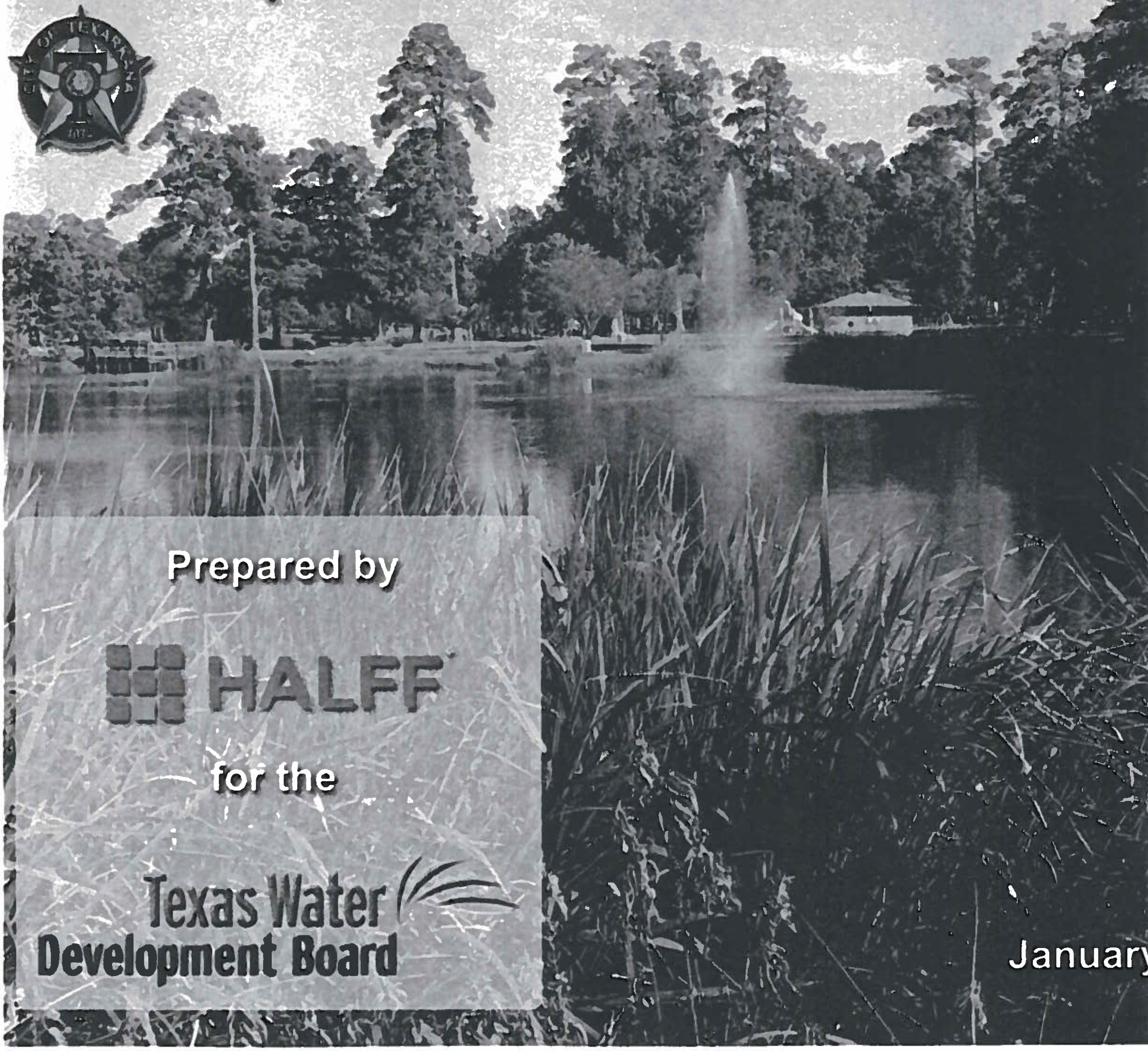
City-wide Flood Protection Planning S
for the City of Texarkana, Texas
Final Report



Prepared by

HALFF

for the

Texas Water Development Board

January

1004831090_Final Report

City-wide Flood Protection Planning Study for the City of Texarkana, Texas
Final Report

Prepared by

HALFF

for the

Texas Water Development Board

January 2012

HALFF

January 31, 2012
27093

Ivan Ortiz
Mitigation Specialist
Texas Water Development Board
PO Box 13231
1700 North Congress Avenue
Austin, TX 78711-3231

RE: Final Report – City of Texarkana, City-wide Flood Protection Planning Study, TWDB Contract No. 1004831090

Dear Mr. Ortiz:

We are pleased to submit the attached Final Report prepared under the above referenced contract. Included are seven (7) copies of the report and each copy contains a CD in Appendix H, with all digital files, models, and a PDF of the report.

Following our submittal of the draft report, we received TWDB comments dated December 19, 2011. These comments have been addressed and were incorporated into the final report submittal. The TWDB comments and responses are included in the final report as Appendix G.

If you have any questions or comments regarding this final report submittal, please contact me at (817) 847-1422. We appreciate your support of the City of Texarkana on this very important project.

Sincerely,

HALFF ASSOCIATES, INC.

Benjamin B. Pylant, PE, CFM
Project Manager

Cc: Gilbert Ward, TWDB
Kyle Dooley, PE, CFM, City of Texarkana, Texas
Cindy Mosier, PE, CFM, Halff Associates, Inc.

HALFF ASSOCIATES, INC.
4000 FOSSIL CREEK BLVD.
FORT WORTH, TX 76137-2720
TEL (817) 847-1422
FAX (817) 232-9784
WWW.HALFF.COM

City of Texarkana
City-wide Flood Protection
Planning Study
Final Report

Prepared for:

Texas Water Development Board

&

The City of Texarkana, Texas

Prepared by:

HALFF

Halff Associates, Inc.
4000 Fossil Creek Blvd.
Fort Worth, TX 75081
TBPE Firm No. F-312

STATE OF TEXAS
BENJAMIN B. PYLANT
105125
LICENSED PROFESSIONAL ENGINEER
1-30-2012

AVO: 27093

January 2012

STATE OF TEXAS
CINDY HULA MOSIER
85527
LICENSED PROFESSIONAL ENGINEER
1-30-2012

Acknowledgements

Halff Associates, Inc. gratefully acknowledges the key contributions and support provided for the City of Texarkana Flood Protection Planning Study by the individuals listed below.

City of Texarkana:

Stephen A. Mayo, Mayor
F. Larry Sullivan, Ed. D., City Manager
Shirley Jaster, Executive Director of Community and Public Works
Kyle Dooley, PE, CFM, City Engineer
Mashell Daniel, PE, CFM, Design Engineer
Dustin Henslee, PE, CFM, Stormwater Engineer
Lindy Coffee, Stormwater Coordinator
Vicki Melde, Marketing and Communications Manager

Texas Water Development Board:

Gilbert Ward
Ivan Ortiz, CFM
David Carter

Texas Department of Transportation:

Kenneth Icenhower, PE, Area Engineer

Texarkana Water Utilities:

David Latham

Halff Associates, Inc. Primary Staff Involved on the Project:

Cindy Mosier, PE, CFM
Benjamin Pylant, PE, CFM
Scott Rushing, EIT, CFM
Pamela Salvador, EIT, CFM
William Wiegand, CFM
Stephen Crawford, PE, CFM
Erin Atkinson, PE, CFM, GISP
Matt Kocian, GISP
Angela Wright, PE, CFM

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List of Acronyms

ASPRS	American Society of Photogrammetry and Remote Sensing
B/C	Benefit Cost
BCAD	Bowie County Appraisal District
cfs	Cubic Feet per Second
CDBG	Community Development Black Grant
CN	Curve Number
D/S	Downstream
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Map
FDA	Flood Damage Reduction Analysis
FEMA	Federal Emergency Management Agency
FIPS	Federal Information Processing Standard
FIS	Flood Insurance Study
FMA	Flood Mitigation Assistance
ft	Feet
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HMGP	Hazard Mitigation Grant Program
HMS	Hydrologic Modeling System
IP	Individual Permit
LiDAR	Light Detection and Ranging
mi	Miles
NAD83	North American Datum 1983
NAVD88	North American Vertical Datum of 1988
NRCS	Natural Resources Conservation Service
NSSDA	National Standards for Spatial Data Accuracy
NWP	Nationwide Permit
RAS	River Analysis System
RMSE	Root Mean Square Error
SCS	Soil Conservation Service
sq. mi	Square Miles
SSURGO	Soil Survey Geographic database
t_c	Time of Concentration
TCEQ	Texas Commission on Environmental Quality
TNRIS	Texas Natural Resources Information System
TR	Technical Release
TWDB	Texas Water Development Board
TxDOT	Texas Department of Transportation
U/S	Upstream
USACE	United States Army Corps of Engineers
USFW	United States Fish and Wildlife Service
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WSEL	Water Surface Elevation

1. Executive Summary

1. Executive Summary

The City of Texarkana located in Bowie County, Texas has experienced chronic flooding due to inadequate drainage systems in the watersheds located within the City. The purpose of the City of Texarkana City-wide Flood Protection Planning Study is to create new hydrologic and hydraulic models and perform a flood damage reduction alternative analysis to aid local officials in planning efforts. The City of Texarkana was awarded a Flood Protection Planning Grant from the Texas Water Development Board (TWDB) to help fund half of the project cost for this study.

New detailed hydrologic and hydraulic modeling was performed on Clear Creek, Corral Creek, Howard Creek, South Wagner Creek, Stream WC-1, Stream WC-2, Swampoodle Creek, Swampoodle Creek East Tributary, Swampoodle Creek West Channel, and Wagner Creek. This analysis was combined with the 2009 City of Texarkana Master Drainage Plan for Cowhorn Creek to create a basin wide study of the Texarkana, Texas watersheds. Detailed Light Detection and Ranging (LiDAR) elevation data, provided by the City of Texarkana, and cross section and bridge/culvert surveys were used to enhance the accuracy of the models. The analysis resulted in updated and more accurate discharges and water surface elevations (WSELs) for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year storm events. The resulting hydraulic data was then used to determine the annual flood damages and analyze flood reduction alternatives throughout the City of Texarkana.

Several flood reduction alternatives were identified during the flood damage reduction analysis (FDA). Structural and non-structural options were considered to help reduce flooding in the identified damage reaches. It was concluded from the analysis that detention options are costly and the benefits in flood damage reduction are predicted to be much lower than the cost of the project. Channel widening alternatives were analyzed but only a few damage reaches would realize benefits exceeding the cost of the project. The recommended alternatives that typically produce the highest benefit cost (B/C) ratios are structural acquisitions. The damage reduction (benefits) provided by each alternative over the existing conditions was compared to project costs with a B/C ratio and the results are included in the results section of this report.

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2. Introduction and Background

2. Introduction and Background

2.1. Community and Watershed Description

The City of Texarkana, Texas (the City) is a rapidly developing community that is concerned about the increasing threat of flooding and associated damages due to increased urbanization, specifically in the upstream (northern) portions of the City. The City of Texarkana's future population growth and associated development will require careful planning and management in order to minimize flood damages and to ensure the maximum possible preservation of the City's flood drainage corridors.

The City of Texarkana is located in the eastern portion of Bowie County in the northeast corner of Texas. It is bordered by the Cities of Nash and Wake Village, Texas to the west; Texarkana, Arkansas to the east; and Bowie County unincorporated area to the north, south, and west as shown in Figure 1: Location Map located in Appendix A. The City is the transportation, commercial, and industrial center for the surrounding areas, as well as the hub for portions of Oklahoma and Louisiana. The City has an estimated 2010 population of 36, 411 (Reference 1). Texarkana continues to grow, relying on the vast agricultural industry of the area as well as a variety of commercial and manufacturing facilities.

The City of Texarkana is located in a region of temperate mean climatological conditions, experiencing occasional extremes of temperature and rainfall of relatively short duration. Temperatures range from an average daily minimum of 33 degrees Fahrenheit in December to an average daily maximum of 94 degrees Fahrenheit in August. Average annual rainfall is 52 inches (Reference 2).

There are five (5) main watersheds within the City of Texarkana that encompass a total watershed area of approximately 40.5 square miles: Clear Creek, Cowhorn Creek, Howard Creek, Swampoodle Creek and Wagner Creek. Elevations in the study area range from a high of about 380 feet (ft) in the upper reaches to a low of about 260 feet at the watershed outlet. The existing conditions range from flat non-defined channels to deep, well defined and improved channels. Most of the stream crossings are concrete bridges and culverts. Several stream crossings restrict natural flow and cause water to backup and overflow.

2.2. Purpose of Report

The purpose of this report, "City of Texarkana, City-wide Flood Protection Planning Study," is to provide a comprehensive, updated floodplain management master plan for the City of Texarkana watersheds. This study addresses existing flooding problems within the City and provides planning alternatives and design concepts to help alleviate potential flood damages. The information presented in this report will provide the City with the necessary updated drainage information to coordinate future development and to help minimize existing potential flood damages along major stream corridors within the City.

This report provides a summary of the procedures used to analyze the existing flood problems and presents results and recommendations that were derived from the analyses. Additional information (e.g. field survey notes, photographs, and work maps) and digital files used in the production of this report are located in the Appendices.

2.3. Principal Flooding Problems

The City of Texarkana has experienced chronic flooding for decades due to inadequate drainage systems within the City. Until recently, the City has been forced to construct improvements on a case-by-case basis that included channelization, detention, and other structural improvements. A comprehensive flood study is necessary to determine the overall effect these changes have had on existing and future flood elevations.

Many of the City's flood damages or related problems are caused by inadequate capacity of the existing channels and bridges. Existing development, subject to overbank flooding, is primarily residential, but also includes some commercial property. Primary flooding locations exist near the Howard Creek confluence with Days Creek, Wagner Creek near the confluence with Cowhorn Creek, Stream WC-2, Cowhorn Creek upper reaches, Swampoodle Creek between 5th Street and 14th Street, and Swampoodle East Tributary. The Swampoodle Creek flooding is of particular importance as it impacts structures utilized by many of the City's first responders. The Swampoodle East Tributary is the City's most concentrated area of documented flood losses, as reported by the NFIP.

There are approximately 248 residential structures and 90 commercial structures located within the limits of the current effective 100-year floodplain. Based on 2009 Bowie County Appraisal Data, the estimated value of these structures exceeds $46,000,000. The existing hydrology and hydraulics of the City watersheds are based on studies from the late 1980s and early 1990s. These studies were the basis for the floodplain elevations which were remapped as part of the Federal Emergency Management Agency (FEMA) 2010 Bowie County Flood Insurance Study (FIS) (Reference 3). This FIS Study contained no new studies and is considered to be outdated and unusable for current planning and floodplain management purposes.

Historically, severe damage to existing properties has occurred as a result of heavy rainfall events. The United States Army Corps of Engineers (USACE) produced a document titled "Flood Plain Information Days Creek and Tributaries, Texarkana Arkansas-Texas" in 1970 (Reference 4). This report cited major flooding in the City of Texarkana in 1926, 1930, 1932, 1938, 1940, 1945, 1958, and 1968. The 1968 event is considered the greatest known flood and was the result of 9.29 inches of rainfall in a 24-hour period. Newspaper accounts of the flood describe a number of boating rescues, flooded streets, and property damage. In 1940, a 9.7 inch rainfall was recorded that reportedly left 750 people homeless and required the rescue of a number of citizens stranded by flooded streets and threatened by rising flood waters. More recent flood events were documented in 1976, 1991, 1998, 2001, 2003, and 2009.

2.4. Community Involvement

This project commenced with the first of three public meetings in the City of Texarkana on October 28, 2010. At the meeting, the project scope was discussed with the residents. A breakout session followed where maps were provided and residents voiced their flooding concerns. The second public meeting was held on April 20, 2011. The meeting focused on presenting the results of the hydrologic and hydraulic modeling and the resulting flood hazard mapping. The third and final public meeting was held on November 15, 2011. During the meeting every phase of the project was reviewed and the results of the flood damage assessment and flood reduction alternatives were discussed in detail. Final comments from residents and the TWDB were considered prior to the submittal of this final report.

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3. Study Procedure

3. Study Procedure

3.1. City of Texarkana

This City of Texarkana City-wide Flood Protection Planning study incorporates the detailed hydrology and hydraulics models developed as part of the 2009 Master Drainage Plan for Cowhorn Creek (Reference 5) and includes every major watershed impacting the City. The total study area encompasses approximately 25,950 acres (40.5 square miles (sq. mi.)). The City is divided into five (5) major watersheds: Clear Creek, Cowhorn Creek, Howard Creek, Swampoodle Creek, and Wagner Creek. Two (2) tributaries to Cowhorn Creek that were included in the 2009 study were Cowhorn Creek East Tributary and Cowhorn Creek West Tributary. Two (2) tributaries to Swampoodle Creek that were included in the study were Swampoodle Creek East Tributary and Swampoodle Creek West Tributary. One (1) tributary to Howard Creek included in the study was Corral Creek. Three (3) tributaries to Wagner Creek that were included in the study were Stream WC-1, Stream WC-2, and South Wagner.

Table 1, Study Streams, is a summary of the source and description of each study stream. Figure 2, Study Streams, is a graphical representation of this information.

Table 1. Study Streams

Stream Name	Study	Downstream Limit	Upstream Limit	Length (miles)
Clear Creek	New Detailed	Bringle Lake	Wyatt Lane	1.67
Corral Creek	New Detailed	Confluence with Howard Creek	Texarkana City limits	1.88
Cowhorn Creek	2009 Study	Confluence with Wagner Creek	1,400 feet upstream of Cowhorn Creek Road	3.99
Cowhorn Creek East Trib	2009 Study	Confluence with Cowhorn Creek	Summerhill Road (FM 1397)	0.55
Cowhorn Creek West Trib	2009 Study	Confluence with Cowhorn Creek	500 feet upstream of Saint Michael Drive	0.64
Howard Creek	New Detailed	Confluence with Days Creek	Texarkana City limits	3.79
South Wagner	New Detailed	Confluence with Wagner Creek	300 feet upstream of W 7th Street (US Hwy 59)	2.47

Stream Name	Study	Downstream Limit	Upstream Limit	Length (miles)
Steam WC-1	New Detailed	Confluence with Wagner Creek	350 feet downstream of Richmond Road	1.75
Stream WC-2	New Detailed	Confluence with Wagner Creek	2,300 feet upstream of Concord Place	1.25
Swampoodle Creek	New Detailed	Confluence with Days Creek	750 feet upstream of 40th Street	3.36
Swampoodle Creek East Trib	New Detailed	Confluence with Swampoodle Creek	100 feet upstream of Pine Street	0.46
Swampoodle Creek West Channel	New Detailed	Confluence with Swampoodle Creek	College Drive	0.28
Wagner Creek	New Detailed	Confluence with Days Creek	2,100 feet upstream of McKnight Road	7.88
			Total Length:	**30.0**

3.2. Survey

3.2.1. Site Reconnaissance

Field reconnaissance was performed during multiple site visits to walk the streams and collect structure inventories during the end of 2010 and during the first half of 2011. Photographs of the channels and structures were taken to aid in hydraulic modeling and to assign Manning's channel "n" values.

3.2.2. Survey

The survey task included identifying and establishing survey control, conducting channel and structure surveys, and obtaining the physical dimensions of hydraulic and flood control structures. Survey was conducted by Halff from October 2010 through November 2010 with some additional survey data collected in February and June 2011.

Ninety-five (95) structure surveys and ninety (90) channel surveys (not including channel surveys near structures) were taken. For each surveyed structure, the channel upstream of the structure was surveyed and the cross section downstream of the structure was modeled with the upstream channel survey data adjusted according to a survey shot of the flowline downstream of the structure.

In addition to the survey collected for this study, survey was performed on Cowhorn Creek as part of the 2009 City of Texarkana study performed by Halff. Thirty (30) structure surveys and sixteen (16) channel surveys (not including channel surveys near structures) were taken.

The location and name of all survey data incorporated into this study can be seen in Figure 3 Study Survey Summary. The text file survey point data, photographs, and sketches are included on the CD-ROM in Appendix H.

The field survey was performed using vertical survey datum North American Vertical Datum of 1988 (NAVD88). The survey data included in Appendix H is in State Plane Coordinates, Texas North Central Federal Information Processing Standard (FIPS) 4202 (GRID – feet), North American Datum 1983 (NAD 83).

3.2.3. Topographic Data

The topographic data utilized for this study was the City of Texarkana 2006 Lidar data. The LiDAR data was processed in ESRI's ArcGIS software to create a terrain and Digital Elevation Model (DEM) data set for the project area.

3.2.4. Data Collection

Past studies in the City of Texarkana were received through an External Data Request from the Federal Emergency Management Agency in January 2010. The following is a summary of reports and data collected for the watershed.

Hydrology:

- HEC-1 model – Original Effective FEMA Hydrology (1988)

Hydraulics:

- HEC-2 models - Original Effective FEMA Hydraulics Model (1988)

Reports:

- Flood Plain Information Days Creek and Tributaries, Texarkana, Texas-Arkansas (1970)
- Comprehensive Drainage Report, Texarkana, Texas (1976)
- City of Texarkana FEMA FIS Report (1992)
- Bowie County FEMA FIS Report (2010)
- Texas Department of Transportation (TxDOT) construction plans: Plans of Proposed Highway Improvement Federal Aid Project IMD 0303 (120), etc. Bowie County I.H. 30, From: North 0.6 Miles W. of FM 989 to Arkansas State Line, dated April 2006

- Texas Department of Transportation (TxDOT) construction plans: Plans of Proposed State Highway Improvement, Federal Aid Project STP 93 (21) UM Bowie County FM 559, From 0.2 Miles N or FM 2240 to FM 1297, dated November 1992

3.3. Hydrologic Analysis

A detailed hydrologic analysis was performed on four of the five major watersheds within the City of Texarkana which includes Clear Creek, Howard Creek, Swampoodle Creek, and Wagner Creek. The USACE Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS, Version 3.5) was utilized for the hydrologic modeling in this study (Reference 6). The Cowhorn Creek detailed hydrology model prepared as part of the 2009 "Master Drainage Plan for Cowhorn Creek" was combined with this report. Rainfall events selected for this study include the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year frequency floods.

3.3.1. Drainage Areas

Watershed boundaries were delineated using visual inspection of the 2006 City of Texarkana topographic data. The sub-basin boundaries were adjusted based on visual identification of above ground storm sewer features from 2010 aerial photos obtained from the City of Texarkana as well as field identification. The five (5) main watersheds: Clear Creek, Cowhorn Creek, Howard Creek, Swampoodle Creek and Wagner Creek encompass a total watershed area of approximately 40.5 square miles. The watershed was divided into 133 subbasins with an average subbasin size of 0.30 square miles.

Figure 4 shows the drainage areas that were delineated for this study. A general description of each watershed and the streams contained within each watershed can be found below. Drainage areas include all upstream area draining to the creeks including their tributaries.

Clear Creek Watershed

The Clear Creek watershed is located in the northern portion of the City of Texarkana, Texas. Approximately half of the watershed is located within the limits of the City of Texarkana, Texas and the rest of the watershed is in the Bowie County unincorporated area. The existing upper watershed is heavily developed primarily with residential properties. The entire Clear Creek watershed drains to Bringle Lake located in the lower watershed. The Texas A&M University Texarkana campus is centrally located within the Clear Creek watershed.

There is one studied tributary within the Clear Creek watershed; Clear Creek. Clear Creek is a tributary to Bringle Lake and is approximately 1.67 miles in length through the study area with an average slope of 0.3%. Clear Creek originates just upstream of Wyatt Lane and generally flows north to the confluence with Bringle Lake. The total contributing watershed draining to Clear Creek is about 5.05 square miles or approximately 3,230 acres.

Cowhorn Creek Watershed

The Cowhorn Creek watershed is centrally located in the City of Texarkana, Texas. Nearly the entire watershed is contained within the limits of the City of Texarkana, Texas. The watershed is currently about 80% urbanized. The existing upper watershed, upstream of FM 559, is heavily developed along Interstate 30 with commercial and retail properties which include the mall and Christus St. Michaels Hospital. The central and lower watershed consists of some retail development along the major roadways with a larger percentage of residential properties bordering Cowhorn Creek. Texarkana College is centrally located in the watershed with the water treatment plant and Army Reserve Facilities located farther downstream.

There are three studied tributaries within the Cowhorn Creek watershed; Cowhorn Creek, Cowhorn Creek East Tributary, and Cowhorn Creek West Tributary.

Cowhorn Creek is approximately 3.99 miles in length through the study area with an average slope of 0.3%. Cowhorn Creek originates approximately 1,400 feet northwest of Cowhorn Creek Road and generally flows south to the confluence with Wagner Creek. The total contributing watershed draining to Cowhorn Creek is about 5.52 square miles or approximately 3,530 acres.

Cowhorn Creek East Tributary is approximately 0.55 miles in length through the study area with an average slope of 0.5%. Cowhorn Creek East Tributary originates near Summerhill Road and generally flows southwest before joining Cowhorn Creek just upstream of Saint Michael Drive. The total contributing watershed draining to Cowhorn Creek East Tributary is about 0.62 square miles or approximately 397 acres.

Cowhorn Creek West Tributary is approximately 0.64 miles in length through the study area with an average slope of 0.7%. Cowhorn Creek West Tributary originates approximately 500 feet upstream of Saint Michael Drive and generally flows southeast before joining Cowhorn Creek approximately 460 feet upstream of Kennedy Lane. The total contributing watershed draining to Cowhorn Creek West Tributary is about 0.57 square miles or approximately 365 acres.

Howard Creek Watershed

The Howard Creek watershed is located in the southern portion of the City of Texarkana, Texas. Approximately half of the watershed is located within the limits of the City of Texarkana, Texas and the remaining watershed is located in the City of Wake Village and Bowie County unincorporated areas. The watershed is currently about 40% urbanized. The existing commercial and industrial development is along State Highway 93, Kings Highway and U.S. Highway 67. There is a large residential development in the upper watershed upstream of U.S. Hwy 67. Other residential developments are sporadically located within the watershed. The entire Howard Creek watershed drains to Days Creek.

There are two studied tributaries within the Howard Creek watershed; Howard Creek and Corral Creek.

Howard Creek is approximately 3.79 miles in length through the study area with an average slope of 0.2%. Howard Creek originates just upstream of Brown Dr. and generally flows southeast to the confluence with Days Creek. The detailed study extends from the confluence with Days Creek to Loop 151/Jarvis Parkway (Texarkana City limits). The total contributing watershed draining to Howard Creek is about 7.71 square miles or approximately 4,935 acres.

Corral Creek is approximately 1.88 miles in length through the study area with an average slope of 0.4%. Corral Creek originates just downstream of Wingwright Boulevard and generally flows east to the confluence with Howard Creek. The detailed study extends from the confluence with Howard Creek to Loop 151/Jarvis Parkway (Texarkana City limits). The total contributing watershed draining to Corral Creek is about 1.88 square miles or approximately 1,200 acres.

Swampoodle Creek Watershed

The Swampoodle Creek watershed is located in the eastern portion of the City of Texarkana, Texas. The portion of the Swampoodle watershed east of U.S. Highway 71 is located in the City of Texarkana, Arkansas. The watershed is currently about 90% urbanized. The upper and central existing watershed is heavily developed with residential communities. The lower watershed consists primarily of commercial development in downtown Texarkana, Texas. The entire Swampoodle Creek watershed drains to Days Creek.

There are three studied tributaries within the Swampoodle Creek watershed; Swampoodle Creek, Swampoodle Creek East Tributary, and Swampoodle Creek West Channel.

Swampoodle Creek is approximately 3.36 miles in length through the study area with an average slope of 0.3%. Swampoodle Creek originates approximately 750 feet north of 40th Street and generally flows south to the confluence with Days Creek. The total contributing watershed draining to Swampoodle Creek is about 4.43 square miles or approximately 2,835 acres.

Swampoodle Creek East Tributary is approximately 0.49 miles in length through the study area with an average slope of 0.3%. Swampoodle Creek East Tributary originates near Wood Street and generally flows south before joining Swampoodle Creek approximately 1,560 feet downstream of College Drive. The detailed study extends from the confluence with Swampoodle Creek to approximately 100 feet upstream of Pine Street. The total contributing watershed draining to Swampoodle Creek East Tributary is about 0.95 square miles or approximately 610 acres.

Swampoodle Creek West Channel is approximately 0.28 miles in length through the study area with an average slope of 0.1%. Swampoodle Creek West Channel originates near College Drive and generally flows south before joining Swampoodle Creek approximately 1,220 feet downstream of College Drive. The total contributing watershed draining to Swampoodle Creek West Channel is about 0.66 square miles or approximately 420 acres.

Wagner Creek Watershed

The Wagner Creek watershed is the largest watershed in the City of Texarkana, Texas. Approximately 60% of the watershed is located within the limits of the City of Texarkana, Texas with the remaining portion of the watershed in the Cities of Nash, Wake Village, and Red Lick and Bowie County Unincorporated area. The watershed is currently about 50% urbanized. The existing watershed is heavily developed along major thoroughfares with commercial and industrial properties. There are multiple residential communities scattered throughout the watershed. The entire Wagner Creek watershed drains to Days Creek.

There are four studied tributaries within the Wagner Creek watershed; Wagner Creek, South Wagner Creek, Stream WC-1 and Stream WC-2.

Wagner Creek is approximately 7.88 miles in length through the study area with an average slope of 0.1%. Wagner Creek originates near County Road 2213 in the town of Red Lick and generally flows southeast to the confluence with Days Creek. The detailed study extends from the confluence with Days Creek to approximately 2,100 feet upstream of McKnight Road. The total contributing watershed draining to Wagner Creek is about 23.35 square miles or approximately 14,945 acres.

South Wagner Creek is approximately 2.47 miles in length through the study area with an average slope of 0.3%. South Wagner Creek originates 300 feet upstream of U.S. Highway 59 and generally flows east before joining Wagner Creek approximately 530 feet upstream of State Highway 93. The total contributing watershed draining to South Wagner Creek is about 1.92 square miles or approximately 1,230 acres.

Stream WC-1 is approximately 1.75 miles in length through the study area with an average slope of 0.6%. Stream WC-1 originates 300 feet downstream of Richmond Road and generally flows southwest before joining Wagner Creek approximately 450 feet downstream of Interstate 30. The total contributing watershed draining to Stream WC-1 is about 0.92 square miles or approximately 590 acres.

Stream WC-2 is approximately 1.25 miles in length through the study area with an average slope of 0.6%. Stream WC-2 originates approximately 2,300 feet upstream of Concord Place and generally flows southwest before joining Wagner Creek approximately 1,050 feet upstream of McKnight Road. The total contributing watershed draining to Stream WC-2 is about 0.86 square miles or approximately 550 acres.

3.3.2. Precipitation

The standard 24-hour (hr) duration frequency storm event was used to establish rainfall parameters. Point rainfall depths were obtained from the "United States Geological Survey (USGS) Water Resources Investigation Report Atlas of Depth-Duration Frequency of Precipitation Annual Maxima for Texas 98-4044" (Reference 7). The rainfall data is summarized below in Table 2, Rainfall Data.

Table 2. Rainfall Data (inches (in))

Flood Event		Storm Duration							
Year	%	5 Min	15 Min	1 Hr	2 Hr	3 Hr	6 Hr	12 Hr	24 Hr
2	50%	0.50	0.94	1.68	2.22	2.43	2.82	3.24	3.84
5	20%	0.57	1.20	2.18	2.88	3.15	3.78	4.32	5.52
10	10%	0.63	1.39	2.53	3.36	3.66	4.44	5.16	6.48
25	4%	0.72	1.68	3.00	4.00	4.38	5.34	6.36	8.16
50	2%	0.78	1.92	3.38	4.54	4.95	6.12	7.32	9.36
100	1%	0.85	2.20	3.80	5.16	5.61	6.96	8.40	10.56
250	0.4%	0.97	2.63	4.43	6.04	6.60	8.22	10.20	12.72
500	0.2%	1.03	3.01	4.95	6.80	7.44	9.36	11.76	14.16

3.3.3. Rainfall-Runoff Losses

All rainfall-runoff losses were computed using the Soil Conservation Service (SCS) Curve Number (CN) loss method, developed by the Natural Resources Conservation Service (NRCS), formerly SCS. This method is used to predict the direct runoff or infiltration of an area based on the area's land use, aerial photos, hydrologic soil group, hydrologic condition, and ultimate condition.

Land use for the watersheds was determined for existing conditions based on the City of Texarkana 2010 aerial photos and ultimate conditions from the City of Texarkana Zoning Maps. For the purposes of this study, the zoning for office/institutional, retail, and mixed-use development was grouped with commercial land use due to the similar nature of the rainfall runoff characteristics. Residential land use was divided into large-lot low-density, small-lot low-density, small-lot moderate density, and small-lot high-density areas to differentiate between the diverse residential characteristics of the watershed.

Figures 5 and 6 show the Existing conditions and the Ultimate conditions land use, respectively.

Percent impervious is a function of the various land uses within a watershed basin. The City of Texarkana's Comprehensive Drainage Report (Tables VI-2, pg. 114) (Reference 8), along with drainage design information accepted in several comparable Texas communities were used to derive appropriate percent impervious values for each land use. The specific land uses and their corresponding percent impervious values are included in Table 3. A composite percentage of impervious area was computed for each sub-basin for both existing (2010) and ultimate conditions. The percent impervious values input into the HEC-HMS model represent the corresponding amount of existing or anticipated development.

Table 3. Percent Impervious

Land Use Classification	Characteristic Imperviousness
Brush	1%
Open	1%
Commercial	85%
Industrial	72%
Residential – Large-Lot Low-Density	25%
Residential – Small-Lot Low Density	25%
Residential – Small-Lot Moderate Density	35%
Residential – Small-Lot High Density	45%
Residential – Multi-Family	72%
Pavement	100%

The hydrologic soil types in this study were obtained from the NRCS, Soil Survey Geographic database (SSURGO) for Bowie County (Reference 9). Soil properties influence the relationship between rainfall and runoff so the soils are grouped into four hydrologic soil groups: A, B, C, and D based on runoff potential.

All watersheds studied within this report are predominately Group C soil which indicates moderately fine to fine texture and slow infiltration rates. The stream corridors in these watersheds are a mixture of Group D soils and Group B soils. Group D soils are defined as clayey with slow infiltration rates and a high potential for runoff. Group B soils indicate soils having some content of gravelly sand with moderate infiltration rates and a low/ moderate runoff potential.

Figure 7, Soils Map, shows the hydrologic soil types through the watershed.

The antecedent moisture condition (AMC) defines the soil moisture condition prior to a storm. AMC-II, average soil moisture conditions, was used for the purposes of this study.

3.3.4. Unit Hydrograph Method

The SCS Dimensionless Unit Hydrograph method was used and SCS lag times were computed for each sub-basin to generate runoff hydrographs. Time of concentration was computed separately for existing and ultimate conditions. Both were based on TR-55 (Reference 10) methodology for overland flow (sheet flow and shallow concentrated flow). Overland flow length was limited based on existing and ultimate land use conditions. Overland flow was limited to 100 feet for undeveloped and residential land use and 50 feet for industrial/commercial land use. Ultimate conditions shallow concentrated flow was assumed to be all paved in areas where future development is anticipated. Travel times for channel flow were based on velocities from the hydraulic model, where available. Channel flows for non-studied reaches were estimated based on Manning's equation. Storm drain velocities were assumed to be 6 feet per second for the purposes of this study.

The time of concentration is the summation of these phases, where:

$$t_c = t_{sheet} + t_{shallow\ concentrated} + t_{storm\ drain} + t_{channel}$$

Lag times were computed using the following equation:

$$T_p = 0.6 * t_c.$$

Tables B.1 and B.2 located in Appendix B contain lag time calculations for existing and ultimate conditions, respectively, for all sub-basins within the study area. Table 4, Summary of Hydrologic Parameters, summarizes the sub-basin area, SCS lag time, and SCS CN for both existing and ultimate conditions for each sub-basin.

3.3.5. Flood Routing

Routing of flood flows through channels and reservoirs is necessary in order to model the amount of valley storage in the stream reaches. This valley storage reduces peak flows at the downstream end of a reach. The Modified Puls routing method was utilized for this study. This method is based on the conservation of mass and the concept that storage is a function of outflow to route flows through a designated stream reach. To establish storage-outflow relationships, volumes through each reach were determined using a range of steady-flow water surface profiles in Hydrologic Engineering Center River Analysis System (HEC-RAS) hydraulic models created as part of this study. These relationships were imported into HEC-HMS and used to calculate discharges at the downstream end of each designated reach based on the inflow and storage in each reach. Storage-outflow relationships were determined for existing channel and floodplain conditions. The Muskingum-Cunge Routing method was utilized in the current effective models and was explored for this study as well. The Muskingum-Cunge assumes a circular, triangular, trapezoidal, rectangular, or a typical eight-point cross section. The valley storage in the streams could not be modeled as accurately using this method. Therefore, the Modified Puls method was selected based on the accuracy on which it approximated the storage through a given reach. This method is the preferred routing method in similar watersheds where detailed hydraulic modeling is performed.

3.3.6. Detention

Six (6) existing detention ponds were identified as part of the study watersheds, as shown in Figure 8: Existing Detention Ponds. Three (3) of the detention ponds were in the Cowhorn Creek watershed, one (1) was in the Clear Creek watershed, and two (2) were in the Swampoodle Creek watershed. Elevation-Area curves were developed from the City of Texarkana 2006 Lidar data. The outlet structures of each pond were surveyed and modeled in HEC-RAS to develop the Elevation-Discharge curves.

Table 4. Hydrologic Parameters

HEC-HMS Basin Name	Area (ac)	Lag Time		% Water	% Soil Type B	% Soil Type C	% Soil Type D	Composite CN		% Impervious	
		Exist (min)	Ultimate (min)					Existing	Ultimate	Existing	Ultimate
Clear Creek											
CC1	131	11	11	0	0	91	9	75	75	36	46
CC2	108	36	36	7	0	70	23	77	77	46	55
CC3	38	11	11	0	0	100	0	74	74	32	49
CC4	243	21	15	1	0	99	0	74	74	35	62
CC5	157	27	16	0	0	95	5	74	74	40	53
CC6	363	36	28	0	1	75	24	75	75	25	55
CC7	31	6	6	0	0	94	6	74	74	30	53
CC8	138	21	19	0	0	61	39	76	76	17	70
CC9	136	27	21	0	27	70	3	71	71	22	61
CC10	109	24	24	0	8	42	50	76	76	17	71
CC11	312	22	20	0	20	50	30	73	73	27	57
CC12	141	19	17	2	43	53	2	69	69	16	46
CC13	314	30	22	0	49	46	5	68	68	12	41
CC14	106	21	14	2	74	24	0	65	65	8	24
CC15	148	12	8	2	68	30	0	66	66	11	37
CC16	752	24	13	30	34	17	19	79	79	33	48
Cowhorn Creek											
COW1	192	38	35	0	4	74	22	74	75	35	60
COW2	83	17	17	0	32	67	1	68	70	43	81
COW3	22	12	10	0	23	52	26	71	73	56	85
COW4	68	15	13	0	63	18	19	67	67	43	88
COW5	64	16	12	0	84	0	16	62	64	21	85
COW6	25	15	11	0	61	3	36	65	68	13	82

HEC-HMS Basin Name	Area (ac)	Lag Time		% Water	% Soil Type B	% Soil Type C	% Soil Type D	Composite CN		% Impervious	
		Exist (min)	Ultimate (min)					Existing	Ultimate	Existing	Ultimate
COW7	37	11	11	0	64	22	14	66	66	35	59
COW8	218	15	15	0	28	60	12	71	71	67	76
COW9	28	6	6	0	0	100	0	74	74	78	82
COW10	139	25	22	0	0	100	0	74	74	34	55
COW11	146	15	14	0	0	90	11	75	75	40	67
COW12	242	14	12	0	10	74	16	74	74	52	66
COW13	206	13	13	0	0	76	24	75	75	45	58
COW14	63	17	16	0	0	100	0	74	74	23	47
COW15	184	19	17	0	0	94	6	74	74	61	73
COW16	109	10	10	0	0	67	33	76	76	55	68
COW17	346	33	33	0	2	77	21	74	75	45	65
CNT1	126	28	25	0	0	81	19	75	75	42	61
CNT2	71	9	8	0	3	79	18	73	75	39	83
CUT1	181	30	25	0	2	92	6	73	74	33	54
CUT2	99	18	17	0	21	79	0	71	71	42	55
CUT3	121	11	11	0	81	16	3	64	64	67	82
CET1	254	34	34	0	22	66	13	71	72	47	63
CET2	142	30	30	0	16	65	19	72	73	55	76
CWT1	265	24	24	0	31	56	14	70	71	42	72
CWT2	100	27	21	0	30	45	25	71	72	65	87
Howard Creek											
HOW1	696	48	41	0	4	84	12	74	74	25	70
HOW2	352	34	24	1	9	90	0	73	73	26	78
HOW3	297	30	29	0	4	95	1	74	74	41	64
HOW4	387	32	32	0	10	87	3	73	73	25	69
HOW5	220	29	21	0	9	91	0	73	73	19	75

HEC-HMS Basin Name	Area (ac)	Lag Time		% Water	% Soil Type B	% Soil Type C	% Soil Type D	Composite CN		% Impervious	
		Exist (min)	Ultimate (min)					Existing	Ultimate	Existing	Ultimate
HOW6	342	32	23	0	8	90	2	73	73	18	73
HOW7	180	18	10	0	10	90	0	73	73	21	74
HOW8	429	31	23	0	9	90	1	73	73	21	69
HOW9	134	18	18	0	13	87	0	72	72	61	78
HOW10	214	28	28	0	19	81	0	72	72	23	54
HOW11	179	34	33	0	24	67	9	71	71	16	46
HOW12	96	18	18	0	24	76	0	71	71	28	63
HOW13	206	25	17	0	24	66	10	71	71	35	73
COC1	271	37	30	0	3	82	15	75	75	19	79
COC2	120	21	20	0	3	79	18	75	75	39	71
COC3	168	23	14	0	5	95	0	73	73	27	67
COC4	153	23	22	4	0	96	0	75	75	43	62
COC5	132	23	19	0	8	92	0	73	73	38	68
COC6	358	25	25	1	5	94	0	74	74	15	60
Swampoodle Creek											
SPC1	79	21	12	0	0	100	0	74	74	45	82
SPC2	25	11	11	0	0	100	0	74	74	55	68
SPC3	98	24	21	7	0	93	0	76	76	32	39
SPC4	55	19	19	0	0	100	0	74	74	55	63
SPC5	12	7	7	0	58	42	0	67	67	27	72
SPC6	24	13	7	0	83	17	0	63	63	20	73
SPC7	70	11	11	0	5	95	0	73	73	54	63
SPC8	90	9	9	0	3	97	0	74	74	38	64
SPC9	52	13	8	0	16	84	0	72	72	53	80
SPC10	83	15	15	0	6	94	0	73	73	62	71

HEC-HMS Basin Name	Area (ac)	Lag Time		% Water	% Soil Type B	% Soil Type C	% Soil Type D	Composite CN		% Impervious	
		Exist (min)	Ultimate (min)					Existing	Ultimate	Existing	Ultimate
SPC11	89	16	15	0	24	76	0	71	71	60	77
SPC12	114	18	13	0	6	94	0	73	73	55	74
SPC13	79	13	9	0	31	69	0	70	70	59	83
SPC14	348	29	29	0	1	99	0	74	74	58	76
SPC15	256	20	20	0	0	100	0	74	74	75	78
SPC16	326	22	22	0	35	65	0	70	70	74	87
SPCET1	79	14	7	0	0	100	0	74	74	70	78
SPCET2	179	16	16	0	0	100	0	74	74	52	58
SPCET3	88	13	13	0	0	100	0	74	74	46	53
SPCET4	143	20	20	0	0	100	0	74	74	53	59
SPCET5	122	13	8	0	9	91	0	73	73	53	64
SPCWC1	232	31	29	0	0	100	0	74	74	41	52
SPCWC2	191	22	18	0	8	92	0	73	73	55	70
Wagner Creek											
WC1	353	28	20	0	10	81	9	73	73	11	68
WC2	244	23	16	1	37	62	0	69	69	21	51
WC3	470	32	25	1	20	74	5	72	72	16	58
WC4	131	30	29	0	18	77	5	72	72	22	51
WC5	279	27	26	0	0	90	10	75	75	26	48
WC6	166	47	43	0	0	97	3	74	74	24	51
WC7	159	35	33	0	25	75	0	71	71	24	50
WC8	586	44	44	0	9	84	7	73	73	27	55
WC9	479	40	39	0	9	89	2	73	73	23	48
WC10	508	50	49	0	16	72	12	73	73	18	79
WC11	733	36	29	0	11	88	1	73	73	29	75
WC12	621	48	48	0	12	88	0	72	72	29	73

HEC-HMS Basin Name	Area (ac)	Lag Time		% Water	% Soil Type B	% Soil Type C	% Soil Type D	Composite CN		% Impervious	
		Exist (min)	Ultimate (min)					Existing	Ultimate	Existing	Ultimate
WC15	318	26	21	0	7	78	15	74	74	29	75
WC16	384	36	27	0	19	77	4	72	72	55	86
WC17	186	29	29	0	0	69	31	76	76	47	82
WC18	278	30	24	0	0	64	36	76	76	23	68
WC19	276	28	28	0	0	77	23	75	75	32	60
WC20	517	38	27	0	9	68	23	74	74	33	61
WC21	129	26	20	0	18	68	14	73	73	29	72
WC22	255	24	23	0	0	100	0	74	74	43	67
WC23	167	29	28	2	40	58	0	69	69	15	34
WC24	433	39	39	0	43	57	0	68	68	39	55
WC25	158	21	16	3	54	35	8	68	68	41	74
WC26	76	19	12	0	93	7	0	62	62	27	74
WC27	260	20	17	0	0	100	0	74	74	61	81
WC28	260	22	22	0	19	75	6	72	72	30	64
WC29	152	33	27	0	2	65	33	76	76	33	66
WC30	465	38	33	0	18	61	21	73	73	31	66
SWC1	237	33	33	0	6	94	0	73	73	49	64
SWC2	141	19	13	0	12	88	0	72	72	48	63
SWC2A	31	15	9	0	12	88	0	72	72	51	82
SWC3	123	15	15	0	18	82	0	72	72	44	74
SWC4	216	18	15	0	35	65	0	69	69	20	73
SWC5	195	24	14	4	30	66	0	71	71	36	61
SWC6	286	32	29	0	14	84	2	72	72	34	60
WC1_1	45	16	9	0	0	97	3	74	74	68	84
WC1_2	111	24	14	2	0	88	10	75	75	36	76
WC1_3	84	21	14	0	0	100	0	74	74	27	76

HEC-HMS Basin Name	Area (ac)	Lag Time		% Water	% Soil Type B	% Soil Type C	% Soil Type D	Composite CN		% Impervious	
		Exist (min)	Ultimate (min)					Existing	Ultimate	Existing	Ultimate
WC1_4	112	27	27	0	6	94	0	73	73	30	58
WC1_5	68	22	14	0	1	99	0	74	74	12	72
WC1_6	102	15	8	0	6	94	0	73	73	14	86
WC1_7	67	11	11	0	0	92	8	74	74	34	87
WC2_1	111	30	27	0	0	97	3	74	74	32	66
WC2_2	73	11	10	0	0	88	12	75	75	29	66
WC2_3	79	27	17	0	0	96	4	74	74	16	50
WC2_4	36	16	7	0	43	57	0	68	68	34	50
WC2_5	170	26	24	0	30	58	12	71	71	15	71
WC2_6	35	12	11	0	41	59	0	69	69	21	62
WC2_7	45	19	16	0	27	73	0	70	70	9	60

Several other ponds were found in the study area but were not modeled as reservoirs due to limited detention volume or the absence of a defined outlet structure. Inline ponds were modeled with cross sections in the hydraulics model and included as part of the Modified Puls routing for the reach.

3.3.7. Aerial Reduction

The rainfall was adjusted utilizing the TP-40 "Depth-Area-Duration Curves" (Reference 11) for each storm area when the contributing drainage area was greater than 9.6 square miles.

3.4. Hydraulic Analysis

A hydraulic analysis was performed utilizing the USACE HEC-RAS software, version 4.1.0 (Reference 12). The purpose of the analysis was to develop flood profiles for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year storm events for existing and ultimate conditions. The hydraulic models developed for the 2009 City of Texarkana Cowhorn Creek Master Drainage Plan were incorporated with this study to provide a comprehensive City-wide flood protection report.

3.4.1. Stream Centerlines and Cross Sections

Study stream centerlines from the 2010 Bowie County Digital Flood Insurance Rate Map (DFIRM) Database (Reference 13) were adjusted to reflect survey data and 2006 LiDAR. Hydraulic cross sections used for the study streams' HEC-RAS models were placed at close intervals above and below bridges and culverts, where applicable, in order to compute the significant effective flow and backwater effects of these structures. HEC-GeoRAS software was used to extract geographical data for centerlines and cross sections. Elevation data was extracted from the terrain model created from 2006 City of Texarkana LiDAR for each cross section and imported into HEC-RAS. The cross section profiles were supplemented with field survey where available. Flowlines and channels of non-surveyed hydraulic cross sections were interpolated based on nearby channel surveys when the topographic data was not sufficient to define the channels.

3.4.2. Modeling Variables

Channel roughness factors (Manning's "n") were assigned based on field inspection and aerial photographs. Table 5, Manning's Roughness Coefficients by Type, is a summary of n-values used in this study.

Appropriate expansion and contraction coefficients of 0.3 and 0.5 were applied upstream and downstream of structures to account for natural and structural variation in channel cross section shape.

Ineffective flow areas were entered in the overbanks of the channel upstream and downstream of structures to account for overbank loss of conveyance due to the structures. Ineffective flow limits were also used in situations where there was storage without conveyance in the cross section overbanks.

The starting boundary conditions varied for many of the detailed study streams included in this study. The following streams utilized known water surface elevations based on coincident flow elevations as the starting boundary condition: Cowhorn Creek East Tributary, Cowhorn Creek West Tributary, South Wagner Creek, Swampoodle Creek, Swampoodle Creek East Tributary, Swampoodle Creek West Channel, Stream WC-2, and Wagner Creek. The current effective HEC-2 known water surface elevations were utilized for Swampoodle Creek and Wagner Creek. Normal depth was used as the starting boundary condition when it produced higher starting water surface elevations compared to the coincident flow elevations. The following streams utilized normal depth as the starting boundary condition: Corral Creek, Cowhorn Creek, Howard Creek, and Stream WC-1. The starting boundary conditions for Clear Creek utilized the current effective HEC-2 known water surface elevation from Bringle Lake for the 100-year storm event. All other storm events for Clear Creek utilized starting water surface elevations based on normal depth calculations.

Table 5. Manning's Roughness Coefficients by Type

Description	Channel n-Values	Overbank n-Values
Concrete Clean well kept	0.015	
Concrete with cracks, grass and weeds	0.020	
Gabion	0.025-0.032	
Clean, straight, full, no rifts or deep pools	0.030	
Grassed Lined Channel- No weeds	0.030	
Rock Rip Rap	0.035	
Clean Straight, but more stones and weeds	0.035-0.040	
Clean, winding, some pools and shoals	0.040-0.045	
Clean, winding, some pools and shoals, some weeds and stones	0.045	
Clean, winding, some pools and shoals, some weeds and stones, lower stages, more ineffective slopes and sections	0.050	
Clean, winding, some pools and shoals, with weeds and stones, lower stages, more ineffective slopes and sections	0.055	
Clean, winding, some pools and shoals, with lots of weeds and stones	0.060	
Sluggish reaches, weedy. deep pools	0.070	
Sluggish reaches, weedy, deep pools, heavy weeds brush some trees	0.080-0.090	
Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.100	
Open Grassy Areas well maintained (i.e. Golf		0.035

Description	Channel n-Values	Overbank n-Values
Courses)		
Mainly Asphalt, Some Obstructions, Curbs, Few Trees, Small Amounts of Grass, Hwy Frontage		0.040
Open Grassy Areas, wild		0.040-0.050
Industrial/Commercial with more vegetation		0.050-0.070
Industrial (bldgs, cars, workers)		0.060
Grassy, some bushes, some trees,		0.050-0.070
Woods, Fields (50/50)		0.070-0.080
Open Yards, Fences, Few Trees, Houses		0.070-0.090
Close Residential, Streets		0.080-0.090
Residential, Many Trees		0.090
Heavy Wooded		0.100-0.120

3.5. Results of Hydrologic and Hydraulic Analyses

3.5.1. Peak Discharges

Peak flood discharges calculated for this study include the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year flood frequencies for both existing land use conditions and projected ultimate land use conditions. Ultimate land use conditions were analyzed with channel flood routing data based on existing channels and bridges. Peak discharges were computed for each sub-basin. Tables 6 and 7 display peak discharges in cubic feet per second (cfs) for existing and ultimate conditions, respectively. Tables C.1 and C.2 in Appendix C display hydrologic output data for all subbasins in the study area.

3.5.2. Water Surface Elevations

Peak WSELs were calculated for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year flood frequencies for both existing land use conditions and projected ultimate land use conditions. Flood profiles and HEC-RAS output tables (Existing and Ultimate conditions) are included in Appendix D. The 100- and 500-year existing conditions WSELs were mapped on the 2006 City of Texarkana LiDAR and are shown along with the cross sections on Figure 9, Floodplain Workmaps. Floodways were modeled for all study streams and are also show in the Floodplain Workmaps.

3.5.3. Existing vs. Ultimate Conditions

Peak flood discharges for both the existing and ultimate conditions were compared for the 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year flood frequencies. Table 8, Existing Conditions vs. Ultimate Conditions Peak Discharges, shows the difference in flows for the 100- and 500-year events. Appendix D contains the tabular comparison of WSEL between the existing and ultimate conditions for the 100-year event.

The average change in flows between existing and ultimate conditions was approximately 14% for the 100-year event. The more developed watersheds produced a much smaller change while many of the undeveloped Wagner watersheds had a significant difference between the existing and ultimate conditions. The floodplain shapefiles have been included as part of the digital data. In order to assure that any recommended alternatives could sustain future growth within the City, the flood damage assessment and alternative development phases of the study were based on the ultimate development conditions discharges and water surface elevations.

Table 6. Existing Conditions Peak Flood Discharges

HECHMS Node	DA (sq. mi.)	XS Station	Existing Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Clear Creek										
J CC 1	0.2	24,488	290	420	510	650	750	870	1,060	1,220
J CC 1A	0.37	23,626	360	530	640	810	940	1,090	1,330	1,520
J CC 2	0.37	22,854	170	330	450	630	790	950	1,160	1,350
J CC 3	0.62	22,133	360	630	840	1,120	1,340	1,580	1,920	2,210
J CC 4	0.68	21,172	370	650	870	1,160	1,410	1,660	2,020	2,330
J CC 5	1.06	20,643	670	1,010	1,370	1,900	2,320	2,760	3,390	3,910
J_CC 6	1.11	19,427	670	1,030	1,380	1,910	2,330	2,770	3,410	3,930
J_CC 7	1.67	18,947	1,050	1,620	2,110	2,840	3,420	4,030	4,910	5,650
J_CC 8	1.89	18,012	1,100	1,720	2,230	3,010	3,640	4,310	5,310	6,100
J_CC 9	2.27	16,484	1,260	2,000	2,570	3,510	4,250	5,070	6,300	7,250
J_CC 10	2.27	15,694	1,250	2,000	2,570	3,500	4,250	5,070	6,300	7,240
OUTLET	5.25	7,900	540	970	1,240	1,830	2,340	2,920	3,900	4,550
Corral Creek										
J_COC2	0.612	9,909	420	640	790	1,010	1,190	1,380	1,680	1,920
J_COC3	0.874	8,112	550	840	1,040	1,330	1,500	1,650	1,860	2,110
J_COC4	1.113	6,933	750	1,130	1,390	1,770	2,050	2,310	2,710	2,990
J_COC5	1.319	4,923	840	1,260	1,500	1,850	2,100	2,310	2,590	2,960
J_COC6	1.878	1,745	1,080	1,710	2,070	2,560	2,940	3,330	3,850	4,240
Cowhorn Creek										
B_Cow1	0.30	21,052	210	320	390	490	580	670	810	920
J_Cow1	0.43	19,760	250	370	460	580	660	770	930	1,060
J_Cow2	0.74	19,408	420	630	790	1,000	1,170	1,360	1,660	1,920

HECHMS Node	DA (sq. mi.)	XS Station	Existing Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_Cow3	0.77	17,852	430	650	800	1,020	1,190	1,370	1,690	1,950
J_Cow5	1.50	17,197	920	1,280	1,560	2,000	2,310	2,690	3,190	3,590
J_Cow6	1.60	15,792	940	1,300	1,570	2,020	2,340	2,710	3,280	3,680
J_Cow7	2.22	15,010	1,230	1,670	2,020	2,620	3,050	3,580	4,380	4,940
J_Cow8	2.26	14,569	1,230	1,680	2,020	2,620	3,060	3,580	4,400	4,970
J_Cow9	2.83	14,203	1,580	2,270	2,700	3,350	3,850	4,390	5,280	6,010
J_Cow10	2.89	13,577	1,580	2,270	2,710	3,360	3,860	4,410	5,300	6,050
J_Cow11	3.23	11,945	1,700	2,370	2,760	3,300	3,720	4,260	5,450	6,320
J_Cow14	3.72	10,296	2,030	2,700	3,200	3,780	4,220	4,810	6,050	7,300
J_Cow15	4.10	9,613	2,130	2,830	3,400	4,020	4,630	5,200	6,220	7,380
J_Cow16	4.42	7,410	2,210	2,910	3,400	4,100	4,510	5,050	6,060	6,990
J_Cow18	4.81	6,145	2,350	3,120	3,590	4,390	4,840	5,370	6,230	7,180
J_Cow19	4.98	5,369	2,400	3,170	3,610	4,460	4,940	5,450	6,290	7,250
Cow_Outlet	5.52	2,395	2,570	3,320	3,720	4,530	5,070	5,690	6,510	7,480
Cowhorn Creek East Tributary										
B_CET1	0.4	3,016	320	460	560	700	810	940	1,140	1,300
J_CET1	0.62	1,032	480	670	800	990	1,130	1,270	1,470	1,660
Cowhorn Creek West Tributary										
B_CWT1	0.41	3,395	380	550	680	860	1,010	1,170	1,430	1,640
J_CWT1	0.57	2,392	480	780	940	1,190	1,390	1,610	1,950	2,240
Howard Creek										
J_HOW5	3.584	19,989	1,280	2,110	2,630	3,100	3,350	3,650	3,960	4,190
J_HOW6	3.866	18,119	1,240	2,060	2,580	3,110	3,380	3,640	3,970	4,200
J_HOW7	4.537	15,596	1,250	2,080	2,690	3,250	3,530	3,800	4,320	5,090

HECHMS Node	DA (sq. mi.)	XS Station	Existing Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_HOW8	4.747	12,975	1,240	2,090	2,700	3,290	3,580	3,840	4,520	5,320
J_HOW9	5.082	9,598	1,220	2,090	2,700	3,330	3,640	3,910	4,750	5,630
J_HOW10	5.361	5,987	1,210	2,070	2,670	3,330	3,650	3,940	4,760	5,760
J_HOW11	7.239	4,481	1,420	2,310	2,940	3,760	4,480	5,320	6,810	8,850
J_HOW12	7.389	3,801	1,380	2,200	2,860	3,570	4,280	5,370	6,730	8,730
Outlet	7.711	2,373	1,370	2,180	2,850	3,560	4,080	5,250	6,770	8,550
South Wagner										
J_SWC 2	0.27	13,029	310	420	490	610	750	890	1,060	1,220
J_SWC1-1	0.64	12,641	580	840	1,010	1,260	1,470	1,690	2,050	2,340
J_SWC 3	0.83	10,858	560	770	910	1,190	1,440	1,700	2,090	2,410
J_SWC 4	1.17	7,954	590	800	950	1,230	1,460	1,740	2,050	2,320
J_SWC 5	1.47	5,308	690	980	1,160	1,450	1,680	1,900	2,200	2,430
OUTLET	1.92	2,390	700	1,010	1,240	1,710	2,040	2,360	2,840	3,230
Stream WC-1										
B_WC1_1	0.07	9,225	110	150	170	210	240	270	330	370
B_WC2_1	0.244	6,593	140	210	260	330	380	450	540	620
J_WC1_1	0.376	7,891	220	320	430	580	670	780	940	1,070
J_WC1_2	0.551	5,956	170	340	500	730	910	1,080	1,350	1,530
J_WC1_4	0.658	3,310	270	450	590	890	1,120	1,380	1,750	2,000
J_WC1_5	0.818	2,735	350	570	710	960	1,220	1,500	1,930	2,200
Stream WC-2										
B_WC2_1	0.174	6,593	140	210	260	330	380	450	540	620
J_WC2_2	0.288	5,776	200	300	380	490	580	680	840	970
J_WC2_3	0.411	4,699	270	430	530	690	810	960	1,180	1,360

HECHMS Node	DA (sq. mi.)	XS Station	Existing Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_WC2_4	0.468	3,361	300	450	550	760	910	1,080	1,340	1,550
J_WC2_5	0.733	2,795	470	720	880	1,230	1,470	1,750	2,170	2,510
J_WC2_6	0.788	2,442	450	680	890	1,280	1,520	1,830	2,270	2,620
Outlet	0.859	944	460	670	890	1,240	1,540	1,850	2,360	2,750
Swampoodle Creek										
B_SPC1	0.123	17,716	140	200	240	300	340	400	480	540
J_SPC1	0.162	17,307	170	240	290	370	430	500	590	660
J_SPC3	0.315	17,057	310	460	550	690	810	940	1,120	1,280
J_SPC4	0.401	15,246	400	580	700	880	1,030	1,190	1,400	1,590
J_SPCWC_DIV1	-	14,208	470	790	1,010	1,320	1,540	1,750	2,060	2,310
J_SPCWC_DIV2	-	13,977	630	950	1,170	1,480	1,710	1,940	2,260	2,520
J_SPC5	0.419	13,576	630	950	1,170	1,490	1,720	1,940	2,270	2,530
J_SPC6	1.08	12,894	990	1,430	1,730	2,170	2,470	2,750	3,090	3,380
J_SPC7	2.033	12,567	1,670	2,340	2,800	3,460	3,940	4,410	5,220	5,900
J_SPC8	2.07	11,858	1,660	2,290	2,770	3,460	3,950	4,430	5,260	5,940
J_SPC9	2.179	10,765	1,710	2,340	2,820	3,540	4,050	4,540	5,390	6,090
J_SPC11	2.32	10,292	1,760	2,400	2,900	3,650	4,180	4,740	5,750	6,600
J_SPC12	2.402	9,854	1,770	2,430	2,940	3,720	4,260	4,840	5,860	6,670
J_SPC14	2.531	9,277	1,840	2,510	3,040	3,860	4,430	5,060	6,090	6,900
J_SPC15	2.67	7,747	1,900	2,580	3,120	3,970	4,590	5,250	6,230	7,060
J_SPC17	2.848	7,237	1,990	2,720	3,270	4,170	4,840	5,600	6,530	7,360
J_SPC18	2.972	5,656	2,030	2,780	3,300	4,230	4,920	5,670	6,640	7,480
J_SPC20	3.916	4,717	2,880	3,990	4,800	6,100	7,020	8,000	9,450	10,510
Outlet	4.426	2,717	2,800	3,700	4,420	5,430	6,190	7,110	8,840	10,010

HECHMS Node	DA (sq. mi.)	XS Station	Existing Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Swampoodle Creek East Tributary										
J_SPCET3	0.762	2,570	550	770	910	1,130	1,410	1,730	2,250	2,630
J_SPCET4	0.953	1,567	720	940	1,080	1,300	1,480	1,840	2,360	2,770
Swampoodle Creek West Channel										
B_SPCWC1	0.362	1,496	310	450	540	680	800	920	1,110	1,270
SPCWC_DIV1	-	1,338	220	220	220	230	270	340	450	540
SPCWC_DIV2	-	935	70	70	70	70	100	150	250	330
SPCWC_DIV3	0.661	172	390	540	630	740	790	810	850	870
Wagner Creek										
J_WC7	4.481	41,599	1,740	3,080	4,000	5,380	6,450	7,650	9,450	10,960
J_Stream_WC-2	5.34	40,395	1,990	3,680	4,670	6,230	7,390	8,690	10,660	12,340
J_WC8	6.134	35,626	1,700	3,060	3,920	5,270	6,720	8,310	10,650	12,460
J_WC9	7.056	34,191	1,830	3,260	4,140	5,550	7,060	8,740	11,210	13,120
J_WC11	9.171	32,251	2,080	3,660	4,620	6,300	8,170	10,290	13,410	15,830
J_WC12	9.667	29,999	2,100	3,700	4,680	6,360	8,250	10,400	13,580	16,040
J_WC14	10.558	29,154	2,270	3,750	4,780	6,510	8,170	10,380	13,710	16,230
J_WC15	10.992	25,720	2,080	3,660	4,700	6,400	7,950	10,040	13,540	16,130
J_WC17	12.23	22,939	2,240	4,110	5,270	7,160	8,820	10,670	14,380	16,850
J_WC18	12.431	22,112	2,210	3,870	5,080	6,940	8,580	10,410	14,220	16,800
J_WC19	12.83	20,846	2,230	3,910	5,140	7,010	8,680	10,530	14,420	16,950
J_WC20	13.091	19,254	2,220	3,850	5,080	6,960	8,510	10,530	14,120	16,930
J_WC21	13.768	15,547	2,120	3,650	4,730	6,950	8,280	10,040	13,710	16,680
J_WC22	14.015	12,109	2,110	3,650	4,690	6,810	8,290	10,010	13,670	16,600
J_WC23	19.651	10,041	3,060	4,330	5,400	7,940	11,640	13,010	18,240	22,330

HECHMS Node	DA (sq. mi.)	XS Station	Existing Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_WC24	20.057	8,838	3,110	4,400	5,460	7,970	11,690	13,060	18,330	22,440
J_WC25	20.463	7,267	3,070	4,430	5,480	7,860	11,510	13,090	18,290	22,420
J_WC26	20.701	5,421	3,030	4,440	5,460	7,720	11,000	13,090	18,290	22,420
J_Swagner	22.622	4,191	3,440	5,200	6,220	7,950	11,450	13,660	18,960	23,220
WC_Outlet	23.349	1,729	3,360	5,010	6,190	7,770	11,230	13,610	18,910	23,020

Table 7. Ultimate Conditions Peak Flood Discharges

HECHMS Node	DA (sq. mi.)	XS Station	Ultimate Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
Clear Creek										
J CC 1	0.2	24,488	320	440	530	670	770	890	1,080	1,230
J CC 1A	0.37	23,626	390	550	660	830	960	1,110	1,350	1,540
J CC 2	0.37	22,854	190	350	470	660	810	970	1,180	1,370
J CC 3	0.62	22,133	440	680	950	1,300	1,590	1,870	2,270	2,620
J CC 4	0.68	21,172	460	720	980	1,360	1,660	1,970	2,410	2,790
J CC 5	1.06	20,643	910	1,280	1,600	2,210	2,700	3,230	3,980	4,590
J_CC 6	1.11	19,427	910	1,290	1,620	2,220	2,710	3,240	4,010	4,630
J_CC 7	1.67	18,947	1,480	2,090	2,570	3,410	4,080	4,810	5,860	6,730
J_CC 8	1.89	18,012	1,550	2,250	2,780	3,640	4,360	5,150	6,320	7,310
J_CC 9	2.27	16,484	1,830	2,680	3,310	4,300	5,150	6,100	7,490	8,700
J_CC 10	2.27	15,694	1,820	2,680	3,310	4,290	5,140	6,100	7,490	8,690
OUTLET	5.25	7,900	770	1,210	1,560	2,210	2,750	3,360	4,270	5,070
Corral Creek										

HECHMS Node	DA (sq. mi.)	XS Station	Ultimate Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_COC2	0.612	9,909	700	940	1,100	1,340	1,530	1,740	2,070	2,340
J_COC3	0.874	8,112	800	1,090	1,250	1,430	1,600	1,800	2,090	2,490
J_COC4	1.113	6,933	1,040	1,410	1,660	2,000	2,260	2,540	2,960	3,290
J_COC5	1.319	4,923	1,170	1,530	1,760	2,050	2,260	2,420	2,800	3,250
J_COC6	1.878	1,745	1,640	2,210	2,560	3,040	3,400	3,740	4,220	4,650
Cowhorn Creek										
B_Cow1	0.3	21,052	280	390	460	570	650	750	890	1,010
J_Cow1	0.43	19,760	330	460	550	660	750	860	1,030	1,160
J_Cow02	0.74	19,408	580	800	950	1,170	1,360	1,560	1,860	2,110
J_Cow03	0.77	17,852	590	810	970	1,180	1,360	1,560	1,890	2,130
J_Cow05	1.5	17,197	1,110	1,500	1,820	2,230	2,530	2,940	3,400	3,800
J_Cow06	1.6	15,792	1,130	1,520	1,830	2,250	2,560	2,980	3,490	3,900
J_Cow07	2.22	15,010	1,470	1,940	2,340	2,910	3,330	3,960	4,680	5,260
J_Cow08	2.26	14,569	1,490	1,940	2,340	2,910	3,340	3,960	4,710	5,290
J_Cow09	2.83	14,203	2,040	2,720	3,190	3,840	4,350	4,890	5,700	6,450
J_Cow10	2.89	13,577	2,050	2,730	3,200	3,850	4,370	4,930	5,780	6,500
J_Cow11	3.23	11,945	2,130	2,760	3,160	3,670	4,120	4,770	5,890	6,770
J_Cow14	3.72	10,296	2,420	3,170	3,570	4,110	4,620	5,450	6,820	8,060
J_Cow15	4.1	9,613	2,530	3,330	3,780	4,400	4,910	5,590	6,860	7,940
J_Cow16	4.42	7,410	2,620	3,320	3,820	4,370	4,840	5,450	6,520	7,390
J_Cow18	4.81	6,145	2,780	3,480	4,040	4,650	5,110	5,620	6,690	7,580
J_Cow19	4.98	5,369	2,830	3,490	4,060	4,730	5,170	5,690	6,740	7,650
Cow_Outlet	5.52	2,395	2,980	3,580	4,100	4,840	5,380	5,970	6,890	7,890
Cowhorn Creek East Tributary										

HECHMS Node	DA (sq. mi.)	XS Station	Ultimate Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
B_CET1	0.4	2,892	370	510	610	750	870	990	1,190	1,350
J_CET1	0.62	1,032	560	750	880	1,060	1,190	1,330	1,530	1,720
Cowhorn Creek West Tributary										
B_CWT1	0.41	3,395	500	680	800	980	1,130	1,290	1,540	1,750
J_CWT1	0.57	2,392	700	940	1,110	1,360	1,560	1,770	2,110	2,430
Howard Creek										
J_HOW05	3.584	19,989	2,030	2,740	3,020	3,360	3,630	3,820	4,250	4,670
J_HOW06	3.866	18,119	1,960	2,690	3,030	3,360	3,600	3,810	4,100	4,300
J_HOW07	4.537	15,596	1,960	2,790	3,140	3,480	3,740	4,200	5,350	6,240
J_HOW08	4.747	12,975	1,950	2,800	3,160	3,520	3,780	4,390	5,570	6,520
J_HOW09	5.082	9,598	1,940	2,810	3,200	3,560	3,840	4,560	5,810	6,850
J_HOW10	5.361	5,987	1,930	2,790	3,180	3,570	3,840	4,460	5,860	7,020
J_HOW11	7.239	4,481	2,250	3,120	3,700	4,780	5,590	6,370	8,980	10,900
J_HOW12	7.389	3,801	2,090	2,960	3,490	4,740	5,640	6,420	8,890	10,820
Outlet	7.711	2,373	2,060	2,950	3,490	4,410	5,510	6,450	8,590	10,470
South Wagner										
J_SWC 2	0.27	13,029	400	510	590	790	940	1,070	1,310	1,490
J_SWC 1-1	0.64	12,641	660	920	1,090	1,330	1,530	1,760	2,100	2,400
J_SWC 3	0.83	10,858	630	830	980	1,270	1,510	1,770	2,150	2,470
J_SWC 4	1.17	7,954	780	1,020	1,190	1,430	1,620	1,850	2,220	2,530
J_SWC 5	1.47	5,308	860	1,110	1,290	1,550	1,750	1,980	2,330	2,640
OUTLET	1.92	2,390	890	1,210	1,520	1,920	2,230	2,570	3,140	3,650
Stream WC-1										
B_WC1_1	0.07	9,225	160	200	230	280	310	360	420	480

HECHMS Node	DA (sq. mi.)	XS Station	Ultimate Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_WC1_1	0.244	7,891	340	460	600	790	920	1,050	1,260	1,440
J_WC1_2	0.376	5,956	280	550	750	1,020	1,240	1,430	1,770	1,980
J_WC1_3	0.551	4,351	380	600	820	1,140	1,380	1,620	2,010	2,420
J_WC1_4	0.658	3,310	450	660	900	1,240	1,510	1,770	2,190	2,650
J_WC1_5	0.818	2,735	580	790	970	1,330	1,600	1,900	2,330	2,760
Stream WC-2										
B_WC2_1	0.174	6,593	200	270	320	390	450	510	610	690
J_WC2_2	0.288	5,776	280	390	470	590	680	780	940	1,070
J_WC2_3	0.411	4,699	400	560	670	830	970	1,140	1,380	1,590
J_WC2_4	0.468	3,361	400	560	700	880	1,040	1,220	1,490	1,690
J_WC2_5	0.733	2,795	710	960	1,200	1,500	1,760	2,040	2,460	2,800
J_WC2_6	0.788	2,442	620	960	1,260	1,580	1,840	2,130	2,590	2,950
Outlet	0.859	944	640	950	1,190	1,580	1,870	2,210	2,710	3,110
Swampoodle Creek										
B_SPC1	0.123	17,716	230	300	350	430	490	560	660	750
J_SP0C1	0.162	17,307	290	380	450	540	610	690	830	940
J_SPC03	0.315	17,057	440	600	710	870	1,000	1,150	1,380	1,570
J_SPC04	0.401	15,246	540	740	880	1,080	1,250	1,410	1,690	1,920
J_SPCWC_DIV1	-	14,208	640	970	1,200	1,540	1,770	2,000	2,370	2,650
J_SPCWC_DIV2	-	13,977	800	1,130	1,360	1,700	1,940	2,190	2,570	2,860
J_SPC05	0.419	13,576	800	1,140	1,370	1,700	1,940	2,190	2,560	2,860
J_SPC06	1.080	12,894	1,210	1,680	2,000	2,440	2,730	2,990	3,400	3,720
J_SPC07	2.033	12,567	1,890	2,540	3,000	3,640	4,080	4,550	5,400	6,070
J_SPC08	2.070	11,858	1,870	2,470	2,960	3,630	4,080	4,550	5,430	6,100

HECHMS Node	DA (sq. mi.)	XS Station	Ultimate Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_SPC09	2.179	10,765	1,920	2,520	3,020	3,720	4,190	4,670	5,560	6,240
J_SPC11	2.320	10,292	1,990	2,590	3,120	3,840	4,330	4,860	5,870	6,700
J_SPC12	2.402	9,854	2,000	2,620	3,160	3,890	4,400	4,940	5,950	6,760
J_SPC14	2.531	9,277	2,070	2,710	3,280	4,060	4,600	5,220	6,210	7,000
J_SPC15	2.670	7,747	2,130	2,790	3,380	4,190	4,790	5,400	6,400	7,200
J_SPC17	2.848	7,237	2,220	3,010	3,560	4,370	5,030	5,810	6,730	7,560
J_SPC18	2.972	5,656	2,260	3,060	3,600	4,430	5,120	5,890	6,850	7,680
J_SPC20	3.916	4,717	3,300	4,450	5,320	6,580	7,500	8,500	9,930	10,960
Outlet	4.426	2,717	3,120	4,010	4,910	5,740	6,560	7,570	9,280	10,410
Swampoodle Creek East Tributary										
J_SPCET3	0.762	2,570	580	790	940	1,300	1,620	1,970	2,490	2,900
J_SPCET4	0.953	1,567	690	920	1,070	1,310	1,650	2,020	2,530	2,960
Swampoodle Creek West Channel										
B_SPCWC1	0.362	1,496	350	490	590	740	850	980	1,180	1,340
SPCWC_DIV1	-	1,338	220	220	220	250	300	370	490	590
SPCWC_DIV2	-	935	70	70	70	80	120	180	280	370
SPCWC_DIV3	0.661	172	460	630	720	790	810	830	860	880
Wagner Creek										
J_WC07	4.480	41,599	2,850	4,280	5,260	6,680	7,820	9,040	10,980	12,490
J_Stream_WC-2	5.340	40,395	3,410	4,950	6,050	7,600	8,810	10,130	12,240	13,900
J_WC08	6.130	35,626	2,750	4,050	4,940	6,740	8,250	9,870	12,170	14,020
J_WC09	7.040	34,191	2,900	4,250	5,180	7,050	8,620	10,300	12,710	14,650
J_WC11	9.150	32,251	3,220	4,690	5,760	8,050	10,020	12,110	15,100	17,480
J_WC12	9.650	29,999	3,250	4,740	5,820	8,110	10,090	12,230	15,250	17,690

HECHMS Node	DA (sq. mi.)	XS Station	Ultimate Peak Discharges (cfs)							
			2-YR	5-YR	10-YR	25-YR	50-YR	100-YR	250-YR	500-YR
J_WC14	10.560	29,154	3,780	5,380	6,630	8,430	10,060	12,140	15,200	17,770
J_WC15	10.990	25,720	3,660	5,210	6,410	8,240	9,790	11,800	15,050	17,660
J_WC17	12.230	22,939	4,010	5,730	7,040	9,090	10,830	12,440	16,140	18,600
J_WC18	12.430	22,112	3,750	5,520	6,760	8,780	10,450	12,420	16,090	18,560
J_WC19	12.830	20,846	3,780	5,570	6,820	8,860	10,550	12,570	16,340	18,860
J_WC20	13.090	19,254	3,670	5,490	6,750	8,630	10,530	12,280	16,240	18,960
J_WC21	13.770	15,547	3,350	4,760	6,650	8,280	9,690	11,820	15,250	18,190
J_WC22	14.010	12,109	3,310	4,720	6,370	8,270	9,550	11,680	15,250	18,220
J_WC23	19.650	10,041	3,920	5,450	7,170	11,560	12,730	16,110	20,550	24,430
J_WC24	20.060	8,838	3,960	5,500	7,190	11,610	12,780	16,170	20,630	24,530
J_WC25	20.460	7,267	3,960	5,510	7,050	11,490	12,820	16,040	20,640	24,530
J_WC26	20.700	5,421	3,940	5,500	6,940	10,980	12,830	15,940	20,650	24,540
J_Swagner	22.620	4,191	4,440	6,190	7,280	11,390	13,460	16,450	21,360	25,400
WC_Outlet	23.350	1,729	4,280	6,140	7,240	11,160	13,380	16,220	21,250	25,340

Table 8. Existing vs. Ultimate Conditions Peak Flood Discharges

HECHMS Node	DA (sq. mi.)	XS Station	100-YR EXISTING	100-YR ULTIMATE	Delta 100	% Change	500-YR EXISTING	500-YR ULTIMATE	Delta 500	% Change
Clear Creek										
J CC 1	0.2	24,488	870	890	20	2%	1,220	1,230	10	1%
J CC 1A	0.37	23,626	1,090	1,110	20	2%	1,520	1,540	20	1%
J CC 2	0.37	22,854	950	970	20	2%	1,350	1,370	20	1%
J CC 3	0.62	22,133	1,580	1,870	290	18%	2,210	2,620	410	19%
J CC 4	0.68	21,172	1,660	1,970	310	19%	2,330	2,790	460	20%
J CC 5	1.06	20,643	2,760	3,230	470	17%	3,910	4,590	680	17%
J_CC 6	1.11	19,427	2,770	3,240	470	17%	3,930	4,630	700	18%
J_CC 7	1.67	18,947	4,030	4,810	780	19%	5,650	6,730	1,080	19%
J_CC 8	1.89	18,012	4,310	5,150	840	19%	6,100	7,310	1,210	20%
J_CC 9	2.27	16,484	5,070	6,100	1,030	20%	7,250	8,700	1,450	20%
J_CC 10	2.27	15,694	5,070	6,100	1,030	20%	7,240	8,690	1,450	20%
OUTLET	5.25	7,900	2,920	3,360	440	15%	4,550	5,070	520	11%
Corral Creek										
J_COC2	0.612	9,909	1,380	1,740	360	26%	1,920	2,340	420	22%
J_COC3	0.874	8,112	1,650	1,800	150	9%	2,110	2,490	380	18%
J_COC4	1.113	6,933	2,310	2,540	230	10%	2,990	3,290	300	10%
J_COC5	1.319	4,923	2,310	2,420	110	5%	2,960	3,250	290	10%
J_COC6	1.878	1,745	3,330	3,740	410	12%	4,240	4,650	410	10%
Cowhorn Creek										
B_Cow1	0.3	21,052	670	750	80	12%	920	1,010	90	10%
J_Cow1	0.43	19,760	770	860	90	12%	1,060	1,160	100	9%

HECHMS Node	DA (sq. mi.)	XS Station	100-YR EXISTING	100-YR ULTIMATE	Delta 100	% Change	500-YR EXISTING	500-YR ULTIMATE	Delta 500	% Change
J_Cow2	0.74	19,408	1,360	1,560	200	15%	1,920	2,110	190	10%
J_Cow3	0.77	17,852	1,370	1,560	190	14%	1,950	2,130	180	9%
J_Cow5	1.5	17,197	2,690	2,940	250	9%	3,590	3,800	210	6%
J_Cow6	1.6	15,792	2,710	2,980	270	10%	3,680	3,900	220	6%
J_Cow07	2.22	15,010	3,575	3,960	385	11%	4,939	5,260	321	7%
J_Cow8	2.26	14,569	3,580	3,960	380	11%	4,970	5,290	320	6%
J_Cow9	2.83	14,203	4,390	4,890	500	11%	6,010	6,450	440	7%
J_Cow10	2.89	13,577	4,410	4,930	520	12%	6,050	6,500	450	7%
J_Cow11	3.23	11,945	4,260	4,770	510	12%	6,320	6,770	450	7%
J_Cow14	3.72	10,296	4,810	5,450	640	13%	7,300	8,060	760	10%
J_Cow15	4.1	9,613	5,200	5,590	390	8%	7,380	7,940	560	8%
J_Cow16	4.42	7,410	5,050	5,450	400	8%	6,990	7,390	400	6%
J_Cow18	4.81	6,145	5,370	5,620	250	5%	7,180	7,580	400	6%
J_Cow19	4.98	5,369	5,450	5,690	240	4%	7,250	7,650	400	6%
Cow_Outlet	5.52	2,395	5,690	5,970	280	5%	7,480	7,890	410	5%
Cowhorn Creek East Tributary										
B_CET1	0.4	3,016	940	990	50	5%	1,300	1,350	50	4%
J_CET1	0.62	1,032	1,270	1,330	60	5%	1,660	1,720	60	4%
Cowhorn Creek West Tributary										
B_CWT1	0.41	3,395	1,170	1,290	120	10%	1,640	1,750	110	7%
J_CWT1	0.57	2,392	1,610	1,770	160	10%	2,240	2,430	190	8%

HECHMS Node	DA (sq. mi.)	XS Station	100-YR EXISTING	100-YR ULTIMATE	Delta 100	% Change	500-YR EXISTING	500-YR ULTIMATE	Delta 500	% Change
Howard Creek										
J_HOW5	3.584	19,989	3,650	3,820	170	5%	4,190	4,670	480	11%
J_HOW6	3.866	18,119	3,640	3,810	170	5%	4,200	4,300	100	2%
J_HOW7	4.537	15,596	3,800	4,200	400	11%	5,090	6,240	1,150	23%
J_HOW8	4.747	12,975	3,840	4,390	550	14%	5,320	6,520	1,200	23%
J_HOW9	5.082	9,598	3,910	4,560	650	17%	5,630	6,850	1,220	22%
J_HOW10	5.361	5,987	3,940	4,460	520	13%	5,760	7,020	1,260	22%
J_HOW11	7.239	4,481	5,320	6,370	1,050	20%	8,850	10,900	2,050	23%
J_HOW12	7.389	3,801	5,370	6,420	1,050	20%	8,730	10,820	2,090	24%
Outlet	7.711	2,373	5,250	6,450	1,200	23%	8,550	10,470	1,920	22%
South Wagner										
J_SWC 2	0.27	13,029	890	1,070	180	20%	1,220	1,490	270	22%
J_SWC1-1	0.64	12,641	1,690	1,760	70	4%	2,340	2,400	60	3%
J_SWC 3	0.83	10,858	1,699	1,770	71	4%	2,401	2,470	69	3%
J_SWC 4	1.17	7,954	1,740	1,850	110	6%	2,320	2,530	210	9%
J_SWC 5	1.47	5,308	1,900	1,980	80	4%	2,430	2,640	210	9%
OUTLET	1.92	2,390	2,360	2,570	210	9%	3,230	3,650	420	13%
Stream WC-1										
B_WC1_1	0.07	9,225	270	360	90	33%	370	480	110	30%
J_WC1_1	0.244	7,891	780	1,050	270	35%	1,070	1,440	370	35%
J_WC1_2	0.376	5,956	1,080	1,430	350	32%	1,530	1,980	450	29%
J_WC1_3	0.551	4,351	1,230	1,620	391	32%	1,773	2,420	647	36%
J_WC1_4	0.658	3,310	1,380	1,770	390	28%	2,000	2,650	650	33%

HECHMS Node	DA (sq. mi.)	XS Station	100-YR EXISTING	100-YR ULTIMATE	Delta 100	% Change	500-YR EXISTING	500-YR ULTIMATE	Delta 500	% Change
J_WC1_5	0.818	2,735	1,500	1,900	400	27%	2,200	2,760	560	25%
Stream WC-2										
B_WC2_1	0.174	6,593	450	510	60	13%	510	620	110	22%
J_WC2_2	0.288	5,776	680	780	100	15%	780	970	190	24%
J_WC2_3	0.411	4,699	960	1,140	180	19%	1,140	1,360	220	19%
J_WC2_4	0.468	3,361	1,080	1,220	140	13%	1,220	1,550	330	27%
J_WC2_5	0.733	2,795	1,750	2,040	290	17%	2,040	2,510	470	23%
J_WC2_6	0.788	2,442	1,830	2,130	300	16%	2,130	2,620	490	23%
Outlet	0.859	944	1,850	2,210	360	19%	2,210	2,750	540	24%
Swampoodle Creek										
B_SPC01	0.123	17,716	400	560	160	40%	540	750	210	39%
J_SPC01	0.162	17,307	500	690	190	38%	660	940	280	42%
J_SPC03	0.315	17,057	940	1,150	210	22%	1,280	1,570	290	23%
J_SPC04	0.401	15,246	1,190	1,410	220	18%	1,590	1,920	330	21%
J_SPCWC_DIV1	-	14,208	1,750	2,000	250	14%	2,310	2,650	340	15%
J_SPCWC_DIV2	-	13,977	1,940	2,190	256	13%	2,520	2,860	345	14%
J_SPC05	0.419	13,576	1,940	2,190	250	13%	2,530	2,860	330	13%
J_SPC06	1.08	12,894	2,750	2,990	240	9%	3,380	3,720	340	10%
J_SPC07	2.033	12,567	4,410	4,550	140	3%	5,900	6,070	170	3%
J_SPC08	2.07	11,858	4,430	4,550	120	3%	5,940	6,100	160	3%
J_SPC09	2.179	10,765	4,540	4,670	130	3%	6,090	6,240	150	2%
J_SPC11	2.32	10,292	4,740	4,860	120	3%	6,600	6,700	100	2%
J_SPC12	2.402	9,854	4,840	4,940	100	2%	6,670	6,760	90	1%

HECHMS Node	DA (sq. mi.)	XS Station	100-YR EXISTING	100-YR ULTIMATE	Delta 100	% Change	500-YR EXISTING	500-YR ULTIMATE	Delta 500	% Change
J_SPC14	2.531	9,277	5,060	5,220	160	3%	6,900	7,000	100	1%
J_SPC15	2.67	7,747	5,250	5,400	150	3%	7,060	7,200	140	2%
J_SPC17	2.848	7,237	5,600	5,810	210	4%	7,360	7,560	200	3%
J_SPC18	2.972	5,656	5,670	5,890	220	4%	7,480	7,680	200	3%
J_SPC20	3.916	4,717	8,000	8,500	500	6%	10,510	10,960	450	4%
Outlet	4.426	2,717	7,110	7,570	460	6%	10,010	10,410	400	4%
Swampoodle Creek East Tributary										
J_SPCET3	0.762	2,570	1,730	1,970	240	14%	2,630	2,900	270	10%
J_SPCET4	0.953	1,567	1,840	2,020	180	10%	2,770	2,960	190	7%
Swampoodle Creek West Channel										
B_SPCWC1	0.362	1,496	920	980	60	7%	1,270	1,340	70	6%
SPCWC_DIV1	-	1,338	340	370	30	9%	540	590	50	9%
SPCWC_DIV2	-	935	150	180	30	20%	330	370	40	12%
SPCWC_DIV3	0.661	172	810	830	20	2%	870	880	10	1%
Wagner Creek										
J_WC07	4.481	41,599	7,650	9,040	1,390	18%	10,960	12,490	1,530	14%
J_Stream_WC-2	5.34	40,395	8,690	10,130	1,440	17%	12,340	13,900	1,560	13%
J_WC08	6.134	35,626	8,310	9,870	1,560	19%	12,460	14,020	1,560	13%
J_WC09	7.056	34,191	8,740	10,300	1,560	18%	13,120	14,650	1,530	12%
J_WC11	9.171	32,251	10,290	12,110	1,820	18%	15,830	17,480	1,650	10%
J_WC12	9.667	29,999	10,400	12,230	1,830	18%	16,040	17,690	1,650	10%
J_WC14	10.558	29,154	10,380	12,140	1,760	17%	16,230	17,770	1,540	9%
J_WC15	10.992	25,720	10,040	11,800	1,760	18%	16,130	17,660	1,530	9%

HECHMS Node	DA (sq. mi.)	XS Station	100-YR EXISTING	100-YR ULTIMATE	Delta 100	% Change	500-YR EXISTING	500-YR ULTIMATE	Delta 500	% Change
J_WC17	12.23	22,939	10,670	12,440	1,770	17%	16,850	18,600	1,750	10%
J_WC18	12.431	22,112	10,410	12,420	2,010	19%	16,800	18,560	1,760	10%
J_WC19	12.83	20,846	10,530	12,570	2,040	19%	16,950	18,860	1,910	11%
J_WC20	13.091	19,254	10,530	12,280	1,750	17%	16,930	18,960	2,030	12%
J_WC21	13.768	15,547	10,040	11,820	1,780	18%	16,680	18,190	1,510	9%
J_WC22	14.015	12,109	10,010	11,680	1,670	17%	16,600	18,220	1,620	10%
J_WC23	19.651	10,041	13,010	16,110	3,100	24%	22,330	24,430	2,100	9%
J_WC24	20.057	8,838	13,060	16,170	3,110	24%	22,440	24,530	2,090	9%
J_WC25	20.463	7,267	13,090	16,040	2,950	23%	22,420	24,530	2,110	9%
J_WC26	20.701	5,421	13,090	15,940	2,850	22%	22,420	24,540	2,120	9%
J_Swagner	22.622	4,191	13,660	16,450	2,790	20%	23,220	25,400	2,180	9%
WC_Outlet	23.349	1,729	13,610	16,220	2,610	19%	23,020	25,340	2,320	10%

3.5.4 Comparison to Effective Discharges

The 2010 Bowie County FIS Report (Reference 3) includes flows derived from the original study performed in 1988. Table 9, Peak Flow Comparison to Previous Studies, is a comparison of the 10-, 50-, 100- and 500-year peak flood discharges of the 2010 Bowie County FIS Report to the discharges computed for this study. Figure 10, Effective Floodplain Comparison, has the new study 100-year floodplain overlaid on the Effective 2010 Bowie County FIRM panels which show the effective floodplains through the study area.

Table 9 shows the change in flows from the 1988 study to this current study. Many of the changes can be attributed to the more detailed subbasin delineations and better topographic data available for this study. Many watersheds experienced increased discharges due to the increased impervious areas resulting from development. Some basins, such as Howard, actually realized reduced discharges due to the more accurate routing calculations included with this study.

3.6 Flood Damage

3.6.1 Purpose

The main purpose for an economic analysis is to identify and quantify the extent of flood problems and, on a comparable basis, evaluate solutions to reduce flood losses. The USACE Hydrologic Engineering Center Flood Damage Reduction Analysis (HEC-FDA, Version 1.2.5) software was utilized in the economic analyses. A base flood damage assessment was developed to represent the expected annual damages if no alternatives are implemented. Estimates of flood damages and benefits presented in this report reflect 2011 dollars using ultimate development conditions.

3.6.2 Inventory of Structures

The economic analysis study area included all properties within the 500-year floodplain limits for the City of Texarkana, Texas. The City of Texarkana provided a buildings shapefile that was intersected with the 500-year floodplain to identify flood prone properties. The Bowie County Appraisal District (BCAD) 2010 parcel data (Reference 14) was used to assign values to structures and property. Where property values were not available, they were approximated based on an average square foot value of structures with similar occupancy types in the surrounding area. Finished floor elevations were extracted for each building based on the City of Texarkana 2006 Lidar data. The 2009 Master Drainage Plan for Cowhorn Creek included finished floor surveys for a selected sample of flood prone structures.

Table 9. Peak Flow Comparison to Previous Studies

Location	10-YR			50-YR			100-YR			500-YR		
	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change
Clear Creek												
Upstream Face of Skyline Road	----			----			820	950	16%	----		
Below confluence with Stream CC-8	----			----			2,270	2,770	22%	----		
Below confluence with Stream CC-9	----			----			3,060	4,030	32%	----		
Above confluence with Stream CC-6	----			----			3,110	4,310	39%	----		
Below confluence with Stream CC-6 above Bringle Lake	----			----			3,350	5,070	51%	----		
Upstream of Bringle Lake	----			----			7,920	,5070	-36%	----		
Below Bringle Lake	----			----			3,180	2,920	-8%	----		
Cowhorn Creek												
Approx. 1,850 feet northwest of north frontage road of Interstate Route 30	320	460	44%	450	660	47%	520	770	48%	670	1,060	58%
Approx. 550 feet upstream of north frontage road of Interstate Route 30	960	800	-17%	1,330	1,190	-11%	1,510	1,370	-9%	1,880	1,950	4%

Location	10-YR			50-YR			100-YR			500-YR		
	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change
At Interstate Route 30	1,390	1,560	12%	1,920	2,310	20%	2,180	2,690	23%	2,750	3,590	31%
Approximately 1,500 feet upstream of Kennedy Lane	1,510	1,570	4%	2,090	2,340	12%	2,370	2,710	14%	2,950	3,680	25%
At College Street	2,640	2,760	5%	3,650	3,720	2%	4,140	4,260	3%	5,200	6,320	22%
At Tucker Street	3,240	3,400	5%	4,380	4,630	6%	4,950	5,200	5%	6,140	7,380	20%
At New Boston Road (USHwy82)	3,910	3,400	-13%	5,200	4,510	-13%	5,850	5,050	-14%	7,200	6,990	-3%
At West 15th	3,980	3,610	-9%	5,240	4,940	-6%	5,870	5,450	-7%	7,200	7,250	1%
At confluence with Wagner Creek	4,100	3,720	-9%	5,300	5,070	-4%	5,900	5,690	-4%	7,200	7,480	4%
Howard Creek												
At Jarvis Parkway	2,500	2,630	5%	3,380	3,350	-1%	3,820	3,650	-4%	5,200	4,190	-19%
At Findley Street	-------	2,580	-------	-------	3,380	-------	-------	3,640	-------	-------	4,200	-------
At Lake Drive	2,970	2,690	-9%	4,020	3,530	-12%	4,550	3,800	-16%	6,200	5,090	-18%
At Flower Acres Road	3,130	2,700	-14%	4,250	3,580	-16%	4,830	3,840	-20%	6,600	5,320	-19%
At a point approximately 4,430	-------	2,700	-------	-------	3,640	-------	-------	3,910	-------	-------	5,630	-------

Location	10-YR			50-YR			100-YR			500-YR		
	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change
feet downstream of Flower Acres Road												
Just upstream of confluence of Corral Creek	3,600	2,670	-26%	4,950	3,650	-26%	5,650	3,940	-30%	7,700	5,760	-25%
Downstream of confluence with Corral Creek	-------	2,940	-------	-------	4,480	-------	-------	5,320	-------	-------	8,850	-------
At Buchanan / FM 558	-------	2,860	-------	-------	4,280	-------	-------	5,370	-------	-------	8,730	-------
Just upstream of confluence with Days Creek	3,600	2,850	-21%	4,950	4,080	-18%	5,650	5,250	-7%	7,700	8,550	11%
South Wagner Creek												
Upstream of US Route 67	240	490	104%	320	750	134%	370	890	141%	440	1,220	177%
At Falvey Street	750	910	21%	1,020	1,440	41%	1,150	1,700	48%	1,400	2,410	72%
At Robison Road	930	950	2%	1,270	1,460	15%	1,450	1,740	20%	1,840	2,320	26%
At Findley Street	950	1,160	22%	1,310	1,680	28%	1,490	1,900	28%	1,900	2,430	28%
At confluence with Wagner Creek	900	1,240	38%	1,300	2,040	57%	1,540	2,360	53%	2,050	3,230	58%

Location	10-YR			50-YR			100-YR			500-YR		
	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change
Stream WC1												
At Interstate Route 30	--		--	--	--	--	1,210	1,380	14%	--	--	--
At a point approximately 0.57 miles upstream of Interstate Route 30	--		--	--	--	--	1,010	1,500	49%	--	--	--
Stream WC2												
Approximately 2,350 feet upstream of Concord Place	--		--	--	--	--	350	450	29%	--	--	--
Upstream of Unnamed Tributary at a point approximately 660 feet downstream of Independence Place	--		--	--	--	--	760	1,080	42%	--	--	--
At Pleasant Grove	--		--	--	--	--	1,280	1,830	43%	--	--	--
At confluence with Wagner Creek	--		--	--	--	--	1,260	1,850	47%	--	--	--
Swampoodle Creek												
At 40th Street	500	550	10%	650	810	25%	730	940	29%	880	1,280	45%
Above confluence of Swampoodle Creek West Channel	590	1,170	98%	810	1,720	112%	910	1,940	113%	1,120	2,530	126%

Location	10-YR			50-YR			100-YR			500-YR		
	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change
Below confluence of Swampoodle Creek East Tributary	1,920	2,800	46%	2,540	3,940	55%	2,860	4,410	54%	3,420	5,900	73%
Above 24th Street / Richmond Road	2,760	2,770	0%	3,670	3,950	8%	4,120	4,430	8%	5,000	5,940	19%
At US Highway 82	3,110	3,040	-2%	4,060	4,430	9%	4,540	5,060	11%	5,600	6,900	23%
At 13th Street	3,260	3,270	0%	4,250	4,840	14%	4,670	5,600	20%	5,700	7,360	29%
Above US Highway 67	3,410	3,300	-3%	4,440	4,920	11%	4,840	5,670	17%	5,800	7,480	29%
At confluence with Days and Nix Creeks	4,600	4,480	-3%	5,930	6,530	10%	6,620	7,570	14%	8,000	10,220	28%
Swampoodle Creek East												
At confluence with Swampoodle Creek	1,330	1,080	-19%	1,740	1,480	-15%	1,950	1,840	-6%	2,400	2,770	15%
Wagner Creek												
Above Stream WC-2	-------	4,000	-------	-------	6,450	-------	4,860	7,650	57%	-------	10,960	-------
Below Stream WC-2	-------	4,670	-------	-------	7,390	-------	5,925	8,690	47%	-------	12,340	-------
Above IH-30	-------	3,920	-------	-------	6,720	-------	5,250	8,310	58%	-------	12,460	-------
Below Stream WC-1 and upstream of IH-30	-------	4,620	-------	-------	8,170	-------	8,460	10,290	22%	-------	15,830	-------

Location	10-YR			50-YR			100-YR			500-YR		
	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change	2010 FEMA FIS	2011 FPP Study	% Change
Approximately 1,200 feet upstream of Westlawn	5,250	4,700	-10%	7,600	7,950	5%	8,800	10,040	14%	11,600	16,130	39%
At East Frontage Road of State Route 151	5,800	5,140	-11%	8,450	8,680	3%	9,750	10,530	8%	12,900	16,950	31%
At Texas Pacific Railroad	5,800	5,080	-12%	8,450	8,510	1%	9,750	10,530	8%	12,900	16,930	31%
At US Route 67	5,800	4,730	-18%	8,450	8,280	-2%	9,750	10,040	3%	12,900	16,680	29%
At confluence of Cowhorn Creek	5,800	5,400	-7%	8,450	11,640	38%	9,750	13,010	33%	12,900	22,330	73%
Just upstream of confluence of South Wagner Creek	5,800	5,460	-6%	9,000	11,000	22%	10,900	13,090	20%	15,000	22,420	49%
At Lake Drive	6,450	6,220	-4%	9,850	11,450	16%	11,900	13,660	15%	16,300	23,220	42%
At confluence with Days Creek	6,450	6,190	-4%	9,850	11,230	14%	11,900	13,610	14%	16,300	23,020	41%

The inventory of structures was divided into damage categories based on the building shapefile provided by the City, as shown in Table 10, Major Damage Categories.

Table 10. Major Damage Categories

Damage Category	Description
Residential	Single-Family Residential
Apartments	Apartments, Townhomes, Duplexes
Commercial	Retail and Wholesale Businesses
Public	Municipal Services
Hospital	Hospital

Damage curves from the USACE database were used for the flood damage analysis since they covered the types of structures found in the study area and were considered as best available data. For commercial structures, the most appropriate of the 87 commercial damage curves from the USACE study was selected according to the type of structure.

Damage reaches were determined by forming logical groupings of structures fully or partially inundated by the 500-year floodplain limits. A total of 30 damage reaches were defined for the study area. Within HEC-FDA, damage reach extents were defined in relation to the corresponding stream stationing. The damage reaches' locations are listed and described in Table 11, Description of Damage Reaches. Figure 12, FDA Damage Reaches and Affected Properties, shows all structures identified and the corresponding FDA damage reach.

Once the current market values of the structures were identified from BCAD parcel data, the value of investment (structures and contents) was estimated for each structure. The value of the contents was estimated to be 50% of the value of the structure. The damage calculations exclude damages to the water treatment plant along Cowhorn Creek. Damage curves were not available for this type of structure. The number of structures and type of structure are shown along with their estimated structure and content values in Table 12, Estimated Value by Damage Reach.

Table 11. Description of Damage Reaches

Stream Name	Damage Reach Name	Beginning Station (Feet)	Ending Station (Feet)	# of Flood Analyzed Structures	Description
Clear	CC1	21,172	24,488	26	Wyatt Lane to Skyline Boulevard
Corral	COR1	6,518	7,784	10	Martha Road to Leopard Drive
Cowhorn	COW1	1,164	4,361	20	U.S. Highway 67 to Lemon Street
Cowhorn	COW2	5,043	5,649	16	Along Lester Street
Cowhorn	COW3	6,145	9,463	53	U.S. Highway 82 to Market Street
Cowhorn	COW4	9,832	11,755	26	College Drive to Richmond Road
Cowhorn	COW5	11,945	13,346	23	Richmond Road to Kennedy Lane
Cowhorn	COW6	13,577	14,438	10	Along Lambeth Road
Cowhorn East	COWET1	682	2,790	23	Interstate 30 to Summerhill Road
Howard	HOW1	3,662	5,380	14	Just Upstream of Buchanan Road
Howard	HOW2	8,797	9,598	9	Along Bender Road
Howard	HOW3	12,159	14,445	5	Flower Acre Road to Lake Drive
South Wagner	SWC1	9,490	10,858	3	Along Falvey Avenue
South Wagner	SWC2	11,897	12,944	8	Waco Street to U.S. Highway 67
Stream WC1	WC1-1	4,890	5,956	3	Along Jonathan Street & Sarah Circle
Stream WC2	WC2-1	3,361	4,699	17	Along Independence Circle
Swampoodle	SPC1	765	3,668	14	Confluence with Days Creek to 5th Street
Swampoodle	SPC2	3,757	7,747	81	5th Street to 16th Street
Swampoodle	SPC3	8,403	9,277	10	Along U.S. Highway 82
Swampoodle	SPC4	11,101	11,858	2	Along Spruce Street
Swampoodle	SPC5	13,576	14,367	8	Just Upstream of College Drive
Swampoodle	SPC6	16,806	17,057	7	Along 40th Street and Terrace Lane
Swampoodle East	SPCET1	837	966	9	Just Downstream of Texas Boulevard
Swampoodle East	SPCET2	1,455	2,570	24	Texas Boulevard to Olive Street
Wagner	WC1	980	2,758	29	Along Buchanan Road
Wagner	WC2	2,994	6,895	56	Lake Drive to Jameson Street
Wagner	WC3	7,926	8,838	20	Along Sulphur Street and Elliot Street
Wagner	WC4	10,041	14,437	36	Confluence of Cowhorn Creek to Robison Road
Wagner	WC5	22,528	22,939	3	Along Elliot Road
Wagner	WC6	39,286	41,599	7	Along Cooper Lane and McKnight Road

Table 12. Estimated Value by Damage Reach

Damage Reach	Damage Category	Number of Structures	Total Estimated Structure Value	Total Estimated Content Value	Total Value Per Reach
CC1	Residential	26	$ 6,300,000	$ 3,150,000	$ 9,450,000
COR1	Residential	10	$ 596,000	$ 298,000	$ 894,000
COW1	Residential	9	$ 304,000	$ 152,000	$ 1,720,000
	Commercial	8	$ 437,000	$ 219,000	
	Apartment	3	$ 405,000	$ 203,000	
COW2	Residential	16	$ 474,000	$ 237,000	$ 711,000
COW3	Residential	44	$ 874,000	$ 437,000	$ 3,324,000
	Commercial	8	$ 1,342,000	$ 671,000	
COW4	Residential	19	$ 1,578,000	$ 789,000	$ 4,772,000
	Commercial	3	$ 569,000	$ 285,000	
	Public	4	$ 1,034,000	$ 517,000	
COW5	Commercial	1	$ 394,000	$ 197,000	$ 5,343,000
	Apartment	22	$ 3,168,000	$ 1,584,000	
COW6	Residential	10	$ 1,491,000	$ 745,000	$ 2,236,000
COWET1	Commercial	10	$ 246,000	$ 123,000	$27,235,000
	Apartment	12	$ 4,013,000	$ 2,006,000	
	Hospital	1	$ 13,898,000	$ 6,949,000	
HOW1	Residential	13	$ 466,000	$ 233,000	$ 747,000
	Commercial	1	$ 32,000	$ 16,000	
HOW2	Residential	9	$ 90,000	$ 45,000	$ 135,000
HOW3	Residential	4	$ 230,000	$ 115,000	$ 387,000
	Commercial	1	$ 28,000	$ 14,000	
SWC1	Commercial	3	$ 4,392,000	$ 2,196,000	$ 6,588,000
SWC2	Residential	5	$ 198,000	$ 99,000	$ 3,217,000
	Commercial	3	$ 1,947,000	$ 973,000	
WC1-1	Residential	3	$ 686,000	$ 343,000	$ 1,029,000
WC2-1	Residential	17	$ 2,490,000	$ 1,245,000	$ 3,735,000
SPC1	Commercial	11	$ 433,000	$ 217,000	$ 3,235,000
	Public	3	$ 1,723,000	$ 862,000	
SPC2	Residential	47	$ 859,000	$ 429,000	$ 4,200,000
	Commercial	25	$ 915,000	$ 457,000	
	Apartment	1	$ 182,000	$ 91,000	
	Public	8	$ 845,000	$ 422,000	
SPC3	Commercial	10	$ 413,000	$ 206,000	$ 619,000
SPC4	Residential	1	$ 7,000	$ 4,000	$ 29,000

Damage Reach	Damage Category	Number of Structures	Total Estimated Structure Value	Total Estimated Content Value	Total Value Per Reach
	Commercial	1	$ 12,000	$ 6,000	
SPC5	Residential	7	$ 572,000	$ 286,000	$ 877,000
	Commercial	1	$ 13,000	$ 6,000	
SPC6	Residential	7	$ 501,000	$ 251,000	$ 752,000
SPCET1	Residential	9	$ 355,000	$ 177,000	$ 532,000
SPCET2	Residential	20	$ 2,000,000	$ 1,000,000	$ 3,827,000
	Commercial	2	$ 163,000	$ 81,000	
	Public	2	$ 389,000	$ 194,000	
WC1	Residential	23	$ 824,000	$ 412,000	$ 2,013,000
	Commercial	6	$ 518,000	$ 259,000	
WC2	Residential	51	$ 1,105,000	$ 553,000	$ 2,051,000
	Commercial	4	$ 78,000	$ 39,000	
	Public	1	$ 184,000	$ 92,000	
WC3	Residential	19	$ 671,000	$ 336,000	$ 1,135,000
	Public	1	$ 85,000	$ 43,000	
WC4	Residential	11	$ 245,000	$ 122,000	$ 4,942,000
	Commercial	25	$ 3,050,000	$ 1,525,000	
WC5	Residential	3	$ 230,000	$ 115,000	$ 345,000
WC6	Residential	7	$ 3,743,000	$ 1,872,000	$ 5,615,000

3.6.3 Evaluation of Flood Damages

The water surface profile elevations for 2-, 5-, 10-, 25-, 50-, 100-, 250-, and 500-year flood events based on existing (2011) channel and bridge conditions with ultimate developed watersheds, were used to evaluate flood damages. Four hundred eleven (411) structures have estimated finished floor elevations below the ultimate 100-year flood elevations.

Table 13, Affected Structures per Flood Event Year, shows the number of structures affected by each flood event, and the value of the structures that were affected.

Once the expected damages per event were determined, FDA generated the expected annual damages. This value is a weighted average of the expected damages per flood event multiplied by the probability of the flood event occurring; taking into account uncertainty in discharges, damages curves, and stage-damage relationships.

In addition to the structures, a majority of the roadways that cross the study streams are inundated during even small events. Figure 11, Inundated Roadways, illustrates the flood event when the crossing, or a portion of, could be inundated in a given storm event. Table 14 shows the minimum elevation of each roadway crossing (related to Figure 11 by the Structure ID) and the corresponding water surface elevation for each flood event calculated at the upstream face of the structure.

Table 13. Affected Structures per Flood Event Year

Flood Event Year	Affected Structures	Value of Affected Structures	Value of Affected Content	Total Estimated Damage
2-Year	85	$ 5,479,002	$ 2,739,501	$ 498,641
5-Year	157	$ 11,658,394	$ 5,829,197	$ 1,397,098
10-Year	210	$ 29,133,017	$ 14,566,509	$ 2,024,394
25-Year	280	$ 32,910,098	$ 16,455,049	$ 3,321,578
50-Year	342	$ 39,314,315	$ 19,657,158	$ 4,508,949
100-Year	411	$102,879,126	$ 51,439,563	$ 6,184,134
250-Year	474	$112,561,590	$ 56,280,795	$ 8,979,436
500-Year	510	$117,835,586	$ 58,917,793	$ 11,943,100

Table 14. Inundated Road Crossings

ID Location	River Station	Roadway Crossing	Minimum Top of Road Elevation	50 % Event WSEL	20 % Event WSEL	10 % Event WSEL	4 % Event WSEL	2 % Event WSEL	1 % Event WSEL
			(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
Howard Creek									
1	3,662	Buchanan / FM 558	268.6	263.62	265.37	266.7	268.37	269.87	270.36
2	12,329	Flower Acres	280.2	280.83	281.62	282.01	282.34	282.49	282.61
3	14,699	State Route 93 / Lake Drive	286.5	285.24	286.91	287.3	287.56	287.68	287.79
4	17,532	Findley	287.5	289.83	290.7	291.18	291.61	291.83	292.01
5	17,606	RR Bridge	301.0	290.46	291.76	292.51	293.21	293.56	293.89
6	19,897	Jarvis Parkway / Loop 151	307.0	293.76	295.91	297.11	299.03	300.05	301.28
Corral Creek									
7	4,316	Loop 151 - East / West	283.6	276.91	278.5	279.32	280.49	282.21	284.02
8	4,878	Chelf	282.6	279.33	280.87	281.71	283.08	284.22	284.92
9	6,450	Martha	286.5	287.25	287.51	287.62	287.82	288.03	288.2
10	8,021	Leopard	294.0	290.65	291.92	292.71	293.96	294.39	294.58
11	9,795	Loop 151-Jarvis - North / South	305.7	296.13	297.21	298.09	300.48	301.66	302.25
Wagner Creek									
12	2,994	RR Bridge	268	266.08	267.15	267.82	268.62	269.36	270.56
13	3,848	Lake Drive	270.1	267.75	269.09	270.02	271.08	271.75	272.05
14	4,797	Garber	268.44	270.01	271.06	271.52	272.37	273.28	273.76
15	6,449	Findley	270.15	271.89	272.81	273.31	274.2	275.3	275.78
16	7,013	RR Bridge	277.9	272.69	273.63	274.18	275.23	276.62	277.18
17	7,635	Jameson	272.57	273.74	275.09	275.85	277.04	278.11	278.61

ID Location	River Station	Roadway Crossing	Minimum Top of Road Elevation	50 % Event WSEL	20 % Event WSEL	10 % Event WSEL	4 % Event WSEL	2 % Event WSEL	1 % Event WSEL
			(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
18	7,751	RR Bridge	274.2	274.19	275.53	276.13	277.31	278.35	278.81
19	14,110	US Hwy 67	284.8	281.21	283.23	284.21	284.5	285.54	286.94
20	14,302	Robison	285.19	281.66	284.2	285.84	286.18	286.89	288.05
21	18,279	RR Bridge	292.4	285.76	287.93	289.1	289.95	290.11	291.25
22	21,181	Piney	293.9	289.7	292.08	293.13	295.01	296.24	297.49
23	21,343	Loop 151	311.64	289.97	292.45	293.84	295.85	296.79	297.71
24	21,481	Loop 151	311.72	290.54	293.17	294.46	296.17	297.09	297.99
25	21,869	Westlawn	294.02	290.54	293.17	294.46	296.17	297.09	297.99
26	29,075	US Hwy 82	300.6	300.28	301.41	301.84	302.37	302.77	303.23
27	33,743	I30	309.41	304.88	306.65	307.58	309.53	310.23	310.5
28	33,882	I30 Frontage	308.39	305.26	307.59	309.05	310.25	310.84	311.18
29	39,568	FM 2878	311.58	312.81	313.66	314.08	314.93	315.61	316.31
South Wagner									
30	710	Buchanan	267.88	269.44	269.87	270.15	270.62	271.07	271.52
31	2,282	West	273.42	273.39	274.32	274.65	275.04	275.19	275.28
32	2,911	Garber	277.2	275.81	277.19	277.6	277.92	278.11	278.26
33	4,453	Findley	280.9	277.27	278.32	278.83	279.52	280.06	280.85
34	4,524	RR Bridge	289.8	277.94	279.05	279.62	280.43	281.02	281.73
35	6,829	Robison	291.11	285.4	286.32	286.92	287.96	288.75	289.85
36	9,708	Falvey	298.2	296.99	298.02	298.58	299.01	299.24	299.51
37	10,652	Kilgore	301.44	300.04	300.83	301.34	302.05	302.31	302.57
38	11,028	Abandoned RR	301.4	300.69	301.76	302.05	302.33	302.47	302.62
39	11,803	Waco	300.9	302.40	302.68	302.84	303.05	303.27	303.49
40	12,622	Private Access Drive	304.8	305.90	306.34	306.56	306.83	307.00	307.16
41	12,842	US Hwy 67	307.49	306.99	307.84	307.98	308.12	308.23	308.37

ID Location	River Station	Roadway Crossing	Minimum Top of Road Elevation	50 % Event WSEL	20 % Event WSEL	10 % Event WSEL	4 % Event WSEL	2 % Event WSEL	1 % Event WSEL
			(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
Stream WC-1									
42	2,057	University	310.69	306.46	307.23	307.74	308.52	309.1	309.78
43	3,216	Gibson	318.77	314.96	315.59	316.03	316.85	317.42	318.32
44	5,571	Jonathan	327.36	327.55	328	328.17	328.38	328.5	328.65
45	6,858	McKnight	334.73	334.86	334.96	335.11	335.23	335.3	335.38
46	8,363	Arista	343.11	338.34	338.61	339.03	339.59	339.9	340.23
Stream WC-2									
47	2,097	Pleasant Grove / FM 2878	321.66	320.11	321.95	322.37	322.78	322.97	323.14
48	3,489	Independence Circle	327.45	325.61	327.15	327.75	327.99	328.1	328.22
49	3,936	Lexington Place	329.53	327.72	329.22	329.92	330.2	330.37	330.48
50	4,340	Concord Place	330.71	329.86	330.71	331.00	331.10	331.12	331.38
Cowhorn									
51	1,350	Hwy 67	282.1	281.76	282.63	283.13	284.11	284.48	284.74
52	2,273	Railroad	284.42	282.74	283.84	284.95	285.47	285.87	286.21
53	4,988	West 15th Street	290.08	287.82	288.85	289.38	290.71	290.9	291.24
54	6,704	US Hwy 82	295.91	292.01	293.16	294.00	295.51	296.27	297.43
55	8,952	Tucker Street	297.29	297.93	298.51	298.78	299.02	299.25	299.54
56	9,592	Martine Street	299.76	300.54	300.92	301.15	301.31	301.46	301.61
57	10,956	College Drive	302.84	303.39	304.79	305.34	305.3	305.55	305.88
58	11,910	FM 559 / Richmond Road	310.52	305.92	307.24	307.82	308.59	309.15	309.84
59	13,538	Kennedy Lane	311.14	311.51	312.39	312.67	312.99	313.2	313.39
60	16,699	IH 30 Frontage Road / Mall Drive	326.58	323.10	324.49	325.74	327.18	327.56	327.94
61	17,038	IH30	331.44	323.52	324.95	326.21	327.73	328.3	328.96

ID Location	River Station	Roadway Crossing	Minimum Top of Road Elevation	50 % Event WSEL	20 % Event WSEL	10 % Event WSEL	4 % Event WSEL	2 % Event WSEL	1 % Event WSEL
			(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
62	17,175	Saint Michael Drive	327.39	324.36	326.31	328.01	329.08	329.47	329.87
63	18,139	Private Drive	330.26	326.66	327.64	329.1	330.65	331.03	331.3
64	18,339	Pedestrian Bridge	327.58	327.32	328.16	329.34	330.71	331.1	331.37
65	18,601	Michael Meagher	330.15	328.38	329.18	330.4	331.25	331.52	331.73
66	19,719	Cowhorn Creek Road	334.71	332.64	333.26	333.62	334.07	334.4	334.85
Cowhorn Creek West Tributary									
67	2,691	IH 30	334.57	326.78	328.07	328.96	330.11	331.01	331.93
68	3,001	Saint Michael / IH30 Frontage	331.1	327.11	328.48	329.6	331.16	331.61	332.04
Cowhorn Creek East Tributary									
69	496	Private Drive	330.3	325.89	327.1	328.92	330.6	331	331.27
70	850	Michael Meagher	330.14	327.28	328.25	330.04	330.93	331.15	331.36
71	1,883	Morris Lane	333.43	331.07	332.94	331.72	331.91	332.16	332.45
72	2,310	Apartment Culvert	333.8	334.08	334.54	334.82	335.15	335.4	335.68
73	2,373	Northwood	335.1	334.21	334.86	335.3	335.72	335.97	336.19
Swampoodle Creek									
74	1,460	Railroad	284.88	275.24	276.44	277.38	278.55	279.41	282
75	1,828	Railroad	285.15	278.32	279.72	281.45	282.54	283.94	286.26
76	2,080	Railroad	285.6	279.15	280.61	282.22	283.49	284.91	286.91
77	2,299	Texas Viaduct	308.66	279.31	280.87	282.49	283.8	285.18	286.95
78	2,574	Broad Street	280.95	280.87	282.26	283.37	284.29	285.25	286.97
79	2,924	W 3rd Street - Texas Viaduct Rd	288.89	281.89	283.13	284.03	284.97	285.81	287.29
80	3,081	W 3rd Street	284.19	282.61	284.23	285.34	286.45	287.41	288.41
81	3,284	Viaduct / W 4th Street	283.74	283.04	284.96	285.78	286.77	287.5	288.54

ID Location	River Station	Roadway Crossing	Minimum Top of Road Elevation	50 % Event WSEL	20 % Event WSEL	10 % Event WSEL	4 % Event WSEL	2 % Event WSEL	1 % Event WSEL
			(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
82	3,362	W 4th Street (North)	283.41	283.81	285.46	286.12	287.03	287.72	288.67
83	3,757	W 5th Street	282.38	284.24	285.59	286.26	287.16	287.9	288.81
84	4,567	W 7th Street	284.93	286.22	286.78	287.11	287.58	288.16	289
85	4,944	M L King / 8th Street	293.59	286.86	287.69	288.2	288.88	289.34	289.89
86	7,116	W 13th Street	293.91	288.96	290.13	290.86	291.92	292.4	293.61
87	8,290	W 17th Street	294.58	291.37	294.33	294.9	295.09	295.47	295.76
88	9,180	US Highway 82	296.65	296.71	297.8	298.74	299.37	299.58	299.75
89	11,101	Richmond	305.13	302.34	304.68	306.00	306.72	307.07	307.35
90	14,310	College	308.18	313.17	314.64	315.22	315.78	316.16	316.57
91	17,013	W 40th Street	324.61	325.49	326.36	326.62	326.82	326.91	327.49
Swampoodle Creek West Channel									
92	134	Railroad	315.5	309.65	311.34	312.26	313.32	314.06	314.37
93	1,439	College	309.31	311.1	312.17	312.83	313.62	314.21	314.51
Swampoodle Creek East Trib									
94	1,134	Texas Blvd / State Loop 14	313.02	313.17	313.19	313.41	313.69	314.04	314.40
95	1,959	Main Street	315	315.26	315.77	315.83	315.89	316.45	316.95
96	2,206	Pedestrian Bridge	315.3	316.20	317.43	317.62	317.97	318.27	318.68
97	2,341	Pine Street	315.96	316.60	317.48	317.66	318.1	318.40	318.80
Clear Creek									
98	22,839	Skyline	329.12	325.87	329.29	329.66	329.89	330.05	330.2
99	24,477	Wyatt	333.7	334.27	334.81	335.02	335.22	335.41	335.51

4. Flood Mitigation Alternatives

4. Flood Mitigation Alternatives

4.1. Alternative Objectives

Alternatives were developed considering the following objectives:

- Reduce or prevent damages to structures and their contents along the studied reaches within the City of Texarkana.
- Reduce the flood risk to human health and safety associated with inundation, high velocities, and/or overtopping of roads and bridges.
- Reduce flood damages to public facilities, such as roads, bridges, utilities, schools, and churches, within Texarkana.
- Reduce the public and private costs associated with flood fighting and recovery.
- Reduce business and commercial losses resulting from a loss of production and/or economic activity due to flooding.
- Improve the overall health, safety, and quality of life of the citizens of Texarkana

In the development of flood damage alternatives, the following limitations were identified:

- Alternatives were focused on alleviating flood damages for the citizens residing within the City of Texarkana political limits. Benefits of these alternatives may also impact the surrounding communities, but these effects were not examined.
- The formulation of alternatives that reduce flood damages and costs in one area should not result in measurable increases in the extent and magnitude of flooding in another area.
- The formulations of alternatives should avoid adverse impacts to structures.
- Total annual benefits should equal or exceed total annual costs for a plan to be recommended. It is understood that not all benefits are quantifiable.

4.2. Alternative Concepts

In general, five concepts were considered for this project:

- Storm Water Detention Pond Facilities
- Channel Modifications
- Culvert/Bridge Structure Upgrade
- Property Buyouts / Acquisition
- "Do Nothing" Alternative

Storm Water Detention Pond Facilities were explored to minimize flood damages along the downstream reaches of Wagner Creek . The City is conscious of the negative impact that prior unmitigated development in the upper watersheds has had on downstream structures. Although the benefits did not exceed the cost of the project, the City may decide to investigate a large regional type detention facility as a means to provide flood damage relief to structures in the lower Wagner Creek watershed.

The main hydraulic function of a detention basin is twofold. The first is reducing the peak flow and releasing it slowly. The second is attenuating the peaks. Usually the most significant results are obtained by offsetting the timing of peak discharges to impact the timing of peak flows downstream. Therefore flow timing was another factor taken into consideration when analyzing the detention facilities.

Channel Modifications were explored in areas where the growth of the brush was obstructing the conveyance of the stream. A clearing alternative considers removing the brush within the lower channel banks of the streams. This provides a "smoother" channel which increases the conveyance within the channel and reduces the water surface. Channelization was explored in areas where the existing terrain allowed for enough grade and horizontal space to modify the channel. The concept of channelization considers a new channel to convey flow. The City currently maintains a number of previously improved concrete channels. Along Swampoodle Creek East Tributary and Stream WC-2, specifically, the improved channels do not have the capacity to convey larger storm events and resizing of these channels was included in the alternative analysis for these streams. Maintenance and reconstruction of these existing channels is a task that the City may have to undertake in the future; therefore, the project was included with the proposed alternatives even though the benefit to cost was not always favorable.

Culvert/Bridge Structure Upgrades were taken into account in those areas where there was a viable, hydraulically practical, and economical solution, especially for those structures owned by the City or within City right-of-way. Structure sizing for the selected damage reaches are included with the alternatives.

Structure re-sizing information for the ultimate 100-year flood event is provided in Table 15 for selected roadway crossings in the City. These improvements do not take into account downstream impacts but the information is provided to assist the City in budgeting future improvements. The roadways were selected based on feasibility of improvements. In some cases, the improvements and impacts to surrounding road grades would be so extensive that a detailed study of the crossing and feasibility of alternative sizing would need to be investigated by the City before moving forward with sizing. These structures are not included in the table. Structural identifiers in the table correspond to Figure 11.

Property Buyouts / Acquisition in flood prone areas are necessary for those streams where other alternatives explored yield a very low benefit cost ratio. If the City of Texarkana would like to pursue Property Buyouts as a solution, once the land is purchased and the structure removed, this area should be utilized as green space.

“Do Nothing” concept is an alternative where economical, political or other factors play a role. In areas where the benefit/cost ratio is low, surrounding structures are minimal, and flooded area covers empty or undeveloped land, the “do nothing” (no-action) concept could be a suggested option.

Table 15. Re-sized Roadway Structures

Stream Name	ID	Roadway	Approx. River Station	100-Year Ultimate Discharge	Existing Crossing	Minimum Top of Road Elevation		Approx. Bridge Span/ Improvement
						Existing	Proposed	
				(cfs)		(ft)	(ft)	
Clear Creek	CC-BR01	Skyline	22,788	980	3-42" RCP	329.12	332	30' Span
Corral Creek	COR-BR01	Chelf	4,815	2,420	3-9'x7' RCB	282.59	285	100' Span
Corral Creek	COR-BR02	Martha	6,423	2,540	5-36" RCP	286.49	289.5	100' Span
Corral Creek	COR-BR03	Leopard	7,952	1,800	3-9'x5' RCB	293.98	293.98	Add 2-9'x5' RCB
Howard Creek	HOW-BR01	Buchanan	3,544	6,590	150' Span	268.6	272	Raise Road in LOB
Howard Creek	HOW-BR02	Flower Acres	12,304	4,300	5-9'x9' RCB	280.2	285	200' Span
Howard Creek	HOW-BR03	Lake Drive	14,609	4,120	5-8'x6' RCB	286.47	289	300' Span
Howard Creek	HOW-BR04	Findley	17,469	3,810	6-8'x4' RCB	287.54	294	200' Span
South Wagner	SWC-BR02	West	2,226	2,570	3-8'x6' RCB	273.42	276.5	200' Span
South Wagner	SWC-BR03	Garber	2,845	1,980	3-8'x6' RCB	277.2	280	100' Span
South Wagner	SWC-BR04	Findley	4,407	1,980	40' Span	280.9	282	100' Span
South Wagner	SWC-BR07	Falvey	9,613	1,770	4-8'x5' RCB	298.2	299	75' Span
South Wagner	SWC-BR08	Kilgore	10,582	1,770	4-8'x4' RCB	301.44	303	75' Span
South Wagner	SWC-BR10	Waco	11,721	1,760	5-5'x3' RCB	300.9	305	200' Span
Stream WC1	SWC1-BR01	University	2,010	1,900	6-10'x4' RCB	310.69	310.69	Add 1-10'x4'
Stream WC1	SWC1-BR02	Gibson	3,175	1,770	5-10'x3.5' RCB	318.77	318.77	Add 1-10'x3.5' RCB
Stream WC1	SWC1-BR03	Jonathan	5,540	1,430	3-36" RCP	327.36	331	6-9'x6' RCB
Stream WC1	SWC1-BR04	McKnight	6,831	1,050	4-36" RCP	334.37	337	6-9'x6' RCB
Stream WC2	SWC2-BR01	Pleasant Grove	2,050	2,130	3-60" RCP	321.66	323	5-8'x6' RCB
Stream WC2	SWC2-BR02	Independence	3,452	1,140	2-6'x4' RCB	327.45	328	Add 3-6'x4' RCB
Stream WC2	SWC2-BR03	Lexington	3,909	1,140	2-6'x4' RCB	329.53	331	Add 3-6'x4' RCB
Stream WC2	SWC2-BR04	Concord	4,308	1,140	2-6'x4' RCB	330.71	332	40' Span

Stream Name	ID	Roadway	Approx. River Station	100-Year Ultimate Discharge	Existing Crossing	Minimum Top of Road Elevation		Approx. Bridge Span/ Improvement
						Existing	Proposed	
				(cfs)		(ft)	(ft)	
Swampoodle	SPC-BR06	Texas Viaduct	2,880	8,500	Super Elevated	286.08	288	Raise Road in LOB
Swampoodle	SPC-BR10	5th Street	3,705	8,500	75' Span	282.38	290.5	250' Span
Swampoodle	SPC-BR13	14th Street	7,055	5,810	70' Span	293	294	Raise Road in LOB
Swampoodle	SPC-BR14	17th Street	8,241	5,220	50' Span	294.58	300	200' Span
Swampoodle	SPC-BR16	Richmond	11,049	4,550	2-10'x9' RCB	305.13	307	100' Span
SwampEast	SPCET-BR01	State Loop 14	1,060	2,020	2-6'x6' RCB	313.02	317	75' Span
SwampEast	SPCET-BR02	Main	1,874	1,970	2-6'x6' RCB	315	320	7-9'x9' RCB
SwampEast	SPCET-BR03	Pine	2,308	1,970	Arch Span	315.96	323	50' Span
Wagner Creek	WC-BR02	Lake Drive	3,743	16,900	110' Span	270.1	275	500' Span
Wagner Creek	WC-BR03	Garber	4,679	16,320	105' Span	268.44	276.5	450' Span
Wagner Creek	WC-BR04	Findley	6,400	16,350	100' Span	270.15	279	425' Span
Wagner Creek	WC-BR06	Jameson	7,586	16,410	105' Span	272.57	281.5	400' Span
Wagner Creek	WC-BR08	US Hwy 67	14,054	11,990	75' Span	284.8	290	300' Span
Wagner Creek	WC-BR09	Robison	14,224	11,990	75' Span	285.19	290	300' Span
Wagner Creek	WC-BR15	US Hwy 82	29,020	12,140	70' Span	300.6	306.5	400' Span
Wagner Creek	WC-BR16	I30	33,616	10,290	5-11'x9' RCB	309.41	309.41	Add 15-11'x9' RCB
Wagner Creek	WC-BR17	I30 Frontage	33,812	10,290	6-11'x7' RCB	308.39	310	Add 14-11'x7' RCB
Wagner Creek	WC-BR18	FM 2878	39,488	10,070	4-8'x5' RCB	311.58	318.5	250' Span

Note: Bridge Spans / Improvements are approximate and do not take into account downstream impacts or potential mitigation required to offset the negative impacts to surrounding structures. This table is intended only to provide some comparison for future budgeting and planning of improved roadway structures.

4.3. Alternative Hydrology and Hydraulics

A hydrologic and hydraulic model was created for each alternative based on the ultimate land use conditions models developed as part of this study. The alternative storage discharge relationships from the HEC-RAS models were exported and inserted into the alternative hydrologic (HEC-HMS) models to create the alternative hydrology. This was done to ensure that there were no adverse impacts downstream due to the reduction of storage and the change in timing that can be caused by the addition of structural alternatives.

4.4. Damage Center Alternatives

In general, all of the previous described concepts were explored for the City of Texarkana. During the analysis, eight (8) damage centers were identified as the focus of the alternatives. These damage centers represent areas where concentrated flood damages during relatively frequent flood events could potentially justify the costs of structural improvements. The damage centers are shown in Figure 12, FDA Damage Reaches and Affected Properties.

4.4.1. Damage Center I (DCI)

Damage Center I is located in the lower reach of Wagner Creek between the confluence with Days Creek and the confluence with Cowhorn Creek. This area has significant flooding in multiple neighborhoods along Wagner Creek as well as many commercial properties along Lake Drive. This area has 75 structures inundated by the 100-year event worth approximately $2,315,00. Table 16 summarizes DCI affected property.

Table 16. DCI Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	21	$752,000	$376,000
5-year	28	$946,000	$473,000
10-year	34	$1,174,000	$587,000
25-year	50	$1,654,000	$827,000
50-year	56	$1,865,000	$933,000
100-year	75	$2,315,000	$1,158,000
250-year	89	$2,624,000	$1,312,000
500-year	98	$3,258,000	$1,629,000

4.4.2. Damage Center I Alternative I (DCI-ALTI)

Damage Center I Alternative I consists of an approximate 400'-450' wide clearing corridor along Wagner Creek to increase the conveyance capacity of flood waters. The proposed clearing would involve the removal of all trees and brush within the proposed corridor followed by maintaining the cleared area by mowing 3 times a year. The proposed improvements are shown in Figure 13, Alternative Sites Explored.

4.4.3. Damage Center I Alternative II (DCI-ALTII)

Damage Center I Alternative II was developed independently of the structural solutions of DCI-ALTI. This alternative includes a buyout of all residential structures identified within the 10-year floodplain.

4.4.4. Damage Center II (DCII)

Damage Center II is located along Swampoodle Creek from U.S. Highway 67 to approximately 800' upstream of West 14th Street. Multiple municipal structures are affected by flood waters within the reach that includes the City's first responder equipment. There are also numerous residential structures that experience significant flooding in this location. This area has 57 structures inundated by the 100-year event worth approximately $1,907,000. Table 17 summarizes DCII affected property.

Table 17. DCII Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	9	$156,000	$78,000
5-year	16	$625,000	$312,000
10-year	23	$787,000	$394,000
25-year	39	$1,478,000	$739,000
50-year	48	$1,592,000	$796,000
100-year	57	$1,907,000	$954,000
250-year	71	$2,307,000	$1,153,000
500-year	78	$2,744,000	$1,372,000

4.4.5. Damage Center II Alternative I (DCII-ALTI)

Damage Center II Alternative I consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- 2,900 LF 3:1 grass-lined shelf cut just beyond the limits of the stream's ordinary high water mark from stream stations 41+30 to 70+03.

4.4.6. Damage Center II Alternative II (DCII-ALTII)

Damage Center II Alternative II consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- 2,900 LF 3:1 grass-lined shelf cut just beyond the limits of the stream's ordinary high water mark from stream stations 41+30 to 70+03.
- Replace all 6'x8' reinforced concrete box culverts at 7^{th} Street (U.S. Highway 67) with a 75' wide bridge opening.

Damage Center II Alternative III (DCII-ALTIII)

Damage Center II Alternative III was developed independently of the structural solutions of DCII-ALTI and DCII-ALTII. This alternative includes a buyout of all residential structures identified within the 10-year floodplain.

4.4.7. Damage Center III (DCIII)

Damage Center III is located along Swampoodle Creek East Tributary from Texas Boulevard to Olive Street. This area has significant flooding for multiple residential properties along the creek. The existing concrete lined U-shaped channel does not contain the existing 2-year flood event in many locations according to the hydraulic analysis performed as part of this study. The majority of the City's repetitive loss properties, as documented by FEMA, are located along Stream WC-2. This area has 14 structures inundated by the 100-year event worth approximately $1,353,000. Table 18 summarizes DCIII affected property.

Table 18. DCIII Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	7	$782,000	$391,000
5-year	8	$904,000	$452.000
10-year	9	$1,047,000	$524,000
25-year	9	$1,047,000	$524,000
50-year	13	$1,257,000	$629,000
100-year	14	$1,353,000	$677,000
250-year	16	$1,561,000	$781,000
500-year	19	$1913,000	$956,000

The options for alternatives through DCIII are restricted due to multiple residential structures almost directly adjacent to the existing concrete lined channel. If channel improvements are pursued, it is expected that at least 4 properties would need to be bought out to allow for channel widening.

4.4.8. Damage Center III Alternative I (DCIII-ALTI)

Damage Center III Alternative I consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- Widen the existing concrete lined U-channel to 20' maintaining a constant 8' depth for approximately 1450 LF from stream stations 11+34 to 25+70.
- Remove pedestrian bridge at stream station 21+96.
- Buyout four (4) properties in order to widen channel.
- Replace both 6'x6' reinforced concrete box culverts at Main Street with 2-5'x9' reinforced concrete box culverts.
- Replace arch opening at Pine Street with 2-4'x9' reinforced concrete box culverts.

4.4.9. Damage Center III Alternative II (DCIII-ALTII)

Damage Center III Alternative II consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- Remove the existing concrete lined U-channel and replace it with a 50' wide 1450 LF 3:1 grass-lined channel from stream stations 11+34 to 25+70
- Remove pedestrian bridge at stream station 21+96.
- Buyout four (4) properties in order to widen channel.
- Replace both 6'x6' reinforced box culverts at State Loop 14 with a 55' wide bridge opening.
- Replace both 6'x6' reinforced concrete box culverts at Main Street with 2-6'x8' reinforced concrete box culverts.
- Replace arch opening at Pine Street with a 45' wide bridge opening.

4.4.10. Damage Center III Alternative III (DCIII-ALTIII)

Damage Center III Alternative III was developed independently of the structural solutions of DCIII-ALTI and DCIII-ALTII. This alternative includes a buyout of all residential structures identified within the 5-year floodplain.

4.4.11. Damage Center IV (DCIV)

Damage Center IV is located along Cowhorn Creek from approximately 520' downstream of College Drive to Richmond Road. This area has significant flooding for multiple residential properties just upstream of College Drive. This area has 22 structures, which include several commercial and public properties, inundated by the 100-year event worth approximately $3,012,000. Table 19 summarizes DCIV affected property.

Table 19. DCIV Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	12	$929,000	$26,000
5-year	18	$2,594,000	$1,297,000
10-year	18	$2,594,000	$1,297,000
25-year	19	$2,697,000	$1,348,000
50-year	21	$2,905,000	$1,452,000
100-year	22	$3,012,000	$1,506,000
250-year	23	$3,052,000	$1,526,000
500-year	23	$3,052,000	$1,526,000

4.4.12. Damage Center IV Alternative I (DCIV-ALTI)

Damage Center IV Alternative I consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- 520 LF 3:1 grass-lined shelf cut just beyond the ordinary high water mark from stream stations 102+96 to 108+10.
- New bridge construction at College Drive to widen the bridge opening.

4.4.13. Damage Center IV Alternative II (DCIV-ALTII)

Damage Center IV Alternative II consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- 520 LF 3:1 grass-lined shelf cut just beyond the ordinary high water mark from stream stations 102+96 to 108+10.
- New bridge construction at College Drive to widen the bridge opening.

- 800 LF 3:1 grass-lined shelf cut just beyond the limits of the stream's ordinary high water mark (stream stations 109+56 to 117+55).

4.4.14. Damage Center IV Alternative III (DCIV-ALTIII)

Damage Center IV Alternative III consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- New bridge construction at College Drive to widen the bridge opening.

4.4.15. Damage Center IV Alternative IV (DCIV-ALTIV)

Damage Center IV Alternative IV was developed independently of the structural solutions of DCIV-ALTI, DCIV-ALTII, and DCIV-ALTIII. This alternative includes a buyout of all residential structures identified within the 10-year floodplain.

4.4.16. Damage Center V (DCV)

Damage Center V is located along Cowhorn Creek just upstream of Kennedy Lane. This area has significant flooding for multiple residential properties along Lambeth Road in the left overbank of Cowhorn Creek. This area has 10 structures inundated by the 100-year event worth approximately $1,491,000. Table 20 summarizes DCV affected property.

Table 20. DCV Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	2	$267,000	$133,000
5-year	8	$1,158,000	$579,000
10-year	9	$1,361,000	$680,000
25-year	10	$1,491,000	$745,000
50-year	10	$1,491,000	$745,000
100-year	10	$1,491,000	$745,000
250-year	10	$1,491,000	$745,000
500-year	10	$1,491,000	$745,000

4.4.17. Damage Center V Alternative I (DCV-ALTI)

Damage Center V Alternative I consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- West bank clearing upstream of Kennedy Lane (stream stations 135+38 to 144+38). The proposed clearing would involve the removal of approximately 5 acres of trees and brush followed by maintaining the cleared area by mowing 3 times a year.

- Two additional 9'x5' concrete box culverts at Kennedy Lane.

4.4.18. Damage Center V Alternative II (DCV-ALTII)

Damage Center V Alternative II consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- West bank clearing upstream of Kennedy Lane (stream stations 135+38 to 144+38). The proposed clearing would involve the removal of approximately 5 acres of trees and brush followed by maintaining the cleared area by mowing 3 times a year.

4.4.19. Damage Center V Alternative III (DCV-ALTIII)

Damage Center V Alternative III was developed independently of the structural solutions of DCV-ALTI and DCV-ALTII. This alternative includes a buyout of all residential structures identified within the 10-year floodplain.

4.4.20. Damage Center VI (DCVI)

Damage Center VI is located along Cowhorn Creek East Tributary from Morris Lane to Northwood Avenue. There are several multi-family buildings that have the potential to experience flooding. This area has 20 structures inundated by the 100-year event worth approximately $3,590,000. Table 21 summarizes DCVI affected property.

Table 21. DCVI Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	2	$669,000	$334,000
5-year	15	$1,918,000	$959,000
10-year	17	$2,587,000	$1,293,000
25-year	19	$3,256,000	$1,628,000
50-year	20	$3,590,000	$1,795,000
100-year	20	$3,590,000	$1,795,000
250-year	20	$3,590,000	$1,795,000
500-year	21	$3,924,000	$1,962,000

4.4.21. Damage Center VI Alternative I (DCVI-ALTI)

Damage Center VI Alternative I consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- Five 9'x4' concrete box culverts at Morris Lane (already constructed and not included in the cost estimate) and remove low-water crossing upstream.

- 370 LF grass-lined shelf cut just beyond the limits of the stream's ordinary high-water mark and sloped 3:1 up to the edge of the apartments. Grass-lined channel will be supplemented with turf reinforcement mat (stream stations 18+83 to 22+49).

4.4.22. Damage Center VII (DCVII)

Damage Center VII is located along Stream WC-2 from Independence Circle to Concord Place. This area has significant flooding for multiple residential properties along the stream. This area has 14 structures inundated by the 100-year event worth approximately $2,007,000. Table 22 summarizes DCVII expected damages.

Table 22. DCVII Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	3	$445,000	$223,000
5-year	7	$1,001,000	$500,000
10-year	7	$1,001,000	$500,000
25-year	9	$1,297,000	$649,000
50-year	12	$1,702,000	$851,000
100-year	14	$2,007,000	$1,003,000
250-year	16	$2,313,000	$1,156,000
500-year	16	$2,313,000	$1,156,000

4.4.23. Damage Center VII Alternative I (DCVII-ALTI)

Damage Center VI Alternative I consists of the following proposed improvements and can be seen in Figure 13, Alternative Sites Explored:

- Replace existing 2-6'x4' box culverts at Independence Circle with a 60' wide bridge opening.
- Replace existing 2-6'x4' box culverts at Lexington Place with a 40' wide bridge opening.

4.4.24. Damage Center VII Alternative II (DCVII-ALTII)

Damage Center VII Alternative II was developed independently of the structural solutions of DCVII-ALTI. This alternative includes a buyout of all residential structures identified within the 10-year floodplain.

4.4.25. Damage Center VIII (DCVIII)

Damage Center VIII is located along Howard Creek just upstream of Buchanan Road. This area has significant flooding for multiple residential and commercial properties along the stream. This area has 14 structures inundated by the 100-year event worth approximately $497,00. Table 23 summarizes DCVIII affected property.

Table 23. DCVIII Affected Property Summary

Storm Event	Total Number of Structures Affected	Total Value of Affected Structures	Total Value of Affected Contents
2-year	5	$162,000	$82,000
5-year	12	$364,000	$182,000
10-year	13	$408,000	$204,000
25-year	14	$497,000	$249,000
50-year	14	$497, 000	$249,000
100-year	14	$497, 000	$249,000
250-year	14	$497, 000	$249,000
500-year	14	$497, 000	$249,000

4.4.26. Damage Center VIII Alternative I (DCVIII-ALTI)

Damage Center VIII Alternative I was developed as a non-structural solution to eliminate flood damages to all analyzed structures within Damage Center VIII. DCVIII-ALTI proposes to buyout all residential properties and one commercial property located just upstream of Buchanan Road along Howard Creek.

4.4.27. Damage Center VIII Alternative II (DCVIII-ALTII)

Damage Center VIII Alternative II was developed as a non-structural solution to eliminate flood damages to analyzed structures within the 5-year floodplain only for Damage Center VIII. DCVIII-ALTII proposes to buyout twelve (12) residential properties located just upstream of Buchanan Road along Howard Creek.

4.5. Construction Costs

Probable construction costs were determined for each alternative including costs associated with the design and construction of the alternative. Standard practices were used to develop the cost estimates. TXDOT bid tabs and recent construction bids were both utilized. Alternative probable construction costs include the following:

- Construction cost
- Engineering and Survey (15 percent)
- Contingencies (20 percent)

Right-of-way acquisition costs were determined for each alternative based on the parcels impacted by the alternative. Property appraised values were obtained from BCAD. Due to the conceptual level of the study, all excavation computations are based on 2006 City of Texarkana LiDAR data. No survey information was obtained for the alternatives section of this study. Appendix E contains itemized probable construction cost tables for all proposed alternatives.

4.6 Permitting

Possible permitting requirements were identified for the structural alternatives.

USACE, acting under Section 404 of the Clean Water Act, regulates the discharge of dredge or fill material into waters of the United States. Waters of the United States include any part of the surface water tributary system down to the smallest of streams, any lake, pond, or other water body on those streams, and adjacent wetlands. Activities requiring a permit from the USACE under Section 404 of the Clean Water Act may be permitted by Nationwide Permit (NWP) or Individual Permit (IP). Stream features associated with the proposed project are likely considered waters of the United States under current guidance and are subject to USACE jurisdiction.

The USACE utilizes NWPs to authorize the discharge of dredged and fill material into waters of the United States when the discharge is expected to result in less than minimal adverse impacts to the aquatic environment. It is likely that on-channel detention alternatives would exceed the NWP program criteria; therefore authorization under an IP would be required. Individual permits are issued for activities that have more than minimal adverse impacts to waters of the United States. The evaluation of the IP application involves a more thorough review of the potential environmental and socioeconomic effects of the proposed activity.

While the USACE is responsible for the final decision, various natural resource agencies have an important role in the regulatory program. Assistance to the USACE on the permit process is provided by the Environmental Protection Agency (EPA), United States Fish and Wildlife Service (USFW), and state agencies. A detailed delineation of waters of the United States, historical resources review, threatened and/or endangered species evaluation, and public comment period are also a components of the IP process. Unavoidable impacts such as the loss of streams, wetlands, or other open waters would be compensated through a mitigation plan.

Section 401 of the Clean Water Act requires that an applicant for a federal permit provide a State certification that any discharges from the facility would comply with the Act, including water quality standard requirements. The Texas Commission on Environmental Quality (TCEQ), the state delegated agency for compliance of Section 401 of the Clean Water Act, has a two tiered process to determine potential impacts to waters of the state. Tier I certification is applicable to projects with direct impacts less than three acres or 1,500 linear feet of streams. Tier II certification authorizes impacts greater than the Tier I threshold. Since most channel alternatives could impact greater than 1,500 linear feet of streams, Tier II certification would apply. Tier II certification involves a complete description of impacts to waters of the United States, discussion of water quality impacts, and a detailed alternatives analysis. The Section 401 permitting process is applied in conjunction with the Section 404 permitting process.

4.7 Benefit Cost Analysis

A Benefit to Cost (B/C) analysis was conducted to determine which alternative provides the best benefit considering probable construction cost and the value of properties all or partially removed from the high risk flood areas. HEC-FDA model runs were created for each alternative from water surface profiles generated by the alternative HEC-RAS model. Average annual benefits were computed by subtracting the alternative (improved) channel conditions average annual damages from the existing channel conditions average annual damages. A B/C ratio was determined by dividing the average annual benefits by the alternative probable construction annualized costs. The B/C ratio was used to determine the economic strength of a project. Alternatives with B/C ratios greater than 1.0 have annual benefits that outweigh the reduction in annual damage and represent a feasible alternative.

The primary benefit, to be derived from a proposed plan of improvement, is a reduction in flood damages. Social, environmental, and other intangible benefits are not quantified in monetary terms and were not considered in this B/C analysis.

The average annual costs and benefits were calculated for a 50-year period of analysis. Benefit and cost accruals were made comparable by conversion to an equivalent annual basis using an interest rate of 5.50 percent (Assumed Average Current Federal Discount Rate).

4.8 Results

4.8.1. Damage Center I

A Benefit to Cost (B/C) Analysis was performed for both alternatives in DCI. Table 24 is a summary of the cost and the overall B/C ratio of each DCI alternative considered.

Table 24. DCI Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCI-ALTI	$897,000	$71,000	$41,400	0.58
DCI-ALTII	$1,871,000	$111,000	$119,500	1.08

No structures downstream of the proposed alternatives were identified that would experience significant negative flooding impacts due to the proposed alternatives.

- **DCI-ALTI** – The proposed clearing corridor along the lower reach of Wagner Creek would increase the hydraulic conductivity and flow capacity resulting in a decrease in water surface elevations of approximately 0.5-1.0 feet throughout the reach.

- **DCI-ALTII –** Buyout - The buyout alternative is more costly than DCI-ALTI but does provide a higher B/C ratio compared DCI-ALTI. Note the buyout option does not provide any relief from flooding beyond the selected structures.

4.8.2 Damage Center II

A Benefit to Cost (B/C) Analysis was performed for all alternatives in DCII. Table 25 is a summary of the cost and the overall B/C ratio of each DCII alternative considered.

Table 25. DCII Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCII-ALTI	$1,005,000	$70,000	$10,100	0.14
DCII-ALTII	$1,726,000	$113,000	$19,500	0.17
DCII-ALTIII	$126,000	$7,400	$3,700	0.50

The unmitigated flood elevations resulting from the proposed alternatives show some rise for the lower frequency events downstream of 7th street. Detention (approximately 4 ac-ft) upstream of the improvements is necessary to compensate for the valley storage loss for DCII-ALTI and DCII-ALTII.

- **DCII-ALTI** – Two alternatives were considered for Damage Center II along Swampoodle Creek which includes the City of Texarkana first responder structures/equipment and many residential properties. DCII-ALTI proposed cutting a shelf in both overbanks to provide additional conveyance capacity through the reach. The shelf cut reduced water surface elevations upstream of 7th Street benefiting multiple residential properties and the City's first responder location. However, the shelf cut also adversely affected the 7th Street bridge crossing by increasing water surface elevations across 7th Street.
- **DCII-ALTII** – In order to compensate for the additional discharge through Damage Center II at 7th Street, DCII-ALTII proposes to widen the bridge opening at 7th Street in conjunction with the shelf cut. The proposed increase in flow capacity at 7th Street would lower the water surface elevations across 7th Street compared to existing conditions and provide an additional decrease in water surface elevations upstream of 7th Street compared to DCII-ALTI. Access to the first responder location during a major flood event would be hindered by the 7th Street bridge crossing which is currently overtopped by the 2-year flood event. The Railroad crossing just west of the 7th Street bridge crossing at Swampoodle Creek prohibits raising the road deck in this location. 7th Street would have to be super-elevated similar to 8th Street if the road deck were to be raised. A hydraulic analysis was performed with 7th Street super-elevated, however it provided no additional benefits for flood mitigation throughout Damage Center II and would be economically unfeasible from a benefit to cost standpoint. Super-elevating 7th Street could beneficial for access to the first responder location but not for flood mitigation.

- **DCII-ALTIII –** Buyout - The buyout alternative is the least costly and provides the greatest B/C ratio. However, the buyout option does not provide any relief from flooding beyond the selected structures.

4.8.3. Damage Center III

A Benefit to Cost (B/C) Analysis was performed for all alternatives in DCIII. Table 26 is a summary of the cost and the overall B/C ratio of each DCIII alternative considered.

Table 26. DCIII Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCIII-ALTI	$3,617,000	$217,600	$95,300	0.44
DCIII-ALTII	$3,070,000	$185,800	$89,500	0.48
DCIII-ALTIII	$1,596,000	$94,000	$95,700	1.02

The unmitigated flood elevations resulting from the proposed alternatives show some rise for the lower frequency events downstream of Texas Boulevard. Detention (approximately 8 ac-ft) upstream of the improvements is necessary to compensate for the valley storage loss for DCIII-ALTI and DCIII-ALTII.

- **DCIII-ALTI** – This alternative significantly lowers the water surface elevations throughout Damage Center III resulting in a significant reduction in expected annual damages. However, replacing the concrete U-channel with a larger U-channel presents continued high channel velocities and hydraulic instability. The size and depth of the proposed concrete U-channel could also present numerous safety concerns to the public. The bridge improvements at Main Street and Pine Street would provide increased conveyance capacity lowering water surface elevations throughout the reach.
- **DCIII-ALTII** – Alternative II also significantly lowers the water surface elevations throughout Damage Center III resulting in a significant reduction in expected annual damages. The grass-lined channel option reduced channel velocities and provided hydraulic stability throughout the reach. The water surface elevations did not lower as much compared to the concrete U-channel options for the more frequent flood events but the grass lined channel provided greater benefits for the less frequent events. The bridge improvements at Texas Boulevard, Main Street, and Pine Street would provide increased conveyance capacity lowering water surface elevations throughout the reach.
- **DCIII-ALTIII** – Buyout - The buyout alternative is the least costly and provides the greatest B/C ratio. However, the buyout option does not provide any relief from flooding beyond the selected structures.

4.8.4. Damage Center IV

A Benefit to Cost (B/C) Analysis was performed for all alternatives in DCIV. Table 27 is a summary of the cost and the overall B/C ratio of each DCIV alternative considered.

Table 27. DCIV Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCIV-ALTI	$791,000	$49,800	$63,700	1.28
DCIV-ALTII	$936,000	$61,000	$81,300	1.33
DCIV-ALTIII	$690,000	$41,300	$47,300	1.15
DCIV-ALTIV	$2,544,000	$150,000	$77,100	0.51

No structures downstream of the proposed alternatives were identified that would experience significant negative flooding impacts due to the proposed alternatives.

- **DCIV-ALTI, ALTII, & ALTIII** – All three alternatives considered for Damage Center IV produced a positive benefit to cost ratio. The resizing of the bridge at College Drive is integral to any successful structural measures at this particular location. Additional benefits could be realized by improving the channel downstream of College Drive (DCIV-ALTI) or upstream and downstream of College Drive (DCIV-ALTIII). Both channel improvements would be grass lined with minimal impacts below the stream's ordinary high water mark.
- **DCIV-ALTIV –** Buyout - The buyout alternative is the most costly and provides the lowest B/C ratio. The buyout option does not provide any relief from flooding beyond the selected structures and is not recommended given the high B/C ratios for the structural solutions.

4.8.5. Damage Center V

A Benefit to Cost (B/C) Analysis was performed for all alternatives in DCV. Table 28 is a summary of the cost and the overall B/C ratio of each DCV alternative considered.

Table 28. DCV Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCV-ALTI	$347,000	$27,200	$24,700	0.91
DCV-ALTII	$153,000	$16,200	$23,700	1.46
DCV-ALTIII	$2,601,000	$154,000	$45,300	0.29

No structures downstream of the proposed alternatives were identified that would experience significant negative flooding impacts due to the proposed alternatives.

- **DCV-ALTI** – Damage Center V Alternative I would involve the clearing and maintenance of the property upstream of Kennedy Lane and West of Cowhorn Creek as well as installing two additional culverts at the Kennedy Lane crossing. The increased hydraulic conveyance would create a slight decrease in water surface elevation of approximately 0.5 feet that provides a benefit of approximately $24,700 annually.

- **DCV-ALTII –** Damage Center V Alternative II involves only the clearing and maintenance of the west bank upstream of Kennedy Lane, which creates a benefit of approximately $23,700. Both alternatives remove three (3) structures from the 100-year floodplain, but the clearing seems to be the effective improvement.
- **DCV-ALTIII –** Buyout - The buyout alternative is the most costly and provides the lowest B/C ratio. The buyout option does not provide any relief from flooding beyond the selected structures and is not recommended given the high B/C ratios for the structural solutions.

4.8.6. Damage Center VI

A Benefit to Cost (B/C) Analysis was performed for Alternative I in DCVI. Table 29 is a summary of the cost and the overall B/C ratio for DCVI-ALTI.

Table 29. DCVI Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCVI-ALTI	$71,000	$5,100	$21,300	4.18

The unmitigated flood elevations resulting from the proposed alternatives show some rise for the higher frequency events downstream. However, no structures downstream of the proposed alternatives were identified that would experience significant negative flooding impacts due to the proposed alternatives.

- **DCVI-ALTI –** Proposed improvements through Damage Center VI, from Northwood Avenue to Morris Lane would remove three (3) residential structures from the 100-year future floodplain. DCV-ALTI proposed conceptual solutions reduce the expected annual damages by approximately $21,300. The conceptually improved channel top of slope would be very close to the edge of the existing apartment buildings. The final design of any improvements would need to consider the structural integrity of the buildings as well as the functionality of the apartment complex.

4.8.7. Damage Center VII

A Benefit to Cost (B/C) Analysis was performed for all alternatives in DCVII. Table 30 is a summary of the cost and the overall B/C ratio of each DCVII alternative considered.

Table 30. DCVII Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCVII-ALTI	$446,000	$26,000	$30,000	1.15
DCVII-ALTII	$1,727,000	$102,000	$36,000	0.35

The unmitigated flood elevations resulting from the proposed alternatives show some rise for the higher frequency events downstream. However, no structures downstream of the proposed alternatives were identified that would experience significant negative flooding impacts due to the proposed alternatives.

- **DCVII-ALTI** – Proposed improvements through Damage Center VII would remove six (6) residential structures from the 100-year future floodplain. The inadequate flow capacities of the existing bridge openings at Independence Circle and Lexington Place cause a backwater effect upstream of each structure resulting in the potential for flooding. Water surface elevations would be greatly reduced by widening both bridge openings proposed in DCVII-ALTI. The existing level of protection at Independence Circle and Lexington Place is currently estimated as the 5-year flood event. If the proposed improvements for DCVII-ALT1 were implemented, Independence Circle would achieve 50-year flood event protection and Lexington Place would achieve 100-year flood protection.
- **DCVII-ALTII –** Buyout - The buyout alternative is more costly than DCVII-ALTI and does not provide a higher B/C ratio compared DCVII-ALTI. Note the buyout option does not provide any relief from flooding beyond the selected structures.

4.8.8. Damage Center VIII

A Benefit to Cost (B/C) Analysis was performed for Alternative I in DCVIII. Table 31 is a summary of the cost and the overall B/C ratio for DCVIII-ALTI.

Table 31. DCVIII Alternative Analysis

Alternative	Total Cost	Annual Cost	Reduction in Annual Damages	B/C
DCVIII-ALTI	$858,000	$51,000	$37,000	0.73
DCVIII-ALTII	$629,000	$37,000	$35,000	0.95

- **DCVIII-ALTI –** Buyout – Two buyout options were considered for Damage Center VIII. DCVIII-ALTI considered the buyout of all structures that experience flooding within Damage Center VIII. This non-structural solution was designed to eliminate flood damages to all analyzed structures within Damage Center VIII and provided a B/C ratio of 0.73.
- **DCVIII-ALTII –** Buyout – This alternative considered the buyout of structures only within the 5-year floodplain. The 5-year buyout option provides a higher B/C ratio than DCVIII-ALTI, however, the B/C ratio is still less than 1. Note the buyout option does not provide any relief from flooding beyond the selected structures.

5. Recommendations

5. Recommendations

5.1. Damage Center I

Based on the Alternative Analysis, the channel clearing alternative would not provide enough reduction in annual damages to warrant the expense of such a large project. Therefore, the DCI - ALTII - Buyout option is recommended for Damager Center I. The buyouts of all properties impacted by the 10-year flood event would be a significant expense, but would significantly reduce flood damage in the area and provide benefits to the residents. A phased approach, beginning with the properties impacted by the most frequent events is recommended.

5.2. Damage Center II

Based on the Alternative Analysis, any structural or buyout alternative would not provide enough reduction in annual damages to warrant the expense. All three alternatives would provide a benefit to critical first responder facilities, but no alternatives can be recommended based solely on the flood reduction benefits of the project.

5.3. Damage Center III

Based on the Alternative Analysis, any structural alternative would not provide enough reduction in annual damages to warrant the expense. The DCIII-ALTIII buyout option produced a benefit to cost ratio greater than 1. As always is the case with buyouts, the City will need to take into account the impact to residents and the neighborhood.

Based on the condition of the existing channel, it is anticipated that future maintenance or reconstruction of the channel will be required for the channel to continue to operate even at its current capacity. At which point it is recommended that either DCIII-ALTI or DCIII-ALTII be implemented to reduce flood damages through the DCIII reach.

5.4. Damage Center IV

The improvements to the College Drive crossing along with channel improvements upstream and downstream of the roadway (DCIV-II) produced favorable benefits compared to the cost of the project. It is recommended that DCIV-II be implemented to reduce the flooding impacts in the DCIV reach.

5.5. Damage Center V

The clearing alternative evaluated in DCV-ALTII produced favorable benefits compared to the cost of the project. It is recommended this alternative be implemented to reduce the flooding impacts in the DCV reach.

5.6. Damage Center VI

The channel improvements evaluated in DCVI-ALTI produced favorable benefits compared to the cost of the project. The project could impact the adjacent property owners and coordination with these residents should be considered prior to implementation. It is recommended this alternative be pursued to reduce the flooding impacts in the DCVI reach.

5.7. Damage Center VII

The improvements to the existing roadway crossings at Independence Circle and Lexington Place evaluated in DCVII-ALTI produced favorable benefits compared to the cost of the project. The alternative would significantly reduce flooding potential in the DCVII reach and it is recommended this alternative be implemented.

5.8. Damage Center VIII

Based on the Alternative Analysis, the DCVIII-ALTI buyout alternative would not provide enough reduction in annual damages to warrant the expense. DCVIII-ALTII would be a more favorable option in terms of the flood reduction benefits and project costs. However, DCVIII-ALTII would leave two properties in this area that were not considered in the buyout, which could have a very negative impact on the remaining residents. It is recommended that the City consider DCVIII-ALTI and offer buyouts to all properties impacated by flooding in this area.

5.9. Funding

The City of Texarkana is in the process of implemented a storm water utility fee to fund storm water management and improvements. The City also plans to research a number of funding sources to assist in the implementation of the recommended alternative for flood protection. Funding sources that will be researched include:

- FEMA's Hazard Mitigation Grant Program (HMGP)
- FEMA's Flood Mitigation Assistance (FMA)
- U.S Army Corps of Engineers' Section 205, Small Flood Control Projects Program
- TWDB Financial Assistance Programs

5.10 Preventative Alternatives

In addition to the recommended structural and buyout alternatives, the following non-structural alternatives are strongly recommended in order to reduce increases in annual flood damages.

5.10.1. Land Use Zoning and Subdivision Regulations

One means of preventing flood damage is to keep industrial, commercial, and residential structures from being built within the floodplain. Floodplain zoning restricts floodplain utilization to uses that can sustain floods without endangering life or valuable property. Regulatory ordinances are intended to secure the maximum benefits and productivity of flood-prone land by allowing floodplains to convey the design flood; promoting the public's health, safety, and general welfare; and minimizing potential flood losses.

Non-structural measures such as land use zoning and subdivision regulations allow a community to regulate development within the floodplain. As participants in the National Flood Insurance Program, the City of Texarkana has adopted regulations that equal or exceed the minimum FEMA requirements of regulating the existing 100-year floodplain.

5.10.2. Construction Regulations

Construction regulations constitute an important means of preventing flood damage in a developing watershed. Some cities have building codes that contain general flood protection provisions whereby the building inspector tries to route all building-permit applications in flood prone areas through the City Engineer. The City Engineer should then carefully review each application to determine if the proposed building may be flooded and ensure that all buildings adjacent to a flood-hazard area are built with a ground elevation that is at least one (1) foot above, and a finished floor elevation that is at least two (2) feet above the fully urbanized 100-year flood elevation. The City should require that all finished floor elevations be specified on the final plat of each new subdivision to help ensure all new structures are built above 100-year floodplain elevations.

To limit erosion and downstream sediment, construction projects should be phased to limit the land area that is bare at any one time, and vegetation should be left undisturbed wherever possible. Other practices, such as proper placement of erosion and sedimentation protection should also be required. Graded areas should be replanted as soon as possible, and mulches should be used during periods that are not suitable for replanting.

5.10.3. Informing the Public

Studies have indicated that most flood-related deaths in Texas occur at undersized bridges that are either overtopped or washed out by floodwaters. Using the hydrologic and hydraulic methods discussed in this report, the frequency of flooding and the elevation of water overtopping each roadway was calculated. Figure 11, Inundated Roadway, shows the calculated flood capacity of each roadway and flood profiles that supplement this report also show this information.

An alternative to improving dangerous bridges and culverts is to install flood warning signs, barricades, or other systems to inform and alert motorists of hazardous crossings.

The City should consider the need for a flood warning sign at all crossings that are overtopped by water during the 100-year and more frequent floods.

Flood warning systems can be passive or active. A passive system would be a warning sign, such as "BEWARE OF HIGH WATER", which would notify people using the bridge that flooding may occur. A gage with easy-to-read depth markings, measured in feet, should show motorists the height of water over the roadway. Guardrails can be installed to prevent vehicles from being washed off a dangerous road crossing, and can be used to identify the edge of the road surface where it may be obscured by floodwater.

Passive warning systems are feasible on lightly traveled residential streets where the motorists are familiar with the area, and are used at crossings with minor flooding. Installation of a passive warning system would be relatively inexpensive. Features include warning signs, staff gages, and guardrails.

Active warning systems use a sensing device which monitors the water level in the channel and alerts motorists before the water is actually flowing over the roadway. The active system could be an automatic unfolding warning sign with flashing lights and sirens, or a relayed signal that would alert city workers to barricade the crossings. An active system could also be used to alert local residents of rising floodwaters and to evacuate prior to the flood. Active warning systems are necessary on heavily traveled thoroughfares or at crossings which are extremely hazardous, but these systems typically require a minimum lead time in order to be effective. Wagner Creek is the only watershed anticipated to provide enough time between rainfall and peak flood elevations to allow an active warning system to be feasible.

The National Weather Service uses radar to locate severe and turbulent weather. The Weather Service declares a flash-flood watch when potentially severe storms are likely. A flash-flood warning is issued when a severe storm has developed and flooding is imminent. The warning is sent to weather wire services, counties and municipalities in the area, and to local Civil Defense authorities. Flood-prediction and early-warning systems usually give populated areas time to prepare flood defenses, evacuate flood-hazard areas, and close dangerous stream crossings.

A City of Texarkana flood warning system could be used to alert city officials to barricade flood prone streets in the City that become treacherous when overtopped. This system would not reduce or prevent property inundation or flood damages; however, it would increase public safety.

Many developed areas are flood prone, even if floods have not occurred within the memory of local residents. Flood hazard maps delineating flood prone areas, such as those included with this report, have been prepared by the FEMA and by USACE. Dissemination of such flood hazard information helps landowners to understand the need for compliance with floodplain zoning regulations. It also gives residents in dangerous flood prone areas evidence of the need to consider relocating their families and businesses.

This report, by accurately updating and delineating the flood prone areas, identifies dangerous flood prone stream crossings, informs residents of local flood hazards, and will assist the city and the public to evaluate proposed plans to minimize existing and future flood problems.

5.10.4. Watershed Management

The reduction of runoff in a watershed lowers peak discharges and flood stages. Soil conservation and the maintenance of vegetative ground cover retain water on the soil's surface, allowing infiltration into the soil. Urban development increases the percentage of impervious surfaces in an area, which generally increases the runoff potential. The preservation of trees, the maintenance of lawns, and the discharge of roof drains into vegetated areas increase the infiltration of storm water into soils in developed areas.

Bare soils are easily eroded, resulting in transportation of sediment through water courses. The flood carrying capacity of creeks and the storage capacity of flood control reservoirs are greatly reduced by deposits of this sediment. To limit erosion, vegetation should be left undisturbed wherever possible.

5.10.5. Debris Removal

The accumulation of trees, brush, sediment, and other debris at bridges, culverts, or other obstructions can have dangerous consequences. Obstructions to flow could cause higher flood stage elevations upstream of the crossing. In addition, masses of debris can break loose as flood flows increase, producing a destructive wall of water and debris that surges downstream. The force of water on the upstream side of a bridge plugged by debris may exceed the structural capacity of the bridge, causing it to fail. Prevention of debris obstructions can reduce flood damage and potential hazards.

The City should designate a maintenance division responsible for creek debris removal. This department could inspect bridges quarterly, or upon request, and remove debris from bridge openings. It is not always economically practical for the city to take responsibility for debris removal on private property especially in Texarkana where a significant portion of the floodplain land is privately owned. The removal of debris is an essential flood reduction technique.

Creeks should be inspected periodically to identify, cut, and remove dead trees or trees whose root systems have been undermined by erosion. An inspection program of this type should be aimed at the prevention of stream obstructions before they occur. Erosion-prevention measures should be instituted in areas where significant trees would be in danger of being uprooted by floodwaters. The inspection program should also identify areas in which siltation and debris could significantly decrease the flood-carrying capacity of the stream channel or the waterway under a bridge.

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