TCEQ's dam safety program hydraulic capaCity requirements. These require a high hazard dam, like Lake Eastland, to safely convey the dam safety design flood equal to 75% of the probable maximum flood (PMF) without breach the reservoir. There could be an opportunity to increase the height of the embankment along with modifications to the spillways and meet both goals: TCEQ dam safety compliance and added flood storage. Further evaluations, engineering, and construction of such spillway capaCity and dam embankment improvement projects will require future funding from either state or federal sources.

This CIPs (Flood Management Project (FMP)) was submitted to the State Flood Plan's Region 8 (Lower Brazos) on May 19, 2023. This included the associated modeling, cost-benefit analysis, and floodplain maps proving a no-negative impact. Submitting the CIP project to the State Flood Plan may qualify it for future funding from the Texas Water Development Board.

7.1.4 CIP 04 structural buyouts and raising of finished floor elevations

Although the CIPs previously listed will significantly reduce the inundation depths throughout the City, it is impossible to remove every property from the floodplain. For the properties that will continue to experience significant and frequent flooding during storm events, the City should consider either raising the finished floor elevations (FFEs) of selected structures or buying out the most flood-prone properties.

A hydraulic model run was developed by combining all three of the aforementioned recommended structural flood mitigation CIPs. This to determine which properties are still inundated by 2.50 feet or more above FFE during the 100-year event. The 2.50-foot criteria was determined based on this flood depth creating "heavy damage" onto a home or business property. This was determined by using the results from the model, City of Eastland parcel data, aerial imagery, and Google Earth street view to approximate the inundation depths above the FFEs for the properties that remain in the 100-year floodplain. Homes were the primary candidates for this CIP; however, small businesses were also taken into consideration.

It is recommended that **16 properties** be bought out **(**all in the North Fork watershed in close proximity to downtown and Main Street), while **11 properties'** FFEs are proposed to be raised to reduce flooding depth or remove structures from the 100-year floodplain entirely. This CIP would result in a total of **27 properties** being removed from the floodplain, as shown in **Figure 7-15**. **Table 7-4** lists each property selected for CIP 04 and the corresponding addresses. The City informed HDR that various homes were already part of a different buy-out program. These homes are listed in **Table 7-4** and were not included in CIP 04. The properties are also shown in **Exhibit D-1** of **Appendix D. The total** amount of the improvements and buy-outs has an estimated total cost of $3,560,990. **Section 7.4.1.4** includes more information on how the cost estimate was developed, provides a detailed breakdown of the costs associated with each individual property, and the criteria for raising the FFE of a house.

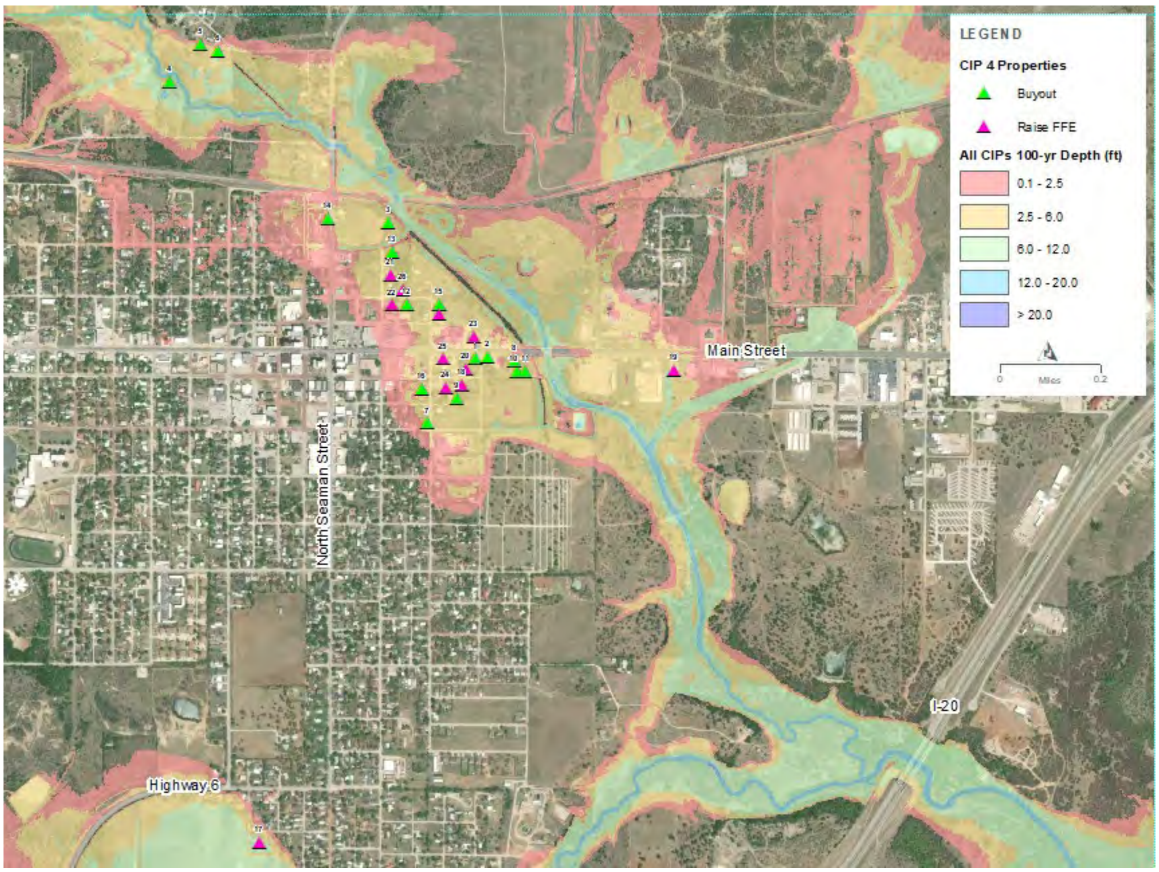

Figure 7-15. CIP 04 Properties

Table 7-4. List of Properties Involved in CIP 04.

Location ID	Property	100-yr Inundation Depth (ft)
	Property Buyouts	
1	417 E Main St	3.39
2	501 E Main St	4.01
3	412 N Bassett St	**2.**58
4	606 W St Charles St	2.58
5	100 Ringling Lake Rd	2.86
6	100 Ringling Lake Rd	2.59
7	310 E Plummer St	2.64
8	515 E Main St	2.60
9	408 E Olive St	2.51
10	514 E Commerce St	3.30
11	518 E Commerce St	3.07
12	309 Patterson St*	2.29
13	413 N Bassett St	2.51
14	400 N Seaman St	3.09
15	210 N Halbryan St	4.31
16	305 E Commerce St	2.67
	Raising of FFEs	
17	300 W Frost St	6.39
18	411 E Commerce St	3.19
19	921 E Main St	3.51
20	412 E Commerce St	3.22
21	307 N Bassett St	2.78
22	305 E Patterson St	2.68
23	412 E Main St	2.83
24	405 E Commerce St	2.80
25	403 E Main St	2.72
26	308 E Patterson St	3.96
27	208 N Halbryan St	2.85
	Excluded Properties from Different Buyout Program	
	714 N Seaman St	
	715 N Seaman St	
	716 N Seaman St	
	720 N Seaman St	
	722 N Seaman St (Property Owner)	
	722 N Seaman St (Rental)	
	723 N Seaman St	
	715 N Lamar St	

*Exception made due to proximity to other properties that are part of CIP 4

CIP 04 no adverse impact

Structural buyouts to remove homes from the flood inundation area, does not inundate additional structures and therefore causes no impact. Additionally, this CIP does not change or add flows in the area, therefore causes no hydraulic impact. The raising of finished floor is a standard construction practice, and therefore the project is constructable. A desktop and in-person review of site conditions did not reveal any non-permittable circumstances, therefore it is deemed generally permittable for planning purposes.

7.1.5 Combined CIPs

CIPs 01, 02, and 03 all incrementally improve downstream flood hazard conditions. If combined, these three CIPs work together to compound improvements to some of the existing site conditions observed in the modeling process.

The residential area on the northwest side of town is currently being inundated from the inefficient railroad culverts and from the North Fork spilling out of its banks. CIP02 and 03 address these issues, respectively.

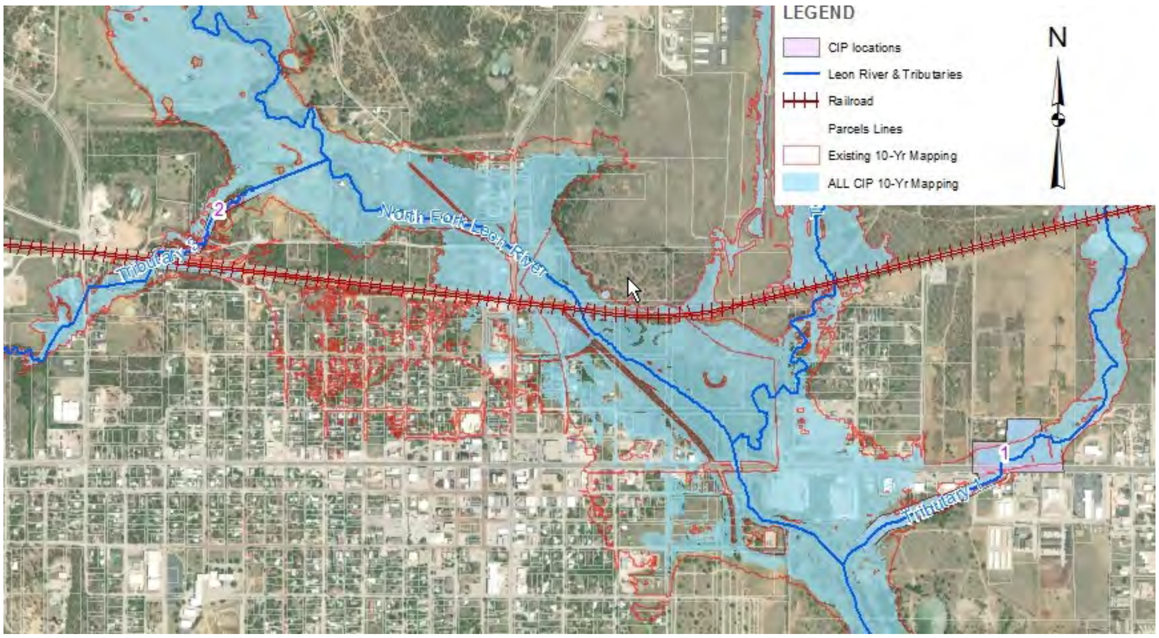

Figure 7-16. Combined CIP 10-Year Inundation Limits

In existing conditions, Main Street is inundated to depths of up to 2 feet. With all three CIPs combined, 2000 LF of Main Street are no longer inundated, while the remaining depths are reduced to about 1 foot in the 10-year event. All three CIPs contribute: flow is no longer breaching Weaver Creek's banks, flow from the neighborhood overflow is no longer overtopping Main Street, and reduced flow from Lake Eastland contributes to lower overtopping depths along Main Street. **Figure 7-17** shows the inundation depths as compared to the existing 10-year event boundary.

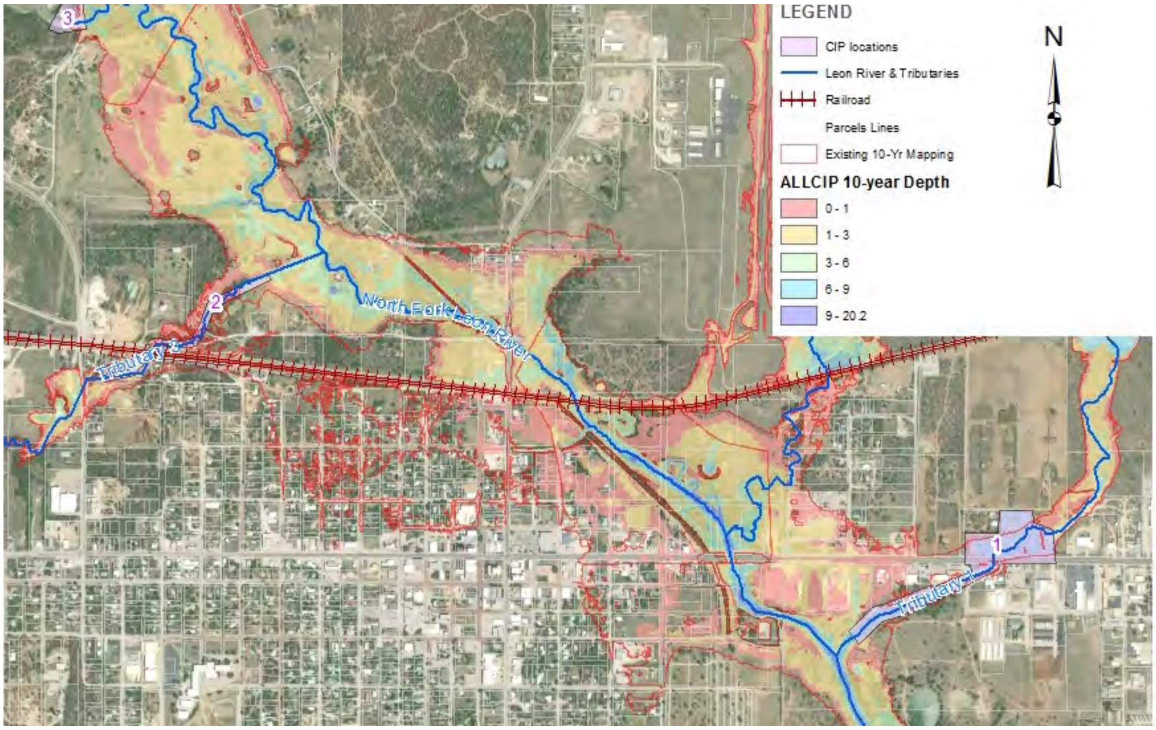

Figure 7-17. **Combined CIP 10-yr Inundation Depths**

7.1.6 Additional evaluations

The following scenarios were considered (as listed in the Measles chart – Table 7-6) but did not show results as promising as CIPs 01, 02, 03, and 04. These could be considered for further evaluation in the future. The following scenarios would be good candidates for Flood Mitigation Evaluations (FMEs) in the future.

FME 07 Efficiency improvements to the North Fork

Additional Evaluations explores regarding the confluence to improvements efficiency and conveyance of the North Fork.

Figure 7-18. **FME 07 Confluence of North and South Fork**

The confluence of the North and South Fork reflects channel meandering to a significant degree. The two streams also appear to cause backwater to each other at the time of their respective peaks. A potential hypothesis that was explored was straightening the North Fork to allow it to increase its velocity and "miss the peak" of the South Fork. However, that approach may not work when actual rainfall events occur with variable timing across the watersheds of the North and South Forks of the River as opposed to the simultaneous and equally distributed rainfall simulated in model studies.

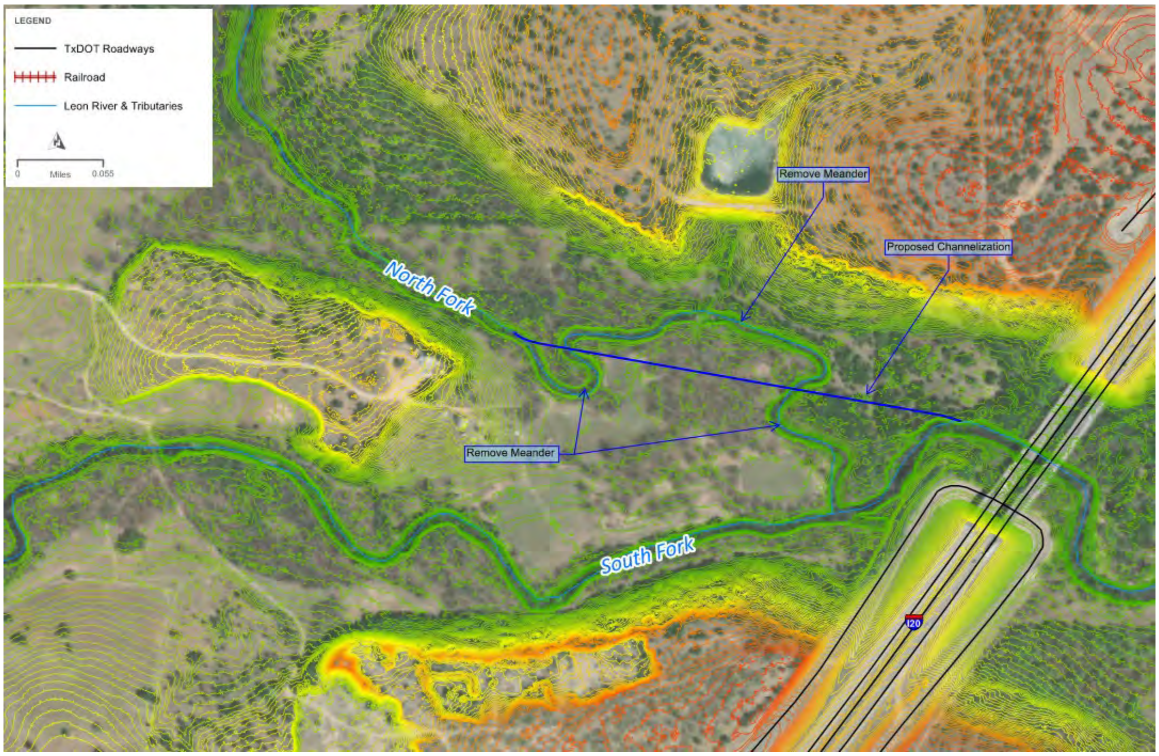

Figure 7-19. FME 07 Proposed Efficiency Improvements to the North Fork

The North Fork also spills out of its banks and into the South Fork. Therefore, in addition to straightening the North Fork, some fill was placed along the North Fork's banks to contain it.

With Lake Ogden downstream, it appears there is a limit to what this project can accomplish, as the water surface downstream is fixed.

FME 08 North Fork containment

Downstream of the North Fork Railroad Crossing, on the Right stream bank, there appears to be a berm or levee. Flow from the North Fork leaves the bank of the North Fork via a break in the levee and travels parallel to the levee and through the neighborhood west of the levee.

FME 09 Benching of reaches

An option explored in modeling was benching north of Weaver Creek between Main Street and the railroad. The results of this option did not eliminate any structures from flooding in any storm event. While nature-based solutions are encouraged by TCEQ, this design did not yield significant results.

An option was also explored on benching the North Fork. The amount of flow coming from Lake Eastland without spillway improvements was not contained via the extent of benching explored. No reductions were seen to the inundation of Main Street through this option, so it was not pursued.

FME 10 Decommissioning Ringling Lake

Refer to **Section 6.6** of this report for further background on the Lake and recommended further evaluations associated with decommissioning Ringling Lake.

Ringling Lake was modeled in the HMS model based on the elevation-area-discharge relationship developed in connection with the H&H Study performed by Jacob & Martin, Inc., as shown in **Table 7-5**. The lake does not appear to be providing much detention based on the computed inflow and outflow values for each event, which are very similar.

Table 7-5. Inflows and Outflows of Ringling Lake.

Event	Inflow (cfs)	Outflow (cfs)
10-year	2,367.3	2,229.2
25-year	3,047.1	2,912.2
50-year	3,588.6	3,500.8
100-year	4,172.9	4,116.2
500-year	5,825.5	5,770.9

A plan run was performed in the model to represent removal of the embankment from Ringling Lake, and no adverse impacts were observed. By providing a controlled breach, the Lake would be removed from TCEQ regulating authority. This was not pursued as a Flood Mitigation CIP as it does not provide a flood reduction benefit. However, further evaluation via alternate funding alternatives is recommended to further explore the potential for decommissioning Ringling Lake and providing wetland mitigation (as noted in **Section 6.6** of this report).

FME 11 Regional detention

Regional detention was explored on the North Fork by simulating an embankment along the North Fork with a height not to exceed 7 feet. The proposed embankment would tie into an existing embankment on the west bank of the North Fork of the Leon River as shown in **Figure 7-20**.

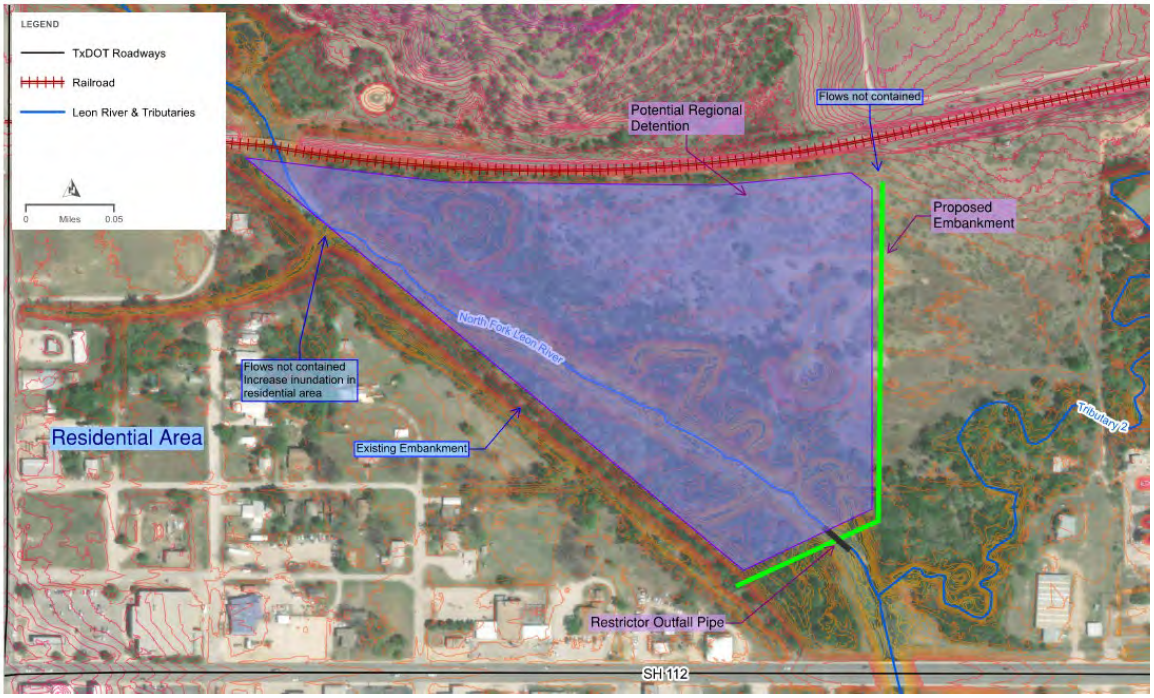

Figure 7-20. **Potential Regional Detention Location (FME 11)**

The embankment and restriction caused flows to be uncontained by the existing embankment and flows went around the proposed embankment. This caused increased inundation to the residential area. An initial analysis revealed that due to its proximity to Lake Eastland, this alternative is not a top priority. If regional detention is to be explored, the volume available in Lake Eastland is greater than any detention option pursued. However, this alternative could be evaluated further if the Lake Eastland CIP 03 measures are deemed non-viable. Potentially, the West Berm could be improved to contain flows, but this measure would require levee certification permitting with FEMA.

7.2 Non-structural alternatives

7.2.1 CIP 05 - Stream or rain gauge addition

Installation of stream gauges would be very beneficial to the City of Eastland. There are specific flood prone areas and streets that are not provided with any means of issuing a warning to the public. These areas are highly sensitive during intense storm events and could experience loss of life or property if the public is not informed of the dangerous condition ahead. Stream gauges could also provide a means of alerting emergency personnel of imminent danger to try to warn the public.

Since Eastland does not have any form of flood alert systems or warnings, it is recommended to start simple and move into a more robust system later. Simple also means less expensive and less staff involvement. **Less robust systems** are focused on providing immediate warnings for specific roadways and flood prone areas as opposed to a more complex and robust flood warning and forecasting system for large regions. The flood gauges can just be simple ones that flash during a high flow condition. Others may also include a flood level marker. More complex gauges can include a sensor and a means of sending notifications to inform emergency management personnel of high-water situation at specific locations. These gauges do not require too many staff to operate and maintain.

The flood gauges can be used to help gather more data on the major flood sources (such as the North and South Fork of the Leon River) and to improve modeling efforts and future flood mitigation project planning. There are various types of flood gauges and flood sensors available according to the vendors contacted. These include the following.

- Pluvial (rain) gauges – not so much for real-time flooding, but more for informational purposes to determine storm events rainfall for future studies or to determine level of impact per rainfall total and timeframe. These can be installed in the following locations.
    - At the upper part of watershed or at the Lake Eastland dam
    - At public building such as a fire station or emergency management office
- Flood gauges (flood sensors). Great for alerting the community of a flood threat and communicating the flood level. The various types of flood sensors include the following.
    - Flood detection system and warning system with gate closure

Figure 7-21. Example of a flood detection warning system with gate closure.

    - Stage flood sensors

Figure 7-22. Example of a flood senser.

HDR recommends that these be installed at critical flood prone locations or in frequently flooded areas of town. Possible locations for flood gauges include the following.

- Best at low water crossing or low lying such as:
  - Low water crossing on N. Seaman St. along North Fork Leon River

    A simple gage that reads rising water levels and sends signals to initiate or stop the flashing beacons. Optional road closure gates can be part of a more robust system during hazardous conditions.

Figure 7-23. Example gage location on North Seaman Street

- At Lake Eastland – monitor pool level remotely
  - The gage at this location will read lake levels via a pressure transducer controller and send out warning signal commands as the lake levels are rising as well as warning messages to authorities when elevations exceed the given thresholds.

Figure 7-24. Potential location of a flood sensor on Lake Eastland.

- At Main Street and Weaver Creek - Basic Warning Systems
  - The gages at the Main Street location can function as simple flashing beacons that light up once the water ponding levels are high enough to create hazardous conditions. A more robust system can include road closing gates automatically activated when a prescribed flooding depth is reached.

Figure 7-25. Potential location of a flood warning system on Main Street

It is very important to note the costs of installing and activating stream sensors. These are broken down to include capital costs, installation costs, calibration costs (periodic), and operation and maintenance (O&M) costs. Someone at the City or an independent company needs to be assigned with the operation and O&M. It is more common for an agency to fund the USGS to maintain gages where needed since the USGS has accepted standards for gage type and maintenance and the staff with the appropriate experience. If Eastland wants to establish their own gages, it will require staff with the correct experience to provide the O&M and a long-term commitment to keep these gages functional.

We recommend Eastland communicating directly with some of the companies the manufacture the flood gauges. Here's a list of some of the companies we have contacted:

1. Eltec - Traffic Flood Warning Systems | Flood Detection Systems | ELTEC (elteccorp.com)
2. TAPCO - www.TAPCOnet.com
3. One Rain - Flooded Roadway Warning - OneRain
   - OneRain offers a full flood warning system service customizable to the client's needs. There are flashing beacon systems with water elevation sensors available as well as sensors to detect water levels in reservoirs via a pressure transducer controller. Their manufactures, installs, and provides annual/bi-annual maintenance upon request. Independent software operation is encouraged. To facilitate operations, they offer software training, webinars, and opportunities to shadow their technicians. The software has notification capabilities as well as remote signaling to emergency offices. Technicians are available to help the client troubleshoot systems.

     OneRain's budget friendly alternative installation costs are roughly $10,000 per location. A more robust system will be more costly. Maintenance fees are not included in the initial installation costs. OneRain has experience working with agencies in Central Texas such as TxDOT.

HDR also recommends for the City to get connected to one or more agencies that have gage systems. HDR contacted the Tarrant Regional Water District (TRWD), and the United States Geological Service (USGS). These agencies can provide guidance, cost data, lessons learned, etc.

USGS - Depending on the difficulty, USGS will typically charge $20,000 to $40,000 to install a gage with annual O&M costs ranging from $8,000 to $16,000.

TRWD – Their gage installation costs typically range between $10,000 to $15,000. This cost includes data recorder, housing, and battery along with the solar panels, wiring, conduits, and telemetry. The cost does not include labor which will take a 1- to 2-man crew from 1-3 full days. The costs and time to complete the install vary by gage location and difficulty of install. The annual O&M budget for gages is roughly around $12,000 with an additional $5,000 annually for software licenses.

CIP 05 No adverse impact

CIP 05, stream gage addition does not inundate additional structures and therefore causes no impact. Additionally, this CIP does not change or add flows in the area, therefore causes no hydraulic adverse impact. Stream gages are easily constructable and permittable. The proposed project does not include any unusual structures, construction techniques, or site conditions, therefore it is deemed generally constructable for planning purposes. No permitting is required for stream gages, so the project is considered permittable.

7.2.2 CIP 06 - Evaluation and recommendations on floodplain management practices

Floodplain management and land use practices look at regulations, policies, and trends in a community. From a flood risk perspective, these management practices improve protection of life and property. The City of Eastland is currently a participant of FEMA's National Flood Insurance Program (NFIP). Therefore, residents are able to purchase flood insurance. However, City's staffing limitations make it difficult to adequately enact, adopt, and enforce specific floodplain management practices. HDR proposes an opportunity for this flood prone community to obtain funding to strengthen its ability to regulate and adopt consistent minimum floodplain management standards and land use practices.

Eastland is a small City (population of under 4,000) with limited resources and staff; therefore, it is difficult to enact, adopt, and enforce specific floodplain management practices, nor have they worked with FEMA to update Special Flood Hazard Areas (SFHAs) and Flood Insurance Rate Maps (FIRMs).

HDR recommends that Eastland becomes a more involved NFIP participant. This can give the City authority to establish their own policies, standards, and practices to manage land use in and around areas of flood risk. Participating NFIP communities have the responsibility and authority to permit development that is reasonably safe from flooding.

The minimum standards require buildings to be constructed at or above the **Base Flood Elevation or BFE (100-year flood).** The BFE is the elevation of surface water resulting from a flood that has a 1 percent chance of occurring in any given year. Other minimum standards provide for floodproofing options for buildings, and mandate provisions specific to the elevation and anchoring of manufactured houses. The minimum standards are based on maps that represent "current" conditions, which may be based on outdated topography, rainfall, and runoff data. Therefore, minimum standards set at the BFE leave no room for a safety factor, error in maps, or outdated data resulting in limited protection from flood damages. A **higher standard** can provide further protection and can provide detention requirements, freeboard and/or fill restrictions in excess of minimum standards.

Future land-use / property

Eastland is not expected to grow much in the next 20 to 30 years. However, some of the existing floodplain ordinances with higher standards may continue to protect property if they are enforced. The lack of floodplain management practices for Eastland poses an increasing level of flood risk for the population. Local floodplain regulations with at least minimum standards should be adopted.

Consideration of adoption of minimum floodplain management and land use practices

HDR proposes an opportunity for this flood prone community to obtain more funding to strengthen its ability to regulate and adopt consistent minimum floodplain management standards and land use practices. Recommended practices encourage the establishment of minimum floodplain management standards over the next several years to reduce or eliminate potential flooding areas.

This FIF Funded Watershed Study is a step forward at increasing and improving floodplain mapping coverage across the City to reduce flood risk uncertainty and improve the tools for regulating development within the floodplain. **The City should follow with updating the outdated FIRMs via a LOMR request to FEMA**. As development continues, it is important to leverage best available data and the models provided to establish BFEs and update floodplain boundaries (FEMA Zone AE and Zone X). At that point, it will become more likely to advance the flood mitigation practices and floodplain management goals of the City.

Incorporating the existing and future floodplains will allow the City to plan future development around flood-potential areas avoiding the risk of future flooding and damages, thereby reducing future flooding damages and to protect people and property. While Eastland cannot predict the future, adopting minimum practices can be the first incremental step to introducing the community to its potential flood risks.

Flood education outreach

An effective education program about flooding and issues related to flooding can help people make more informed decisions so that they can take steps to protect themselves from flooding by retrofitting their homes and property, purchasing flood insurance, and preparing a personal family plan they will use during the next flood event. Their understanding and awareness of the floodplain risks and issues will cause them to be more supportive of local floodplain management efforts and measures to protect the natural floodplain functions. Effective management of flood risks is a community-wide endeavor that requires the support and cooperation of citizens, businesses, government agencies, and other organizations. A flood education outreach program that informs the public regarding flooding and flood risk is an important step toward managing or reducing those risks and overcoming the false perception that it will never happen again.

Flood Education Goals:

- Promote public safety by encouraging risk reduction actions before, during, and after flood events.
- Reduce and avoid flood damage to infrastructure, public property, and private property.
- Build support for improved public policies that affect flood risks (local, state, and national).
- Promote improved management of floodplains, watersheds, and hydraulic systems.
- Flooding is natural. Build back smarter.

Resources

There are numerous organizations and resources available that provide flood education outreach and materials to both communities and individuals. Some are listed as follows:

1. Texas Floodplain Management Association - TexAnna TADDpole Program - https://www.tfma.org/page/tadd
2. National Weather Service - Turn Around Don't Drown (TADD) Program – https://weather.gov
3. National Weather Service – Flood Safety Education and Outreach - https://www.weather.gov/safety/flood-education
4. Texas A&M University Agrilife Extension – Disaster Education Network - https://texashelp.tamu.edu/browse/by-type/naturally-occurring/floods/
5. Texas Water Development Board – Floodplain Management Training - https://www.twdb.texas.gov/flood/workshop/index.asp
6. Texas Water Development Board – Community Resources - https://www.twdb.texas.gov/flood/resources/index.asp
7. FEMA Floodsmart – National Flood Insurance Program - https://www.floodsmart.gov

CIP 06 No adverse impact

CIP 06 does not inundate additional structures and therefore causes no impact. Additionally, this CIP does not change or add flows in the area, therefore causes no hydraulic adverse impact. This project will not require construction or permitting.

7.3 No adverse impact – Overall Summary

A "No Negative Impact Table" is included in Appendix C of this report. Furthermore, the reduction in inundation to the hydraulic maps available in Appendix C is also clear evidence that no impact occurs to the proposed CIP's.

7.4 Texas Water Development Board alternatives analysis criteria

Each flood mitigation alternative was evaluated based on 21 criteria listed below:

1. Number of structures with reduced 100-year (1% annual chance) flood risk.
2. Number of structures removed from 100-year (1% annual chance) flood risk.

3. Number of structures removed from 500-year (0.2% annual chance) flood risk.
4. Residential structures removed from 100-year (1% annual chance) flood risk.
5. Estimated Population removed from 100-year (1% annual chance) flood risk.
6. Critical facilities removed from 100-year (1% annual chance) flood risk (#).
7. Number of low water crossings removed from 100-year (1% annual chance) flood risk (#).
8. Estimated reduction in road closure occurrences.
9. Estimated length of roads removed from 100-year flood risk (miles).
10. Estimated farm & ranch land removed from 100-year flood risk (acres). Estimated farm & ranch land at 100-year flood risk (acres) should only include farm and ranch land that are negatively impacted by flooding events and should not include land that benefits from floodplains for example rice fields.
11. Estimated reduction in fatalities (if available).
12. Estimated reduction in injuries (if available).
13. Pre-Project Level-of-Service
14. Post-Project Level-of-Service
15. Cost/ Structure removed
16. Percent Nature-based Solution (by cost)
17. Negative Impact (Y/N)
18. Negative Impact Mitigation (Y/N)
19. Social Vulnerability Index (SVI)
20. Water Supply Benefit (Y/N)
21. Traffic Count for Low Water Crossings

A measles chart shown on **Table 7-6** evaluates each alternative based on the 21 point criteria.

Table 7-6. Alternatives Based on the 21 Criteria

Evaluation Parameter	Problem Area Evaluated	Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements	Tributary 3 Culvert and Grading Improvements	Lake Eastland Spillway Reconstruction	Structural Buyouts and Raising of Finished Floor Elevations	Stream or Rain Gauge Addition	Evaluation and Recommendations on Floodplain Management Practices	Efficiency Improvement to the North Fork	North Fork Containment	Benching of Reaches	Decommissioning Ringling Lake	Regional Detention
	Problem Area Number	01	02	03	04	05	06	07	08	09	10	11
1	Structures with reduced 100-year flood risk	2	55	7	0	0	0	0	0	0	0	0
2	Structures removed from 100-year flood risk	2	55	7	27 [1]	0	0	0	0	0	0	0
3	Structures removed from 500-year flood risk	-1	33	4	16 [2]	0	0	0	0	0	0	0
4	Residential structures removed from 100-year	0	48	1	24 [3]	0	0	0	0	0	0	0
5	Population removed from 100-year flood risk	11	192	19	106	0	0	0	0	0	0	0
6	Critical facilities removed from 100-year flood risk	0	0	0	0	0	0	0	0	0	0	0
7	Low water crossings removed from 100-year	0	0	0	N/A	0	0	0	0	0	0	0
8	Reduction in road closure occurrences	10	0	0	N/A	0	0	0	0	0	0	0
9	Length of roads removed from 100-year flood risk	1	1	1	N/A	0	0	0	0	0	0	0
10	Farm & ranch land removed from 100-year	-0.6	0.2	1.2	N/A	0	0	0	0	0	0	0
11	Reduction in fatalities (if available)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12	Reduction in injuries (if available)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13	Pre-project level-of-service	2-yr	10-yr	10-yr	N/A	N/A	N/A	25-yr	N/A	2-yr	N/A	N/A
14	Post-project level-of-service	100-yr	100-yr	100-yr	N/A	N/A	N/A	25-yr	N/A	5-yr	N/A	5-yr
15	Cost/structure removed (Low/Medium/High)	High	Low	High	Medium	N/A	N/A	N/A	N/A	N/A	N/A	N/A
16	Percent Nature-based Solution (by cost)	0	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
17	Negative Impact (Y/N)	N	N	N	N	N	N	N	Y	Y	N	Y

Evaluation Parameter	Problem Area Evaluated	Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements	Tributary 3 Culvert and Grading Improvements	Lake Eastland Spillway Reconstruction	Structural Buyouts and Raising of Finished Floor Elevations	Stream or Rain Gauge Addition	Evaluation and Recommendations on Floodplain Management Practices	Efficiency Improvement to the North Fork	North Fork Containment	Benching of Reaches	Decommissioning Ringling Lake	Regional Detention
	Problem Area Number	01	02	03	04	05	06	07	08	09	10	11
18	Negative Impact Mitigation (Y/N)	N	N	N	N	N	N	N	N	N	N	N
19	Social Vulnerability Index (SVI)	0.70	0.70	0.70	0.70	0.70	0.70	0.78	0.78	0.78	0.78	0.78
20	Water Supply Benefit (Y/N)	N	N	N	N	N	N	N	N	N	N	N
21	Traffic Count Low Water Crossings [4]	N/A	N/A	N/A	N/A	1,680	N/A	N/A	N/A	N/A	N/A	N/A
	Capital Improvement Project Number	01	02	03	04	05	06					
	FMP Number	01	02	03				FME	FME	FME	FME	FME

Notes

1. Includes raising FFEs and buyouts
2. 500-year structure removal is only from buyouts, not raising FFEs. Raising FFEs is not guaranteed to remove a structure from the 100-year FP.
3. A total of 27 structures were removed, the 24 residential noted and 3 commercial structures.
4. Traffic counts from TxDOT

8 Benefit-Cost analysis

For each of the alternatives considered, costs and benefits of the projects were evaluated. Quantifications of cost and benefits are in line with the guidance principles of the TWDB FIF Cat 1 Grantee Subcontract Guidance. The cost estimates for each project are found in **Appendix D – Cost Estimates**, and the benefits are described in **Appendix E – Cost Benefit Analyses**.

8.1 CIP cost estimates

Cost estimates were developed for each of the CIPs to perform a benefit-cost analysis (BCA). The BCA was then used to help rank the CIPs to explore which flood mitigation solutions are the most cost-effective for the City of Eastland. The TxDOT Low Bid Unit Prices from July 2022, TxDOT Online Workbook for Bid Item Averages, and cost estimates from similar drainage infrastructure design projects completed by HDR that have gone to bid were used as references for determining appropriate unit costs for each item. Eastland is part of TxDOT's Brownwood District, therefore, the data available from this local region was preferred.

The quantities developed for excavation were determined by comparing the proposed terrain modifications in the hydraulic model with the existing terrain. To implements some of the CIPs, drainage easements are required to construct the improvements. Real estate specialists were consulted in determining the cost required for each parcel, and City of Eastland County Appraisal District (CAD) data was used in determining the current costs of parcels to accurately estimate the price for each drainage easement. The total costs associated with each CIP are based on design from a conceptual level, and are not intended for permitting, bidding, or construction purposes. Contingencies of 30% were applied to each cost estimate due to the conceptual design stage of each CIP, as well as 20% for consultant design fee and profit, and contract overhead, profit, and insurance. A detailed breakdown of each item, unit cost, and quantity is provided in **Appendix D**.

8.1.1 CIP 01: Weaver Creek and Main Street Culvert upsizing, channel, and grading Improvements

CIP 01 at the Weaver Creek crossing under Main Street consists of upsizing the existing culverts, removing the rock masonry dam just upstream of the culvert crossing, downstream channel regrading, and implementing upstream detention to improve flood mitigation in the area. See **Figure 7-1** for a detailed diagram displaying the proposed improvements. Drainage easements were taken into consideration for the upstream detention and downstream channel regrading. Easements affecting a total of five parcels are required at this location, as previously shown in **Figure 7-3**. Environmental specialists were consulted to estimate the costs related to the environmental permitting required to implement CIP 01.

CIP 01: Weaver Creek and Main Street Culvert upsizing, channel, and grading Improvements

Total Cost Estimate: **$6,848,000**

The span of box culverts proposed is wide enough that a bridge opening was considered as an alternative to box culverts. The cost of a bridge opening is included as an alternative in the Cost Estimate, but the box culverts were ultimately included in the Benefit-Cost Analysis.

8.1.2 CIP 02: Tributary 3 culvert and grading improvements

CIP 02 located at Tributary 3 crossing under the Union Pacific Railroad just east of North College Avenue consists of upsizing the existing culvert, channel regrading and improvements (both upstream and downstream of the railroad crossing), swale improvements, and a small levee to improve flood mitigation at this location. See **Figure 7-2** for a detailed diagram displaying the proposed improvements. It is recommended that the existing culvert be filled and the proposed culverts be installed at an offset from the existing pipe using jack and bore installation techniques to ensure that the UPRR railroad remains operable during construction. In terms of permitting, a pipeline crossing agreement and right of entry will be required to install the pipes. Additionally, proof of both commercial general liability insurance and railroad protective liability insurance is required. A $3,000 application fee for drainage pipes brings the estimated total for railroad permitting to approximately $50,000, as shown in Appendix D. Drainage easements were taken into consideration for the proposed channel regrading upstream and downstream of the crossing. Easements affecting a total of four parcels are required at this location, as previously shown in **Figure 7-9**. Environmental specialists were consulted to estimate the cost related to the environmental permitting required to implement CIP 02.

CIP 02: Tributary 3 culvert and grading improvements

Total Cost Estimate: **$2,912,400**

8.1.3 CIP 03: Lake Eastland spillway reconstruction

CIP 03 at Lake Eastland consists of removing and replacing the existing spillway with a combination ogee / v-notch weir to increase storage in the lake and decrease the flow released during the more frequent storm events. See **Figure 7-12** for a detailed diagram of the conceptual design of the proposed spillway reconstruction. **Appendix I** contains the structural analysis of the existing spillway that includes reconstruction recommendations. Environmental specialists were consulted to estimate the cost associated with the environmental permitting required to construct CIP 03. An AACE Class V Feasibility Level Construction Cost Estimate was developed for replacing the existing spillway structure in-kind. The cost estimate was developed using quantity takeoffs from the existing structure and unit price data from the Texas Department of Transportation and RSMeans. The current cost estimate provides a range between $10.8M and $16.2M. The cost breakdown is shown in **Appendix D**. The cost presented below is the base level price.

CIP 03: Lake Eastland spillway reconstruction

Environmental Permitting Conceptual Cost Estimate: **$100,000**

Structural Cost Estimate: **$15,600,000**

8.1.4 CIP 04: Structural buyouts and raising of finished floor elevations

CIP 04 consists of identifying the properties that are still significantly inundated in a 100-year event despite implementing the previously described structural CIPs.

Structures to be Improved –

To determine which properties would be candidates for raising of FFEs, recommendations and estimates from a foundation repair company were utilized. The property is required to be built on slab-on-grade foundations. The estimated total for each property comes out to $117,000, which includes a structural and condition assessment, raising of the foundation, and utility disconnects and reconnects. It should be noted that if a property does not pass the structural and condition assessment, it may be eligible for buyout. Once a property was determined to be slab-on-grade, the appraisal was pulled from the City of Eastland County Appraisal District If the property was worth more than the estimated cost to raise the FFE, it was determined a suitable candidate for raising. Otherwise, it is recommended that the property is bought out. Additionally, a FEMA Letter of Map Revision on Fill (LOMR-F) will be required to remove the properties that have their FFEs raised above the 100-year base flood elevation.

Buyout Program –

The properties included in the property buyout portion of CIP 04 were selected based on their appraisal cost pulled from the Eastland County Appraisal District. If the appraisal was less than the cost to raise the FFE, the property was determined to be part of the buyout program. A list of properties included in CIP 04 is found in **Table 7-4,** and the property locations are shown on **Exhibit D-1** of **Appendix D**.

CIP 04: Structural buyouts and raising of finished floor elevations

Total Buyout Cost Estimate: **$1,447,900**

Total Cost Estimate of Raising FFEs: **$2,113,090**

Total Cost Estimate: **$3,560,990**

8.2 Benefit analysis

Each CIP has a benefit cost analysis (BCA) performed. The purpose of the BCA is to compute a benefit cost ratio (BCR) using the TWDB's Input Tool. This spreadsheet estimates flood impacts for "Baseline" and "Project" conditions for up to three recurrence intervals. The following impacts are evaluated in at least one BCA for Eastland: Residential Structures, Commercial Structures, Flooded Streets, and Low Water Crossing.

The following assumptions were made for the BCA of each CIP:

Construction year

Each BCA assumed a construction start in 2025, except for CIP 01 which has a construction year start in 2024 because the City of Eastland has already received funding. All BCAs assumed one year for construction to be complete.

Residential structures

Residential structure damages are evaluated by the approximate size of the home and by its flooded depth for Baseline and Project conditions. TWDB classifies homes by either "Small Home", "Average Home", or "Large Home." The following guidelines were used to classify each residential structure:

- Small Home: x < 2,500 square feet
- Average Home: 2,500 square feet < x < 5,000 square feet
- Large Home: x > 5,000 square feet

Where *x* is the approximate footprint of the residential structure.

TWDB's Input Tool spreadsheet only allows 100 structures to be evaluated, and the residential structures impacted were over 100 for most CIPs. To overcome this constraint, each residential structure that had the same structure classification and inundation depths were grouped and evaluated together. All inundation depths were rounded to the nearest inch.

Commercial structures

Commercial structures are evaluated by business type and value of the structure. Each structure was assigned a structure value based on the 2022 Eastland County Appraisal District's Certified Appraisal Roll. Each commercial structure was assumed to be "Retail – Clothing", which is approximately the average cost of damages for all the commercial business types. All inundation depths were rounded to the nearest inch.

Flooded streets

According to the Input Tool, streets are considered impassable when the inundation depths are six inches or more. The daily traffic count for each BCA was recorded from TxDOT's Traffic Count Database System (TCDS) (Traffic Count Database System (TCDS) (ms2soft.com). When calculating additional time for detours, the average speed was assumed to be 35 miles per hour. The Normal Emergency Services response time was assumed to be 14.5 minutes based on the rural mean value from Table 2 of the National Institutes of Health Journal of the American Medical Association Surgery study (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5831456/). For Baseline conditions, the EMS response time was doubled. For Project conditions, the Emergency Medical Services (EMS) response time was scaled based on the ratio between detour routes for Baseline and Project. The number of households impacted by the EMS delay was assumed to be the total number of structures that were impacted by flooding for each recurrence event.

Acquisitions and raising elevations

For CIP 04, the proposed project recommends mitigating flooding in residential and commercial buildings by either property acquisition or raising the FFE of the structure above flooding depths. According to the FEMA memorandum with subject titled "Update to 'Cost-Effectiveness Determinations for Acquisitions and Elevations in Special Flood Hazard Areas Using Pre-Calculated Benefits", the pre-calculated benefits listed in the memorandum were used to calculate the BCR. The pre-calculated benefits of acquisitions and elevations are:

- Acquisitions: $323,000 per structure
- Elevations: $205,000 per structure

The Benefits Cost Analyses are found in **Appendix E – Cost Benefit Analyses** and summarized in **Table 8-1**.

A summary table of the Cost-Benefit Ratios is seen below in **Table 8-1**:

Table 8-1. Benefit-Cost Ratio Summary.

Project	Cost	Benefit	Ratio
CIP 01 – Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements	$6.85M	$724K	0.1
CIP 02 – Tributary 3 Culvert and Grading Improvements	$2.91M	$691K	0.3
CIP 03 – Lake Eastland Spillway Reconstruction	$15.70M	$901K	0.2
CIP 04 – Structural Buyouts and Raising of Finished Floor Elevations	$3.56M	$7.42M	2.5

8.3 State and Federal grant funding opportunities

To finance the design and construction of some of the larger flood mitigation projects, the City of Eastland should consider applying for assistance under one of several federal grant programs for flood mitigation, as described below.

8.3.1 TWDB – State Flood Plan

The formulated CIPs or Flood Management Projects (FMPs) were submitted to the State Flood Plan's Region 8 (Lower Brazos) on May 19, 2023. This included the associated modeling, cost-benefit analysis, and floodplain maps proving a no-negative impact. Submitting the CIP projects to the State Flood Plan may qualify them for future funding from the Texas Water Development Board. The following CIP (FMP) projects were submitted:

- CIP 01 - Weaver Creek and Main Street Culvert Improvements (FMP ID 83001303)
- CIP 02 – Tributary 3 and UPPR Culvert Improvements (FMP ID 83001304)
- CIP 03 – Reconstruction of primary Lake Eastland spillway (FMP ID 83001305)

8.3.2 USACE

The USACE has a Section 205 Flood Risk Management program. Improvements under this program are limited to a total of $15 million, the federal portion of which cannot exceed $10 million.

8.3.3 Hazard mitigation grant program

The purpose of the HMGP is to implement projects or measures that reduce the risk of loss of life and property from future disasters. HMGP requires assessments of damage in the 90 days after the disaster occurs, and inclusion of the project in the Hazard Mitigation Plan. To be eligible for HMGP funding, a project would need to conform with environmental regulations, meet all applicable state and local codes and standards, consider a range of alternatives, and be cost effective. The program reimburses at a 75% Federal to 25% Local ratio.

8.3.4 Pre-Disaster mitigation grant program

FEMA's Pre-Disaster Mitigation (PDM) grant program provides funding for hazard mitigation planning and projects on an annual basis. These funds are locally and nationally competitive. The amount of PDM funding available annually depends on appropriations by Congress. However, since the PDM and HMGP grant applications are almost identical, the same application can be used for both grant programs with minor changes.

8.3.5 Public assistance

The FEMA PA Program reimburses declared government agencies for losses to publicly maintained infrastructure. Under this program, FEMA only pays for repairs up to current codes and standards. Grant management administration is reimbursed if properly procured and costs are reasonable. Major tasks include inspecting damaged facilities, determining the extent of damage, and developing the scope of work and cost estimate required to restore the facilities. Funding can be used in accordance with Section 406 to strengthen facilities damaged by a declared disaster and can be used to reduce the potential of future similar disaster damages.

8.3.6 Community development block grant

The Housing and Urban Development (HUD) Community Development Block Grant (CDBG) Program could also serve as a potential funding source for drainage projects provided that certain conditions are met. A project would need to meet at least one of the three program national objectives to be considered for funding:

- Benefit persons of low and moderate income
- Aid in the prevention or elimination of slums or blight
- Meet other urgent community development needs because existing conditions pose a serious and immediate threat to the health and welfare of the community where other financial resources are not available.

Under the CDBG program, grantees must use at least half of Disaster Recovery funds for activities that principally benefit low-and moderate-income persons.

9 Conclusions

Updated hydrologic and hydraulic modeling of the North and South Forks of the Leon River led to an alternative analysis and proposed flood improvement projects (CIPs). Using the hydrologic and hydraulic models of the North Fork Watershed, an updated dam breach analysis of Lake Eastland and Ringling Lake were performed in which the emergency action plans were updated, and spillway recommendations were developed for each lake.

Key stakeholders in the project were the City of Eastland (City) and TWDB. Secondary ones were FEMA, USACE, TxDOT, TCEQ, and the State Flood Plan’s Region 8 Regional Flood Planning Group.

Hydrologic modeling used gage adjusted rainfall data for two historical events. This concluded in the events representing approximately a 25-year storm event. The 2D hydraulic computations defined the hydraulic characteristics and extents of flood-prone regions within the study area.

Four structural and two non-structural flood mitigation alternatives were analyzed in connection with the study. The four structural alternatives are:

- Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements
- Tributary 3 Culvert and Grading Improvements

- Lake Eastland Spillway Reconstruction
- Structural Buyouts and Raising of Finished Floor Elevations

Cost estimates were developed for each of the CIPs to perform a benefit-cost analysis (BCA). The BCA was then used to help rank the CIPs to explore which flood mitigation solutions are the most cost-effective for the City of Eastland. These ratios are low due to the high cost of each alternative and relative low impact during the 100-year event. Lower frequency events analyzed such as the 10-year storm event, result in a greater benefit in most CIP projects evaluated due to greater reductions in water surface elevations.

The two non-structural flood mitigation alternatives analyzed were:

- Stream Gauge Additions
- Flood Management Practices Recommendations and Education Outreach.

The stream gauge additions are an effective and relatively economical way of detecting high water danger in critical flood prone areas as well as sources for potential flooding such as Lake Eastland water levels. Floodplain management practices improve protection of life and property. HDR proposes an opportunity to obtain funding to strengthen Eastland's ability to regulate and adopt consistent minimum floodplain management standards and land use practices.

A public hearing was held early in the project (May 2022) with stakeholders and the community to inform them of the project progress and to gather public information and flooding concerns. A second public hearing was held in May 2023. This hearing informed the public of the Study results and recommendations and was an opportunity to gather feedback and prioritize flood mitigation alternatives. Based on the BCA analysis, discussions with the City, and public outreach, HDR proposes to prioritize the alternatives as follows in Table 9-1: Table 9-1. Flood Mitigation Rankings.

Ranking	Project
1	CIP 01 – Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements
2	CIP 04 – Structural Buyouts and Raising of Finished Floor Elevations
3	CIP 05 – Stream or Rain Gauge Addition
4	CIP 06 – Evaluation and Recommendations on Floodplain Management Practices
5	CIP 03 – Lake Eastland Spillway Reconstruction
6	CIP 02 – Tributary 3 Culvert and Grading Improvements

9.1 Funding sources

For the TWDB's State Flood Plan, the formulated CIPs or Flood Management Projects (FMPs) were submitted to the State Flood Plan in Region 8 (Lower Brazos) on May 19, 2023. This included the associated modeling, cost-benefit analysis, and floodplain maps proving a no-negative impact. Submitting the CIP projects to the State Flood Plan qualifies them for future funding from the Texas Water Development Board. The following CIP (FMP) projects were submitted:

- CIP 01 - Weaver Creek and Main Street Culvert Improvements (FMP ID 83001303)
- CIP 02 – Tributary 3 and UPPR Culvert Improvements (FMP ID 83001304)
- CIP 03 – Reconstruction of primary Lake Eastland spillway (FMP ID 83001305)

Other funding sources are available and these can be at a state or federal level. Some of them are listed as:

- CIP 01 – Weaver Creek and Main Street Culvert Upsizing, Channel and Grading Improvements
  - Texas GLO – CDBG
  - TWDB FIF or SFP
  - FEMA – Flood Mitigation Assistance Program
  - TxDOT assistance
- CIP 02 – Tributary 3 Culvert and Grading Improvements
  - TWDB FIF or SFP
  - FEMA – Flood Mitigation Assistance Program
  - HMGP Grant
  - UPRR assistance
- CIP 03 – Lake Eastland Spillway Reconstruction
  - TWDB FIF or SFP
  - FEMA – Flood Mitigation Assistance Program
  - USACE Flood Management Program Grant
  - FEMA PDM Program
- CIP 04 – Structural Buyouts and Raising of Finished Floor Elevations
  - TWDB FIF or SFP
  - FEMA – Flood Mitigation Assistance Program
  - FEMA – CDBG Grant
- CIP 05 – Stream or Rain Gauge Addition
  - USGS Assistance
  - FEMA – Flood Mitigation Assistance Program
  - TxDOT assistance
- CIP 06 – Evaluation and Recommendations on Floodplain Management Practices
  - TWDB assistance
  - FEMA

The next step is to submit the modeling and cost-benefit analysis this report provides to the State Flood Plan in Region 8. Submitting the projects to the State Flood Plan qualifies them for future funding from the Texas Water Development Board. FMPs 01, 02, and 03 were submitted and accepted into the Region 8 Regional Flood Plan. Should the City wish to pursue funding for the FMEs in this study, the evaluations can be submitted to future planning cycles.

9.2 Property acquisition

Right-of-way acquisition can delay the implementation of capital projects. Although the CIP projects were developed to maximize the use of public lands the City of Eastland already owns, a few projects will require right-of-way acquisition. Fewer points were awarded in this category for each parcel that has to be acquired.

9.3 Ease of permitting

Environmental permitting can also delay the implementation of drainage projects, and mitigation can increase the project costs. The most significant environmental permit for drainage projects is the Clean Water Act's Section 404 regulatory program, administered by the U.S. Army Corps of Engineers (USACE) Regulatory Branch. This program regulates the loss of wetlands, or waters of the U.S., through a combination of Nationwide Permits (NWP) and Individual Permits (IP). Each NWP has a set of thresholds, below which the permit applies with a set of implementation conditions. If the impacts to wetlands are above the thresholds of the NWP, an IP must be negotiated which often requires mitigation of the impacts on a 1:1 ratio. Many NWPs have a smaller set of thresholds below which a Pre-Construction Notification (PCN) does not have to be submitted to the USACE for verification.

9.4 Geo-Database

The geo-database data for all four structural flood mitigation alternatives has been developed. It is recommended that the City submit these projects to the Regional Flood Planning Group for funding from the Texas Water Development Board.

10 References

(Wilbur L. Meier, 1964) Wilbur L. Meier, Jr

1964 Analysis of Unit Hydrographs for Small Watersheds in Texas

(Freese and Nichols, 1978) Freese and Nichols

1978 Phase 1 Inspection Report for Lake Eastland Dam

(Jacob & Martin, Inc, 1988) Jacob and Martin, Inc

1988 Hydrologic and Hydraulic Study for Eastland and Ringling Lakes

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2009 Review of Lake Eastland Dam

10.1 Acknowledgements

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