Marble Falls
Flood Protection Planning Study
Final Report

TWDB Flood Protection Planning Grant
Project Contract No. 114-832-1284
March 28, 2014

Prepared By:

SUSAN ROTH
water and wastewater consulting

HALFF

CHAD MICHAEL CORMACK
114227

3.28.2014
TBPE Firm #312

This document is for planning purposes only and is not intended for construction, bidding, or issuance of permits. It was prepared by or under the supervision of:

Type or Print Name	PE#	Date
Chad Cormack	114227	March 28, 2014

2014 MAR 32 AM 7:47
CONTRACT ADMINISTRATION

TABLE OF CONTENTS

APPENDIX D: Large Maps

APPENDIX E: Spatial Data – CD Only

LIST OF FIGURES

Appendix A

Appendix B

Appendix C

LIST OF TABLES

Appendix A

Appendix B

EXECUTIVE SUMMARY

The Backbone Creek and Whitman Branch Watershed, located in Burnet County, has been a source of significant flooding for the City of Marble Falls. As a result of the flooding, local officials applied for a Flood Protection Planning Grant through the Texas Water Development Board (TWDB); TWDB awarded the City of Marble Falls, as the primary applicant, the planning grant in April 2011. The City of Marble Falls, in conjunction with the City of Meadowlakes, the Lower Colorado River Authority, Marble Falls/Lake LBJ Chamber of Commerce, and Marble Falls Economic Development Corporation were official project participants to evaluate the development of new hydrologic and hydraulic models, as well as flood damage reduction alternatives for planning purposes. Susan Roth Consulting, LLC and her team, Halff Associates, Inc., served as the engineering consultant for this study.

Hydrologic modeling was performed on the Backbone Creek and Whitman Branch Watershed to quantify the amount of water that flows to the local streams. Detailed hydraulic modeling was conducted along Backbone Creek (including two tributaries) and Whitman Branch (including one tributary) within the city limits of Marble Falls. Limited detail hydraulic modeling was also performed on an unnamed tributary on the western edge of Marble Falls. LiDAR elevation data, cross-section and bridge/culvert surveys, and bridge/culvert as-builts were used to enhance the accuracy of the models. Flood gauge data and high water marks obtained from the June 2007 flood event were used for model calibration and validation. The modeling resulted in updated and more accurate flows and water surface elevations for the existing and ultimate conditions 2-, 5-, 10-, 25-, 50-, 100-, and 500-year events. The resulting hydraulic data was then used to analyze various flood reduction alternatives for the study area.

Eight alternatives were identified during the flood damage reduction analysis portion of the study. Each alternative was evaluated and ranked according to seven criteria factors regarding the tangible and intangible benefits to the community. As a result, three of the eight alternatives showed to be the most promising. It is recommended that The City of Marble Falls should consider developing a “creek walk” trail system to connect the downtown area with the community parks in combination with downtown channel improvements to reduce flood risk and open up more developable land area. While costly, the flood models show that significant land may be reclaimed for potential development through significant creek channelization. It is also recommended to upsize bridge and culvert crossings along U.S. Highway 281. A typical design standard for conveyance along state maintained roads is to be able to pass at a minimum the 25-year flood to avoid flooding of the roadway; two of these crossings along U.S. Highway 281 do not meet this standard and should be considered for future roadway improvements.

The final deliverables from this study may be submitted to the Federal Emergency Management Agency (FEMA) through the Letter of Map Revision (LOMR) process and will be available to the City of Marble Falls for regulation under their floodplain ordinance.

1.0 Introduction and Background

The Backbone Creek and Whitman Branch Watershed is located in Burnet County, as shown in Figure 1. This watershed drainage area is approximately 40 square miles and consists of multiple tributaries that flow into Backbone Creek, which ultimately flows into the Colorado River. The headwaters of the watershed are composed of primarily wooded areas, with relatively steep terrain. Moving towards the center of the watershed, the terrain flattens, with a mixture of grasslands, brush, and wooded areas. The downstream, southernmost portion of the watershed is comprised of steeper grades again, with significant development within the City of Marble Falls and Meadowlakes. There are two distinct gravel pit quarries that exist; one located at the northeastern section of the watershed and the other located in the southwestern region. Multiple small, rural subdivisions are dispersed throughout the upper reaches of the watershed. The elevations vary from 736 ft. above sea level at the confluence with the Colorado River to about 1498 ft. above sea level at the headwaters of the watershed. The average annual precipitation over the watershed is approximately 20 inches.

Significant flooding has occurred in Burnet County over the years, and specifically in the Marble Falls area. The largest and most recent flood in this area occurred on June 27, 2007. Two lines of thunderstorms produced approximately 18 inches of rainfall over much of the Backbone Creek and Whitman Branch Watershed. Multiple flooding deaths were reported in the community, and the Texas Almanac estimated damages to over 300 structures with losses of approximately $130 million. Multiple bridge and culvert crossings were completely washed out. Several high water rescues were necessary. The local community was greatly affected by this natural disaster. Photos of the rainfall destruction can be seen in Figure 2.

As a result of the significant flooding as well as the potential for increased development in the area, the City of Marble Falls and other project participants including the city of Meadowlakes, Lower Colorado River Authority (LCRA), Marble Falls/Lake LBJ Chamber of Commerce, and Marble Falls Economic Development Corporation (EDC) took a proactive lead in applying for a Flood Protection Planning Grant from the Texas Water Development Board (TWDB). To facilitate regional input into the planning process, three public meetings were held in Marble Falls throughout the duration of the study. These public meetings served to inform the public about the planning study and to gather information that could be used to enhance and confirm the study results and conclusions. Several additional meetings were held with the City of Marble Falls staff and other project partners to ensure that analysis of this study would be most beneficial to the community. This study has resulted in new planning and regulatory information for use in floodplain management, as well as flood reduction alternative analyses for the City of Marble Falls.

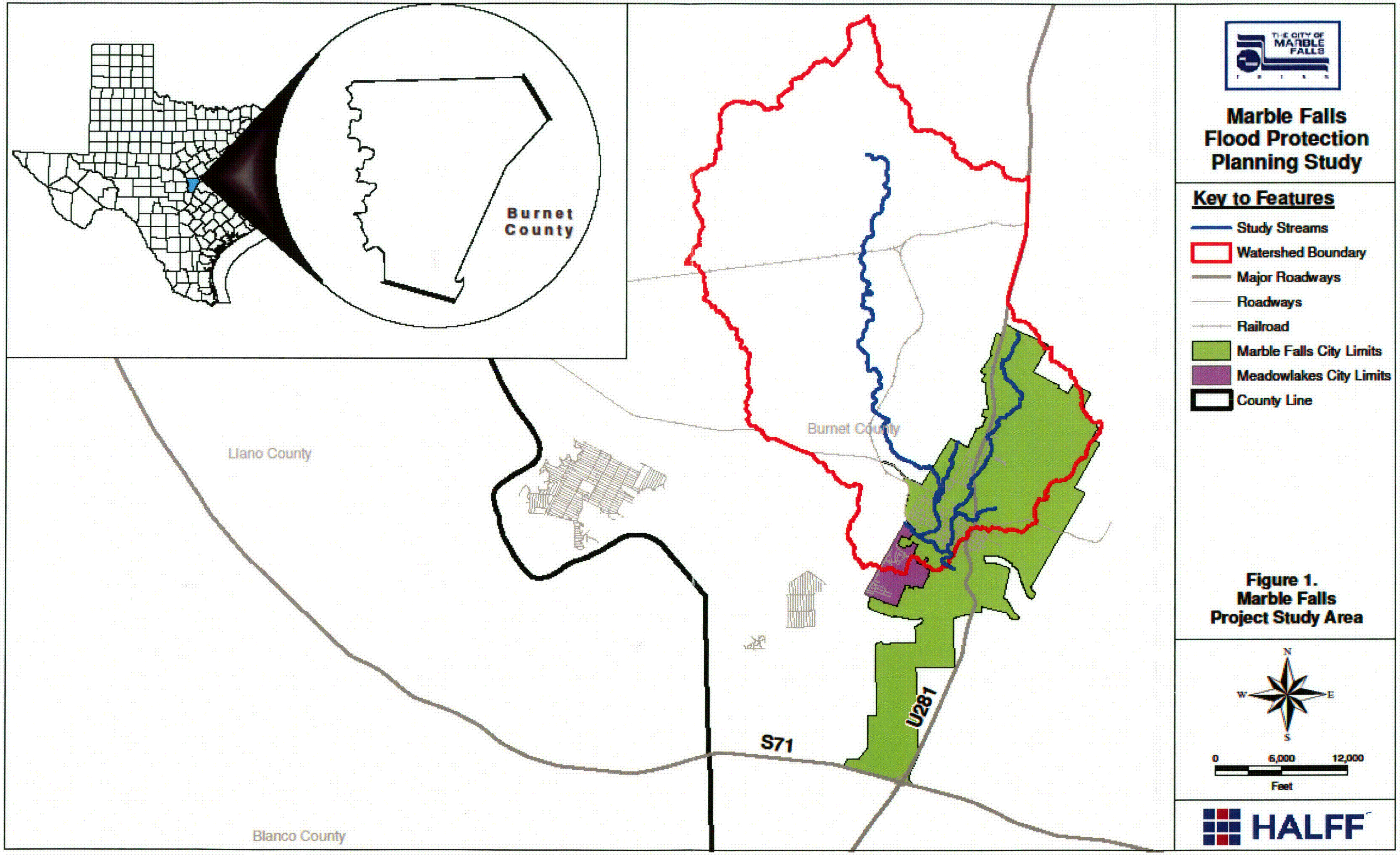


Figure 1.
Marble Falls
Project Study Area

This report presents the results of hydrologic, hydraulic, and alternative analyses of the Backbone Creek and Whitman Branch Watershed. Halff Associates, Inc. was responsible for developing existing and ultimate future conditions hydrologic and hydraulic models for Backbone Creek, Backbone Creek Tributary 1, Backbone Creek Tributary 2, Whitman Branch, and Whitman Branch Tributary 1. Halff Associates, Inc. also conducted a flood damage reduction alternative analysis within the watershed. Items discussed in this report include:

- Data Collection
- Hydrologic Analysis
- Hydraulic Analysis
- Modeling Results and Calibration
- Flood Damage Reduction Alternative Analysis
- Alternative Recommendations

Figure 2 – Impact of June 2007 Flood Event

2.0 Data Collection

Significant effort was put forth to collect necessary data before the hydrologic and hydraulic modeling commenced. Multiple project partners aided with the data collection effort including but not limited to: City of Marble Falls, Burnet County, Capital Area Council of Governments (CAPCOG), Texas Department of Transportation (TxDOT), Texas Natural Resources Information System (TNRIS), Marble Falls EDC, City of Meadowlakes, LCRA, Marble Falls/Lake LBJ Chamber of Commerce, and local citizens within the community. Project engineers also walked numerous stream miles to take photos and notes to better understand the physical creek characteristics. The following information was obtained for the Backbone Creek and Whitman Branch Watershed Study:

- Current Effective Burnet County Flood Insurance Study (FEMA, 2007)
    - US Army Corps of Engineers (USACE) hydrologic and hydraulic models used in the original Burnet County FIS Study
- Digital GIS data of parcels, current and future landuse maps, and soils data
- TxDOT As-Built Roadway Plans
- 2006 LCRA and 2011 TNRIS LiDAR datasets (see Figure 3)
- High water marks and photographs
- Multiple Bridge, Culvert, and Cross Section Surveys (see Figure 4)
- LCRA Historical Gage Data
- Real-time historical gridded rainfall data

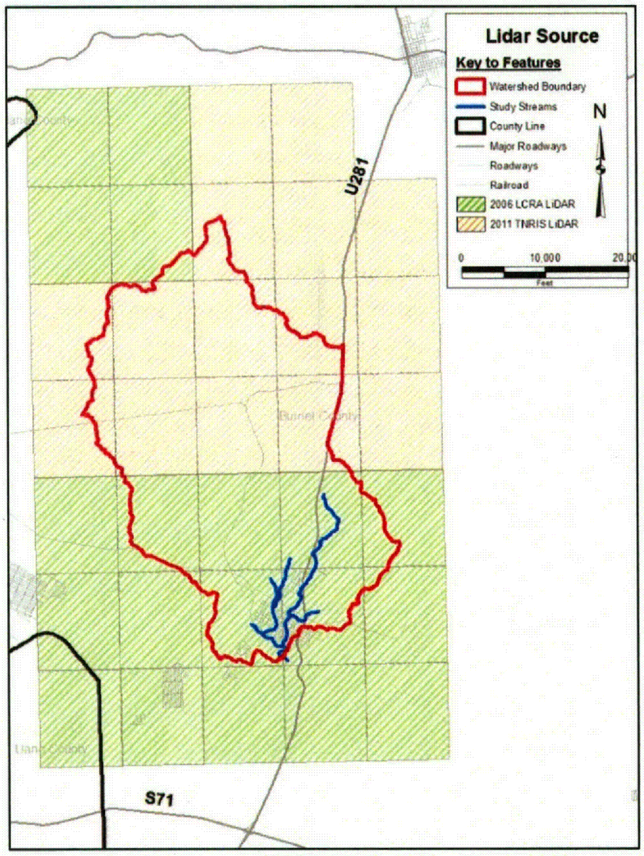
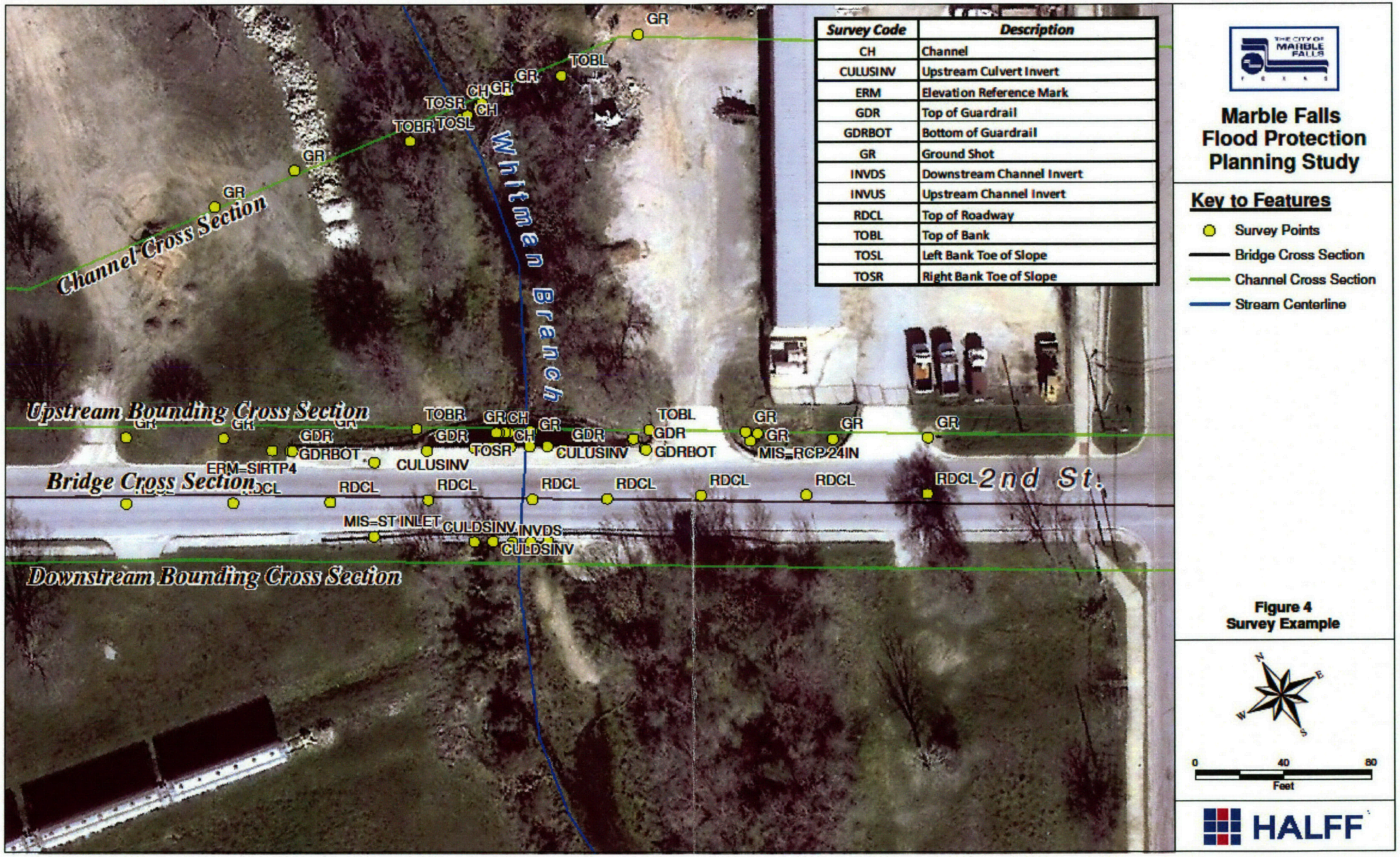


Figure 3 – Summary of LiDAR Data for Burnet County



Survey Code	Description
CH	Channel
CULUSINV	Upstream Culvert Invert
ERM	Elevation Reference Mark
GDR	Top of Guardrail
GDRBOT	Bottom of Guardrail
GR	Ground Shot
INVDS	Downstream Channel Invert
INVUS	Upstream Channel Invert
RDCL	Top of Roadway
TOBL	Top of Bank
TOSL	Left Bank Toe of Slope
TOSR	Right Bank Toe of Slope

Figure 4
Survey Example

3.0 Hydrologic Analysis

A detailed hydrologic analysis was performed on the Backbone Creek and Whitman Branch Watershed with the goal of providing a validated base conditions model for use in developing flood damage reduction alternatives as well as to assist in quantifying the impacts of these alternatives to the surrounding area. A total of 101 sub-basins were delineated using detailed LiDAR ground surface models in the area from the headwaters upstream of Backbone Creek to the edge of the study area at the Colorado River boundary. Figure 5 illustrates the overall watershed delineation for Backbone Creek, Whitman Branch, their tributaries, and each sub-basin.

The hydrologic analysis was simulated with the USACE HEC-HMS software, version 3.5. This modeling package was used to develop flow hydrographs for both existing and ultimate landuse conditions for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year events. Further details of the hydrologic analysis for the Backbone Creek and Whitman Branch Watershed can be found in Appendix A.

4.0 Hydraulic Analysis

Detailed hydraulic analyses were performed for Backbone Creek, Backbone Creek Tributary 1, Backbone Creek Tributary 2, Whitman Branch, and Whitman Branch Tributary within the city limits of Marble Falls to the outfall at the Colorado River for a total stream length of approximately 9.6 miles. The analyses utilized the USACE HEC-RAS version 4.1 software and were conducted to develop existing and ultimate condition peak stages for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year frequency events.

It was observed that hydraulic analysis would be beneficial for a previously unstudied area within the watershed where significant flooding frequently occurred. This unnamed tributary begins near the intersection of FM 1431 and Avenue V. The tributary flows through a primarily residential area until it's confluence with Backbone Creek at the railroad bridge. While field survey in this area was not part of the project scope, limited detail hydraulic models were developed to gain a better understanding of the flood potential in this region. Only the 100-year frequency event was analyzed for the limited detail study area. Study streams and their associated distances are summarized in Table 1. Further details of the hydraulic analysis for the Backbone Creek and Whitman Branch Watershed can be found in Appendix A.

Table 1 – Hydraulic Study Streams

Stream	Length (miles)
Backbone Creek	2.6
Backbone Creek Tributary 1	0.4
Backbone Creek Tributary 2	1.3
Whitman Branch	4.4
Whitman Branch Tributary 1	0.9
Unnamed Tributary	1.1*

*Limited Detail Study (No Survey)

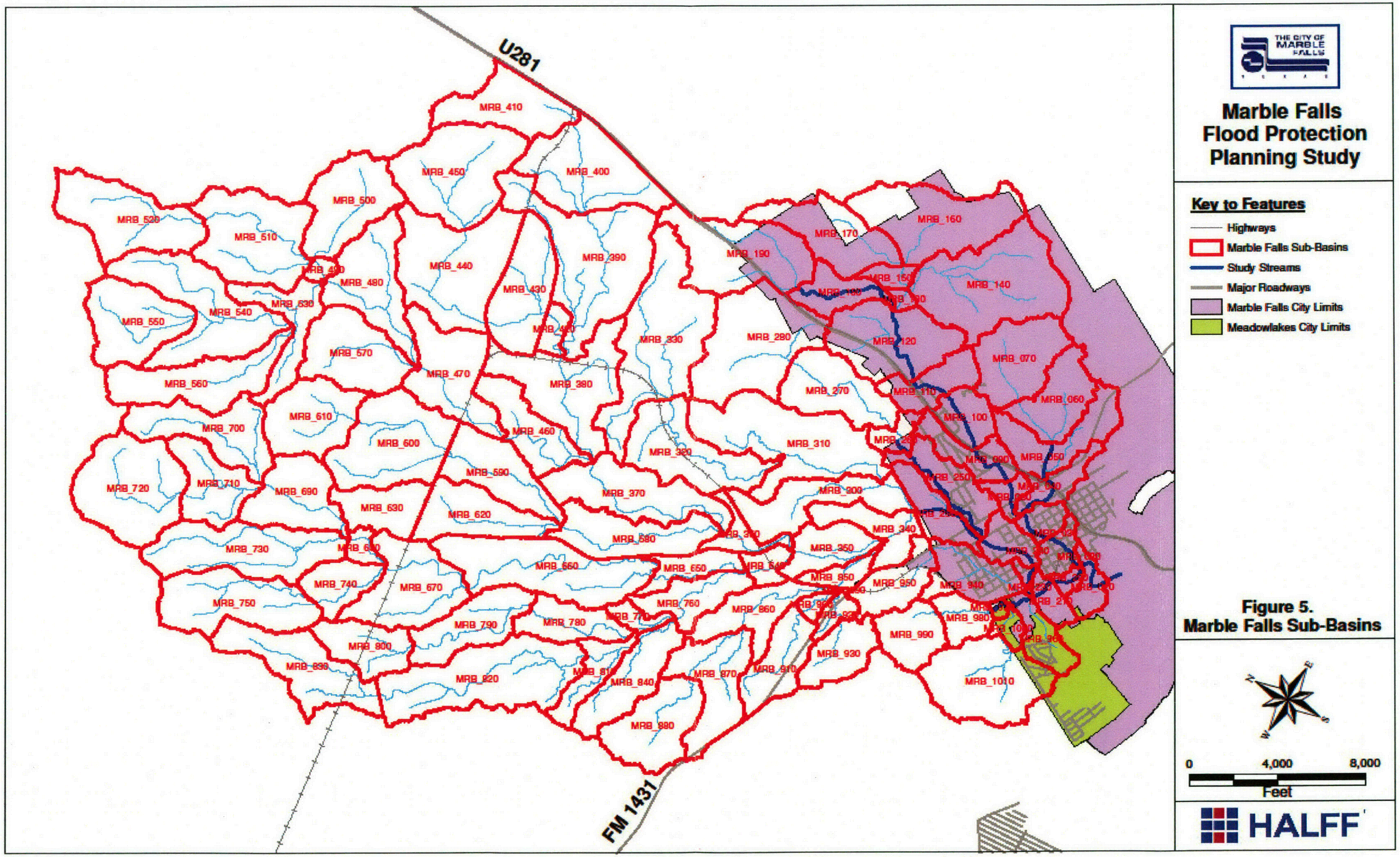


Figure 5. Marble Falls Sub-Basins

5.0 Modeling Results and Calibration

The existing conditions hydrologic and hydraulic analyses resulted in validated flood hazard information that is useful for planning and regulatory purposes. Specifically, the analyses resulted in base flood elevations for the existing and ultimate conditions 2-, 5-, 10-, 25-, 50-, 100-, and 500-year rainfall events. The existing conditions water surface elevation profiles for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year frequency events are provided in Appendix A. These water surface elevations were delineated onto the LiDAR elevation data to create floodplains for each frequency event that were used for the alternatives analysis. All floodplain modeling and mapping conforms to FEMA standards in the event that the community would like to submit a FEMA LOMR in the future to regulate to the new floodplains. The resulting 100-year floodplain delineation is illustrated in the map titled *100-Year Existing Floodplain* included in Appendix D.

The hydrologic, hydraulic, and floodplain results compared relatively well to the previous Flood Insurance Study (FEMA, 2007) results. Details and graphics of this comparison can be seen in Appendix A.

The LCRA gage data and archived high water mark elevations allowed for a detailed calibration of the models. Ground-adjusted, real-time, gridded rainfall for the June 2007 flood event was run through the newly created HEC-HMS model to obtain flow hydrographs throughout the watershed that simulated the actual event. The LCRA gage at FM 1431 and Backbone Creek compared well to the model simulation results for this event. The peak flows from the June 2007 flood event were then input into the HEC-RAS models where they were compared to the estimated high water mark elevations. Finally, the HEC-RAS results were delineated onto the LiDAR to create a simulated floodplain for the June 2007 flood event (Figure 6). These results were presented at the second public meeting and citizen input was collected. Using data gathered from the meeting, several model parameters were adjusted to better match actual observations. Overall, it has been determined that the hydrologic and hydraulic models for the Backbone Creek and Whitman Branch Watershed are simulating reality appropriately. Further information and graphics regarding the model calibration are provided in Appendix A.

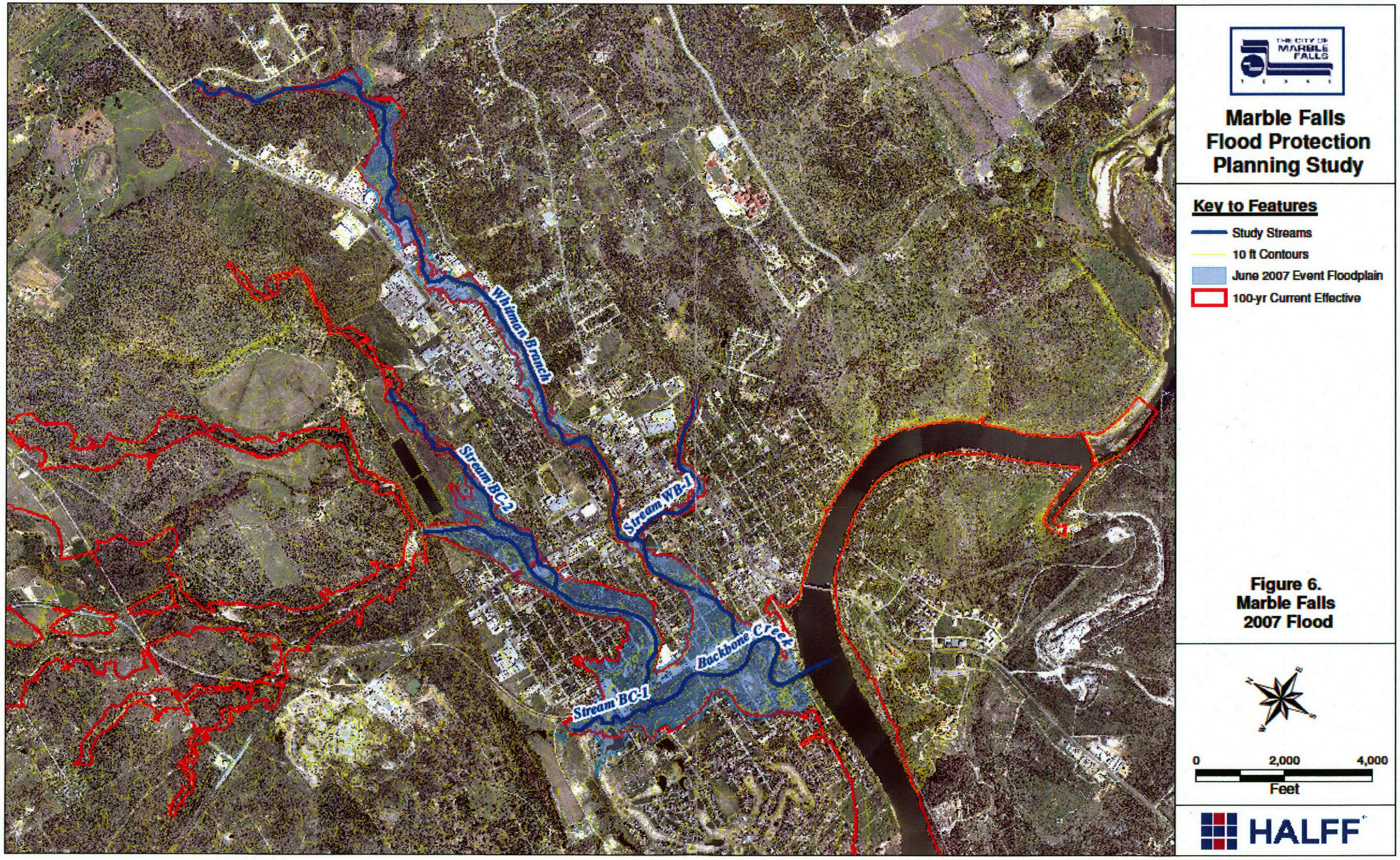


Figure 6.
Marble Falls
2007 Flood

6.0 Alternatives Analysis

A baseline alternatives analysis was performed using the hydrologic and hydraulic model results and impacts to existing structures within the study area. Details of the alternatives analysis are provided in Appendix B.

A total of eight alternatives were identified and evaluated along the study streams. Each alternative is briefly described below:

- ***Alternative 1 – Whitman Bypass Channel***
  This alternative looks at creating a bypass channel or culverts to reduce flooding through the industrial region at the upstream end of Whitman Branch.
- ***Alternative 2 – Upstream Whitman Detention***
  Holding back water near the headwaters of the Whitman Branch Watershed would have the potential to reduce flooding and lessen damages to structures along Whitman Branch during high frequency rainfall events.
- ***Alternative 3 – Upstream Backbone Detention***
  Holding back water on Backbone Creek just north of where it enters the City of Marble Falls would have the potential to reduce flooding and lessen damages to structures along Backbone Creek through the downtown area.
- ***Alternative 4 – Bridge/Culvert Improvements***
  An analysis of the bridge and culvert crossings within Marble Falls was conducted. It was found that two crossings along U.S. Highway 281 are not adequately sized for their traffic demands. The hydraulic models developed for this study were utilized to appropriately upsize these crossings so they will not be overtopped as frequently.
- ***Alternative 5 – Downtown Channel Improvements***
  The Backbone Creek floodplain near the confluence of the Colorado River is expansive. To lessen the impact of flooding in this area, this alternative included multiple scenarios such as channelization and upsizing crossings.
- ***Alternative 6 – Creek Walk***
  The City of Marble Falls, Marble Falls EDC, and Marble Falls/Lake LBJ Chamber of Commerce have a vision for developing a 'creek walk' area to connect the downtown area to the Whitman Branch overbank area. This alternative looks at the feasibility of constructing a trail along the creek that would allow for more development along the creek bank. Three options were analyzed that would also connect the downtown area and the adjacent park areas through the construction of additional trails. This alternative would work in conjunction with Alternative 5, incorporating downtown channel improvements with the creek development. A preliminary design for the proposed creek walk can be seen in Figure 7.
- ***Alternative 7 – Unnamed Tributary Bypass Channel***
  The unnamed tributary that was studied as a Zone A segment through the western edge of Marble Falls causes significant flooding to structures. This alternative looked into constructing a bypass channel that would divert water from the headwaters of the tributary directly into Backbone Creek to reduce flooding in the area.
- ***Alternative 8 – Voluntary Property Acquisition***

Over 50 structures are located within the newly developed 10-year floodplain. This alternative analysis illustrated that it will be extremely expensive to remove these structures out of the 100-year floodplain. This alternative investigated the quantified cost to voluntarily acquire homes located within the 2-, 5-, and 10-year floodplain.

After the initial eight alternatives were identified following the second public meeting, additional discussions with the project participants were held to narrow down the list of alternatives for a detailed analysis. Alternatives 4, 6, and 7 were selected as having the most potential benefit for the City of Marble Falls. As a result, these alternatives were further analyzed; details of the alternatives analysis are located in Appendix B. A summary of environmental constraints associated with implementing the recommended alternatives is located in Appendix C.

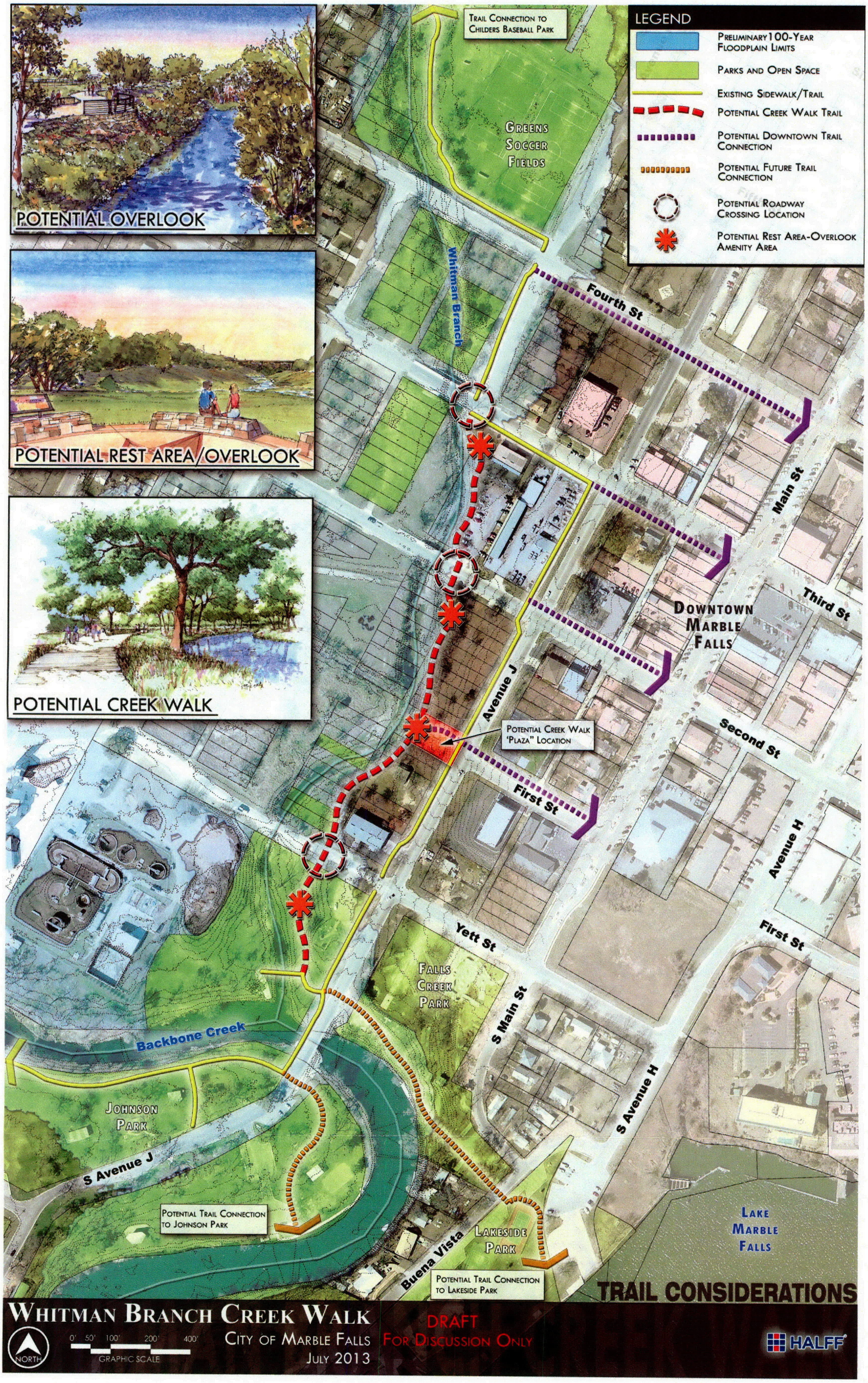


Figure 7 – Creek Walk Plans

7.0 Alternatives Summary

The results of the flood modeling indicate that relative to other communities, the City of Marble Falls has done an excellent job of not allowing development to occur within the floodplain. The initial analysis for most alternatives illustrated that the overall benefit from the alternatives was not enough to justify the estimated construction costs of the projects. The analysis revealed that the proposed improvements yielded benefits beyond strictly economic. A ranking matrix was developed to quantify all potential tangible and intangible benefits for each of the alternatives. The ranking matrix can be seen in Table 2. Detailed descriptions of the criteria used in the rankings are provided in Section B.1 of Appendix B.

Table 2 - Alternative Summary with Rankings

Alternative	Flood Mitigation Benefit/Cost Ratio	Community Beautification	Future Economic Impacts	O&M Costs + Upkeep	Grant Availability	Project Longevity	Community Buy-in	Environmental Contraints	*Total Score*	*Final Ranking*
# 6 - Creekwalk	3	10	9	4	5	8	10	5	*54*	***1***
# 4 - Crossing Improvements	5	1	5	9	8	8	9	7	*52*	***2***
# 7 - Unnamed Tributary Bypass	2	1	9	9	3	9	7	7	*47*	***3***
# 1 - Whitman Bypass	3	1	8	7	7	9	4	7	*46*	***4***
# 8 - Voluntary Property Acquisition	10	1	3	9	7	3	2	3	*38*	***5***
# 5 - Downtown Channel Improvements	1	3	3	7	3	8	3	5	*33*	***6***
# 2 - Whitman Detention	2	5	9	2	5	6	1	1	*31*	***7***
# 3 - Backbone Detention	1	5	4	2	5	6	1	1	*25*	***8***

The creek walk concept shows the greatest benefit to the City and community in combination with the downtown channel improvements. The proposed creek walk plan was broken into three phases. Phase 1 proposes an Americans with Disabilities Act (ADA, 1990) trail along the eastern banks of Whitman Branch with rest areas and overlooks. Phase 2 includes trail connections and street crossings that would connect downtown Marble Falls to the creek walk area. Phase 3 provides additional ADA trails and street crossings that would allow pedestrians to easily access adjacent parks. Beautification to this downstream segment of Whitman Branch in combination with connections to the downtown region, local parks, and the creek walk areas would result in substantial benefits to the community, in combination with the flood reduction benefits due to the downtown channelization. This is the number one recommended alternative for the study area. Detailed descriptions of each phase with cost estimates are provided in Section B.7 of Appendix B.

Alternative No. 4, upsizing the crossings along U.S. Highway 281, ranked as the second most beneficial alternative. This major roadway becomes inundated during small storms creating restricted safety access while producing dangerous driving conditions for motorists. Hydraulic models were utilized to develop recommendations to upsize the affected road crossings so that they will not be overtopped during a 25-year flood event. Detailed descriptions and cost estimates are provided in Section B.5 of Appendix B.

Finally, the unnamed tributary on the western side of Marble Falls causes significant flooding through a residential area. While the option of diverting flow directly into Backbone Creek may be expensive, it is a feasible flood mitigation alternative to significantly reduce risk within the City. Detailed descriptions and cost estimates are provided in Section B.8 of Appendix B.

Potential funding sources for the top three recommended alternatives include grant funding programs offered by FEMA, TxDOT, and the Texas Parks and Wildlife Department (TPWD), More detail regarding phasing and implantation of these projects is detailed in Section B.10.

A

APPENDIX A: Hydrologic and Hydraulic Analysis of the Backbone Creek and Whitman Branch Watershed

A.1 Hydrologic Analysis

A hydrologic analysis was performed in the Backbone Creek and Whitman Branch Watershed utilizing Hydrologic Engineering Center (HEC) Hydrologic Modeling System (HMS) software, version 3.5 (USACE, 2010). The purpose of this hydrologic analysis was to develop peak discharges for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year frequency rainfall events. The hydrologic model required the selection of various parameters. These parameters are as follows:

1. Precipitation Parameters
2. Rainfall Runoff Loss Parameters
3. Unit Hydrograph Parameters
4. Flood Routing Parameters

Each parameter set is discussed in further detail below.

A.2 Precipitation

In the United States Geological Survey (USGS) Water-Resources Investigations Report 98-4044 (Asquith, 1998) was used as a source for rainfall totals for the frequency floods. Although the City of Marble Falls Drainage Criteria Manual recommends the use of rainfall estimations from the Natural Resource Conservation Service (NRCS) Technical Report 55 (USDA, 1986), the USGS study chosen is more recent and contains a greater amount of regionally applicable values. Further explanation for this decision is explained in the Memo Titled *Marble Falls Flood Protection Planning Study Rainfall Data* located in Appendix E.

The regionally derived NRCS Type II rainfall distribution was appropriately used to create the synthetic hyetographs within the HEC-HMS model.

Furthermore, areal reduction was applied to each specific basin over 10 square miles as detailed in Technical Paper 40 (National Weather Service, 1961) and seen in Table A1. Final Precipitation values are shown in table A2.

Table A1 – Areal Reduction Percentages

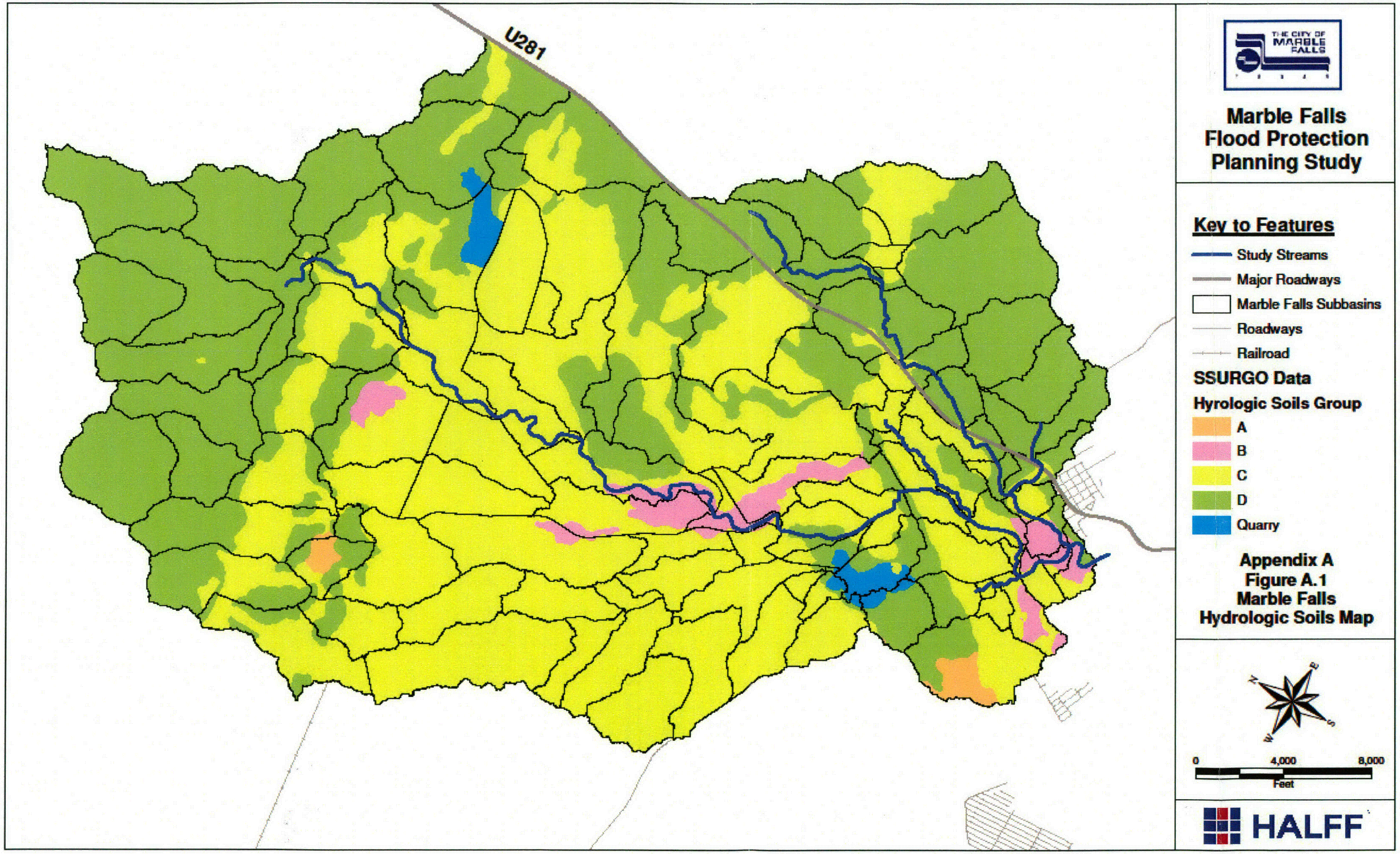
Area (Sq. Mi.)	Percent of Rainfall Area (%)
0	100
10	98.7
20	97.6
30	96.6
40	95.7

Table A2 – Final Precipitation Values

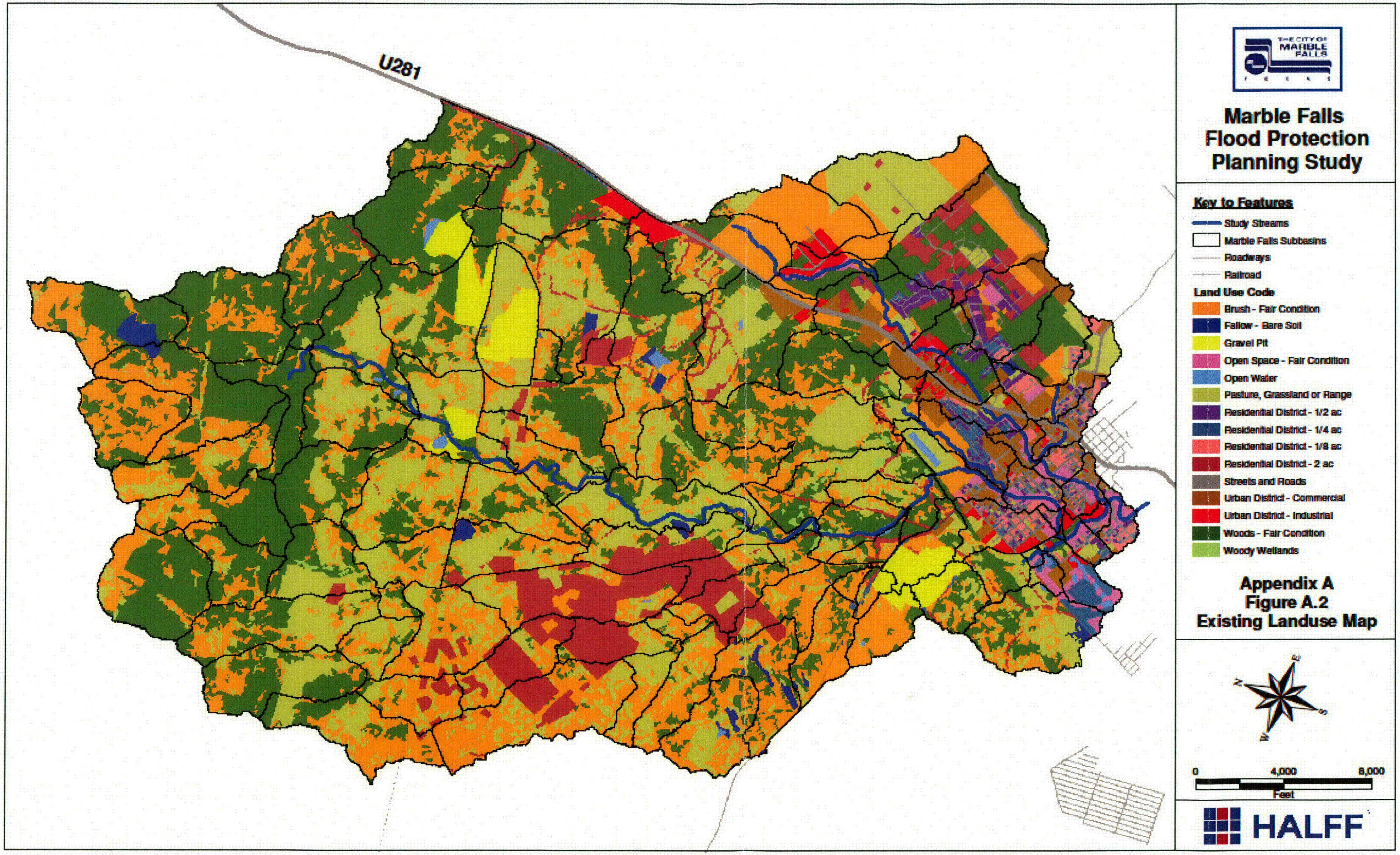
Frequency	24-hour Depth (inches)				
	0 sq. mi.	10 sq. mi.	20 sq. mi.	30 sq. mi.	40 sq. mi.
2-year	3.10	3.06	3.03	2.99	2.97
5-year	4.30	4.24	4.20	4.15	4.12
10-year	5.17	5.10	5.05	4.99	4.95
25-year	6.36	6.28	6.21	6.14	6.09
50-year	7.32	7.22	7.14	7.07	7.01
100-year	8.34	8.23	8.14	8.06	7.98
500-year	10.96	10.82	10.70	10.59	10.49

A.3 Rainfall-Runoff Losses

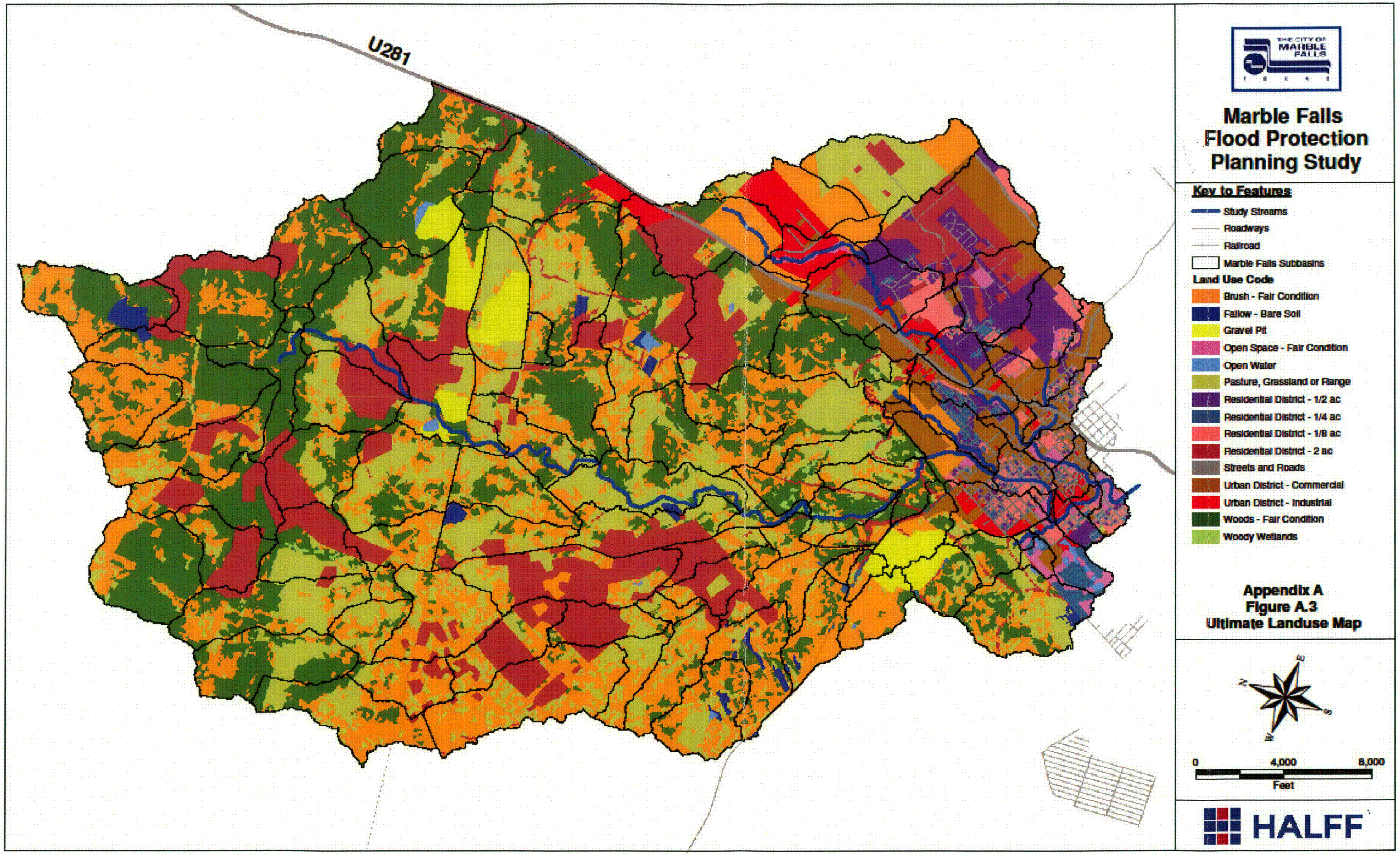
All rainfall-runoff losses were computed using the Soil Conservation Service (SCS) Curve Number Method in accordance to the City of Marble Falls Drainage Criteria Manual (DCM). Curve number assignment is a function of the hydrologic soil group and the landuse of the area of interest. The hydrologic soil groups used in this study were obtained from the Burnet County Soil Survey Geographic Database (SSURGO) and can be seen in Figure A.1. The City of Marble Falls has detailed landuse shapefiles for both existing and future conditions available as a source. Outside of the city limits, within the watershed headwaters, landuse data for existing conditions was obtained from the National Land Cover Dataset (NLCD) (Fry, J. et al., 2006) and modified where necessary to match the most current aerial imagery. Landuse data for future conditions outside of the city limits was calculated by increasing the impervious cover percentage by 15 percent in all basins. Figures A2 and A3 illustrate the respective existing and ultimate landuses. Table A3 displays the relationship between landuse and soil type and illustrates the subsequent SCS curve number. Table 4 displays the resulting curve numbers for each sub-basin. The percentage of impervious cover is included in the calculated curve number and given for display purposes only.



Appendix A
Figure A.1
Marble Falls
Hydrologic Soils Map



Appendix A
Figure A.2
Existing Landuse Map



Appendix A
Figure A.3
Ultimate Landuse Map

Table A3 – Composite Curve Numbers and N-values

Land Use Code (LUCODE)	Major Group (NLCD)	Marble Falls Landuse	TR-55 Cover Type	SCS Composite Curve Number				Average % Impervious*	N-Value
				A	B	C	D		
11	Open Water	N/A	N/A	98	98	98	98	100	1.00
21	Developed, Open Space	Residential-Rural	Residential District - 2 acres	46	65	77	82	12	0.07
22	Developoed, Low Intensity	Residential-Single-Family Detached	Residential District - 1/4 acre	61	75	83	87	38	0.09
N/A	N/A	Residential-Single-Family Detached	Residential District - 1/2 acre	54	70	80	85	25	0.08
23	Developed, Medium Intensity	Residential-Urban, Residential-Multi-Family	Residential District - 1/8 acre	77	85	90	92	65	0.12
24	Developed, High Intensity	Institutional, Lodging, Retail-Neighborhood, Retail-Regional, Retail-Urban, Office-Neighborhood, Office-Regional, Office-Business, Mixed Use-Urban	Urban District - Commercial and Business	89	92	94	95	85	0.12
N/A	N/A	Industrial - Heavy, Light and Research	Urban District - Industrial	81	88	91	93	72	0.12
N/A	N/A	Park-Active and Passive	Open Space - Fair Condition	49	69	79	84	0	0.06
31	Barren Land (Rock/Sand/Clay)	N/A	Fallow - Bare Soil	77	86	91	94	0	0.06
41	Deciduous Forest	N/A	Woods - Fair Condition	36	60	73	79	0	0.10
42	Evergreen Forest	N/A	Woods - Fair Condition	36	60	73	79	0	0.10
43	Mixed Forest	N/A	Woods - Fair Condition	36	60	73	79	0	0.10
52	Shrub/Scrub	N/A	Brush - Fair Condition	35	56	70	77	0	0.08
71	Grassland/Herbaceous	N/A	Pasture, Grassland, or Range - Fair Condition	49	69	79	84	0	0.06
81	Pasture/Hay	N/A	Pasture, Grassland, or Range - Fair Condition	49	69	79	84	0	0.06
90	Woody Wetlands	N/A	N/A	98	98	98	98	100	1.00
95	Emergent Herbaceous Wetlands	N/A	N/A	98	98	98	98	100	N/A
N/A	Gravel Pit	N/A	Streets and Roads: Gravel	76	85	89	91	0	0.10
N/A	N/A	N/A	Streets and Roads: Paved; Open ditches	83	89	92	93	0	0.06

Table A4 - SCS Curve Numbers and Percent Impervious Values (Existing and Ultimate Conditions)

HEC-HMS Sub-basin Name	Sub-basin Area (sq. mi)	EX Final Curve Number (AMC II)	ULT Final Curve Number (AMC II)	EX Computed Percent Impervious	ULT Computed Percent Impervious
MRB_010	0.125	86	86	32.70%	32.70%
MRB_020	0.130	87	88	29.19%	37.95%
MRB_030	0.108	89	89	32.18%	32.18%
MRB_040	0.164	93	93	44.25%	44.25%
MRB_050	0.376	90	93	34.33%	59.90%
MRB_060	0.360	84	88	13.43%	37.62%
MRB_070	0.474	84	86	17.19%	28.39%
MRB_080	0.090	93	93	62.34%	62.34%
MRB_090	0.232	90	90	47.28%	53.08%
MRB_100	0.205	87	90	35.90%	51.83%
MRB_1000	0.069	84	84	32.69%	32.69%
MRB_1010	0.649	70	70	3.40%	3.40%
MRB_110	0.254	88	92	39.62%	60.59%
MRB_120	0.608	84	89	22.51%	46.57%
MRB_130	0.035	76	82	0.00%	22.09%
MRB_140	0.913	82	87	9.08%	33.96%
MRB_150	0.080	72	72	2.92%	3.57%
MRB_160	0.711	80	80	1.91%	2.74%
MRB_170	0.492	79	84	6.36%	30.62%
MRB_180	0.229	83	88	16.34%	38.57%
MRB_190	0.686	81	82	7.99%	13.53%
MRB_200	0.046	85	86	20.18%	45.36%
MRB_210	0.108	85	86	21.08%	33.61%
MRB_220	0.006	86	90	0.90%	34.19%
MRB_230	0.029	87	87	17.09%	27.05%
MRB_240	0.164	90	90	33.10%	33.10%
MRB_250	0.303	84	86	35.21%	43.43%
MRB_260	0.109	81	83	16.88%	29.32%
MRB_270	0.465	77	77	0.89%	0.89%
MRB_280	0.830	79	79	7.84%	12.26%
MRB_290	0.236	84	87	23.43%	46.67%
MRB_300	0.473	73	73	6.84%	6.84%
MRB_310	0.901	75	75	0.60%	0.69%
MRB_320	0.601	77	77	0.24%	0.24%
MRB_330	0.995	78	79	3.45%	5.27%
MRB_340	0.277	75	75	1.87%	1.87%
MRB_350	0.270	78	78	8.88%	8.88%
MRB_360	0.138	70	70	10.18%	10.18%

HEC-HMS Sub-basin Name	Sub-basin Area (sq. mi)	EX Final Curve Number (AMC II)	ULT Final Curve Number (AMC II)	EX Computed Percent Impervious	ULT Computed Percent Impervious
MRB_370	0.593	78	78	5.70%	5.70%
MRB_380	0.714	75	75	1.39%	1.39%
MRB_390	0.999	77	77	0.61%	0.61%
MRB_400	0.711	79	79	7.09%	7.09%
MRB_410	0.460	78	78	1.62%	1.62%
MRB_420	0.095	73	73	0.67%	0.67%
MRB_430	0.512	82	82	0.08%	0.10%
MRB_440	0.870	82	82	0.04%	1.96%
MRB_450	0.770	81	81	2.09%	2.09%
MRB_460	0.384	75	75	1.21%	1.21%
MRB_470	0.559	79	80	2.33%	6.45%
MRB_480	0.557	78	78	0.95%	2.86%
MRB_490	0.047	79	79	0.00%	0.00%
MRB_500	0.530	79	79	0.18%	1.31%
MRB_510	0.739	79	80	0.00%	3.31%
MRB_520	0.650	80	80	0.00%	0.65%
MRB_530	0.353	79	79	0.00%	1.07%
MRB_540	0.786	79	79	0.00%	0.58%
MRB_550	0.535	78	78	0.00%	0.00%
MRB_560	0.569	79	80	0.00%	1.76%
MRB_570	0.530	77	78	0.00%	4.24%
MRB_580	0.479	73	73	5.33%	5.33%
MRB_590	0.445	74	74	0.00%	0.00%
MRB_600	0.719	75	75	0.03%	0.87%
MRB_610	0.482	77	78	0.00%	4.00%
MRB_620	0.433	77	77	1.37%	1.37%
MRB_630	0.311	74	74	0.00%	2.27%
MRB_640	0.110	75	75	5.68%	5.68%
MRB_650	0.190	75	75	6.96%	6.96%
MRB_660	0.800	75	75	7.21%	7.21%
MRB_670	0.593	74	74	1.57%	1.57%
MRB_680	0.078	79	79	0.00%	0.00%
MRB_690	0.456	78	79	2.97%	6.95%
MRB_700	0.519	79	80	0.00%	4.13%
MRB_710	0.379	79	80	0.00%	5.45%
MRB_720	0.756	79	79	0.35%	0.35%
MRB_730	0.714	78	79	0.17%	0.56%
MRB_740	0.248	69	69	0.00%	0.00%
MRB_750	0.633	78	78	0.00%	0.00%

HEC-HMS Sub-basin Name	Sub-basin Area (sq. mi)	EX Final Curve Number (AMC II)	ULT Final Curve Number (AMC II)	EX Computed Percent Impervious	ULT Computed Percent Impervious
MRB_760	0.289	75	75	5.94%	5.94%
MRB_770	0.087	74	74	0.76%	0.76%
MRB_780	0.290	77	77	8.03%	8.03%
MRB_790	0.428	75	75	6.25%	6.25%
MRB_800	0.325	75	75	1.95%	1.95%
MRB_810	0.221	75	75	0.00%	0.00%
MRB_820	0.908	74	74	2.32%	2.32%
MRB_830	0.586	74	74	0.06%	0.06%
MRB_840	0.403	73	73	0.45%	0.45%
MRB_850	0.114	81	81	5.71%	5.71%
MRB_860	0.353	73	73	1.99%	1.99%
MRB_870	0.483	73	73	0.56%	0.56%
MRB_880	0.484	74	74	0.79%	0.79%
MRB_890	0.005	86	86	10.33%	10.33%
MRB_900	0.052	71	71	1.61%	1.61%
MRB_910	0.340	72	72	0.71%	0.71%
MRB_920	0.085	82	82	4.20%	4.20%
MRB_930	0.278	73	73	0.70%	0.70%
MRB_940	0.318	88	89	31.09%	38.83%
MRB_950	0.283	89	89	5.09%	10.43%
MRB_960	0.202	83	84	37.70%	41.57%
MRB_970	0.024	79	79	7.51%	7.51%
MRB_980	0.171	79	79	0.80%	0.80%
MRB_990	0.277	84	84	0.97%	0.97%

A.4 Unit Hydrograph Method

The SCS Unit Hydrograph Method was used to develop the hydrographs and corresponding peak discharges for each sub-basin. As outlined in Marble Falls DCM, the time of concentration (Tc) and lag time (Tlag) for each sub-basin was calculated using the TR-55 (USDA, 1986) approach, with exception for the sheet flow segments. The Marble Falls DCM outlined methodology that gave significantly different values for sheet flow than the standard TR-55 approach. The TR-55 approach was used, with a maximum sheet flow length of 100 ft. SCS unit hydrograph parameters and final lag time results are shown in Table A5.

Table A5: SCS Unit Hydrograph Parameters for the Backbone Creek and Whitman Branch Watershed Sub-Basins

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_010	3,421	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.904	2.99	1.3															**24.6**	**14.7**	**0.25**
								547	2.825	3.42	Paved	2.67												
													1,755	2.438	9.8	20.5	0.04	3.56		3.56	8.23			
													1,019						1.37	1.37	12.4			
MRB_020	3,479	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	3.323	2.99	1															**13.1**	**7.9**	**0.13**
								299	3.024	3.53	Paved	1.41												
													1,319	4.493	4.5	9	0.04	4.94		4.94	4.45			
													1,761						4.71	4.71	6.23			
MRB_030	2,972	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.431	2.99	1.4															**15.1**	**9**	**0.15**
								165	3.856	3.99	Paved	0.69												
													2,272	2.624	4.9	11.4	0.04	3.44		3.44	11.01			
													435						3.78	3.78	1.92			
MRB_040	6,087	100	0.15	Grass-Short Grass Prairie	2.868	2.99	8.8															**43.9**	**26.3**	**0.44**
								409	3.371	2.96	Unpaved	2.3												
													3,437	3.522	1.1	9.7	0.03	2.2		2.2	26.01			
													2,141						5.25	5.25	6.8			
MRB_050	6,814	100	0.15	Grass-Short Grass Prairie	4.238	2.99	7.5															**27.4**	**16.5**	**0.27**
								1,067	1.46	2.46	Paved	7.24												
													5,234	2.69	160	91.5	0.045	7.88		7.88	11.06			
													413						4.27	4.27	1.61			
MRB_060	5,783	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.822	2.99	1.3															**17.1**	**10.3**	**0.17**
								1,833	2.726	2.66	Unpaved	11.47												
													3,850	2.728	402.5	77	0.05	14.82		14.82	4.33			
MRB_070	5,632	100	0.15	Grass-Short Grass Prairie	1.853	2.99	10.5															**46.1**	**27.7**	**0.46**
								3,241	1.32	1.85	Unpaved	29.14												
													2,291	2.434	70.3	58.7	0.045	5.83		5.83	6.55			
MRB_080	3,460	100	0.15	Grass-Short Grass Prairie	1.484	2.99	11.4															**26.8**	**16.1**	**0.27**
								559	1.252	1.81	Unpaved	5.16												
													1,454	2.856	2.1	8.8	0.015	6.53		6.53	3.71			
													1,347						3.44	3.44	6.53			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_090	6,490	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.835	2.99	1.3															39.9	23.9	0.4
								491	1.068	2.1	Paved	3.9												
													3,483	1.003	2.7	13.7	0.015	3.34		3.34	17.4			
													2,416						2.33	2.33	17.27			
MRB_100	3,163	100	0.15	Grass-Short Grass Prairie	2.069	2.99	10															21.3	12.8	0.21
								1,380	6.734	4.19	Unpaved	5.49												
													758	7.918	143.1	51.3	0.06	13.84		13.84	0.91			
													925						3.16	3.16	4.87			
MRB_1000	3,001	100	0.15	Grass-Short Grass Prairie	3.261	2.99	8.3															18.4	11	0.18
								617	5.064	3.63	Unpaved	2.83												
													2,284	1.056	54.4	33.5	0.04	5.29		5.29	7.19			
MRB_1010	7,333	100	0.15	Grass-Short Grass Prairie	3.618	2.99	8															31.2	18.7	0.31
								1,108	1.865	2.2	Unpaved	8.38												
													6,125	1.227	71.4	33.2	0.04	6.87		6.87	14.86			
MRB_110	3,423	100	0.15	Grass-Short Grass Prairie	1.781	2.99	10.6															21.9	13.1	0.22
								837	6.06	3.97	Unpaved	3.51												
													1,861	6.144	154.9	48.6	0.05	16		16	1.94			
													625						1.79	1.79	5.84			
MRB_120	6,384	100	0.15	Grass-Short Grass Prairie	2.286	2.99	9.6															38.8	23.3	0.39
								708	4.868	3.56	Unpaved	3.31												
													3,472	2.723	12.8	26	0.045	3.41		3.41	16.95			
													2,104						3.93	3.93	8.92			
MRB_130	2,133	100	0.15	Grass-Short Grass Prairie	2.47	2.99	9.3															23.4	14.1	0.23
								1,016	1.427	1.93	Unpaved	8.79												
													1,017	0.538	33.9	27.1	0.04	3.17		3.17	5.34			
MRB_140	9,792	100	0.15	Grass-Short Grass Prairie	1.718	2.99	10.8															56.1	33.7	0.56
								2,331	2.314	2.45	Unpaved	15.83												
													7,361	1.324	75.3	56.5	0.05	4.15		4.15	29.54			
MRB_150	2,793	100	0.15	Grass-Short Grass Prairie	7.922	2.99	5.8															21.9	13.1	0.22
								1,835	2.577	2.59	Unpaved	11.81												
													858	0.901	33.9	25.7	0.05	3.41		3.41	4.2			
MRB_160	7,357	100	0.15	Grass-Short Grass Prairie	1.279	2.99	12.1															65.8	39.5	0.66
								3,604	2.961	2.78	Unpaved	21.64												
													3,653	0.702	14.2	30	0.04	1.9		1.9	32.06			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_170	9,353	100	0.15	Grass-Short Grass Prairie	4.309	2.99	7.5															39.9	23.9	0.4
								3,190	2.955	2.77	Unpaved	19.17												
													6,063	1.98	147.6	60.2	0.05	7.62		7.62	13.26			
MRB_180East	5,297	100	0.15	Grass-Short Grass Prairie	2.833	2.99	8.8															31.7	19	0.32
								202	2.935	2.76	Unpaved	1.22												
													1,796	6.402	5.7	23.8	0.04	3.64		3.64	8.22			
													3,199						3.96	3.96	13.46			
MRB_180West	6,359	100	0.15	Grass-Short Grass Prairie	0.928	2.99	13.8															41.4	24.9	0.41
								342	2.867	2.73	Unpaved	2.09												
													611	2.859	30.9	18.1	0.04	9.02		9.02	1.13			
													5,306						3.62	3.62	24.43			
MRB_190	8,700	100	0.15	Grass-Short Grass Prairie	3.639	2.99	8															52.7	31.6	0.53
								790	1.612	2.05	Unpaved	6.43												
													7,810	2.509	5	11.4	0.04	3.4		3.4	38.3			
MRB_200	2,171	100	0.15	Grass-Short Grass Prairie	1.67	2.99	10.9															25.5	15.3	0.25
								137	0.773	1.42	Unpaved	1.61												
													1,082	2.673	1.3	11	0.015	3.93		3.93	4.59			
													852						1.7	1.7	8.38			
MRB_210	3,088	100	0.15	Grass-Short Grass Prairie	1.413	2.99	11.6															32.7	19.6	0.33
								638	2.372	2.49	Unpaved	4.28												
													1,824	2.145	5.6	18.7	0.04	2.45		2.45	12.41			
													526						2.04	2.04	4.31			
MRB_220	1,025	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	2.686	2.99	1.1															8.2	4.9	0.08
								476	3.308	2.93	Unpaved	2.7												
													449						1.7	1.7	4.4			
MRB_230	2,380	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.055	2.99	1.6															12.2	7.3	0.12
								206	1.22	2.24	Paved	1.53												
													1,140	2.008	2	11.8	0.015	4.27		4.27	4.44			
													934						3.39	3.39	4.59			
MRB_240	4,770	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.638	2.99	1.4															29	17.4	0.29
								753	3.144	3.6	Paved	3.48												
													1,366	2.284	4.4	14.7	0.04	2.51		2.51	9.06			
													2,551						2.82	2.82	15.08			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_250	7,641	100	0.15	Grass-Short Grass Prairie	2.231	2.99	9.7															39.6	23.8	0.4
								237	4.479	3.41	Unpaved	1.16												
													1,338	4.017	16.3	13.7	0.04	8.36		8.36	2.67			
													5,966						3.81	3.81	26.11			
MRB_260	3,523	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	2.202	2.99	1.2															15.3	9.2	0.15
								461	0.977	2.01	Paved	3.82												
													1,405	3.024	12.2	12.6	0.04	6.33		6.33	3.7			
													1,557						3.98	3.98	6.53			
MRB_270	9,058	100	0.15	Grass-Short Grass Prairie	0.5	2.99	17.6															48.1	28.8	0.48
								928	2.641	2.62	Unpaved	5.9												
													959	4.84	18.3	28.7	0.045	5.4		5.4	2.96			
													7,071						5.47	5.47	21.56			
MRB_280East	6,075	100	0.15	Grass-Short Grass Prairie	5.609	2.99	6.7															35.5	21.3	0.35
								1,226	4.187	3.3	Unpaved	6.19												
													4,749	1.493	18.4	27.1	0.04	3.51		3.51	22.55			
MRB_280West	5,588	100	0.15	Grass-Short Grass Prairie	9.3	2.99	5.5															32.9	19.7	0.33
								1,042	4.833	3.55	Unpaved	4.9												
													4,446	1.1	33.2	36	0.045	3.29		3.29	22.49			
MRB_290	6,215	100	0.15	Grass-Short Grass Prairie	18.562	2.99	4.2															26.2	15.7	0.26
								284	6.257	4.04	Unpaved	1.17												
													3,664	1.378	31.6	24	0.04	5.26		5.26	11.61			
													2,167						3.92	3.92	9.21			
MRB_300	11,188	100	0.15	Grass-Short Grass Prairie	1.291	2.99	12.1															87	52.2	0.87
								3,482	0.768	1.41	Unpaved	41.05												
													7,606	1.264	12.9	15.3	0.04	3.74		3.74	33.9			
MRB_310	13,347	100	0.15	Grass-Short Grass Prairie	3.538	2.99	8.1															66.2	39.7	0.66
								825	11.415	5.45	Unpaved	2.52												
													12,422	0.89	55.2	42.5	0.045	3.72		3.72	55.65			
MRB_320	11,494	100	0.15	Grass-Short Grass Prairie	5.055	2.99	7															35.6	21.3	0.36
								785	11.745	5.53	Unpaved	2.37												
													10,609	1.027	81.9	28.7	0.045	6.75		6.75	26.2			
MRB_330	10,078	100	0.15	Grass-Short Grass Prairie	2.845	2.99	8.8															31.7	19	0.32
								1,294	4.163	3.29	Unpaved	6.55												
													8,684	2.052	66	25.9	0.045	8.84		8.84	16.37			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_340	12,023	100	0.15	Grass-Short Grass Prairie	3.233	2.99	8.4															**55.7**	**33.4**	**0.56**
								665	2.272	2.43	Unpaved	4.56												
													5,629	0.908	23.1	20.9	0.045	3.38		3.38	27.77			
													5,629						6.25	6.25	15.02			
MRB_350	5,522	100	0.15	Grass-Short Grass Prairie	1.559	2.99	11.2															**40.1**	**24**	**0.4**
								1,186	0.902	1.53	Unpaved	12.9												
													764	2.36	7.1	11.1	0.04	4.26		4.26	2.99			
													3,472						4.46	4.46	12.99			
MRB_360	6,212	100	0.15	Grass-Short Grass Prairie	1.211	2.99	12.4															**51**	**30.6**	**0.51**
								770	1.41	1.92	Unpaved	6.7												
													3,005	0.776	9.5	16.7	0.04	2.24		2.24	22.32			
													2,337						4.08	4.08	9.55			
MRB_370	11,937	100	0.15	Grass-Short Grass Prairie	2.447	2.99	9.4															**88.4**	**53.1**	**0.88**
								2,633	0.5	1.14	Unpaved	38.46												
													1,984	1.256	10.5	17.7	0.04	2.94		2.94	11.25			
													7,220						4.1	4.1	29.38			
MRB_380	9,487	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.316	2.99	1.5															**46.4**	**27.9**	**0.46**
								2,611	0.661	1.31	Unpaved	33.17												
													6,776	0.618	225.2	58.6	0.03	9.57		9.57	11.8			
MRB_390	12,374	100	0.15	Grass-Short Grass Prairie	3.051	2.99	8.6															**36.4**	**21.8**	**0.36**
								2,039	5.336	3.73	Unpaved	9.12												
													10,235	1.076	65.2	27.6	0.03	9.13		9.13	18.68			
MRB_400	4,806	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	3.725	2.99	1															**14.6**	**8.7**	**0.15**
								1,410	3.755	3.13	Unpaved	7.52												
													3,296	2.804	88.2	42.2	0.045	9.06		9.06	6.07			
MRB_410	8,425	100	0.15	Grass-Short Grass Prairie	0.5	2.99	17.6															**70.5**	**42.3**	**0.7**
								5,907	1.689	2.1	Unpaved	46.95												
													2,418	1.983	136.1	65.3	0.05	6.84		6.84	5.89			
MRB_420	3,774	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	2.539	2.99	1.1															**14.5**	**8.7**	**0.15**
								501	2.151	2.98	Paved	2.8												
													3,173	0.559	82.8	28.9	0.045	4.99		4.99	10.6			
MRB_430	6,175	100	0.15	Grass-Short Grass Prairie	5.482	2.99	6.8															**25.1**	**15.1**	**0.25**
								1,764	3.217	2.89	Unpaved	10.16												
													4,311	0.968	45.6	18.9	0.03	8.79		8.79	8.17			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_440	8,615	100	0.15	Grass-Short Grass Prairie	2.863	2.99	8.8															**27.3**	**16.4**	**0.27**
								529	9.816	5.05	Unpaved	1.74												
													7,986	2.581	75.2	41.5	0.045	7.91		7.91	16.82			
MRB_450	7,627	100	0.15	Grass-Short Grass Prairie	2.123	2.99	9.9															**33.7**	**20.2**	**0.34**
								2,730	3.297	2.93	Unpaved	15.53												
													4,797	1.783	198.4	61.9	0.045	9.61		9.61	8.32			
MRB_460	9,581	100	0.15	Grass-Short Grass Prairie	1.112	2.99	12.8															**78.2**	**46.9**	**0.78**
								755	0.766	1.41	Unpaved	8.91												
													3,159	0.997	6.8	34.5	0.04	1.26		1.26	41.7			
													5,567						6.27	6.27	14.8			
MRB_470	9,195	100	0.15	Grass-Short Grass Prairie	0.681	2.99	15.6															**55**	**33**	**0.55**
								1,463	3.463	3	Unpaved	8.12												
													2,325	1.335	8.6	23.6	0.04	2.2		2.2	17.64			
													5,307						6.47	6.47	13.67			
MRB_480	8,946	100	0.15	Grass-Short Grass Prairie	5.203	2.99	6.9															**38.3**	**23**	**0.38**
								3,126	5.624	3.83	Unpaved	13.62												
													2,334	1.727	12.6	17.6	0.045	3.49		3.49	11.15			
													3,386						8.52	8.52	6.62			
MRB_490	1,513	100	0.15	Grass-Short Grass Prairie	2.937	2.99	8.7															**11.1**	**6.7**	**0.11**
								364	11.163	5.39	Unpaved	1.13												
													448	15.344	110.9	31.6	0.06	22.44		22.44	0.33			
													601						10.31	10.31	0.97			
MRB_500	6,699	100	0.15	Grass-Short Grass Prairie	3.502	2.99	8.1															**40.2**	**24.1**	**0.4**
								2,128	2.782	2.69	Unpaved	13.18												
													4,471	2.823	11.2	18.9	0.045	3.94		3.94	18.93			
MRB_510	8,335	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.995	2.99	1.3															**18.9**	**11.3**	**0.19**
								1,265	5.768	3.87	Unpaved	5.44												
													6,970	2.684	72.3	31.1	0.045	9.52		9.52	12.2			
MRB_520	8,543	100	0.15	Grass-Short Grass Prairie	4.541	2.99	7.3															**30.8**	**18.5**	**0.31**
								1,818	5.765	3.87	Unpaved	7.82												
													6,625	2.198	62.4	36.4	0.045	7.04		7.04	15.68			
MRB_530	7,894	100	0.15	Grass-Short Grass Prairie	5.299	2.99	6.9															**24.7**	**14.8**	**0.25**
								1,214	6.95	4.25	Unpaved	4.76												
													3,634	3.741	47	30.3	0.045	8.58		8.58	7.06			
													2,946	1.422	44.7	27.4	0.03	8.22		8.22	5.97			
MRB_540	11,773	100	0.15	Grass-Short Grass Prairie	3.956	2.99	7.7															**27.6**	**16.6**	**0.28**

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
								1,875	5.67	3.84	Unpaved	8.13												
													9,798	2.973	211.2	55.7	0.045	13.88		13.88	11.76			
MRB_550	7,356	100	0.15	Grass-Short Grass Prairie	0.847	2.99	14.3															**30.4**	**18.2**	**0.3**
								1,628	5.527	3.79	Unpaved	7.15												
													5,628	2.814	170.5	65.6	0.045	10.5		10.5	8.94			
MRB_560	11,106	100	0.15	Grass-Short Grass Prairie	7.202	2.99	6.1															**42.1**	**25.3**	**0.42**
								4,151	2.433	2.52	Unpaved	27.49												
													6,855	3.749	380.3	126.5	0.045	13.36		13.36	8.55			
MRB_570	7,058	100	0.15	Grass-Short Grass Prairie	4.828	2.99	7.1															**33**	**19.8**	**0.33**
								2,784	6.815	4.21	Unpaved	11.02												
													4,174	1.184	35.3	24	0.045	4.67		4.67	14.91			
MRB_580	10,012	100	0.15	Grass-Short Grass Prairie	1.751	2.99	10.7															**81.4**	**48.9**	**0.81**
								2,512	0.5	1.14	Unpaved	36.7												
													7,400	0.511	53.8	24.3	0.05	3.62		3.62	34.05			
MRB_590	8,743	100	0.15	Grass-Short Grass Prairie	4.267	2.99	7.5															**61.6**	**36.9**	**0.62**
								1,789	1.12	1.71	Unpaved	17.46												
													6,854	0.5	36.2	23.6	0.045	3.12		3.12	36.63			
MRB_600	6,646	100	0.15	Grass-Short Grass Prairie	2.368	2.99	9.5															**46.5**	**27.9**	**0.46**
								1,344	4.951	3.59	Unpaved	6.24												
													5,202	0.921	40.2	48	0.045	2.82		2.82	30.74			
MRB_610	5,418	100	0.15	Grass-Short Grass Prairie	2.386	2.99	9.4															**28.3**	**17**	**0.28**
								3,375	6.792	4.2	Unpaved	13.38												
													1,943	1.73	43.8	27.3	0.045	5.97		5.97	5.43			
MRB_620	7,633	100	0.15	Grass-Short Grass Prairie	0.759	2.99	14.9															**90.4**	**54.2**	**0.9**
								5,814	0.789	1.43	Unpaved	67.6												
													1,719	0.904	56.5	45.2	0.045	3.65		3.65	7.85			
MRB_630	5,265	100	0.15	Grass-Short Grass Prairie	9.627	2.99	5.4															**45.6**	**27.4**	**0.46**
								3,877	2.5	2.55	Unpaved	25.33												
													1,288	0.582	16.8	46.5	0.04	1.44		1.44	14.87			
MRB_640	3,245	100	0.15	Grass-Short Grass Prairie	1.449	2.99	11.5															**20.5**	**12.3**	**0.21**
								661	2.225	2.41	Unpaved	4.58												
													2,484	0.814	270.6	89.8	0.03	9.34		9.34	4.43			
MRB_650	6,134	100	0.15	Grass-Short Grass Prairie	1.631	2.99	11															**29.7**	**17.8**	**0.3**
								1,500	1.894	2.22	Unpaved	11.26												
													4,534	0.5	329.1	67.1	0.03	10.13		10.13	7.46			
MRB_660	12,665	100	0.15	Grass-Short Grass Prairie	0.567	2.99	16.8															**101.2**	**60.7**	**1.01**
								3,204	1.044	1.65	Unpaved	32.39												

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
													5,119	0.594	13	23.8	0.04	1.92		1.92	44.44			
													4,242	0.5	289.4	67.1	0.03	9.3		9.3	7.6			
MRB_670	7,307	100	0.15	Grass-Short Grass Prairie	2.39	2.99	9.4															**40.5**	**24.3**	**0.4**
								1,658	0.977	1.59	Unpaved	17.33												
													5,549	0.5	122.3	46	0.03	6.74		6.74	13.71			
MRB_680	3,188	100	0.15	Grass-Short Grass Prairie	4.051	2.99	7.6															**13.8**	**8.3**	**0.14**
								516	5.322	3.72	Unpaved	2.31												
													2,572	0.805	198.9	50	0.03	11.19		11.19	3.83			
MRB_690	6,887	100	0.15	Grass-Short Grass Prairie	6.73	2.99	6.2															**23.4**	**14**	**0.23**
								2,438	6.223	4.02	Unpaved	10.1												
													4,349	1.197	395.8	82.7	0.045	10.29		10.29	7.04			
MRB_700	9,125	100	0.15	Grass-Short Grass Prairie	3.664	2.99	8															**29.1**	**17.5**	**0.29**
								1,406	3.888	3.18	Unpaved	7.37												
													7,619	4.278	88.1	56.7	0.045	9.19		9.19	13.82			
MRB_710	6,006	100	0.15	Grass-Short Grass Prairie	2.078	2.99	10															**20.9**	**12.5**	**0.21**
								1,545	6.843	4.22	Unpaved	6.1												
													4,361	5.899	158.3	51.8	0.05	15.24		15.24	4.77			
MRB_720	7,887	100	0.15	Grass-Short Grass Prairie	0.966	2.99	13.6															**36.5**	**21.9**	**0.37**
								1,171	3.311	2.94	Unpaved	6.65												
													6,616	1.694	100.4	51.1	0.045	6.76		6.76	16.32			
MRB_730	11,513	100	0.15	Grass-Short Grass Prairie	0.5	2.99	17.6															**35**	**21**	**0.35**
								1,099	4.626	3.47	Unpaved	5.28												
													10,314	3.444	175.1	49.6	0.045	14.25		14.25	12.06			
MRB_740	5,535	100	0.15	Grass-Short Grass Prairie	1.912	2.99	10.3															**28.6**	**17.2**	**0.29**
								1,293	3.018	2.8	Unpaved	7.69												
													4,142	1.555	55.3	28	0.045	6.5		6.5	10.62			
MRB_750	9,507	100	0.15	Grass-Short Grass Prairie	0.874	2.99	14.1															**36.5**	**21.9**	**0.37**
								880	8.694	4.76	Unpaved	3.08												
													8,527	3.456	38.7	29.6	0.045	7.36		7.36	19.3			
MRB_760	6,710	100	0.15	Grass-Short Grass Prairie	1.569	2.99	11.2															**36.2**	**21.7**	**0.36**
								727	1.808	2.17	Unpaved	5.58												
													2,091	1.132	11.1	20.3	0.04	2.65		2.65	13.16			
													3,792	0.5	510.8	105.8	0.03	10.03		10.03	6.3			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_770	4,237	100	0.15	Grass-Short Grass Prairie	1.471	2.99	11.5															**44.8**	**26.9**	**0.45**
								1,153	1.748	2.13	Unpaved	9.01												
													1,804	0.871	5.1	14.8	0.05	1.36		1.36	22.16			
													1,180	0.73	182.8	57.5	0.03	9.18		9.18	2.14			
MRB_780	7,559	100	0.15	Grass-Short Grass Prairie	1.161	2.99	12.6															**51.3**	**30.8**	**0.51**
								816	2.331	2.46	Unpaved	5.52												
													6,643	0.574	78.6	51.2	0.045	3.34		3.34	33.15			
MRB_790	8,704	100	0.15	Grass-Short Grass Prairie	1.63	2.99	11															**58.6**	**35.1**	**0.59**
								766	1.942	2.25	Unpaved	5.68												
													7,838	0.5	68.9	44.8	0.045	3.12		3.12	41.88			
MRB_800	5,876	100	0.15	Grass-Short Grass Prairie	9.063	2.99	5.5															**35.7**	**21.4**	**0.36**
								3,361	3.532	3.03	Unpaved	18.47												
													2,415	0.786	28.6	26.8	0.04	3.45		3.45	11.67			
MRB_810	7,221	100	0.15	Grass-Short Grass Prairie	3.412	2.99	8.2															**45.9**	**27.6**	**0.46**
								988	1.862	2.2	Unpaved	7.48												
													6,133	0.651	41	28.9	0.045	3.38		3.38	30.28			
MRB_820	12,347	100	0.15	Grass-Short Grass Prairie	0.874	2.99	14.1															**90**	**54**	**0.9**
								1,094	1.921	2.24	Unpaved	8.15												
													11,153	0.5	57.5	45.3	0.045	2.74		2.74	67.75			
MRB_830	9,543	100	0.15	Grass-Short Grass Prairie	3.414	2.99	8.2															**48.7**	**29.2**	**0.49**
								1,805	11.571	5.49	Unpaved	5.48												
													5,381	1.478	58.3	59.5	0.045	3.97		3.97	22.58			
													2,257	0.5	57.1	39	0.045	3.02		3.02	12.47			
MRB_840	8,571	100	0.15	Grass-Short Grass Prairie	2.116	2.99	9.9															**71.3**	**42.8**	**0.71**
								703	2.604	2.6	Unpaved	4.5												
													7,768	0.679	12.7	19.9	0.04	2.28		2.28	56.87			
MRB_850	4,935	100	0.15	Grass-Short Grass Prairie	0.5	2.99	17.6															**39.2**	**23.5**	**0.39**
								1,529	1.466	1.95	Unpaved	13.04												
													3,306	1.068	136.7	52.9	0.045	6.44		6.44	8.55			
MRB_860	8,824	100	0.15	Grass-Short Grass Prairie	3.854	2.99	7.8															**37.7**	**22.6**	**0.38**
								1,435	1.478	1.96	Unpaved	12.19												
													7,289	0.586	136.5	56.1	0.03	6.88		6.88	17.67			
MRB_870	8,366	100	0.15	Grass-Short Grass Prairie	2.395	2.99	9.4															**49.1**	**29.5**	**0.49**
								1,099	1.738	2.13	Unpaved	8.61												
													7,167	0.726	12.5	14.4	0.03	3.84		3.84	31.08			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_880	100	100	0.15	Grass-Short Grass Prairie	1.015	2.99	13.3															**67**	**40.2**	**0.67**
								2,988	0.897	1.53	Unpaved	32.58												
													4,612	0.62	53.3	32.4	0.045	3.63		3.63	21.15			
MRB_890	0	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	8.494	2.99	0.7															**5.5**	**3.3**	**0.05**
								254	0.5	1.14	Unpaved	3.71												
													290	3.623	9	17	0.04	4.65		4.65	1.04			
MRB_900	0	100	0.15	Grass-Short Grass Prairie	2.374	2.99	9.5															**23.4**	**14**	**0.23**
								431	2.707	2.65	Unpaved	2.71												
													2,191	0.5	37.3	41.8	0.03	3.25		3.25	11.23			
MRB_910	0	100	0.15	Grass-Short Grass Prairie	6.102	2.99	6.5															**37.9**	**22.7**	**0.38**
								870	2.747	2.67	Unpaved	5.42												
													6,220	0.558	80.8	39.4	0.045	3.99		3.99	25.96			
MRB_920	0	100	0.15	Grass-Short Grass Prairie	2.079	2.99	10															**27.7**	**16.6**	**0.28**
								495	2.733	2.67	Unpaved	3.09												
													2,255	1.089	15.8	29.3	0.04	2.58		2.58	14.58			
MRB_930	0	100	0.15	Grass-Short Grass Prairie	1.282	2.99	12.1															**30.4**	**18.2**	**0.3**
								693	1.757	2.14	Unpaved	5.4												
													3,798	0.844	74.1	36	0.045	4.92		4.92	12.86			
MRB_940	0	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.232	2.99	1.5															**62.2**	**37.3**	**0.62**
								677	3.396	3.75	Paved	3.01												
													5,670	1.14	14.9	17.1	0.04	3.62		3.62	26.08			
													5,670						2.99	2.99	31.61			
MRB_950	0	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	1.724	2.99	1.3															**20.2**	**12.1**	**0.2**
								1,680	3.407	3.75	Paved	7.46												
													3,659	2.02	24.6	24.1	0.04	5.37		5.37	11.36			
MRB_960	0	100	0.011	Smooth Surface (concrete, asphalt, bare earth)	2.682	2.99	1.1															**15.8**	**9.5**	**0.16**
								365	2.411	3.16	Paved	1.93												
													4,418	1.529	57.9	33.3	0.04	6.67		6.67	11.05			
													242						2.36	2.36	1.71			
MRB_970	0	100	0.15	Grass-Short Grass Prairie	4.915	2.99	7.1															**13.9**	**8.3**	**0.14**
								355	6.59	5.22	Paved	1.13												
													1,060						3.13	3.13	5.64			

Existing Conditions Time of Concentration Calculations

Backbone Creek and Whitman Branch Watershed

HMS Program		Sheet Flow						Shallow Concentrated Flow					Channel Flow									Totals		
Basin Name	Flowpath (ft) [1]	Length (ft) [2]	n-Value [3]	Landuse/Surface Description (4)	Slope (%) [5]	Rainfall (in) [6]	Tc Overland (min) [7]	Length (ft) [8]	Slope (%) [9]	V (ft/s) [10]	Assumption for V (Paved/Unpaved) [11]	Tc Shallow Concentrated (min) [12]	Length (ft) [13]	Channel Slope (%) [14]	Bankfull Area (ft^2) [15]	Bankfull Wet Perimeter (ft) [16]	Channel n-Value [17]	V (ft/s) Manning's [18]	V (ft/s) RAS Model [19]	Selected Velocity (ft/s) [20]	Tc Channel (min) [21]	Final Tc (min) [22]	Tlag (min) [23]	Tlag (hr)
MRB_980	0	100	0.15	Grass-Short Grass Prairie	3.99	2.99	7.7															**24.9**	**14.9**	**0.25**
								899	2.922	2.76	Unpaved	5.43												
													1,097	5.013	100.4	39.6	0.05	12.41		12.41	1.47			
													1,784						2.89	2.89	10.28			
MRB_990	0	100	0.15	Grass-Short Grass Prairie	9.102	2.99	5.5															**25.5**	**15.3**	**0.25**
								452	4.983	3.6	Unpaved	2.09												
													3,999	1.113	17	15.4	0.045	3.74		3.74	17.83			

Notes:
[1] Flowpaths hand-delineated.
[2]Sheet Flow was considered to occur at short distances with a maximum of 100 ft.
(3) n-Value was based on the landuse.
(4) Landuse was determined from orthos.
(5) Sheet flow slope = (US elevation - DS elevation) / overland flow length. Minimum Slope set at 0.5%.
[6] 2-YR 24-HR Rainfall.
(7) Overland Flow Time of Concentration (hr) = (0.007*(nL)^0.8)/((P2)^0.5*s^0.4).
[8] Length of Shallow Concentrated Flow.
(9) Ground Slope over Shallow Concentrated Flow Path. Minimum Slope set at 0.5%.
[10] Channel Velocity: Paved Areas=20.3282*SQRT(Slope/100). Unpaved Areas=16.1345*SQRT(Slope/100).
(11) Obtained from orthos.
(12) Channel Flow Tc (Shallow Concentrated) = L / V.
(13) Main channel length.
(14) Channel Slope. Minimum Slope set at 0.5%.
(15) Average Bankfull Area.
(16) Average Bankfull Wetted Perimeter.
(17) Manning's n-Value for Channel.
(18) Channel Velocity (Manning's Equation).
(19) Channel Velocity from HEC-RAS using WSEL profile at bank full elevation.
(20) User Selected Velocity.
(21) Channel Time of Concentration (Channel Length/Channel Velocity).
(29) Total Tc = Overland Flow+Shallow Concentrated Flow+Channel Flow+Pipe Flow.
(30) Lag Time (Tlag) = 0.6 * Final Tc (Soil Conservation Service).

A.5 Flood Routing

Flood routing through channel reaches in the hydraulic model was calculated using the Modified Puls Routing Method for study streams and the Muskingum-Cunge Routing Method for all other reaches. The Modified Puls Method was used because of its ability to account for the attenuation of the flood hydrograph associated with the effects of bridge/culvert backwater effects and overbank storage. Storage-outflow data for the Modified Puls Routing Method was extracted from the existing conditions hydraulic models for the Backbone Creek and Whitman Branch Watershed. Muskingam-Cunge parameters were extracted from the LiDAR data. Modified Puls and Muskingum-Cunge routing parameters are shown in Tables A6 and A7.

Table A6: Modified Puls Routing Parameters

Modified Puls Routing Step Calculations						
						Time Step (min) =1
Creek/River	**HEC-HMS Reach Name**	**Length**	**Channel Velocity^1**	**Floodwave Velocity^2**	**# Subreaches for Mod Puls^3**	**# Subreaches for Mod Puls^4**
Backbone Creek	RMRB_010	2351	1.8	2.7	14.5	15
	RMRB_200	1766	1.7	2.5	11.7	12
	RMRB_210	1406	2.4	3.6	6.4	7
	RMRB_220	1028	1.8	2.7	6.3	7
	RMRB_230	1240	2.9	4.3	4.8	5
	RMRB_240	2898	3.8	5.7	8.5	9
	RMRB_290	3775	4.2	6.3	10.0	11
	RMRB_340	2749	4.9	7.3	6.3	7
	RMRB_350	5642	4.4	6.6	14.2	15
	RMRB_360	6345	3.9	5.9	18.0	19
	RMRB_370	10742	4.3	6.4	27.9	28
	RMRB_460	8298	5.8	8.7	15.9	16
	RMRB_470	5998	6.9	10.3	9.7	10
	RMRB_480	7630	8.5	12.7	10.0	10
	RMRB_490	2300	10.2	15.2	2.5	3
BC-1	RMRB_960	845	3.0	4.5	3.1	4
	RMRB_970	1569	4.1	6.1	4.3	5
	RMRB_980	2997	3.5	5.3	9.5	10
BC-2	RMRB_250	5689	3.8	5.7	16.5	17
	RMRB_260	2262	3.6	5.4	7.0	8
	RMRB_270	7268	5.4	8.1	14.9	15
Whitman Branch	RMRB_020	1988	4.7	7.0	4.7	5
	RMRB_030	1819	4.3	6.5	4.7	5
	RMRB_080	2098	4.2	6.3	5.5	6
	RMRB_090	2424	2.3	3.4	11.9	12
	RMRB_100	3034	3.4	5.1	10.0	10
	RMRB_110	2047	2.3	3.4	10.0	11
	RMRB_120	4021	3.7	5.5	12.1	13
	RMRB_180	6011	3.6	5.4	18.4	19

Modified Puls Routing Step Calculations

Time Step (min) =1

Creek/River	HEC-HMS Reach Name	Length	Channel Velocity[1]	Floodwave Velocity[2]	# Subreaches for Mod Puls[3]	# Subreaches for Mod Puls[4]
WB-1	RMRB_040	2515	5.6	8.4	5.0	6
	RMRB_050	1989	4.8	7.1	4.6	5
	RMRB_060	2942	2.9	4.3	11.4	12

Notes:

[1] Average channel velocity calculated in RAS Routing Model.

[2] Flood Wave Velocity = 1.5 * average channel velocity.

[4] Rounded Steps = the number of routing steps rounded up.

Modified Puls Routing Tables

Backbone Creek

RMRB_010	
RS_ 2548 to RS_ 197	
Volume (acre-ft)	Q Total (cfs)
0.0	0
22.1	400
33.2	790
58.6	1980
95.3	3950
160.5	7900
311.7	15800
392.5	19600
475.2	23400
569.1	27500
646.7	30500
717.5	33500
850.4	40200
968.7	46900
1127.5	56950
1270.6	67000
1491.6	83750

RMRB_200	
RS_ 4163 to RS_ 2548	
Volume (acre-ft)	Q Total (cfs)
0.0	0
14.1	400
22.1	790
46.5	1980
83.5	3950
115.4	7900
245.4	15800
344.0	19600
443.0	23400
539.0	27500
602.8	30500
658.6	33500
758.8	40200
847.9	46900
975.1	56950
1087.8	67000
1271.0	83750

RMRB_210	
RS_ 5366 to RS_ 4163	
Volume (acre-ft)	Q Total (cfs)
0.0	0
5.8	400
9.4	790
18.3	1980
39.8	3950
64.5	7900
141.6	15800
193.3	19600
244.9	23400
297.1	27500
332.4	30500
363.6	33500
422.8	40200
483.2	46900
566.5	56950
642.2	67000
768.2	83750

RMRB_220

RS_ 5918 to RS_ 5366

Volume (acre-ft)	Q Total (cfs)
0.0	0
3.6	400
5.6	790
9.5	1980
16.8	3950
28.6	7900
64.0	15800
91.6	19530
117.0	23250
146.9	27300
167.5	30200
186.2	33100
221.9	39720
257.3	46340
306.5	56270
351.1	66200
422.8	82750

RMRB_230

RS_ 7120 to RS_ 5918

Volume (acre-ft)	Q Total (cfs)
0.0	0
5.6	400
9.1	790
17.7	1980
31.0	3950
56.3	7900
117.9	15800
159.1	19530
191.5	23250
221.8	27300
247.2	30200
271.8	33100
320.8	39720
371.6	46340
444.4	56270
515.6	66200
637.6	82750

RMRB_240

RS_ 9965 to RS_ 7120

Volume (acre-ft)	Q Total (cfs)
0.0	0
17.7	400
24.9	790
40.7	1980
60.0	3950
93.3	7900
157.2	15800
193.2	19530
228.1	23250
266.0	27300
297.9	30200
331.2	33100
401.1	39720
472.7	46340
578.4	56270
685.9	66200
861.0	82750

RMRB_290

RS_ 13725 to RS_ 9965

Volume (acre-ft)	Q Total (cfs)
0.0	0
15.5	390
24.7	770
44.4	1940
70.4	3870
118.0	7730
218.7	15450
244.5	19080
300.9	22700
359.7	26650
397.9	29450
432.7	32250
504.3	38700
566.9	45150
667.3	54830
762.9	64500
911.9	80630

RMRB_340

RS_ 15932 to RS_ 13725

Volume (acre-ft)	Q Total (cfs)
0.0	0
5.2	360
8.4	730
16.3	1820
27.3	3630
45.6	7250
75.9	14500
90.9	17900
103.1	21300
118.4	24950
127.5	27580
136.5	30200
157.7	36240
178.3	42280
209.3	51340
239.2	60400
288.7	75500

RMRB_350

RS_ 20558 to RS_ 15932

Volume (acre-ft)	Q Total (cfs)
0.0	0
15.9	350
24.9	700
46.3	1750
75.1	3500
127.6	7000
215.8	14000
256.5	17180
291.5	20350
340.2	23800
374.1	26300
407.1	28800
509.2	34560
598.6	40320
730.4	48960
851.0	57600
1040.6	72000

RMRB_360

RS_ 25363 to RS_ 20558

Volume (acre-ft)	Q Total (cfs)
0.0	0
12.2	240
19.1	470
35.9	1190
58.9	2370
106.1	4730
235.4	9450
302.7	11880
366.3	14300
411.1	16850
459.7	18850
508.2	20850
615.8	25020
713.9	29190
857.7	35450
991.7	41700
1201.3	52130

RMRB_370

RS_ 35178 to RS_ 25363

Volume (acre-ft)	Q Total (cfs)
0.0	0
16.6	180
27.4	370
52.1	920
85.7	1830
151.4	3650
317.7	7300
401.1	8980
489.7	10650
582.9	12400
645.4	13650
710.7	14900
883.0	17880
1036.8	20860
1262.8	25330
1489.9	29800
1872.3	37250

RMRB_460

RS_ 41934 to RS_ 35178

Volume (acre-ft)	Q Total (cfs)
0.0	0
6.5	110
11.0	220
21.2	560
34.4	1120
59.9	2230
125.3	4450
164.0	5430
206.0	6400
249.2	7400
278.4	8130
307.4	8850
391.0	10620
481.6	12390
581.6	15050
657.5	17700
782.5	22130

RMRB_470

RS_ 47887 to RS_ 41934

Volume (acre-ft)	Q Total (cfs)
0.0	0
5.9	120
9.4	240
17.7	600
29.3	1200
52.6	2400
110.4	4800
135.3	5780
158.6	6750
182.1	7800
198.6	8500
214.8	9200
264.1	11040
310.1	12880
388.0	15640
452.4	18400
541.2	23000

RMRB_480

RS_ 54433 to RS_ 47887

Volume (acre-ft)	Q Total (cfs)
0.0	0
5.8	120
9.4	240
17.1	590
28.6	1180
46.2	2350
81.4	4700
98.4	5630
119.4	6550
144.8	7500
157.8	8150
187.2	8800
240.7	10560
278.1	12320
345.3	14960
402.8	17600
504.9	22000

RMRB_490

RS_ 55672 to RS_ 54433

Volume (acre-ft)	Q Total (cfs)
0.0	0
0.8	120
1.3	240
2.6	590
4.3	1180
6.8	2350
12.5	4700
15.5	5630
17.8	6550
20.9	7500
24.1	8150
26.1	8800
31.2	10560
36.3	12320
43.9	14960
51.4	17600
62.2	22000

BC-1

RMRB_960

RS_ 1196 to RS_ 351

Volume (acre-ft)	Q Total (cfs)
0.0	0
1.0	50
1.4	90
2.5	240
3.7	470
5.8	930
10.6	1860
13.2	2210
15.8	2550
17.9	2850
19.4	3080
20.7	3300
24.6	3960
28.5	4620
33.6	5610
38.1	6600

RMRB_970

RS_ 2575 to RS_ 1196

Volume (acre-ft)	Q Total (cfs)
0.0	0
0.9	50
1.4	90
2.9	240
4.5	470
7.3	930
12.6	1860
14.8	2210
17.2	2550
19.2	2850
20.8	3080
22.4	3300
27.2	3960
32.3	4620
38.0	5610
42.8	6600

RMRB_980

RS_ 5254 to RS_ 2575

Volume (acre-ft)	Q Total (cfs)
0.0	0
4.3	20
5.0	40
6.9	100
9.4	200
13.1	400
18.2	800
19.7	930
21.8	1050
23.7	1190
24.9	1270
26.1	1350
29.6	1620
33.0	1890
37.8	2300
42.2	2700

BC-2

RMRB_250

RS_ 6110 to RS_ 421

Volume (acre-ft)	Q Total (cfs)
0.0	0
6.2	50
8.2	90
14.0	230
21.8	450
35.2	900
77.9	1800
91.2	2150
103.5	2500
117.5	2900
127.1	3150
131.8	3400
151.4	4080
171.9	4760
198.8	5780
224.2	6800
262.3	8500

RMRB_260

RS_ 8082 to RS_ 6110

Volume (acre-ft)	Q Total (cfs)
0.0	0
1.1	40
1.8	80
3.3	200
5.0	390
8.0	780
14.6	1550
17.0	1850
19.5	2150
22.3	2450
24.1	2650
25.9	2850
31.4	3420
37.5	3990
46.4	4850
53.0	5700
63.5	7130

RMRB_270

RS_ 15289 to RS_ 8082

Volume (acre-ft)	Q Total (cfs)
0.0	0
7.1	30
9.1	70
13.2	170
19.1	340
28.6	680
45.6	1350
51.5	1600
57.3	1850
62.8	2100
66.2	2250
69.6	2400
80.4	2880
90.7	3360
104.3	4080
119.3	4800
141.5	6000

Whitman Branch

RMRB_020

RS_ 2285 to RS_ 297

Volume (acre-ft)	Q Total (cfs)
0.0	0
4.2	130
8.5	250
13.8	630
18.9	1250
28.8	2500
45.9	5000
54.1	6000
62.9	7000
70.7	8050
78.6	8800
84.8	9550
100.5	11460
116.5	13370
153.7	16240
185.9	19100

RMRB_030

RS_ 4024 to RS_ 2285

Volume (acre-ft)	Q Total (cfs)
0.0	0
2.1	130
3.4	250
6.3	630
10.3	1250
18.6	2500
42.7	5000
52.4	6000
61.2	7000
70.0	8050
75.4	8800
79.5	9550
90.5	11460
101.3	13370
117.3	16240
131.8	19100

RMRB_080

RS_ 6184 to RS_ 4024

Volume (acre-ft)	Q Total (cfs)
0.0	0
3.0	100
5.2	210
9.3	520
14.5	1040
23.1	2080
36.6	4150
41.5	5060
46.3	5960
51.6	6900
54.7	7520
58.2	8130
66.3	9760
75.4	11380
91.0	13820
100.5	16260

RMRB_090

RS_ 8388 to RS_ 6184

Volume (acre-ft)	Q Total (cfs)
0.0	0
5.3	100
6.8	210
9.9	520
15.0	1040
24.8	2080
40.6	4150
46.9	5060
52.9	5960
59.0	6900
62.9	7520
66.9	8130
77.3	9760
87.4	11380
102.2	13820
116.0	16260

RMRB_100

RS_ 11716 to RS_ 8805

Volume (acre-ft)	Q Total (cfs)
0.0	0
3.3	100
5.8	200
11.2	500
19.0	1000
35.0	2000
69.6	3990
84.2	4860
97.1	5730
108.1	6620
116.7	7220
125.1	7820
146.7	9380
168.0	10950
197.6	13290
225.0	15640

RMRB_110

RS_ 13704 to RS_ 11716

Volume (acre-ft)	Q Total (cfs)
0.0	0
3.9	100
5.4	200
9.3	500
14.9	1000
27.3	2000
48.9	3990
55.3	4860
62.3	5730
68.0	6620
72.6	7220
77.0	7820
88.1	9380
99.6	10950
116.3	13290
132.6	15640

RMRB_120

RS_ 17595 to RS_ 13704

Volume (acre-ft)	Q Total (cfs)
0.0	0
10.7	100
14.9	200
24.4	500
38.2	1000
63.9	2000
115.5	3990
134.8	4860
154.0	5730
170.7	6620
182.0	7220
192.8	7820
220.2	9380
248.2	10950
287.0	13290
326.2	15640

RMRB_180

RS_ 23235 to RS_ 17595

Volume (acre-ft)	Q Total (cfs)
0.0	0
17.5	30
19.6	60
24.3	150
30.9	290
39.6	570
55.5	1140
61.6	1360
68.1	1580
74.0	1800
78.3	1940
81.8	2070
92.3	2480
102.5	2900
116.5	3520
129.8	4140

WB-1

RMRB_040

RS_ 2670 to RS_ 155

Volume (acre-ft)	Q Total (cfs)
0.0	0
5.4	40
6.6	70
9.6	190
12.8	370
17.7	740
25.4	1480
27.6	1730
29.7	1980
31.7	2210
32.9	2360
34.0	2510
38.3	3010
42.2	3510
48.1	4270
53.5	5020
62.4	6280

RMRB_050

RS_ 4528 to RS_ 2670

Volume (acre-ft)	Q Total (cfs)
0.0	0
0.8	40
1.4	70
2.7	190
4.6	370
8.4	740
15.5	1480
17.7	1730
19.7	1980
21.6	2210
22.7	2360
23.9	2510
27.4	3010
30.8	3510
36.0	4270
40.8	5020
48.0	6280

RMRB_060

RS_ 7166 to RS_ 4528

Volume (acre-ft)	Q Total (cfs)
0.0	0
1.5	50
2.4	110
4.0	270
6.2	530
10.2	1050
18.2	2100
21.6	2480
24.8	2850
28.1	3200
30.5	3430
32.9	3650
41.0	4380
48.7	5110
59.5	6210
70.0	7300
85.6	9130

Table A7: Muskingum-Cunge Routing Parameters

Reach	Length (ft)	Slope (ft/ft)	Channel Manning's n-value	Left Bank Manning's n-value	Right Bank Manning's n-value	Cross Section Shape	Cross Section Table
RMRB_130	1740	0.0075	0.04	0.08	0.08	Eight Point	130
RMRB_150	1302	0.0051	0.05	0.1	0.09	Eight Point	150
RMRB_300	2257	0.0230	0.06	0.1	0.1	Eight Point	300
RMRB_310	1677	0.005	0.05	0.09	0.08	Eight Point	310
RMRB_320	5780	0.0061	0.06	0.08	0.08	Eight Point	320
RMRB_380	9520	0.0057	0.055	0.09	0.09	Eight Point	380
RMRB_390	6180	0.005	0.055	0.1	0.09	Eight Point	390
RMRB_400	1015	0.0576	0.055	0.09	0.08	Eight Point	400
RMRB_420	4898	0.005	0.06	0.1	0.09	Eight Point	420
RMRB_430	3248	0.0053	0.06	0.09	0.08	Eight Point	430
RMRB_440	3178	0.005	0.055	0.1	0.08	Eight Point	440
RMRB_510	7348	0.0125	0.055	0.09	0.08	Eight Point	510
RMRB_530	7255	0.0268	0.05	0.09	0.08	Eight Point	530
RMRB_540	3170	0.0145	0.05	0.1	0.1	Eight Point	540
RMRB_580	5373	0.0268	0.05	0.08	0.1	Eight Point	580
RMRB_590	9354	0.005	0.055	0.08	0.09	Eight Point	590
RMRB_600	7903	0.005	0.055	0.08	0.08	Eight Point	600
RMRB_620	5510	0.0070	0.05	0.08	0.07	Eight Point	620
RMRB_640	7285	0.0062	0.06	0.09	0.08	Eight Point	640
RMRB_650	2453	0.005	0.045	0.09	0.08	Eight Point	650
RMRB_660	5268	0.005	0.045	0.1	0.09	Eight Point	660
RMRB_670	1271	0.0345	0.05	0.08	0.09	Eight Point	670
RMRB_680	5482	0.005	0.045	0.08	0.09	Eight Point	680
RMRB_690	2645	0.0081	0.045	0.08	0.09	Eight Point	690
RMRB_710	5523	0.0126	0.06	0.07	0.07	Eight Point	710
RMRB_740	4641	0.0470	0.055	0.09	0.09	Eight Point	740
RMRB_760	4483	0.0129	0.05	0.07	0.08	Eight Point	760
RMRB_770	5026	0.005	0.045	0.08	0.08	Eight Point	770
RMRB_780	2025	0.005	0.045	0.07	0.08	Eight Point	780
RMRB_790	6302	0.005	0.055	0.08	0.08	Eight Point	790
RMRB_810	8095	0.005	0.055	0.08	0.08	Eight Point	810
RMRB_820	3240	0.005	0.045	0.08	0.08	Eight Point	820
RMRB_850	1308	0.0494	0.045	0.08	0.08	Eight Point	850
RMRB_860	3376	0.005	0.055	0.09	0.09	Eight Point	860
RMRB_870	5945	0.005	0.045	0.08	0.09	Eight Point	870
RMRB_890	3902	0.0061	0.05	0.08	0.07	Eight Point	890
RMRB_900	316	0.0106	0.055	0.09	0.09	Eight Point	900
RMRB_920	2252	0.0084	0.05	0.08	0.08	Eight Point	920
RMRB_940	6046	0.0072	0.05	0.1	0.1	Eight Point	940

Reach	Length (ft)	Slope (ft/ft)	Channel Manning's n-value	Left Bank Manning's n-value	Right Bank Manning's n-value	Cross Section Shape	Cross Section Table
RMRB_1000	1645	0.0068	0.04	0.07	0.08	Eight Point	1000

Note:

Slope was set to a 0.5% minimum.

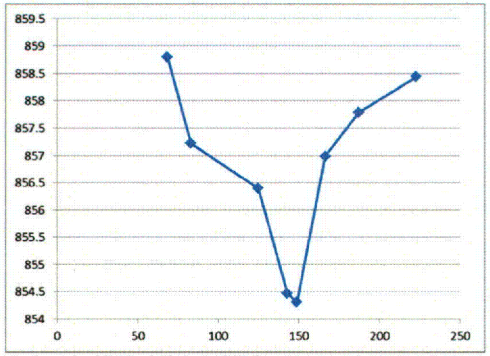
N-values were determined using ortho photos.

Cross-Sections were determined using Hydra_DEM.

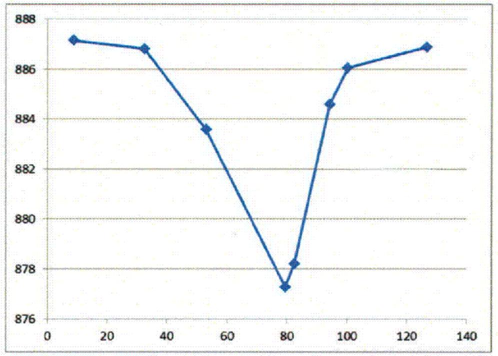
Muskingum-Cunge Routing Cross Sections

8-Point Cross Sections

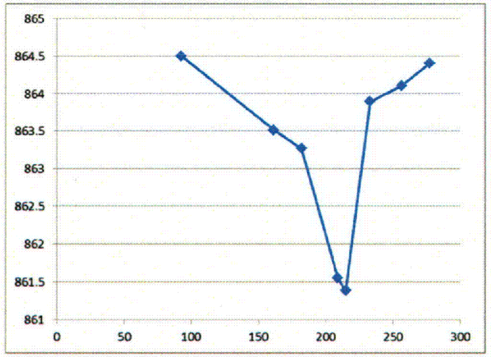
RMRB_130	
x	y
68.4	858.8
83.2	857.2
124.9	856.4
142.7	854.5
148.7	854.3
166.5	857.0
187.3	857.8
223.0	858.4



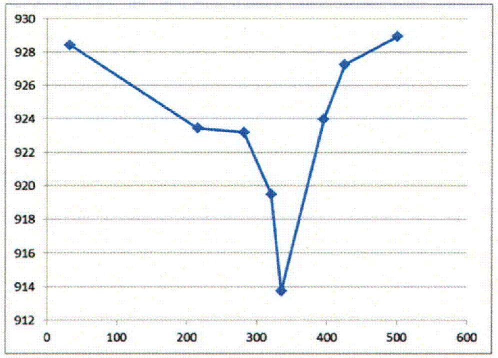
RMRB_320	
x	y
8.8	887.1
32.4	886.8
53.1	883.6
79.6	877.3
82.6	878.2
94.4	884.6
100.3	886.0
126.8	886.9



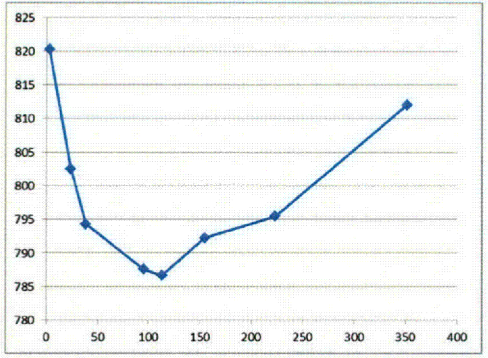
RMRB_150	
x	y
92.6	864.5
161.2	863.5
182.1	863.3
209.0	861.5
215.0	861.4
232.9	863.9
256.8	864.1
277.7	864.4



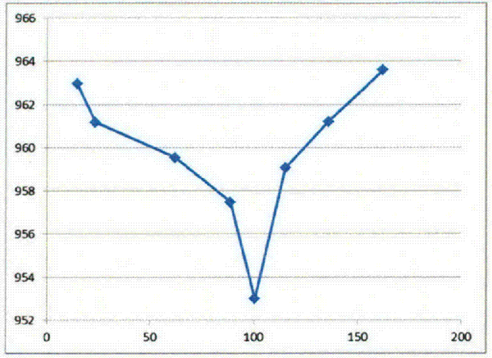
RMRB_380	
x	y
32.9	928.4
215.6	923.4
281.5	923.2
320.5	919.5
335.4	913.7
395.3	924.0
425.3	927.3
500.2	928.9



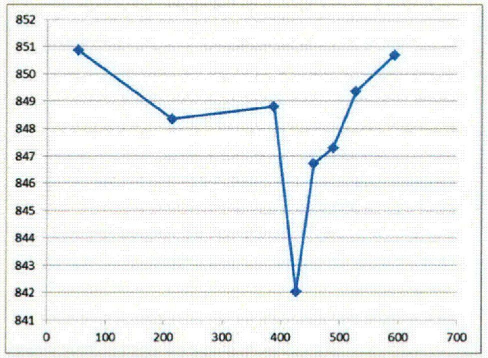
RMRB_300	
x	y
3.0	820.3
23.8	802.6
38.7	794.3
95.3	787.6
113.2	786.6
154.8	792.2
223.3	795.4
351.4	812.0



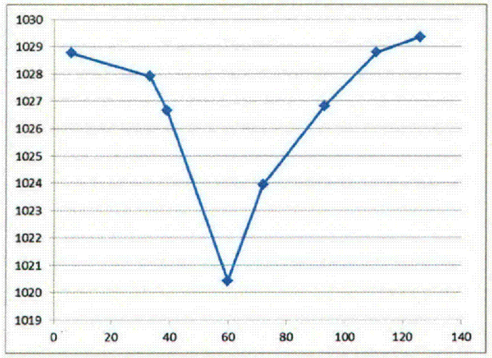
RMRB_390	
x	y
14.8	963.0
23.6	961.2
62.1	959.5
88.7	957.5
100.5	953.0
115.3	959.1
136.0	961.2
162.6	963.6



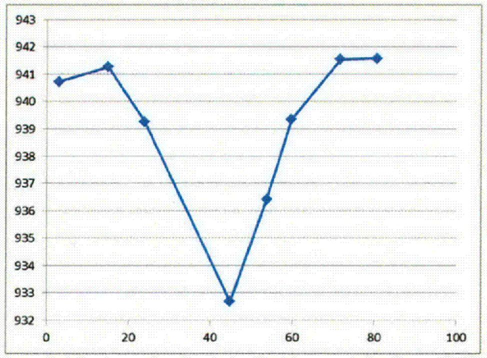
RMRB_310	
x	y
53.5	850.9
214.4	848.3
387.5	848.8
426.3	842.0
456.2	846.7
489.0	847.3
527.8	849.4
593.5	850.7



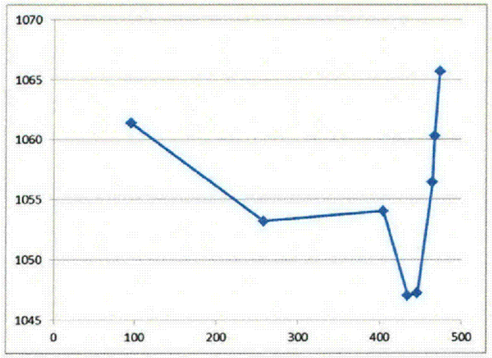
RMRB_400	
x	y
6.0	1028.8
33.0	1027.9
39.0	1026.7
60.0	1020.4
72.0	1023.9
92.9	1026.8
110.9	1028.8
125.9	1029.4



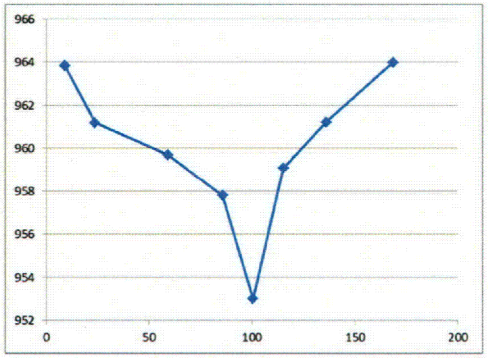
RMRB_420	
x	y
3.0	940.7
14.9	941.3
23.9	939.3
44.8	932.7
53.8	936.4
59.7	939.3
71.7	941.5
80.6	941.6



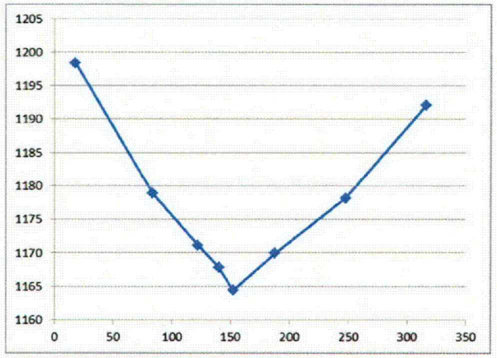
RMRB_530	
x	y
95.9	1061.4
257.7	1053.2
404.6	1054.0
434.6	1047.0
446.5	1047.2
464.5	1056.4
467.5	1060.3
473.5	1065.7



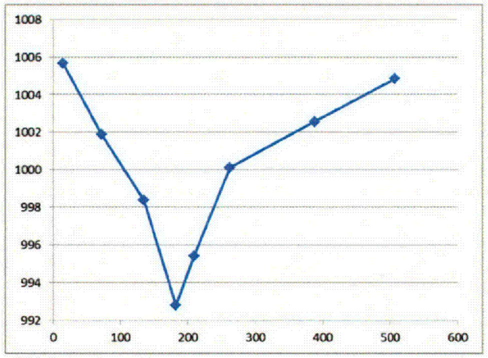
RMRB_430	
x	y
8.9	963.8
23.6	961.2
59.1	959.7
85.7	957.8
100.5	953.0
115.3	959.1
136.0	961.2
168.5	964.0



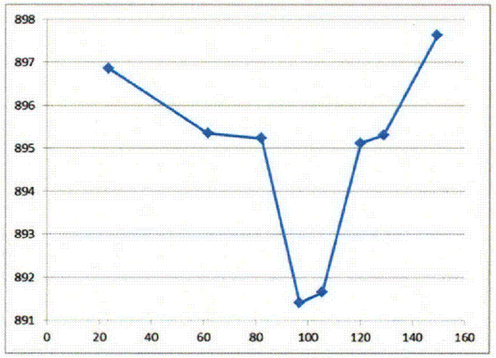
RMRB_540	
x	y
17.9	1198.4
83.5	1178.8
122.3	1171.1
140.2	1167.8
152.2	1164.4
188.0	1169.9
247.6	1178.1
316.3	1192.1



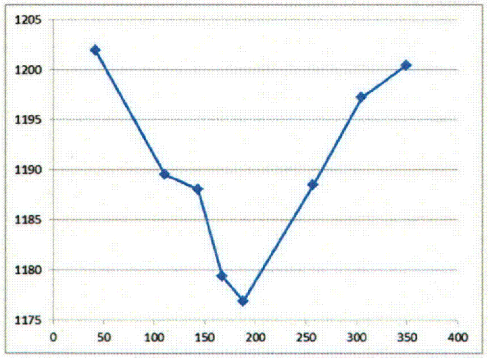
RMRB_440	
x	y
15.0	1005.6
71.9	1001.9
134.7	998.4
182.3	992.8
209.1	995.4
262.7	1000.1
387.7	1002.6
507.1	1004.9



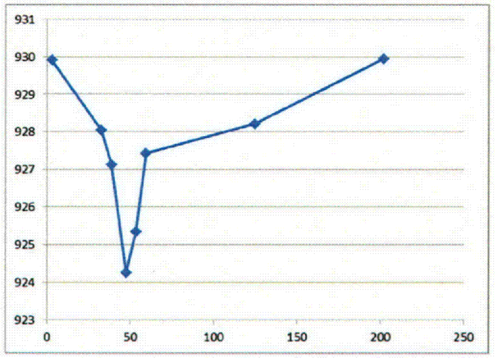
RMRB_580	
x	y
23.5	896.9
61.7	895.4
82.1	895.2
96.7	891.4
105.5	891.7
120.1	895.1
128.9	895.3
149.3	897.6



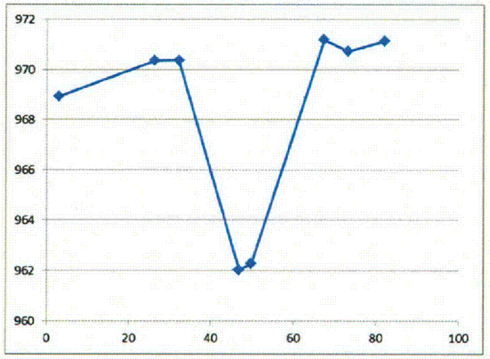
RMRB_510	
x	y
41.8	1201.9
110.6	1189.5
143.5	1188.0
167.4	1179.4
188.3	1176.9
257.0	1188.4
304.9	1197.2
349.7	1200.4



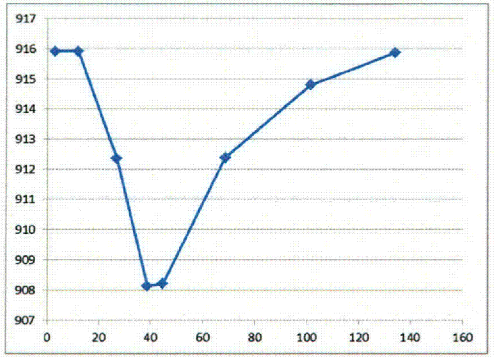
RMRB_590	
x	y
3.0	929.9
32.6	928.0
38.6	927.1
47.5	924.3
53.4	925.3
59.3	927.4
124.6	928.2
201.7	929.9



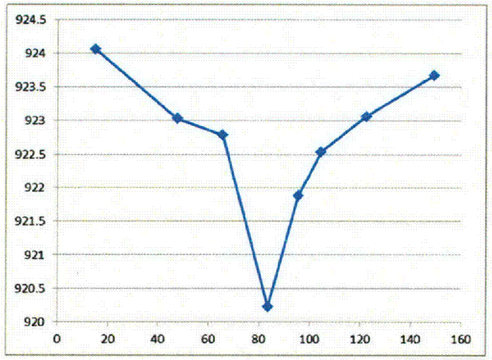
RMRB_600	
x	y
2.9	968.9
26.3	970.4
32.2	970.4
46.8	962.0
49.8	962.3
67.3	971.2
73.2	970.7
82.0	971.1



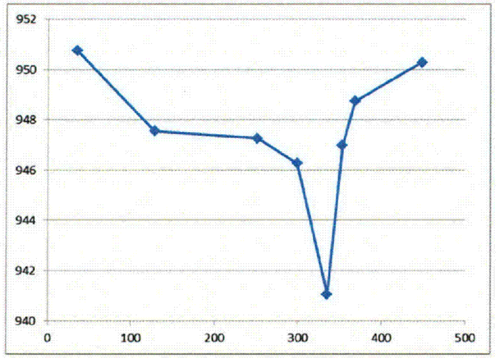
RMRB_660	
x	y
3.0	915.9
11.9	915.9
26.8	912.4
38.8	908.1
44.7	908.2
68.6	912.4
101.4	914.8
134.2	915.9



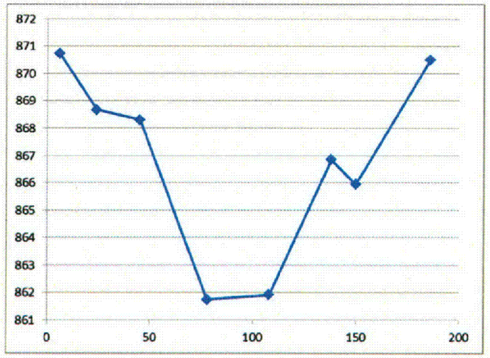
RMRB_620	
x	y
14.9	924.1
47.8	923.0
65.7	922.8
83.6	920.2
95.6	921.9
104.6	922.5
122.5	923.1
149.4	923.7



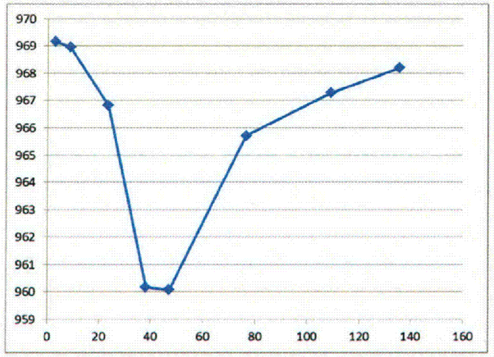
RMRB_670	
x	y
35.9	950.7
128.6	947.5
251.2	947.3
299.1	946.3
335.0	941.1
352.9	947.0
367.9	948.7
448.6	950.3



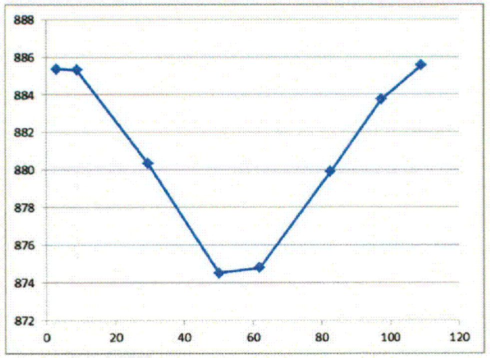
RMRB_640	
x	y
6.0	870.7
24.0	868.7
45.0	868.3
78.0	861.7
108.0	861.9
137.9	866.8
149.9	865.9
185.9	870.5



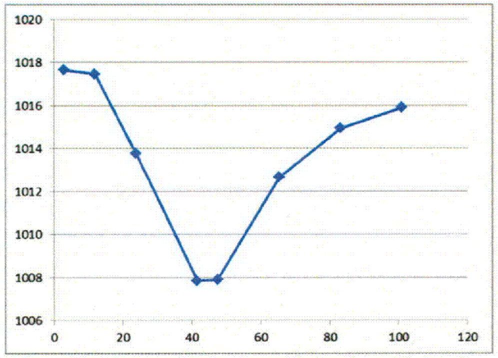
RMRB_680	
x	y
2.9	969.2
8.8	969.0
23.6	966.8
38.3	960.2
47.1	960.1
76.6	965.7
109.0	967.3
135.5	968.2



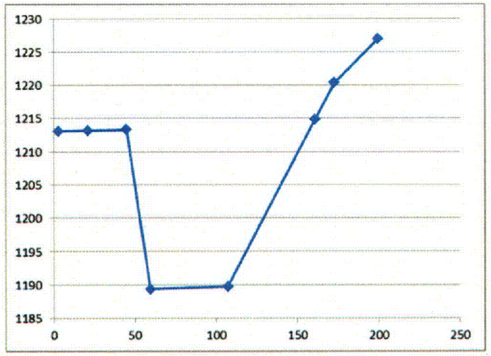
RMRB_650	
x	y
3.0	885.4
8.9	885.3
29.5	880.4
50.2	874.5
62.0	874.8
82.7	879.9
97.4	883.7
109.2	885.5



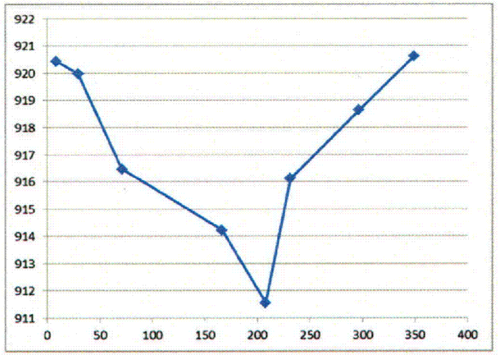
RMRB_690	
x	y
3.0	1017.6
11.9	1017.5
23.8	1013.8
41.6	1007.8
47.5	1007.9
65.3	1012.6
83.1	1014.9
101.0	1015.9



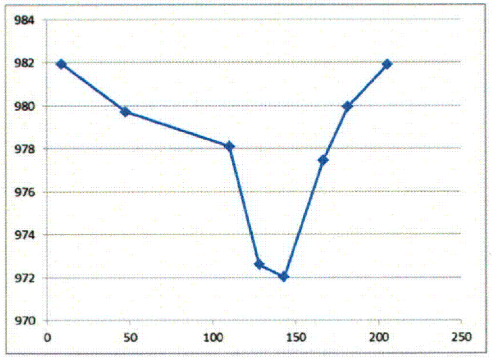
RMRB_710	
x	y
3.0	1213.1
20.8	1213.2
44.7	1213.3
59.6	1189.3
107.2	1189.7
160.8	1214.8
172.7	1220.4
199.5	1227.0



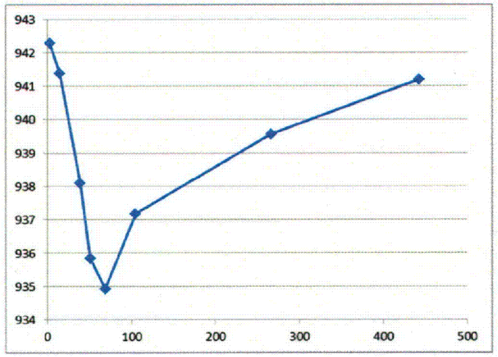
RMRB_780	
x	y
8.9	920.4
29.7	920.0
71.3	916.5
166.2	914.2
207.7	911.6
231.4	916.1
296.3	918.6
348.9	920.6



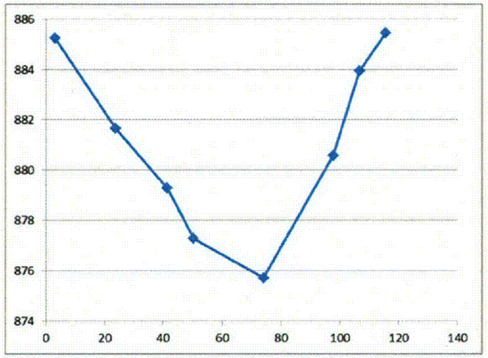
RMRB_740	
x	y
8.9	981.9
47.7	979.7
110.2	978.1
128.1	972.6
143.0	972.0
166.9	977.4
181.7	979.9
205.6	981.9



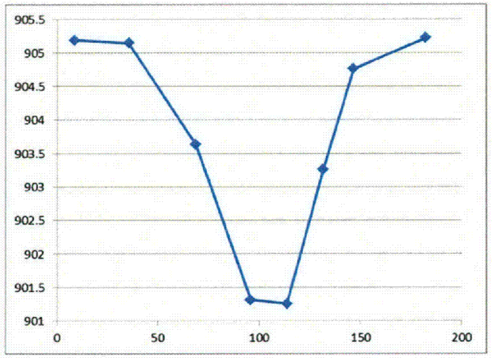
RMRB_790	
x	y
3.0	942.3
15.0	941.4
38.9	938.1
50.9	935.8
68.8	934.9
104.7	937.2
266.3	939.6
442.8	941.2



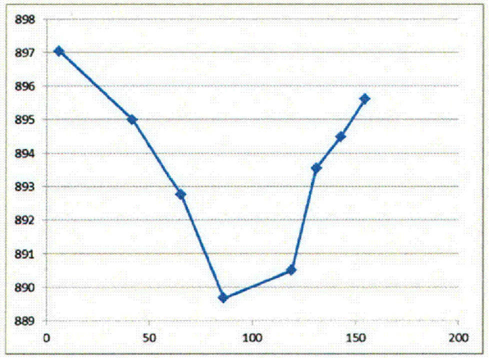
RMRB_760	
x	y
3.0	885.3
23.7	881.7
41.5	879.3
50.4	877.3
74.1	875.7
97.8	880.6
106.7	883.9
115.6	885.4



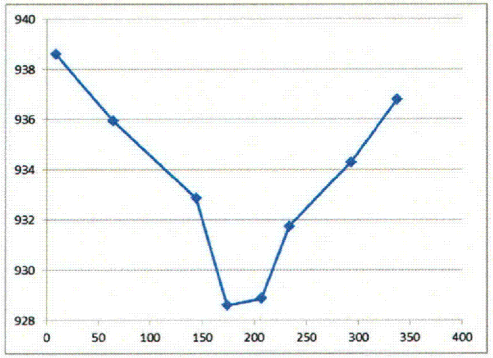
RMRB_810	
x	y
9.0	905.2
35.9	905.1
68.8	903.6
95.7	901.3
113.7	901.3
131.6	903.3
146.6	904.8
182.5	905.2



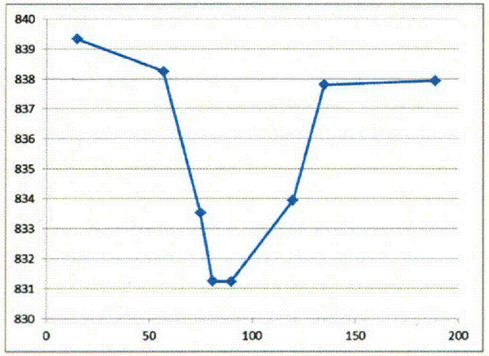
RMRB_770	
x	y
6.0	897.0
41.7	895.0
65.5	892.8
86.3	889.7
119.1	890.5
131.0	893.5
142.9	894.5
154.8	895.6



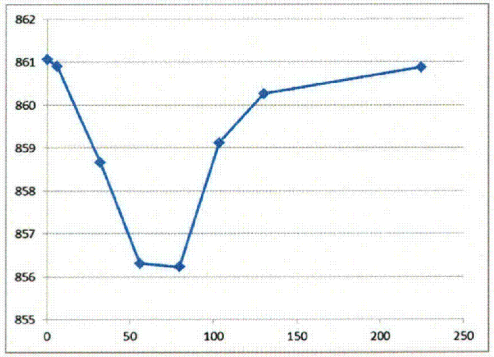
RMRB_820	
x	y
8.8	938.6
64.4	935.9
144.4	932.9
174.2	928.6
206.9	928.9
233.7	931.7
293.2	934.3
337.9	936.8



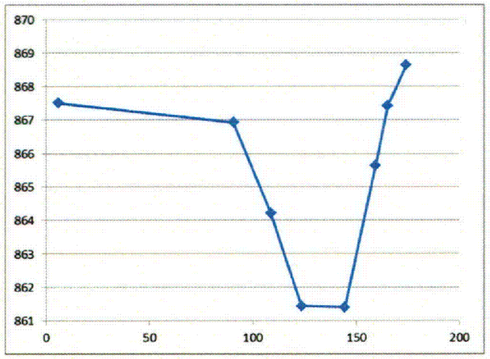
RMRB_850	
x	y
15.0	839.3
56.9	838.2
74.9	833.5
80.9	831.2
89.8	831.2
119.8	833.9
134.8	837.8
188.7	837.9



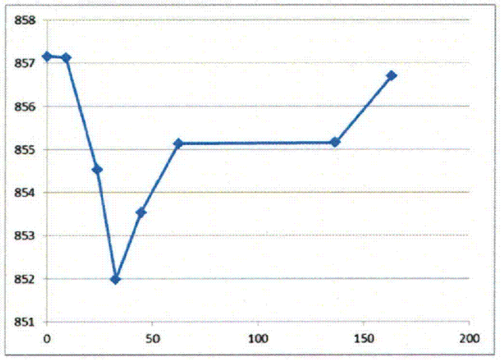
RMRB_900	
x	y
0.0	861.1
5.9	860.9
32.3	858.7
56.0	856.3
79.7	856.2
103.4	859.1
130.1	860.3
224.9	860.9



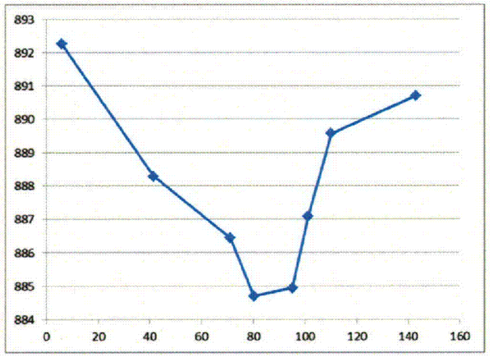
RMRB_860	
x	y
5.8	867.5
90.7	866.9
108.6	864.2
123.6	861.4
144.5	861.4
159.4	865.6
165.4	867.4
174.3	868.6



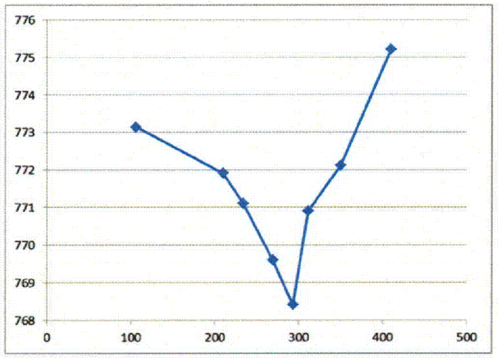
RMRB_920	
x	y
0.0	857.2
8.9	857.1
23.7	854.5
32.6	852.0
44.5	853.5
62.3	855.1
136.5	855.2
163.1	856.7



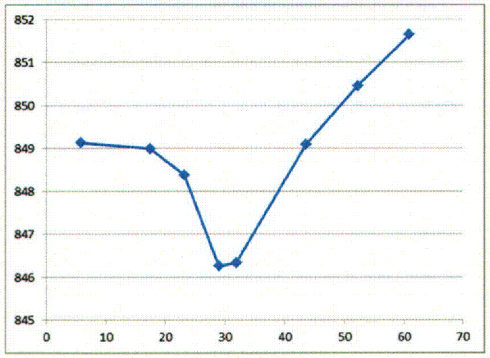
RMRB_870	
x	y
5.9	892.3
41.4	888.3
71.3	886.4
80.2	884.7
95.2	884.9
101.2	887.1
110.2	889.6
143.1	890.7



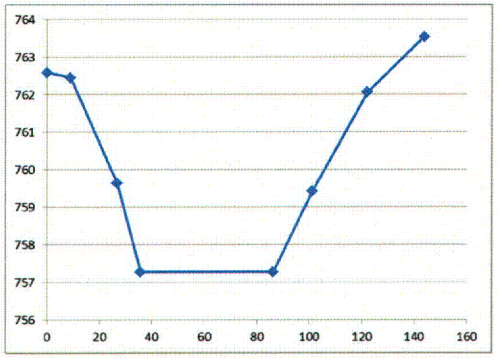
RMRB_940	
x	y
106.1	773.1
209.9	771.9
233.8	771.1
269.6	769.6
293.4	768.4
311.3	770.9
350.1	772.1
409.8	775.2



RMRB_890	
x	y
5.8	849.1
17.4	849.0
23.2	848.4
29.0	846.3
31.9	846.3
43.5	849.1
52.3	850.4
61.0	851.6



RMRB_1000	
x	y
0.0	762.6
8.9	762.4
26.8	759.6
35.7	757.3
86.3	757.3
101.2	759.4
122.1	762.1
143.8	763.5



A.6 Peak Discharges

Peak discharges were computed at the downstream end of each sub-basin. Table A8 displays peak discharge results from the HEC-HMS model.

Table A8: Computed Peak Discharges

Hydrologic Element	HEC-RAS Cross-Section	Drainage Area (mi^2)	Existing Conditions Areally Reduced Peak Discharge (cfs)							Future Conditions Areally Reduced Peak Discharge (cfs)						
			50% ACE	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.2% ACE	50% ACE	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.2% ACE
Backbone Creek																
JMRB_300_340	13725	29.927	6580	11980	15670	21130	25390	28640	39330	7060	12520	16150	21770	25740	29020	39760
JMRB_250_290	12132	31.605	6750	12190	16020	21370	25750	29330	41800	7220	12740	16490	22030	26130	29770	42500
JMRB_240	8144	31.769	6760	12190	15960	21340	25720	29330	41700	7230	12730	16480	21980	26100	29740	42400
JMRB_230	6481	31.798	6750	12160	15910	21270	25660	29290	41550	7220	12700	16410	21900	26040	29700	42240
JMRB_230_940	6119	32.399	6800	12220	15980	21360	25790	29450	42090	7270	12770	16490	22000	26170	29850	42780
JMRB_220_960	5366	33.796	6860	12310	16080	21470	25940	29660	42660	7330	12860	16590	22120	26340	30080	43350
JMRB_210	4835	33.904	6860	12290	16050	21380	25850	29630	42530	7330	12830	16530	22010	26250	30050	43230
JMRB_200	3426	33.949	6860	12240	15960	21190	25670	29550	42360	7330	12780	16430	21790	26090	29970	43050
JMRB_020_200	2397	40.127	7640	13160	17230	22680	27960	34060	51220	8250	13770	18160	23560	28870	34930	52200
Outlet1	838	40.253	7630	13130	17100	22570	27730	33710	51010	8240	13730	18020	23420	28590	34680	51970
Backbone Creek Trib 1																
JMRB_980	2575	0.448	320	600	820	1100	1330	1520	2090	330	620	840	1110	1350	1530	2100
JMRB_970	1816	0.471	300	590	820	1110	1340	1530	2100	320	610	840	1120	1350	1540	2110
JMRB_970_1000	1196	1.190	500	1130	1620	2300	2840	3390	4800	540	1190	1680	2360	2900	3450	4850
JMRB_960	759	1.391	520	1200	1730	2410	3000	3640	5180	580	1270	1790	2470	3070	3700	5240
Backbone Creek Trib 2																
JMRB_260	7106	1.375	670	1260	1700	2330	2860	3410	4840	720	1310	1740	2380	2910	3450	4880
JMRB_250	3867	1.678	640	1190	1610	2250	2820	3360	5080	700	1240	1650	2320	2870	3420	5130
Whitman Branch																
JMRB_190	23235	0.686	380	650	860	1160	1400	1650	2310	410	690	910	1200	1440	1690	2350
JMRB_180	19811	0.944	300	720	1000	1340	1610	1900	2690	340	810	1060	1400	1670	1970	2750
JMRB_130_180	17595	3.175	1160	2250	3280	4550	5490	6490	9060	1420	2610	3660	4870	5820	6820	9380
JMRB_120	14848	3.784	1270	2270	3310	4830	5940	7120	10020	1560	2600	3730	5250	6320	7510	10400
JMRB_110	12460	4.038	1300	2310	3340	4900	6050	7250	10200	1580	2650	3760	5330	6430	7640	10580
JMRB_100	9843	4.244	1300	2320	3340	4860	6060	7250	10270	1590	2670	3760	5320	6460	7660	10650
JMRB_090	7644	4.476	1330	2370	3390	4940	6190	7390	10490	1620	2720	3810	5410	6580	7800	10870
JMRB_080	5171	4.566	1340	2380	3400	4950	6190	7420	10520	1620	2730	3820	5420	6610	7820	10910
JMRB_040_080	4024	5.940	1710	3010	3980	5600	7060	8530	12190	2030	3380	4370	6160	7580	8970	12630
JMRB_030	2790	6.048	1720	3010	3970	5570	7030	8540	12210	2040	3370	4350	6120	7540	9000	12660
JMRB_020	1032	6.178	1720	3020	4000	5560	7000	8500	12210	2050	3390	4370	6090	7530	8970	12650
Whitman Branch Trib 1																
JMRB_060	4528	0.834	500	910	1190	1580	1890	2230	3090	610	1010	1300	1690	2000	2340	3190
JMRB_050	3219	1.210	930	1560	2000	2620	3140	3680	5070	1080	1710	2160	2790	3300	3840	5210
JMRB_040	2174	1.374	1070	1760	2270	2950	3510	4120	5660	1220	1920	2420	3100	3680	4270	5780

A.7 Hydraulic Analysis

A hydraulic analysis was performed along several streams within the Backbone Creek and Whitman Branch Watershed utilizing HEC-RAS software, version 4.1. The purpose of this hydraulic analysis was to develop flood profiles for the existing and ultimate conditions 2-, 5-, 10-, 25-, 50-, 100-, and 500-year frequency rainfall events. No hydraulic geometric modifications were made between the existing and ultimate scenarios; differences between these two water surfaces are only the result of the different simulated hydrologic flow rates. The locations of the detailed bridge surveys used in this study are listed in Table A9 below. The river station is measured in feet from the outfall of each listed stream.

Table A9. Structure survey locations

Stream	Road	Station
Backbone Creek	S Avenue J	2357
	S Avenue N	4205
	RR Bridge	5876
	2nd St	7095
	Broadway St	10040
	FM 1431	10890
BC-1	S Avenue S	976
BC-2	FM 1431	922
	Earthen Dam	2477
Whitman Branch	S Yett St	490
	2nd St	1324
	3rd St	1751
	4th St	2235
	Pedestrian Bridge	3651
	Broadway St	3996
	FM 1431	5087
	Mission Hills Dr	6154
	US 281	8646
	Public Dr	11689
	Commerce St	12863
	Nature Heights Dr	13539
	Private Dr	14474
	Dam	20915
WTM-1	Avenue L	381
	Avenue J	1268
	Main St	1685
	US 281	2038
	FM 1431	2597
	12th St	3533

Non-surveyed cross-sections were cut from LiDAR elevation data. Structures located on streams modeled with limited detail methods were estimated using LiDAR elevation data, aerial photos, and field visits.

The computed peak discharges from the hydrologic model were input into the hydraulic model to develop existing and ultimate condition flood profiles for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year frequency events. All Manning's n-values were selected from a combination of aerial photos, site visits, and landuse shapefiles. N-values were primarily assigned according to Table A.3. The downstream boundary condition for Backbone Creek and all tributary models was set to normal depth. The confluence of Backbone Creek Tributary 2 into Backbone Creek main stem proved to be a complicated area. After detailed analysis, it was observed that Backbone Creek controls the flooding along Backbone Creek Tributary 2 for most events over the 25-year event up to Cross Section 2245 (BCB2). For this reason, all water surfaces for cross sections downstream of XS 2245 on Backbone Creek Tributary 2 were set to equal the corresponding water surface elevation of Backbone Creek. While this approach may overestimate flooding on Backbone Creek Tributary 2 for lower frequency events, it felt to be the most appropriate way to simulate all events properly for this study.

A.8 Flood Profiles

Flood profiles for existing conditions were computed along the study streams for the various frequency events previously mentioned. The results for each stream can be seen in Figures A4 - A8.

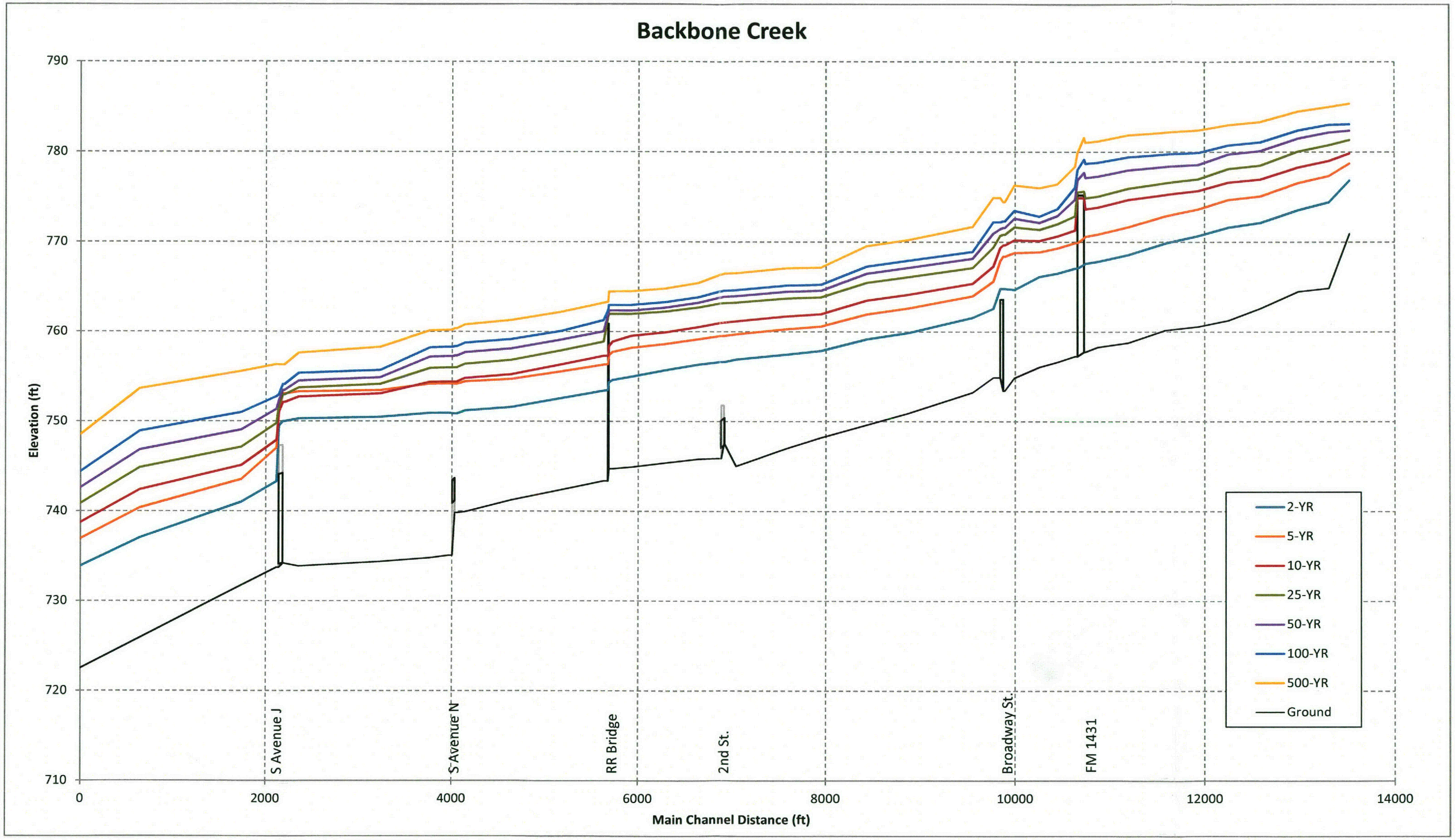


Figure A4: Backbone Creek Frequency Profiles

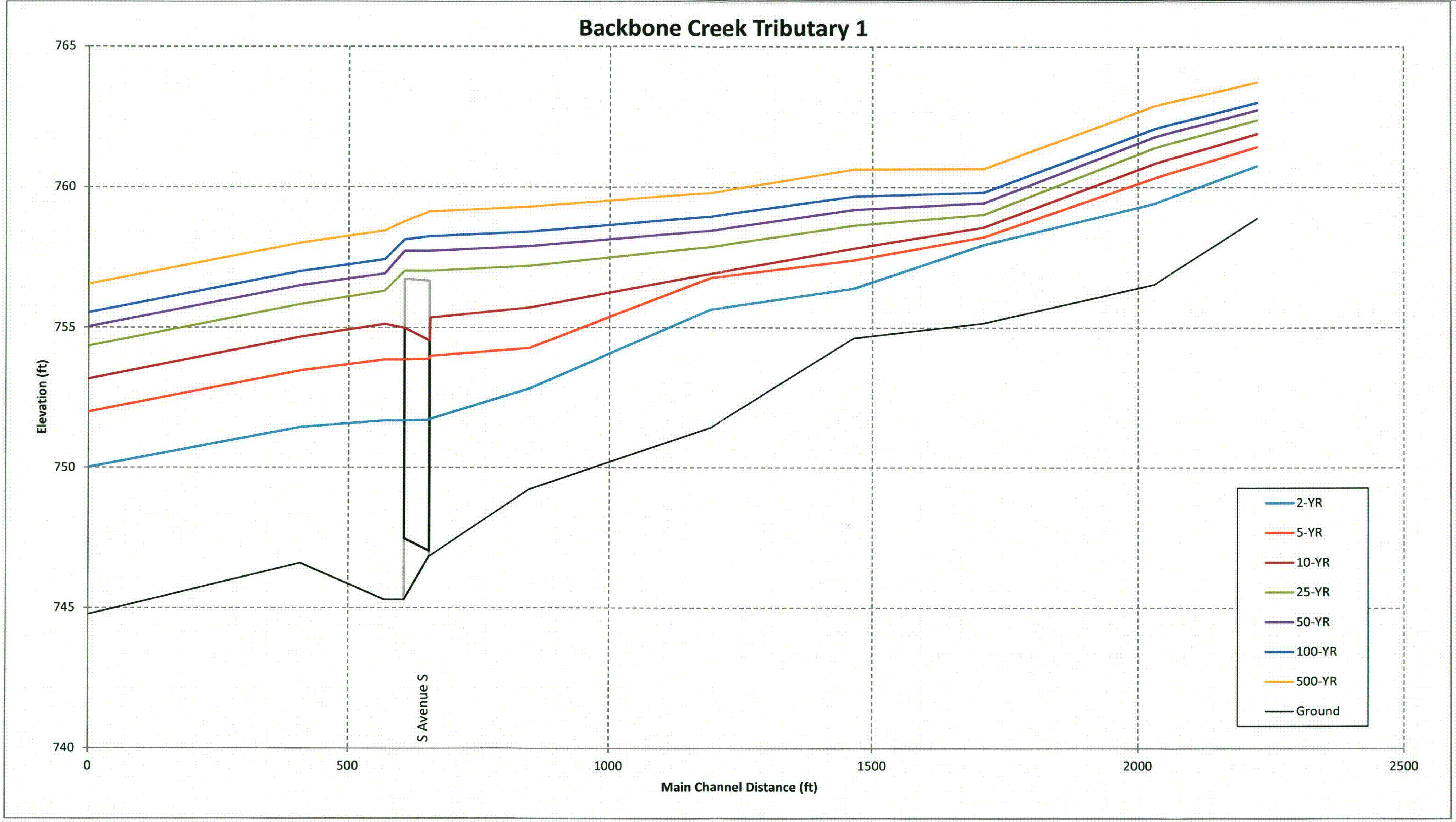


Figure A5: Backbone Creek Tributary 1 Frequency Profiles

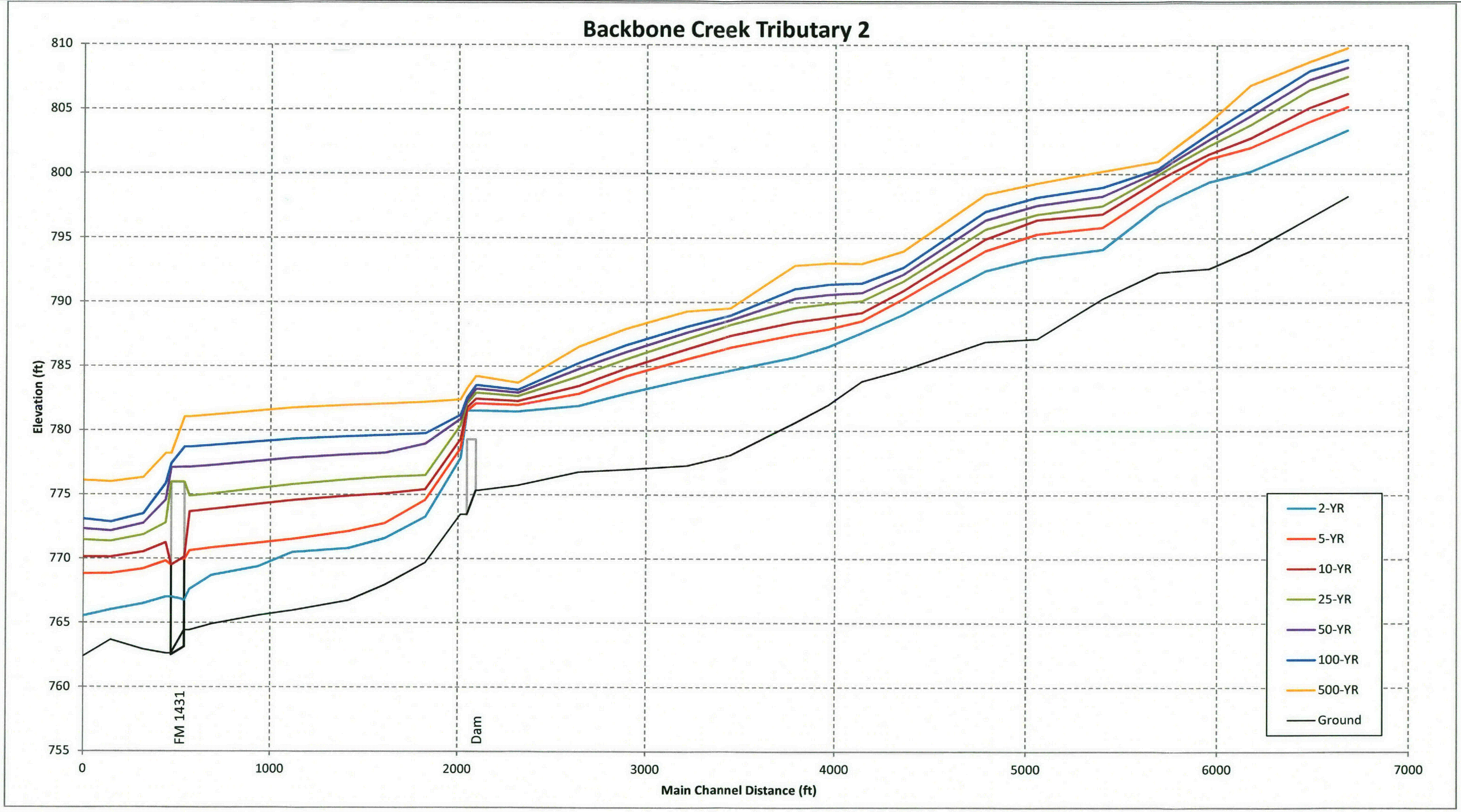


Figure A6: Backbone Creek Tributary 2 Frequency Profiles

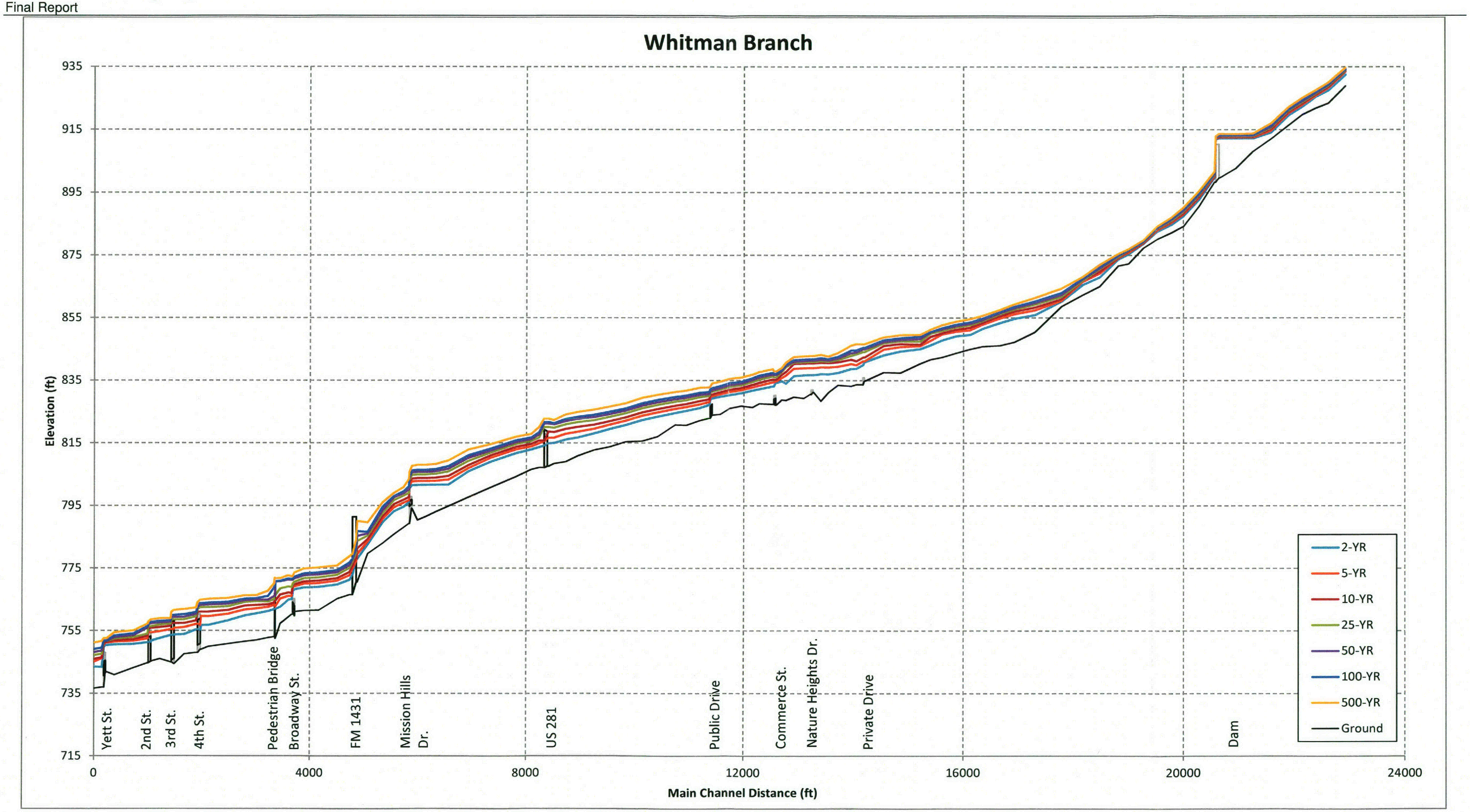


Figure A7: Whitman Branch Frequency Profiles

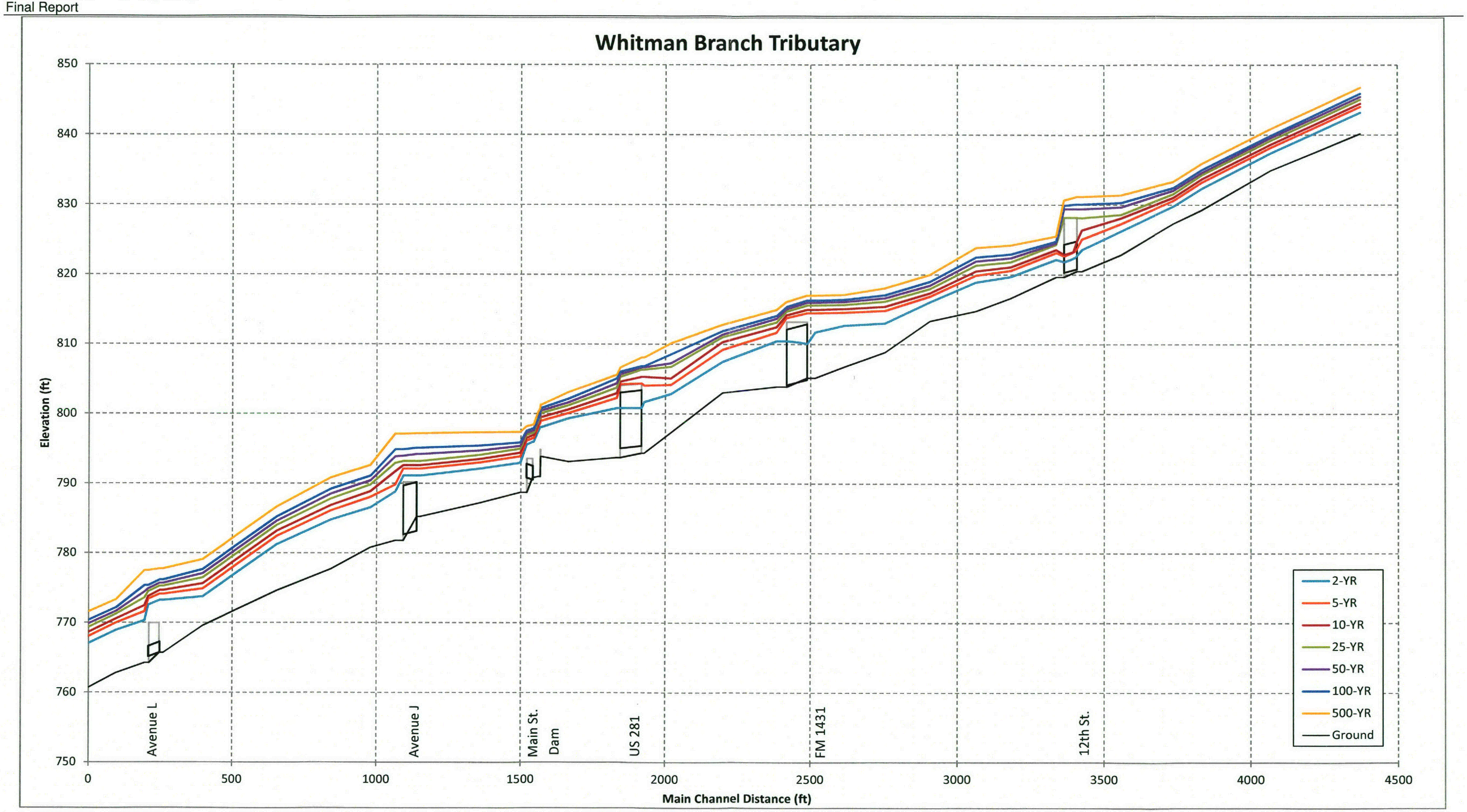


Figure A8: Whitman Branch Tributary 1 Frequency Profiles

A.9 FIS Comparison

A comparison was made between the results from this study and the current effective base flood elevations and discharges listed in the Burnet County current effective FEMA Flood Insurance Study. The 100-year flood elevation comparisons are shown in Figures A9 - A13 and discharge comparisons are displayed in Table A10.

Differences in the water surface profiles and discharges can be attributed to many factors. The following is a list of reasons the results could vary:

1. Spills and diversions were accounted for in the new model.
2. Hydrologic and Hydraulic parameters were calculated with different methodology.
3. Differences in the amount and accuracy of field survey available.
4. The use of detailed LiDAR topographic data.
5. Physical watershed changes may have occurred.

Table A10: Peak Flow Comparison to FIS

Stream	HMS JUNCTION	10-YR			50-YR			100-YR			500-YR		
		FIS Flow (cfs)	HMS Flow with AMC II Conditions (cfs)	Percent Change (%)	FIS Flow (cfs)	HMS Flow with AMC II Conditions (cfs)	Percent Change (%)	FIS Flow (cfs)	HMS Flow with AMC II Conditions (cfs)	Percent Change (%)	FIS Flow (cfs)	HMS Flow with AMC II Conditions (cfs)	Percent Change (%)
Backbone Creek													
	JMRB_480	4700	5690	21.06%	6550	8740	33.44%	7500	10240	36.53%	8800	15540	76.59%
	JMRB_470	4800	6450	34.38%	6750	9660	43.11%	7800	10900	39.74%	9200	16480	79.13%
	JMRB_460	4450	6350	42.70%	6400	9730	52.03%	7400	11040	49.19%	8850	16520	86.67%
	JMRB_370	7300	10240	40.27%	10650	15720	47.61%	12400	18070	45.73%	14900	24060	61.48%
	JMRB_360	9450	11680	23.60%	14300	17910	25.24%	16850	20530	21.84%	20850	27930	33.96%
	JMRB_350	14000	14880	6.29%	20350	23770	16.81%	23800	26780	12.52%	28800	36960	28.33%
	JMRB_340	14500	15250	5.17%	21300	24530	15.16%	24950	27630	10.74%	30200	38050	25.99%
	JMRB_290	15450	15720	1.75%	22700	25260	11.28%	26650	28650	7.50%	32250	39300	21.86%
	JMRB_250_290	15900	16020	0.75%	23400	25750	10.04%	27500	29330	6.65%	33250	41800	25.71%
	JMRB_220	15800	15970	1.08%	23250	25750	10.75%	27300	29430	7.80%	33100	42040	27.01%
	JMRB_200	15800	15960	1.01%	23400	25670	9.70%	27500	29550	7.45%	33500	42360	26.45%
	Outlet1	18000	17100	-5.00%	26900	27730	3.09%	31500	33710	7.02%	38300	51010	33.19%
Backbone Creek Trib 1													
	JMRB_980	800	820	2.50%	1050	1330	26.67%	1190	1520	27.73%	1350	2090	54.81%
	JMRB_960	1860	1730	-6.99%	2550	3000	17.65%	2850	3640	27.72%	3300	5180	56.97%
Backbone Creek Trib 2													
	JMRB_270	1350	1680	24.44%	1850	2840	53.51%	2100	3390	61.43%	2400	4840	101.67%
	JMRB_260	1550	1700	9.68%	2150	2860	33.02%	2450	3410	39.18%	2850	4840	69.82%
	JMRB_250	1800	1610	-10.56%	2500	2820	12.80%	2900	3360	15.86%	3400	5080	49.41%
Whitman Branch													
	JMRB_180	1140	1000	-12.28%	1580	1610	1.90%	1800	1900	5.56%	2070	2690	29.95%
	JMRB_130_180	4060	3280	-19.21%	5580	5490	-1.61%	6320	6490	2.69%	7260	9060	24.79%
	JMRB_100	3990	3340	-16.29%	5730	6060	5.76%	6620	7250	9.52%	7820	10270	31.33%
	JMRB_080	4150	3400	-18.07%	5960	6190	3.86%	6900	7420	7.54%	8130	10520	29.40%
	JMRB_040_080	5600	3980	-28.93%	8050	7060	-12.30%	9300	8530	-8.28%	11000	12190	10.82%
	JMRB_020	5000	4000	-20.00%	7000	7000	0.00%	8050	8500	5.59%	9550	12210	27.85%
Whitman Branch Trib 1													
	JMRB_060	1480	1190	-19.59%	1980	1890	-4.55%	2210	2230	0.90%	2510	3090	23.11%
	JMRB_040	2100	2270	8.10%	2850	3510	23.16%	3200	4120	28.75%	3650	5660	55.07%

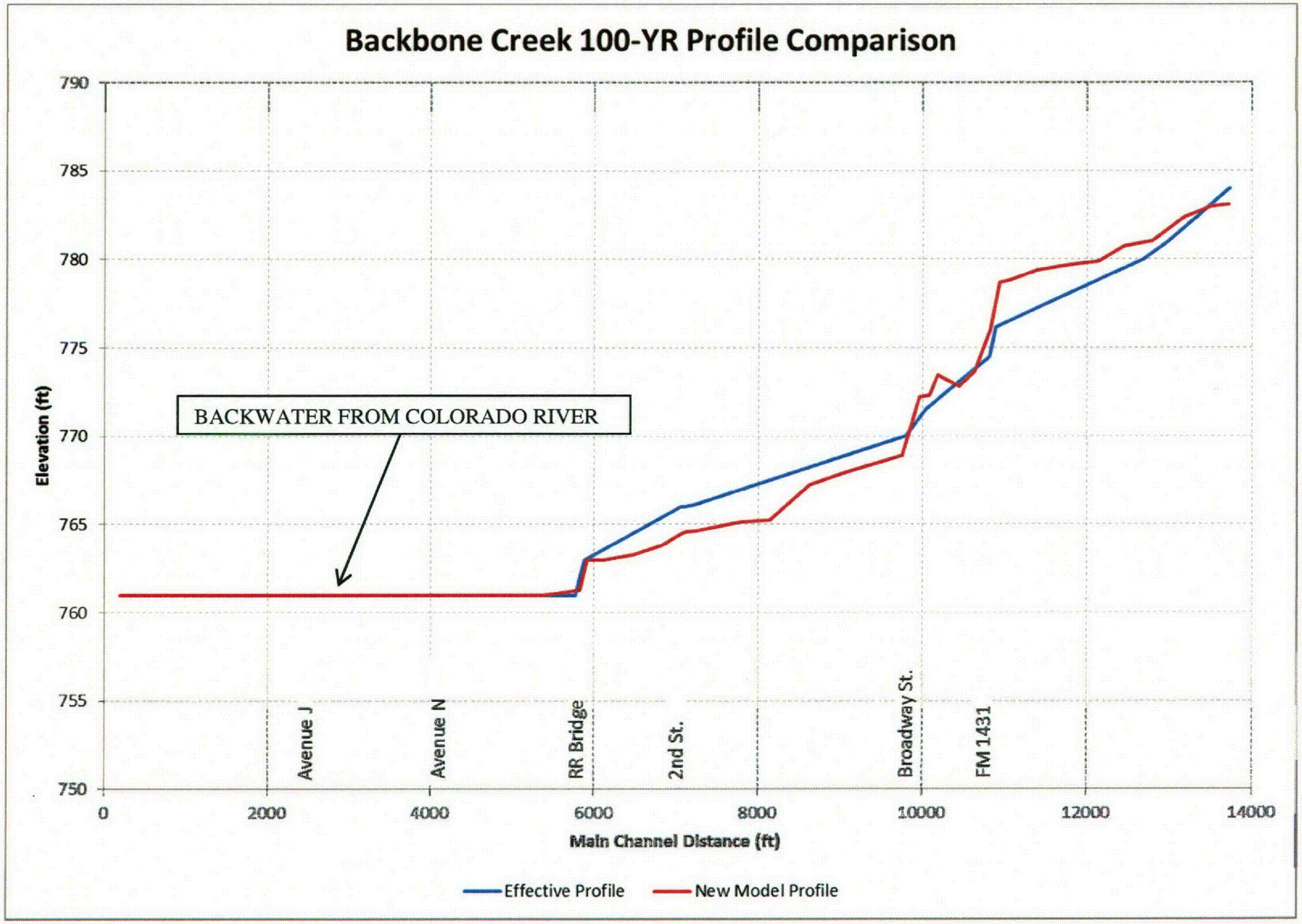


Figure A9: Backbone Creek 100-yr Profile Comparison to FEMA Current Effective

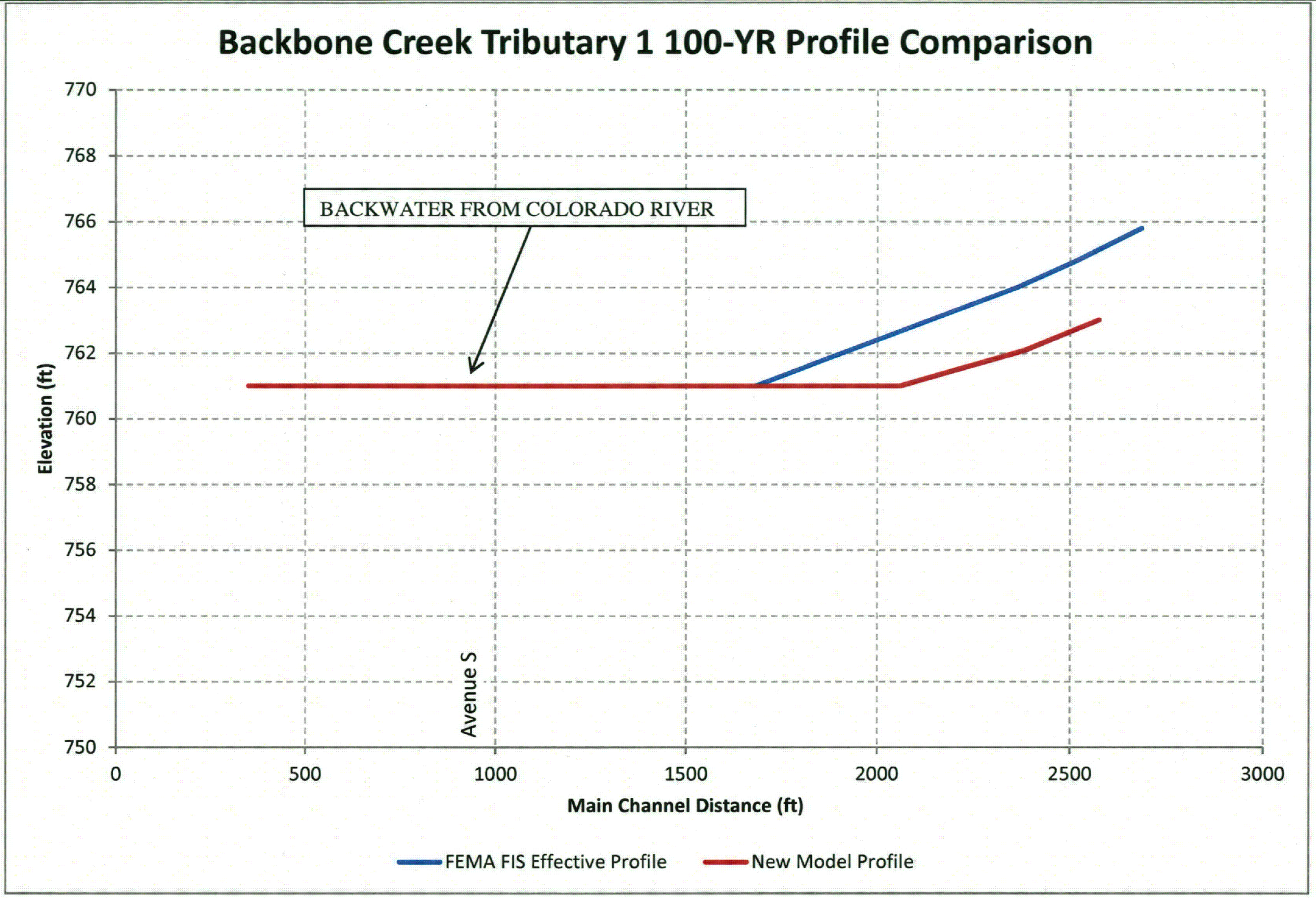


Figure A10: Backbone Creek Tributary 1 100-yr Profile Comparison to FEMA Current Effective

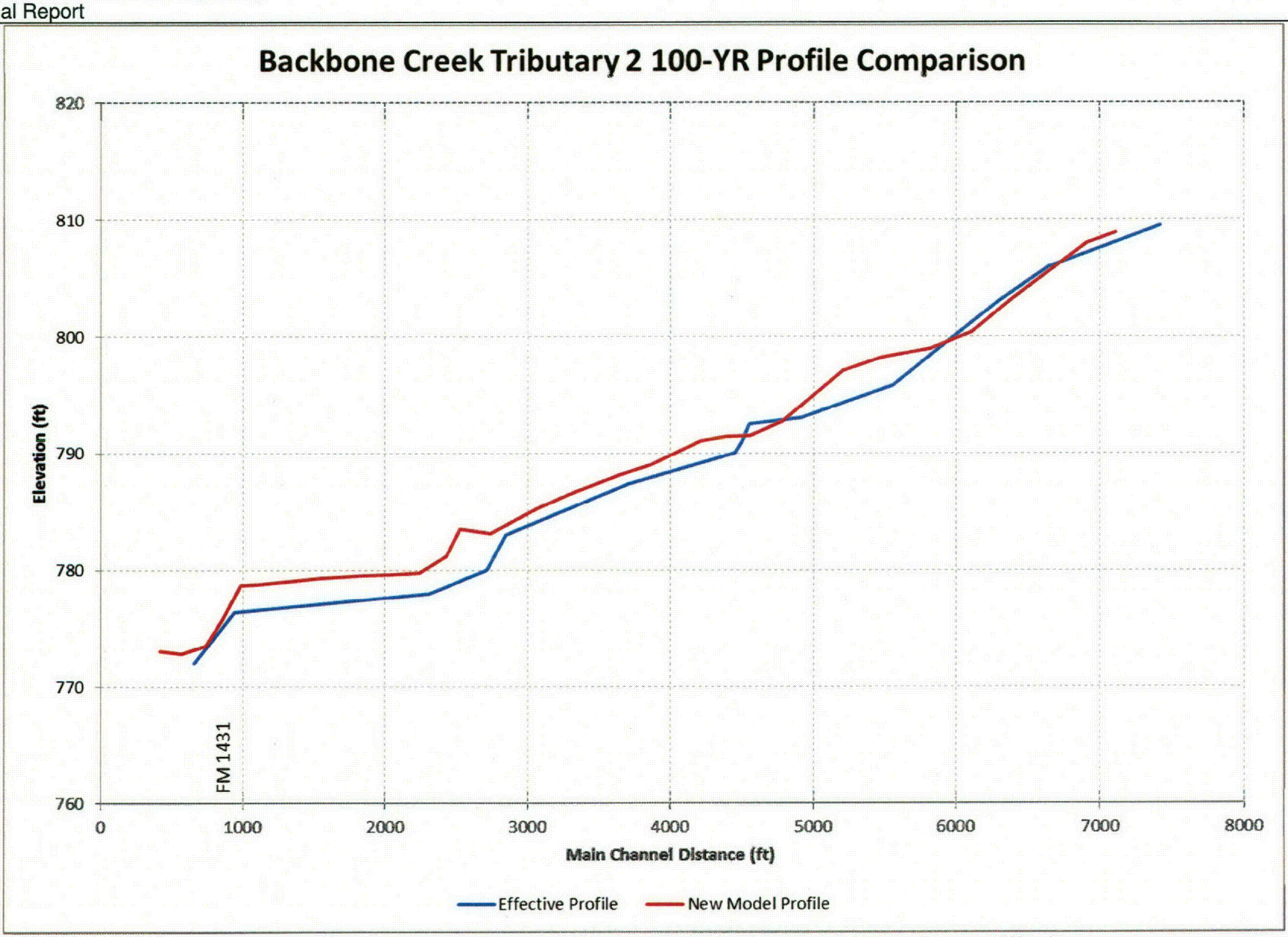


Figure A11: Backbone Creek Tributary 2 100-yr Profile Comparison to FEMA Current Effective

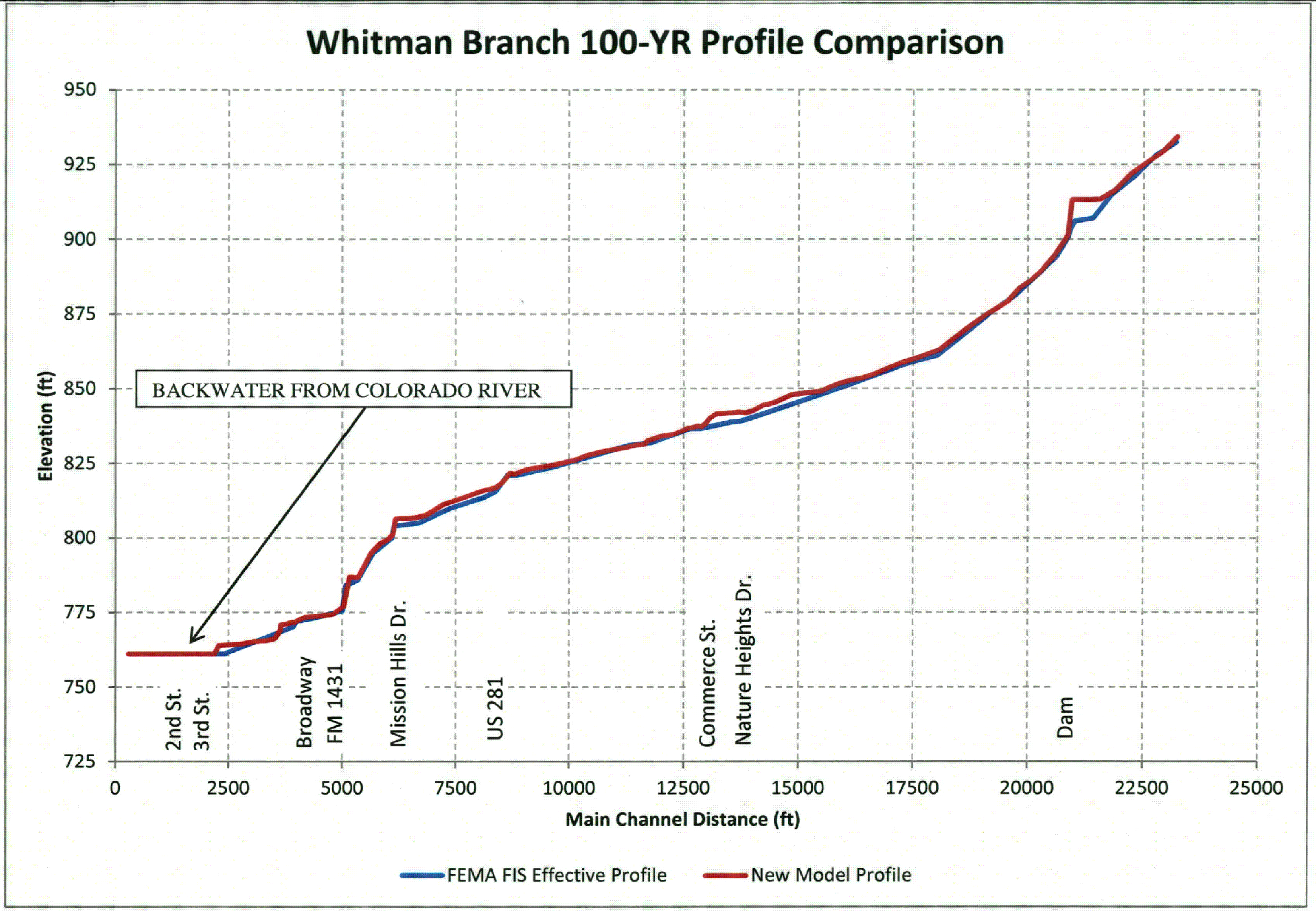


Figure A12: Whitman Branch 100-yr Profile Comparison to FEMA Current Effective

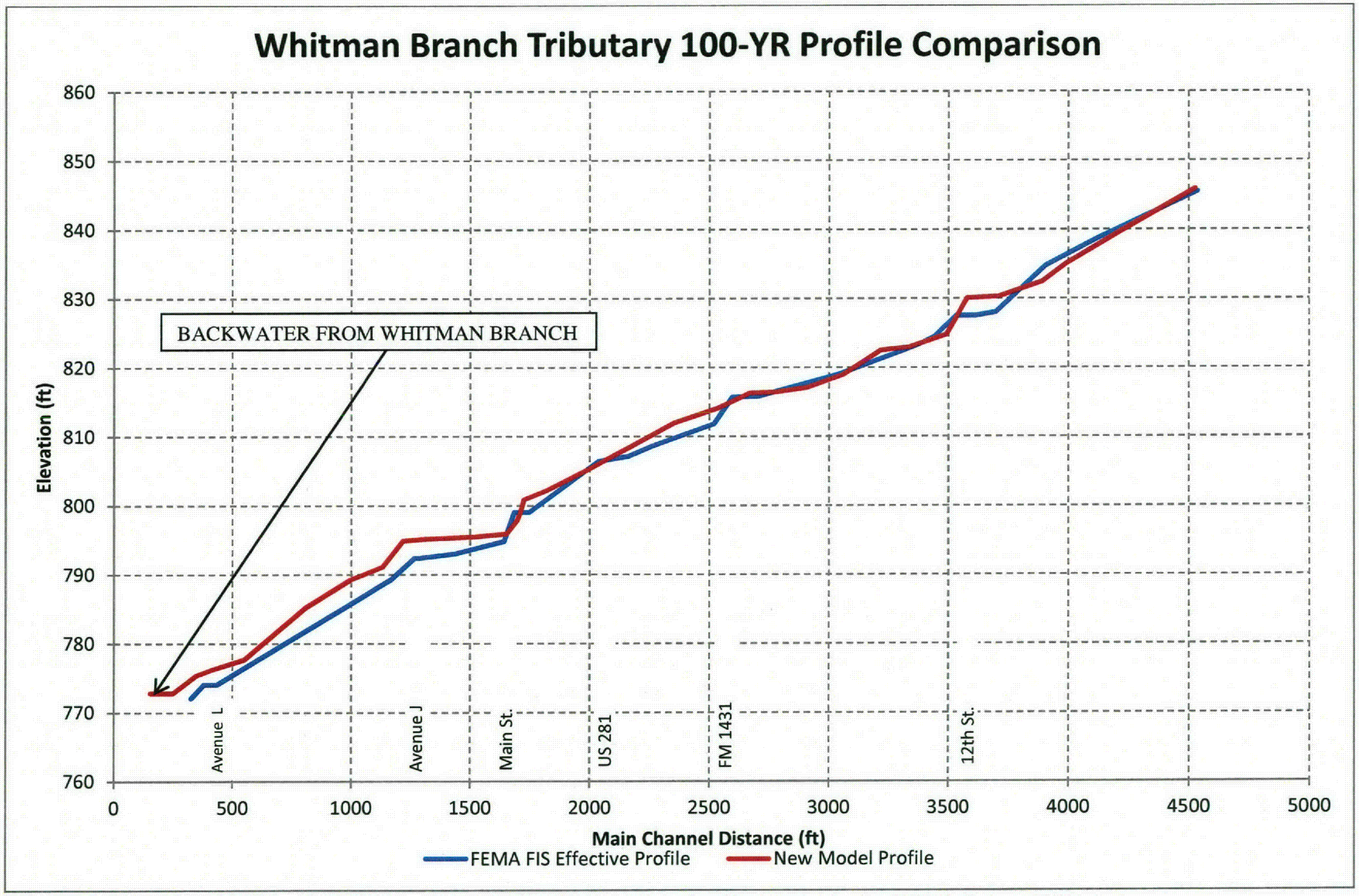


Figure A13: Whitman Branch Tributary 1 100-yr Profile Comparison to FEMA Current Effective

A.10 Calibration

The hydrologic and hydraulic models were calibrated to the June 2007 flood event.

The LCRA maintains a flow gage at the FM 1431 crossing at Backbone Creek. Ground-adjusted, real-time, gridded precipitation was applied to the HEC-HMS model to simulate the June 2007 flood event. Initial results matched the observed hydrograph shape. However, overall, the simulated peak flow and volume were significantly higher than what was observed. Upon further investigation, precipitation records indicated that little to no rainfall had occurred in the watershed for several months leading up to the flood event. This warranted lowering the antecedent moisture conditions in the model to Type I, since the ground was presumably dry and able to absorb more water than normal conditions. This parameter change produced a hydrograph that matched the observed gage hydrograph, as seen in Figure A14.

TWDB, TNRIS, Halff Associates, and many local citizens obtained high water marks during or just after the June 2007 flood event. Approximate peak flood elevations were estimated using LiDAR data and these high water mark photographs. It is important to note that these high water mark elevations were not surveyed and are considered approximate estimations of flood depths during the event. The June 2007 flood event peak flows were applied to the HEC-RAS models to simulate flood stage during the event. The estimated high water mark elevations were then compared to the computed water surface elevations of the June 2007 simulation. The high water marks matched the simulated flood stage fairly well in most locations, as displayed in Figures A15 - A18. Physical parameters along Backbone Creek were calibrated to better match the observed high water marks.

The results of both the FIS comparisons and calibration indicate that the flood models are simulating reality well and can appropriately be used in flood mitigation alternative analysis.

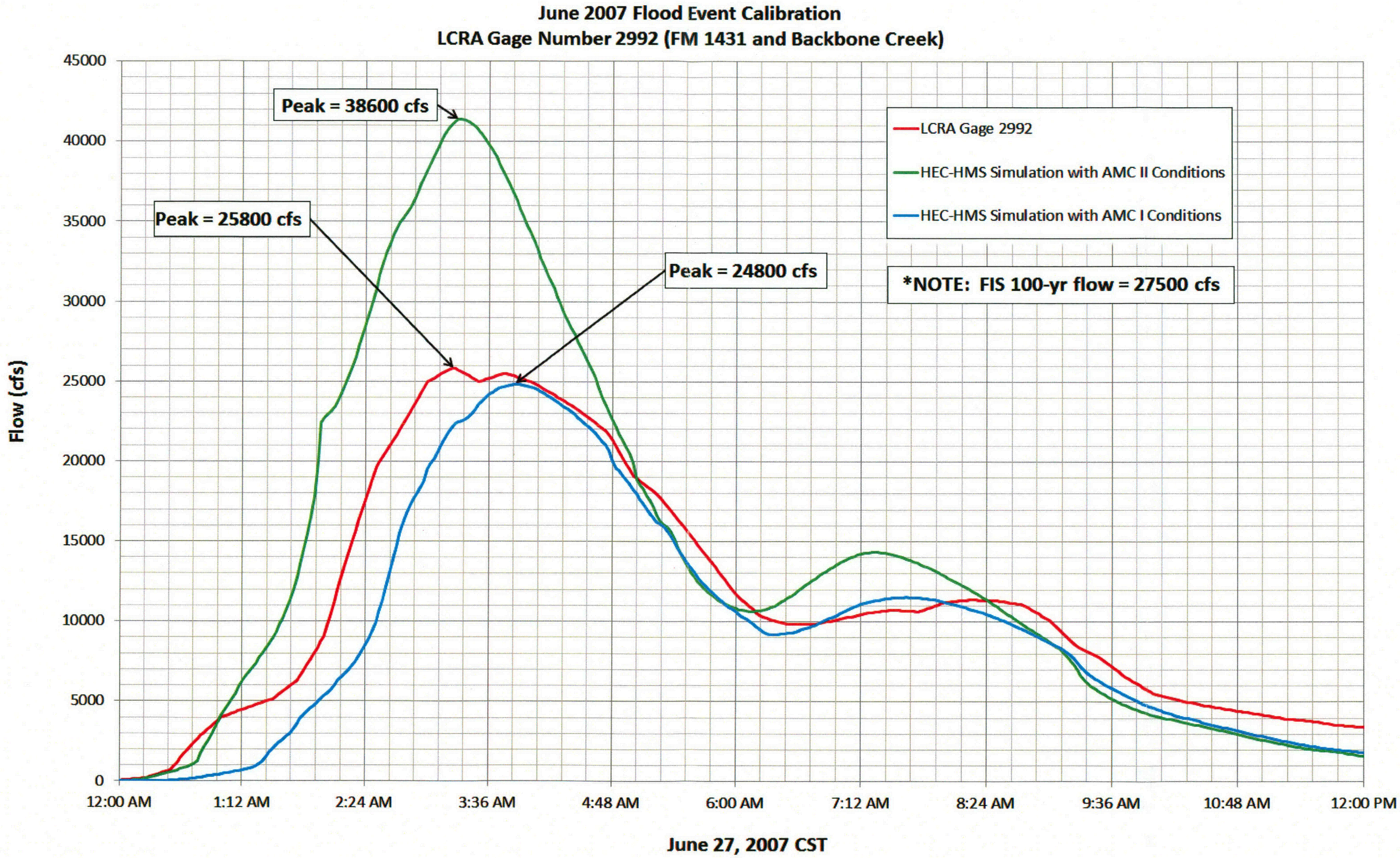


Figure A14: Calibration Results at LCRA Flow Gage

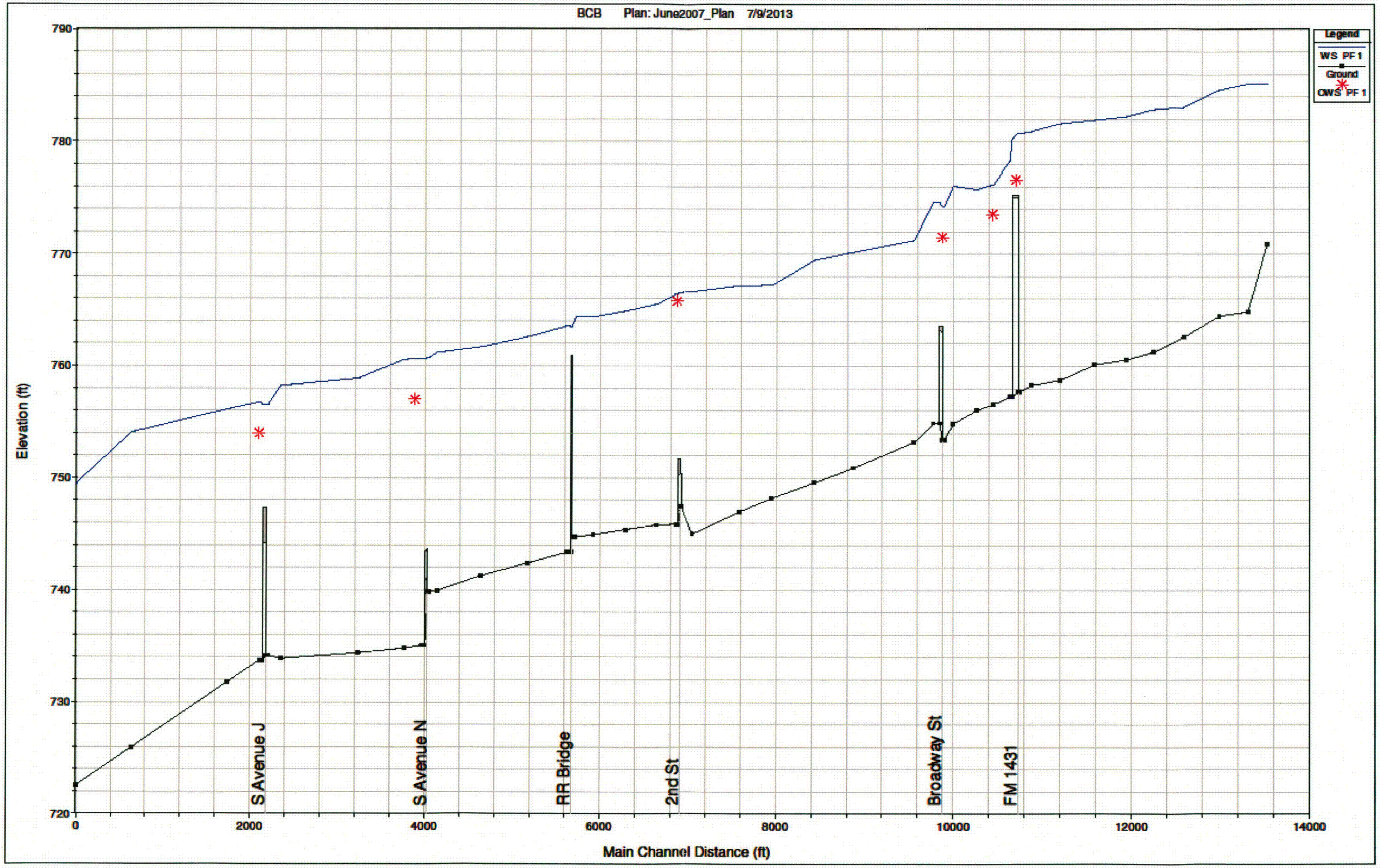


Figure A15: Backbone Creek 2007 Profiles and High Water marks

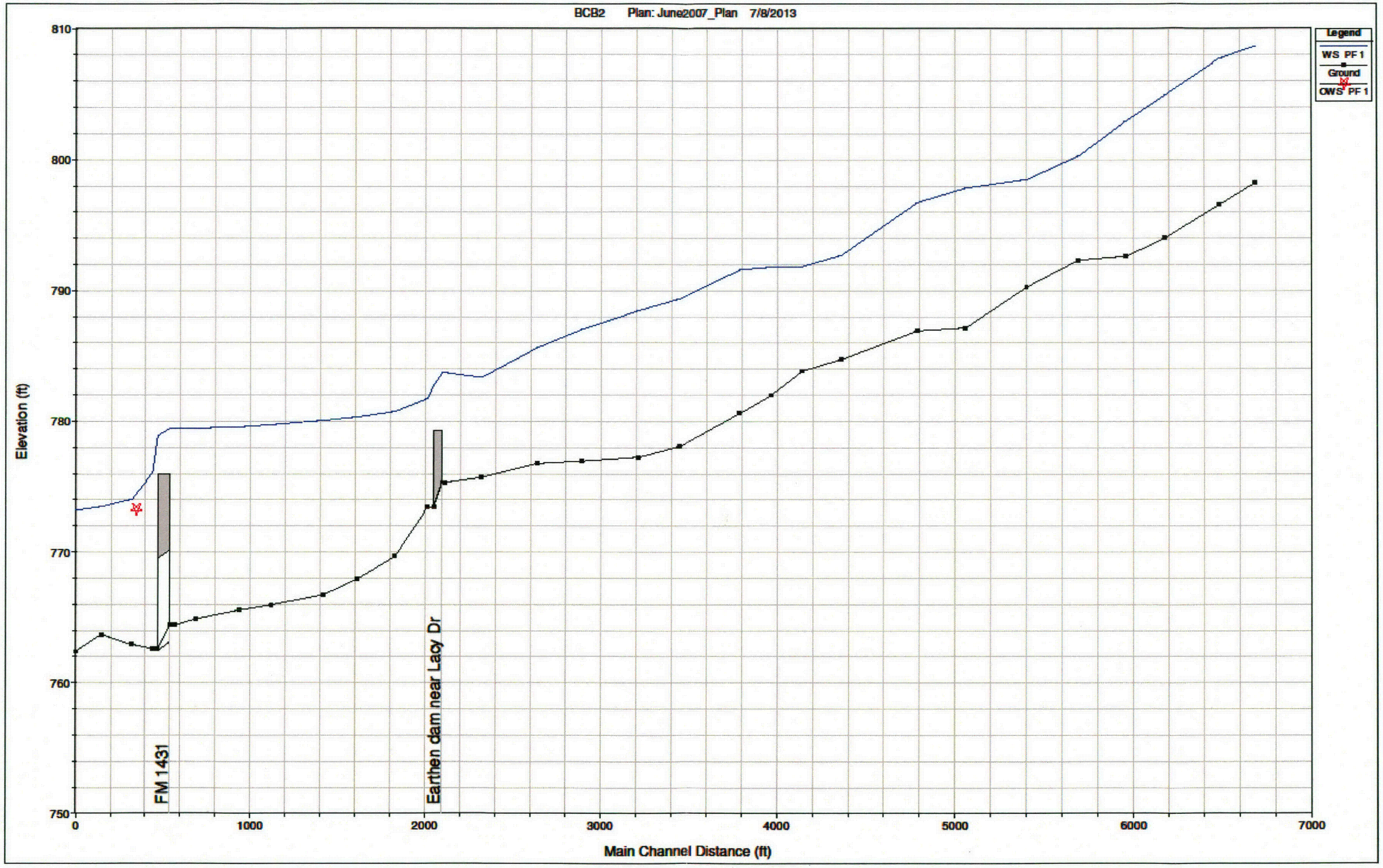


Figure A16: Backbone Tributary 2, 2007 Profiles and High Water marks

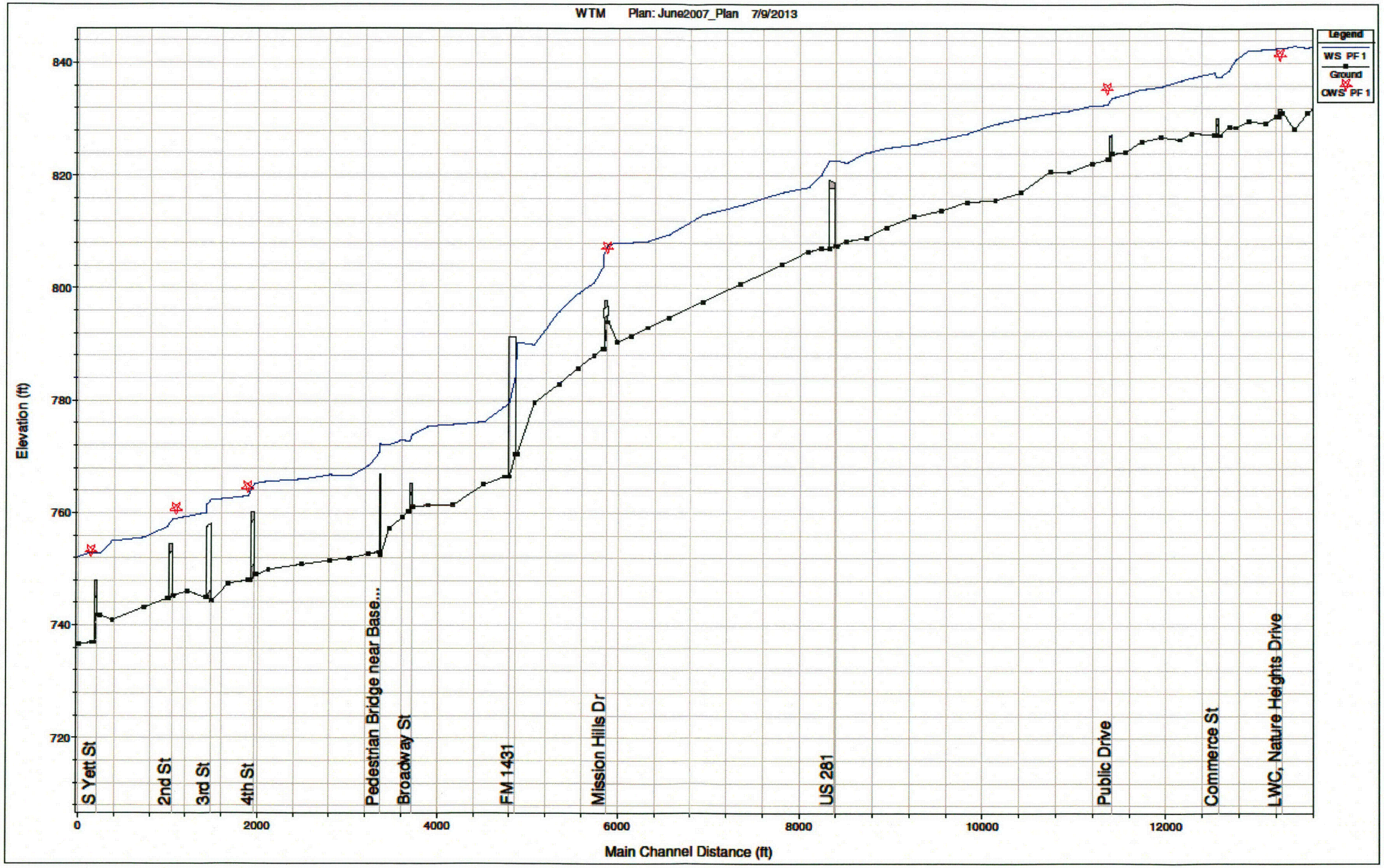


Figure A17: Whitman Branch, 2007 Profiles and High Water marks

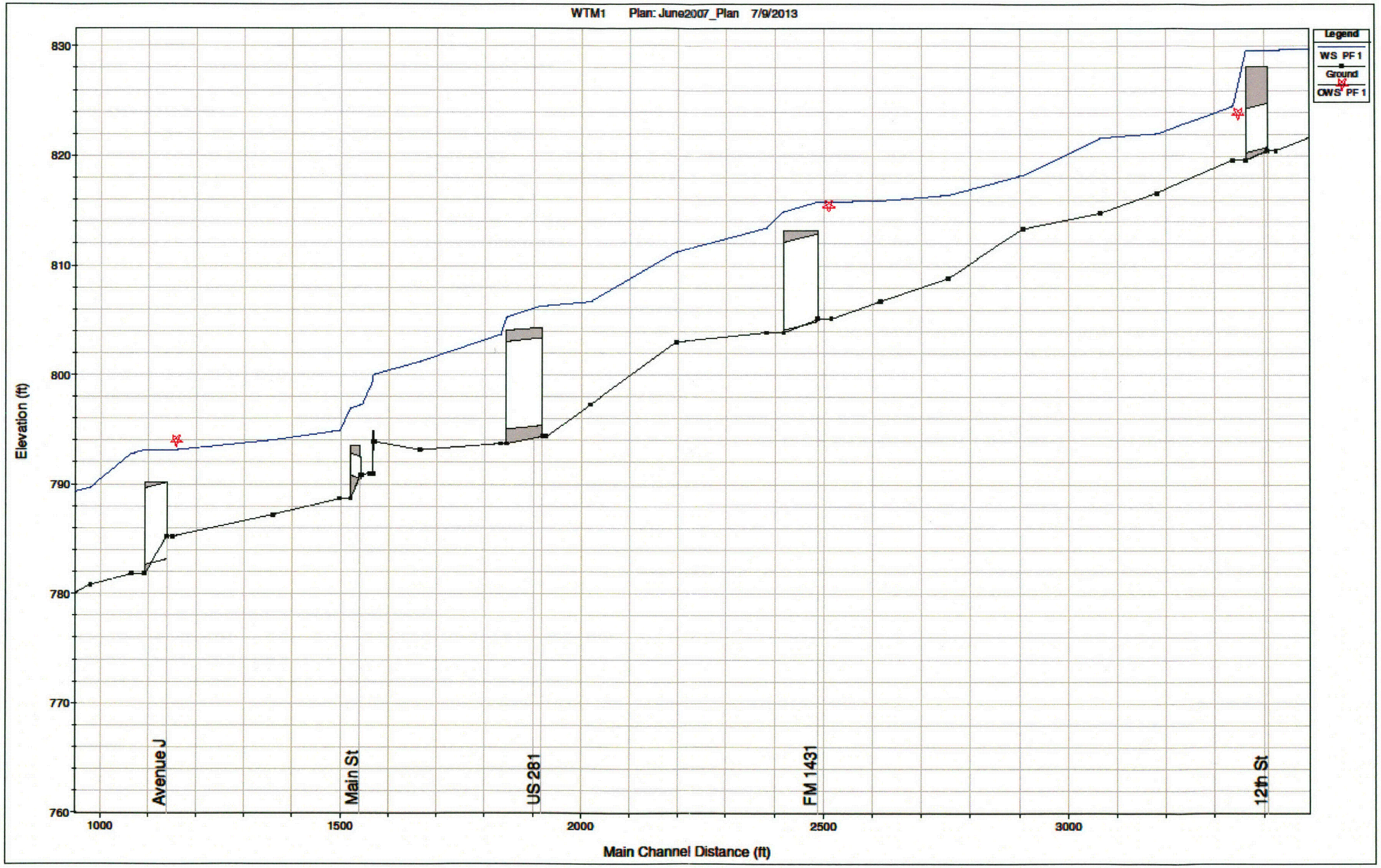


Figure A18: Whitman Tributary 1, 2007 Profiles and High Water marks

B

APPENDIX B: Flood Damage Reduction Alternative Analysis for the Backbone Creek and Whitman Branch Watershed

The alternative analysis for the Backbone Creek and Whitman Branch Watershed included flood damage reduction alternatives for the City of Marble Falls. A map summarizing the recommended alternatives for each hazard area is included in the map titled *Potential Flood Hazard Reduction Areas* in Appendix D.

A total of eight flood damage reduction alternatives were considered to reduce flooding within the study area, as shown in Table B1. A "first run" analysis was conducted on all alternatives, followed by a meeting with project participants. During this meeting, three alternatives were identified as candidates for further analysis. The alternatives to be analyzed in more detail included Alternatives 4, 5, and 7. Initial analysis indicated that Alternatives 1, 2, and 3 were not beneficial enough to warrant such a costly project. However, the initial analyses of these alternatives are provided in this report for future use and planning.

Potential funding sources for the alternatives recommended below include FEMA grant programs, TxDOT grants, USACE, Texas Trail Network (TTN), and TPWD.

Table B1: City of Marble Falls Alternatives

Alternative	Description
1	Whitman Bypass Channel
2	Upstream Whitman Branch Detention
3	Upstream Backbone Creek Detention
4	Bridge/Culvert Improvements
5	Downtown Channel Improvements
6	Creek Walk
7	Unnamed Tributary Bypass
8	Voluntary Property Acquisition

B.1 Ranking Matrix Criteria

During the analysis of the various alternatives it was discovered that several of the proposed alternatives desired by the City were difficult to quantify a direct monetary benefit and cost associated with the project. Many of the proposed alternatives provide benefits not seen in a standard benefit/cost analysis. For this reason a ranking matrix was established to score each alternative between 0 and 10 based on multiple criteria as established below:

Flood Mitigation Benefit/Cost Ratio
The benefit of each alternative (reduction in flood damages) was divided by the associated cost of each project. Methods for how the overall flood reduction benefits, as well as the project cost estimates were calculated are detailed under each alternative sub-section. Alternatives with a high benefit/cost ratio were given higher scores than those with lower benefit cost ratios.

Community Beautification
This criterion took into account how a proposed alternative would affect the aesthetics of the local community. For example, a concrete lined channel option would not enhance or improve the appearance of the community and would be given a low score for this criterion.

Future Economic Impacts
How does the proposed project increase potential for economic benefits as the City develops and grows? Projects with a higher future economic benefit to the community were given the highest scores, and those with little to no future economic benefit were given lower scores. For example, a flood reduction project that decreased the 100-year floodplain would potentially allow for more developable land that could increase the tax base of the community, and would be given a high score.

Operation and Maintenance Upkeep
Many, if not all of the proposed flood protection projects will require significant upkeep to ensure they continue to function properly. The City of Marble Falls will likely be required to fund these routine maintenance concerns. The proposed projects having the lowest upkeep costs were scored the highest, with the projects requiring significant maintenance scoring the lowest.

Grant Availability
Marble Falls will likely not be able to fully fund the proposed flood reduction alternatives. This criterion looks at the realistic potential that a project has for receiving a federal or state grant to help fund the project. Alternatives with the highest potential for receiving funding were scored the highest, with those with the smallest potential being scored the lowest.

Project Longevity
Manmade flood control projects do not last forever. This criterion looked at the continued effectiveness a project would have as the City of Marble Falls grows and develops. Projects that had the potential to remain functional the longest scored the highest, and those with shorter lifetimes were scored lower.

Community Buy-in

The community of Marble Falls must be committed and involved in a proposed flood mitigation project for it to be successful. Multiple meetings with community leaders were held to gage interest and feasibility of the proposed alternatives. The alternatives that the community were most interested in were given the highest score.

Environmental Constraints

This criterion looks at the effects a proposed alternative may have on the environmental constraints detailed in Appendix C. Alternatives that will have little impacts on these environmental concerns were given higher scores than those that would greatly impact the environment.

B.2 Alternative # 1 - Whitman Branch Bypass Channel

The industrial area along Whitman Branch near US 281 and Nature Heights sustained heavy flood damages during the June 2007 flood. Diverting flow around this area through either an open channel or culverts would reduce flooding to the structures.

Two options were analyzed to reduce flooding: an open channel and a series of box culverts. In order to significantly reduce flooding, the open grass-lined channel would need to be a five ft. deep trapezoidal channel with a bottom width of 50 ft. and 3:1 side slopes. A similar reduction in flooding would require nine 10ft. x 5ft. concrete box culverts.

A comparison of existing and "Bypass Channel on Whitman Branch" 100-year floodplains is displayed in Figure B1. This alternative removes 16 structures from the 100-year floodplain with a combined improvement value of approximately $2,262,800.

Cost Estimate

The cost estimate for this alternative was based on the open channel option, as the cost of constructing nine 10ft. x 5ft. box culverts would be significantly higher. Table B2 shows that the approximate construction cost of a bypass channel would be $470,607.

Table B2: Preliminary Probable Cost Estimate for Whitman Branch Bypass Channel

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
110-2003	Channel Excavation (Cut + Removal)	24,290	CY	$ 10.00	$ 242,900
COA 609S	Native Grassland and Seeding and Planting	18,301	SY	$ 6.00	$ 109,806
500-2001	Mobilization (10%)	1	LS		$ 35,771
	Engineering Fees (10%)	1	LS		$ 39,348
	SUBTOTAL				**$ 427,824**
	30% CONTINGENCY				**$ 42,782**
	TOTAL				**$ 470,607**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

Benefit Cost Ratio

To conduct a benefit cost analysis, it was necessary to determine the value of the structures being removed from the 100-year floodplain. The Burnet County tax database was utilized to obtain the improvement value for each structure. The summation of these values was then multiplied by the annual probability of a 100-year event (1%, or 0.01) to calculate an annual flood damage benefit. The analysis period for the benefit cost analysis was chosen to be 50 years, the estimated effective lifetime of the proposed alternative. Annual inflation was assumed to be 7% over the 50 years of the project. To bring the annual benefits to a present dollar value, the following equation was applied:

$$Present\ Value = A * \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

Where A = Annual Benefit in dollars
i = Inflation (7%)
n = Period of Analysis (50 years)

Results of the benefit cost analysis are provided in Table B3.

Table B3: Benefit Cost Results for Whitman Bypass

Mitigation Alternative 6: Whitman Bypass	
50 Yr Projected Annual Benefit	$312,266
Project Cost	$476,107
Benefit Cost Ratio Value	0.656

Summary of Scoring

Alternative #1 Scoring Summary - Whitman Bypass

Criteria	Description	Score
Flood Mitigation Benefit/Cost Ratio	Benefit Cost Ratio = 0.656.	3
Community Beautification	The proposed improvements will not offer aesthetic benefit to the area.	1
Future Economic Impacts	The proposed improvements will significantly decrease the 100-year floodplain in the area, opening up more land to be developable in the future	8
Operation and Maintenance Upkeep	An open trapezoidal grass lined channel will require minimal operation and maintenance upkeep to sustain integrity. Mowing and sedimentation removal will be routinely required.	7
Grant Availability	This alternative is a potential candidate for hazard mitigation grants from FEMA, USACE, TDEM, and TWDB. The area's documented flood damages from 2007 increases the potential candidacy for grant approval, however a more favorable B/C ratio would be needed.	7
Project Longevity	The two options for this alternative, concrete box culverts or an open trapezoidal channel, are both associated with longevity and performance with proper upkeep.	9
Community Buy-in	The community was open to, but not overly excited about this alternative.	4
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Tree removal will be minimal with this alternative. No Impacts to waters of the U.S.	7

Figure B1: Whitman Bypass Flood Reduction

B.3 Alternative # 2 - Upstream Whitman Branch Detention

Potential detention was evaluated along the upstream reach of Whitman Branch. The proposed detention would utilize available topography and volume to reduce the 100-year inflow down to a 2-year outflow. It was determined that the outlet structure would need to be approximately 20 ft. high and 1800 ft. long in order to store the required 780 acre-feet of water to reduce flooding.

A comparison of existing and "Whitman Branch Upstream Detention" 100-year floodplains for Whitman Branch can be seen in Figure B2. The upstream detention alternative removes 36 habitable structures from the 100-year floodplain with a combined improvement value of approximately $5,100,000.

Cost Estimate

A pond of this magnitude would be very expensive to construct and would likely outweigh the benefits it could provide. In addition, this alternative would require approval from multiple government agencies prior to construction. The volume of earthen fill required to construct the dam would be over 120,000 cubic yards alone. At $20/cubic yard, the material cost of fill would be over $2.5 million dollars. A very simplified cost estimate is shown in Table B4. The actual cost of such a structure would likely be upwards of $4 million dollars.

Table B4: Preliminary Probable Cost Estimate for Whitman Branch Detention

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
TxDOT 132	Earth Fill for Dam	120,000	CY	$ 20.00	$ 2,400,000
500-2001	Mobilization (10%)	1	LS		$ 240,000.00
	Engineering Fees (10%)	1	LS		$ 264,000.00
	SUBTOTAL				**$ 2,904,000.00**
	30% CONTINGENCY				**$ 871,200.00**
	TOTAL				**$ 3,775,200.00**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

Benefit Cost Ratio

To conduct a benefit cost analysis, it was necessary to determine the value of the structures being removed from the 100-year floodplain. The Burnet County tax database was utilized to obtain the improvement value for each structure. The summation of these values was then multiplied by the annual probability of a 100-year event (1%, or 0.01) to calculate an annual flood damage benefit. The analysis period for the benefit cost analysis was chosen to be 50 years, the estimated effective lifetime of the proposed alternative. Annual inflation was assumed to be 7% over the 50 years of the project. To bring the annual benefits to a present dollar value, the following equation was applied:

$$Present\ Value = \frac{A * (1 + i)^n - 1}{i(1 + i)^n}$$

Where A = *Annual Benefit in dollars*
i = *Inflation (7%)*
n = *Period of Analysis (50 years)*

Results of the benefit cost analysis are provided in Table B5.

Table B5: Benefit Cost Results for Whitman Detention

Mitigation Alternative 7: Whitman Detention	
50 Yr Projected Annual Benefit	$704,675
Project Cost	$3,775,200
Benefit Cost Ratio Value	0.187

Summary of Scoring

Alternative #2 Scoring Summary - Upstream Whitman Detention		
Criteria	**Description**	**Score**
Flood Mitigation Benefit/Cost Ratio	Benefit Cost Ratio = 0.187	2
Community Beautification	The proposed improvement has the potential to offer a moderate aesthetic benefit with the addition of a local pond.	5
Future Economic Impacts	The proposed improvements will significantly decrease the 100-year floodplain in the area, opening up more land to be developable in the future	9
Operation and Maintenance Upkeep	Detention options would require a higher degree of operation and maintenance upkeep when compared with channelization options. Algal blooms, shoreline erosion, odors, pests, and sediment accumulation are factors to that would have to be monitored and maintained.	2
Grant Availability	This alternative is a potential candidate for hazard mitigation grants from FEMA, USACE, TDEM, and TWDB, however a more favorable B/C ratio would be needed.	5
Project Longevity	If properly maintained, the detention ponds are associated with moderate longevity.	6
Community Buy-in	The community did not see this as a viable alternative.	1
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Detention has a higher probability of potential impact within the disturbed area when compared with channelization options. Detention is not an environmentally preferred mitigation alternative as it disrupts the natural ecology of the area.	1

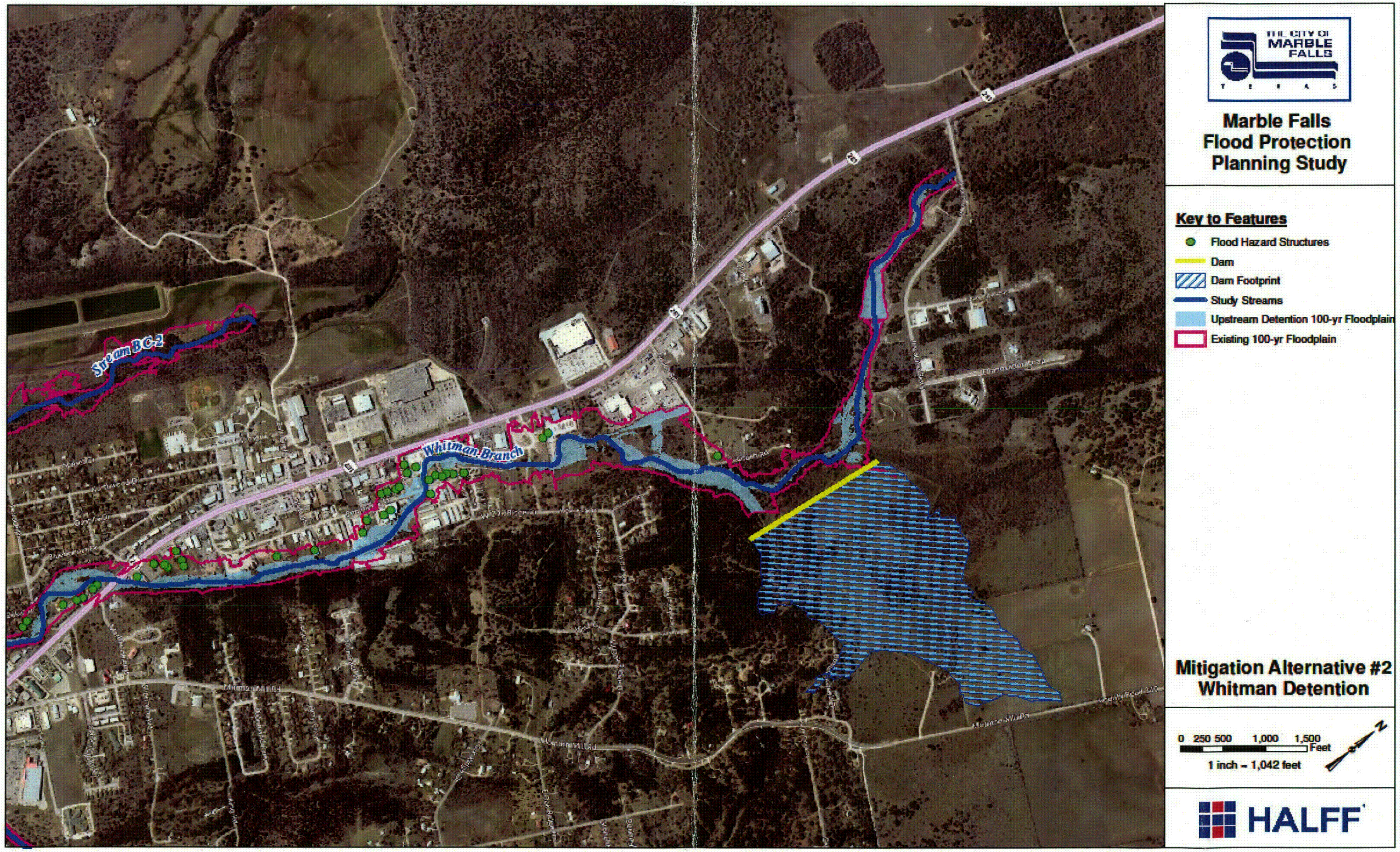


Figure B2: Whitman Detention Flood Reduction

B.4 Alternative # 3 - Upstream Backbone Creek Detention

Potential detention was evaluated along Backbone Creek just upstream of the city limits. This upstream detention would utilize available topography and volume to reduce the 100-year inflow to a 50-year outflow. The location of the proposed pond is situated behind the natural fault line. This location was selected because the fault serves a natural dam in this area. The only construction required would be an outlet structure within the gap in the fault where Backbone Creek flows into the City. It was determined that the outlet structure would need to be approximately 50 ft. high and 600 ft. long in order to store the required 1,500 acre-feet of water to reduce flooding.

A comparison of existing and "Backbone Creek Upstream Detention" 100-year floodplains for Backbone Creek can be seen in Figure B3. The upstream detention alternative removes 12 habitable structures from the 100-year floodplain with a combined improvement value of approximately $1,409,000.

Cost Estimate

A pond of this magnitude would be very expensive to construct and would likely outweigh the benefits it could provide. In addition, this alternative would require approval from multiple government agencies prior to construction. The dirt fill alone for a detention structure of this size would be over 200,000 cubic yards. A very simplified cost estimate is provided in Table B6.

Table B6: Preliminary Probable Cost Estimate for Backbone Creek Detention

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
TxDOT 132	Earth Fill for Dam	200,000	CY	$ 20.00	$4,000,000
500-2001	Mobilization (10%)	1	LS		$400,000
	Engineering Fees (10%)	1	LS		$440,000
	SUBTOTAL				**$4,840,000**
	30% CONTINGENCY				**$1,452,000**
	TOTAL				**$6,292,000**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

Benefit Cost Ratio

To conduct a benefit cost analysis, it was necessary to determine the value of the structures being removed from the 100-year floodplain. The Burnet County tax database was utilized to obtain the improvement value for each structure. The summation of these values was then multiplied by the annual probability of a 100-year event (1%, or 0.01) to calculate an annual flood damage benefit. The analysis period for the benefit cost analysis was chosen to be 50 years, the estimated effective lifetime of the proposed alternative. Annual inflation was assumed to be 7% over the 50 years of the project. To bring the annual benefits to a present dollar value, the following equation was applied:

$$Present\ Value = A * \frac{(1 + i)^n - 1}{i(1 + i)^n}$$

Where A = *Annual Benefit in dollars*
i = *Inflation (7%)*
n = *Period of Analysis (50 years)*

Results of the benefit cost analysis are provided in Table B7.

Table B7: Benefit Cost Results for Backbone Detention

Mitigation Alternative 8: Backbone Detention	
50 Yr Projected Annual Benefit	$194,437
Project Cost	$6,292,000
Benefit Cost Ratio Value	0.031

Summary of Scoring

Alternative #3 Scoring Summary - Upstream Backbone Creek Detention		
Criteria	**Description**	**Score**
Flood Mitigation Benefit/Cost Ratio	Benefit Cost Ratio = 0.031	1
Community Beautification	The proposed improvement has the potential to offer a moderate aesthetic benefit with the addition of a local pond.	5
Future Economic Impacts	The proposed improvements will minimally decrease the 100-year floodplain in the area, opening up more land to be developable in the future.	4
Operation and Maintenance Upkeep	Detention options would require a higher degree of operation and maintenance upkeep when compared with channelization options. Algal blooms, shoreline erosion, odors, pests, and sediment accumulation are factors to that would have to be monitored and maintained.	2
Grant Availability	This alternative is a potential candidate for hazard mitigation grants from FEMA, USACE, TDEM, and TWDB, however a more favorable B/C ratio would be needed.	5
Project Longevity	If properly maintained, the detention ponds are associated with moderate longevity.	6
Community Buy-in	The community did not see this as a viable alternative.	1
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Detention has a higher probability of potential impact within the disturbed area when compared with channelization options. Detention is not an environmentally preferred mitigation alternative as it disrupts the natural ecology of the area.	1

Figure B3: Backbone Detention Flood Reduction

B.5 Alternative # 4 - Bridge/Culvert Improvements

A combination of crossing improvements and modifications were analyzed for U.S. Highway 281 over Whitman Branch and Whitman Branch Tributary 1 to reduce each floodplain and allow the structures to convey more flow during flood events. A summary of the alternatives can be seen in Table B8.

Table B8: Crossing Improvements at US 281

Alternative	Channel	Existing Frequency Capacity	Modifications	Alternative Frequency Capacity
4A	Whitman Branch	10-YR	Widen US 281 bridge	25-YR
4B	Whitman Branch Tributary	2-YR	Channelization; remove small dam; add culverts to US 281	25-YR

Potential hazard mitigation funding to implement these improvements is available through FEMA, Texas Department of Emergency Management (TDEM), and TWDB. It is also possible that TxDOT may wish to improve the crossing at a future date.

A. Bridge Improvements on Whitman Branch

Bridge improvements on Whitman Branch provide U.S. Highway 281 the capacity to pass the 25-year flood versus the current capacity to pass the 10-year flood. To pass the 25-year event, the bridge will need to be widened from 63ft. to 88 ft. A profile comparison for the improvements can be seen in Figure B4. The comparisons reveal that widening the bridge opening under US 281 allows the bridge to pass the 25-year event, but it may not have a significant impact on upstream flooding because the profile improvements do not continue very far upstream. However, the improvement allows for roadway access during flood events and reduces risks to motorists.

A preliminary estimate of probable cost for the design and construction of the modifications is shown in Table B9. The total preliminary estimate of probable cost for the improvements is $155,870.

Table B9: Preliminary Probable Cost Estimate for US 281 at Whitman Branch Crossing Improvements

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
	Abutment Removal and Stabilization	1,600	CY	$ 65.00	$ 104,000
502-2001	Barricades, Signs, and Traffic Handling	1	MO	$ 5,000.00	$ 5,000
500-2001	Mobilization (10%)	1	LS	$ 10,900.00	$ 10,900
	Engineering Fees (10%)	1	LS	$ 10,900.00	$ 10,900
	SUBTOTAL				**$ 119,900**
	30% CONTINGENCY				**$ 35,970**
	TOTAL				**$ 155,870**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

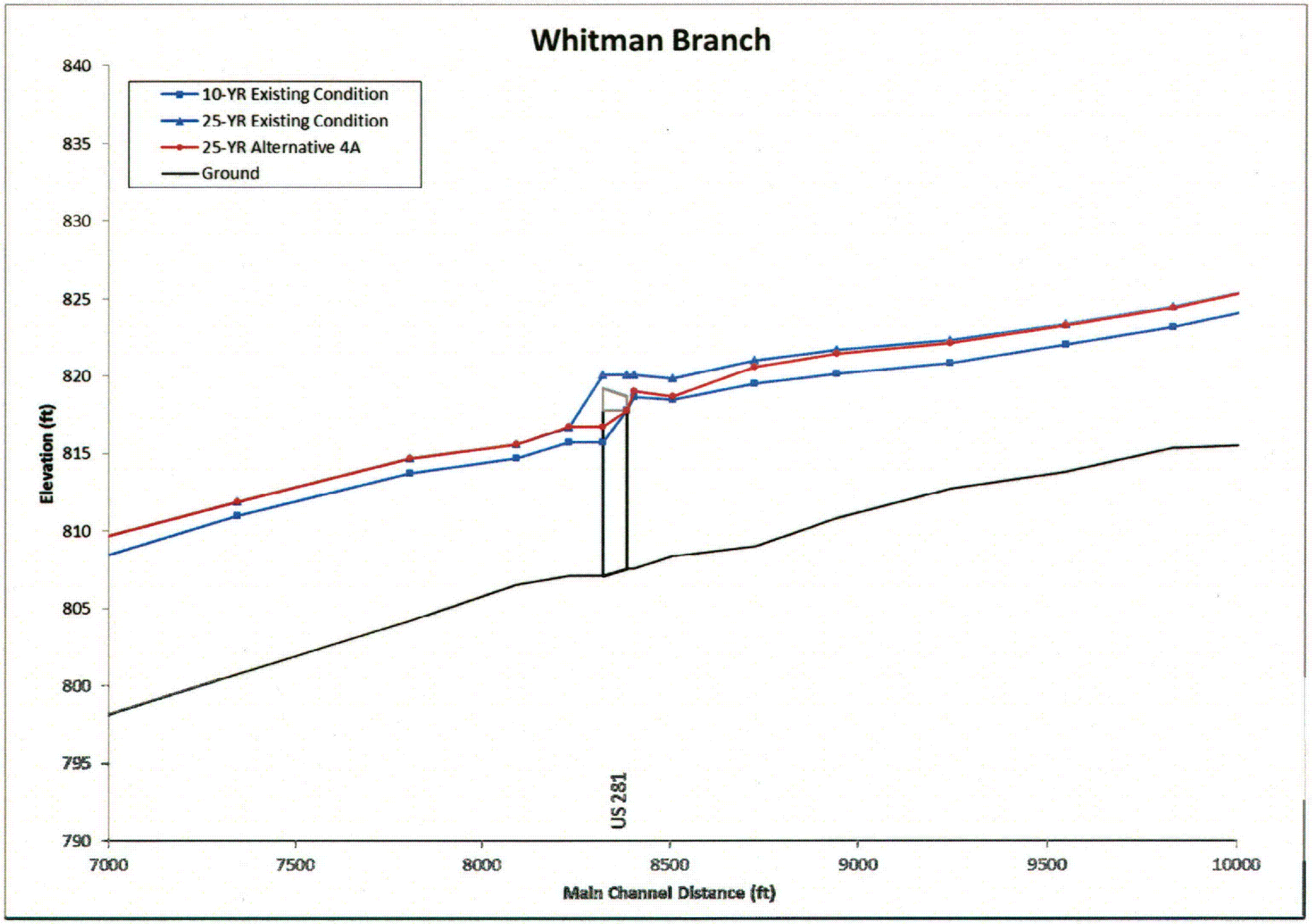


Figure B4: Whitman Branch Crossing Improvements at US 281 Profile Comparison

B. Channelization, Dam Removal, and Culvert Additions on Whitman Branch Tributary 1

Channelization, dam removal and culvert additions on Whitman Branch Tributary 1 provide US 281 the capacity to pass the 25-year flood versus the current capacity to pass the 2-year flood. In order to pass the 25-year event, it is recommended that the channel be widened to 65 ft. from just upstream of Main Street to US 281. In order to avoid expensive permitting, the proposed channel modifications remained above the ordinary high water marks of the creeks. The small existing dam just upstream of Main Street should also be removed. In addition, it is also recommended that two 10-ft. X 8-ft. concrete boxes be added to the existing three 8-ft. X 8-ft. concrete boxes.

A profile comparison can be seen in Figure B5. The comparisons reveal that channelizing, removing the dam, and adding culverts under US 281 will reduce flooding between US 281 and Main Street. The comparisons indicate that the improvements do not have a significant impact on upstream flooding because the profile improvements do not continue very far upstream. However, the improvement allows for roadway access during flood events and reduces risks to motorists.

A preliminary estimate of probable cost for the design and construction of the modifications is shown in Table B10. The total preliminary estimate of probable cost for the improvements is $211,782.

Table B10: Preliminary Probable Cost Estimate for US 281 at Whitman Branch Tributary 1 Crossing Improvements

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
110-2003	Channel Excavation (Cut + Removal)	2,832	CY	$ 10.00	$ 28,320
0496-2040	Remove Structure (Ret. Wall)	35	LF	$ 48.77	$ 1,707
462-2032	Concrete Box Culvert (10' x 8') x 2	148	LF	$ 672.97	$ 99,600
	Cut and Restore Paving	247	SY	$ 60.00	$ 14,820
502-2001	Barricades, Signs, and Traffic Handling	1	LS	$ 5,000.00	$ 5,000
500-2001	Mobilization (10%)	1	LS	$ 13,462.65	$ 13,463
	Engineering Fees (10%)	1	LS	$ 14,944.65	$ 14,945
	SUBTOTAL				**$ 162,909**
	30% CONTINGENCY				**$ 48,873**
	TOTAL				**$ 211,782**

REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available

NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting

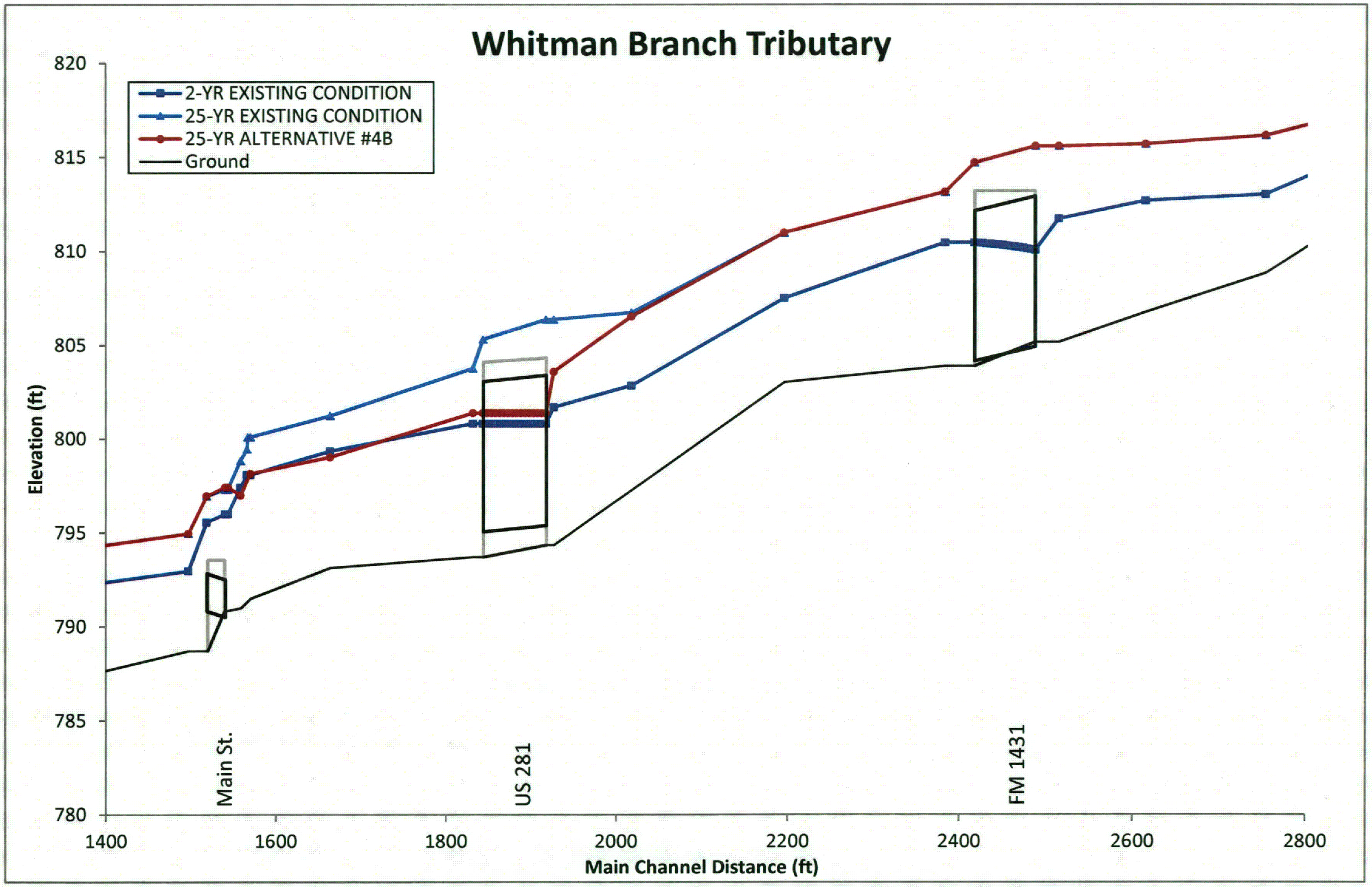


Figure B5: Whitman Branch Tributary 1 Crossing Improvements at US 281 Profile Comparison

Benefit Cost Ratio

The main purpose of these proposed projects is to keep major roadways from being overtopped during flooding events. While some reduction in the floodplain will result from these proposed projects, it is not significant enough to remove adjacent structures from flooding risks. Therefore the primary monetary benefit from these projects would be the reduced probability that the crossings will be washed out as frequently requiring rebuilding. Roadway crossings do not wash out with every flood event where they are overtopped; therefore it is difficult to estimate the frequency that the existing crossings will need to be replaced, as well as the cost for continued repair. It is safe to assume that proactively upgrading the existing crossings would result in less frequent repair costs, and likely an overall greater benefit than cost.

Summary of Scoring

Alternative #4 Scoring Summary - Bridge/Culvert Improvements		
Criteria	**Description**	**Score**
Flood Mitigation Benefit/Cost Ratio	At a combined projected cost of $367,652, the proposed improvements along U.S. Highway 281 would increase the both crossing's frequency capacities from withstanding a 2-year storm event to passing a 25-year storm event, decreasing the probability and frequency that the crossings require repair	5
Community Beautification	The proposed improvements will not offer aesthetic benefit to the area.	1
Future Economic Impacts	The proposed improvements will allow for safe travel, and more access during flooding events.	5
Operation and Maintenance Upkeep	The two options for this alternative two proposed modifications are associated with minimal operation and maintenance upkeep to sustain integrity.	9
Grant Availability	This alternative is a potential candidate for hazard mitigation grants from TxDOT, FEMA, USACE, TDEM, and TWDB.	8
Project Longevity	The two proposed modifications will withstand flood events much better than the current roadway crossings, resulting in longer lasting projects.	8
Community Buy-in	The community is very open and interested in this alternative	9
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Although there is a possibility of negative impact during the construction process, the potential for negative impact is negligible when compared with alternatives that are disturbing previously undisturbed areas. Most of the proposed improvements for these alternatives will occur within TxDOT right of way.	7

B.6 Alternative # 5 - Downtown Channel Improvements

Three mitigation options were analyzed on Lower Backbone Creek and Whitman Branch to provide a flood reduction benefit in the downtown area. The goal of this alternative was to remove structures from the 100-year floodplain as well as create more developable land on the western side of Whitman Branch for future development. It is important to note that most of the analysis area for this alternative is located within the Colorado River current effective 100-year floodplain. All proposed alternatives only reduce flooding from the Backbone Creek and Whitman Branch Watershed.

The mitigation options below are listed with Option A representing the least costly and easiest to implement, to Option C representing the most expensive and most difficult to implement. Option B falls between Options A and C. The three options are summarized below.

A. Channelization along Lower Backbone Creek and Whitman Branch

Option A is the channelization of both Backbone Creek and Whitman Branch near their confluences with the Colorado River. It was determined that backwater from Backbone Creek significantly influences Whitman Branch through the proposed "creek walk" region (the area of most interest to the City of Marble Falls). Therefore, channelization is necessary along both Backbone Creek and Whitman Branch to reduce the Whitman Branch floodplain.

The channel of Backbone Creek was widened to 200 – 300 ft. for a distance of approximately 0.50 stream miles requiring approximately 118,500 cubic yards of excavation. The channel of Whitman Branch was widened to 150 ft. for a distance of approximately 0.25 stream miles, requiring approximately 32,000 cubic yards of excavation. In order to avoid expensive permitting, the proposed channel modifications remained above the ordinary high water marks of the creeks.

Results of the analysis show an average decrease in flood stage of approximately 0.3 ft. along Backbone Creek and 1.0 ft. along Whitman Branch. A comparison of the existing and proposed Option A floodplains can be seen in Figure B6. A preliminary estimate of probable cost for the design and construction of the modifications is shown in Table B11.

Table B11: Preliminary Probable Cost Estimate for Downtown Channel Improvements Option A

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
110-2003	Channel Excavation (Cut + Removal)	118,550	CY	$ 10.00	$ 1,185,500
500-2001	Mobilization (10%)	1	LS	$ 118,550.00	$ 118,550
	Engineering Fees (10%)	1	LS	$ 130,405.00	$ 130,405
	SUBTOTAL				**$ 1,304,050**
	30% CONTINGENCY				**$ 391,215**
	TOTAL				**$ 1,695,265**

REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available

NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting

B. Channelization and Culvert Additions, along Lower Backbone Creek and Whitman Branch

Option B is the channelization in combination with the addition of culverts to Avenue J over Backbone Creek and 2nd Street over Whitman Branch. Results from the existing condition hydraulic analysis indicated potential for flood reduction near these structures because these crossings appeared to hold restricted flow. The proposed channelization in this option was not modified from the channelization in Option A.

Upon further analysis, it was found that significant culvert additions were necessary to reduce the flood profiles. Five 10 ft. x 8 ft. box culverts were added to 2nd Street along Whitman Branch, and five 10 ft. x 10 ft. box culverts were added to Avenue J along Backbone Creek for this analysis.

Results of the analysis show an average decrease in flood stage of approximately 0.5 ft. along Backbone Creek and 1.4 ft. along Whitman Branch. A comparison of the existing and proposed Option B floodplains can be seen in Figure B6. A preliminary estimate of probable cost for the design and construction of the modifications is shown in Table B12.

Table B12: Preliminary Probable Cost Estimate for Downtown Channel Improvements Option B

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
110-2003	Channel Excavation (Cut + Removal)	118,550	CY	$ 10.00	$ 1,185,500
462-2032	Concrete Box Culvert (10' x 8') x 5	220	LF	$ 672.97	$ 148,053
462-2034	Concrete Box Culvert (10' x 10') x 5	210	LF	$ 827.82	$ 173,842
	Cut and Restore Paving	5,160	SY	$ 60.00	$ 309,600
502-2001	Barricades, Signs, and Traffic Handling	1	LS	$ 5,000.00	$ 5,000
500-2001	Mobilization (10%)	1	LS	$ 182,199.56	$ 182,199.56
	Engineering Fees (10%)	1	LS	$ 200,419.52	$ 200,419.52
	SUBTOTAL				**$ 2,204,614.68**
	30% CONTINGENCY				**$ 661,384.40**
	TOTAL				**$ 2,865,999.08**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

C. Channelization, Culvert Additions, and Bridge Additions on Lower Backbone Creek and Whitman Branch

The final option includes the modifications described in Option B, with the exception of Avenue J. In this option, Avenue J was converted from a culvert crossing to a bridge crossing. The deck was raised to an elevation of 751ft. to allow more water to pass during high frequency events.

Results of the analysis show an average decrease in flood stage of approximately 0.6 ft. along Backbone Creek and 1.4 ft. along Whitman Branch. A comparison of the existing and proposed Option B floodplains can be seen in Figure B6. A preliminary estimate of probable cost for the design and construction of the modifications is shown in Table B13.

Table B13: Preliminary Probable Cost Estimate for Downtown Channel Improvements Option C

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
110-2003	Channel Excavation (Cut + Removal)	118,550	CY	$ 10.00	$ 1,185,500
462-2032	Concrete Box Culvert (10' x 8') x 5	220	LF	$ 672.97	$ 148,053
	Bridge Construction	12,600	SF	$ 100.00	$ 1,260,000
	Cut and Restore Paving	5,160	SY	$ 60.00	$ 309,600
502-2001	Barricades, Signs, and Traffic Handling	1	LS	$ 5,000.00	$ 5,000
500-2001	Mobilization (10%)	1	LS	$ 290,815.34	$ 290,815.34
	Engineering Fees (10%)	1	LS	$ 319,896.87	$ 319,896.87
	SUBTOTAL				**$ 3,518,865.61**
	30% CONTINGENCY				**$ 1,055,659.68**
	TOTAL				**$ 4,574,525.30**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

In summary, Figure B6 displays the potential floodplain footprint of each mitigation option. As displayed, the difference between the three options is very small. It should be noted that it may be possible to remove the wastewater treatment plant from of the Backbone Creek and Whitman Branch 100-year floodplains.

Because this area is at the base of such a large basin, channelization and upsizing of crossings has very little effect on the floodplain. The cost of each option compared to the minimal benefits demonstrates that this alternative is not likely feasible. However, if the City of Marble Falls may see these downtown channel improvements as more desirable when used in conjunction with the Creek Walk described in section B.7 below. The Creek Walk option combined with the floodplain reclamation with the channel improvements may provide more benefits than simply reducing flood risk to structures.

Potential funding sources include hazard mitigation grants through FEMA, USACE, TDEM, and TWDB.

Figure B6: Option A, B, and C Floodplain Comparison to Existing 100-yr

Benefit Cost Ratio

The benefit cost analysis was conducted based on the lowest cost alternative, Option A, as all 3 options saw similar benefit values.. To conduct a benefit cost analysis, it was necessary to determine the value of the structures being removed from the 100-year floodplain. The Burnet County tax database was utilized to obtain the improvement value for each structure. The summation of these values was then multiplied by the annual probability of a 100-year event (1%, or 0.01) to calculate an annual flood damage benefit. The analysis period for the benefit cost analysis was chosen to be 50 years, the estimated effective lifetime of the proposed alternative. Annual inflation was assumed to be 7% over the 50 years of the project. To bring the annual benefits to a present dollar value, the following equation was applied:

$$\text{Present Value} = \frac{A * (1 + i)^n - 1}{i(1 + i)^n}$$

Where A = *Annual Benefit in dollars*
i = *Inflation (7%)*
n = *Period of Analysis (50 years)*

Results of the benefit cost analysis are provided in Table 14.

Table B14: Benefit Cost Results for Downtown Channelization

Mitigation Alternative 4: Downtown Channelization	
50 Yr Projected Annual Benefit	$5,039
Project Cost	$1,695,265
Benefit Cost Ratio Value	0.001

Summary of Scoring

Alternative #5 Scoring Summary - Downtown Channel Improvements

Criteria	Description	Score
Flood Mitigation Benefit/Cost Ratio	The proposed improvement options A-C involve a projected preliminary probable cost estimate ranging from approximately $1.7 million to $4.6 million. When considered without the added aesthetic, environmental, and potential future economic benefits of incorporating the creek walk option, the costs overshadow the hazard benefit they would yield. Benefit Cost Ratio = 0.001	1
Community Beautification	The proposed improvements will not offer aesthetic benefit to the area without the creekwalk alternative included.	3
Future Economic Impacts	The proposed improvements will minimally decrease the 100-year floodplain in the area, opening up more land to be developable in the future.	3
Operation and Maintenance Upkeep	The proposed improvements will require minimal maintenance and therefore negligible future economic investment is projected. Mowing and sedimentation removal will be routinely required.	7
Grant Availability	This alternative is a potential candidate for hazard mitigation grants from FEMA, USACE, TDEM, and TWDB, however a more favorable B/C ratio would be needed.	3
Project Longevity	The three options for this alternative are all associated with longevity and performance.	8
Community Buy-in	The community was not open to this as a stand alone alternative alone, but rather in combination with the Creek Walk Alternative	3
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Tree clearing will be minimal. However it is likely that the waters of the U.S. could be affected by the significant channel modifications. This would be avoided at all costs.	5

B.7 Alternative # 6 - Creek Walk

The potential route for the 'creek walk' trail could be located along the east side of Whitman Branch. Placing the trail on the eastern side of Whitman Branch would minimize the amount of creek crossings that will be needed to serve the adjacent uses in the project area. This proposed trail corridor has the potential to be a key connection to Downtown Marble Falls. It has the additional benefit of connecting multiple parks located within the project area. Natural aesthetics and existing tree preservation are also driving factors to be considered during final alignment design. To assist with the design and construction of the creek walk, the City of Marble Falls could investigate opportunities for grant funding assistance. Potential grant opportunities include TxDOT enhancement grants and TPWD grants.

This alternative would be used in conjunction with Alternative 4, Downtown Channel Improvements, Options A, B, or C. The combination of these two alternatives would allow for more development along the creek bank while actively providing flood mitigation as flood models show that land may be reclaimed for potential development through significant creek channelization. The creek walk option offers the City a means of efficient and beneficial development adjacent to the channel that is without the risk of typical hazards associated with development in an area in close proximity to active streams.

This alternative is presented in three phases. Phase 1 includes construction of an Americans with Disabilities Act (ADA) trail along Whitman Branch with rest areas and overlooks, as illustrated by the red line on Figure 7. Phase 2 includes trail connections and street crossings that would connect Downtown Marble Falls to the creek walk, as illustrated by the purple lines on Figure 7. Finally, Phase 3 would connect the creek walk to existing sidewalks and trails to unite the parks and existing amenities, as illustrated by the orange lines on Figure 7.

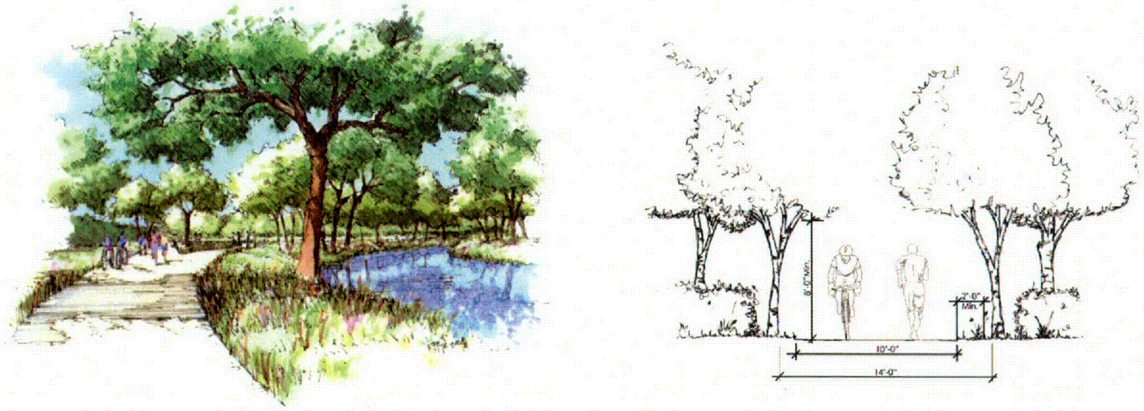


Figure B7 – Potential Trail Designs

Phase 1. Trail Construction Including Rest Areas and Overlooks

Phase 1 includes construction of an ADA trail along the eastern banks of Whitman Branch incorporating amenities such as rest areas and overlooks, as illustrated in Figure 7. Creek walk amenities could be placed at unique locations throughout the project based on the level of need for each item. These amenity areas could include enhanced paving, monument or signage elements that identify the trail corridor, seating areas, and possibly interpretive signage along with landscaping for shade. Rest areas could occur along the trail in areas that do not have access points nearby, or in close proximity to areas that may offer interesting views. Rest areas and overlooks could include seating areas on a paved surface adjacent to the trail and could incorporate interpretive features. Trail distance or way finding markers could be placed as landmarks in 0.25 or 0.50 mile increments along the proposed trail, to help users navigate the trail corridor.

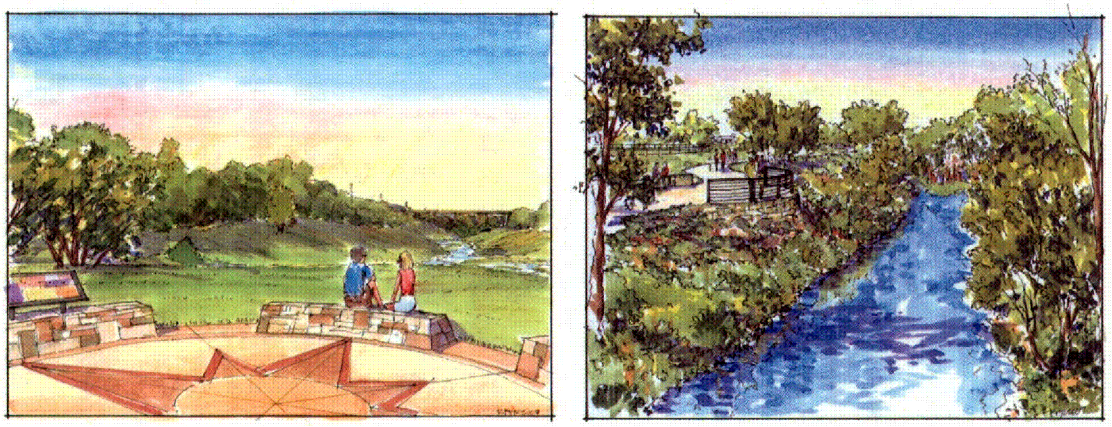


Figure B8 – Overlook and Creek

Phase 2. Trail Connections and Street Crossings to Downtown Marble Falls

Phase 2 includes trail connections and street crossings that would connect Downtown Marble Falls to the creek walk, as illustrated in Figure 7. The connection of the creek walk to that area will greatly enhance the amenities associated with the downtown area as well as increase the value and functionality of nearby property. Trail improvements at roadway crossings must comply with Texas Accessibility Standards (TAS) as well as with the Manual of Uniform Traffic Control Devices (MUTCD) requirements. The improvements may include ADA curb ramps, the installation of signage improvements, crosswalk signs, or pavement markings.

Figure B9 – Street Crossings

Trail construction impacts to the significant trees in the area should be minimized or avoided through careful planning, detailed on-site observations, and the implementation of design and construction techniques that are sensitive to existing trees and vegetation.

Phase 3. Trail Connections to Existing Sidewalks, Trails, and Parks

Phase 3 includes trail connections from the creek walk to existing sidewalks, trails, and parks. These connections would unite existing parks and amenities, as illustrated n Figure 7. The trail would be constructed with concrete due to its location within the 100-year floodplain. ADA curb ramps, crosswalk signals, and pavement markings may also be considered. The proposed trails in Phase 3 would connect the creek walk area to both Johnson and Lakeside Parks.

Short and long-term maintenance will be required for any proposed landscape improvements. The proposed landscaping will need to be watered regularly to promote proper establishment. Trees located adjacent to the trail will need to be pruned regularly to prevent overgrown limbs from causing encroachment of the trail.

Cost estimates were prepared for each phasing option as shown below in Tables B15 – B17.

Table B15: Phase 1 – Main Trail (Backbone Creek to Third Street)

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
531-2029	Concrete Trail (10' wide)	1,725	SY	$ 80.00	$ 138,000
531-2054	Pedestrian ADA curb ramps	7	EA	$ 2,000.00	$ 14,000
666-2001	Painted Crosswalks	3	EA	$ 500.00	$ 1,500
	Rest Area/Overlooks	3	EA	$ 25,000.00	$ 75,000
	Regulatory Signage	1	LS	$ 5,000.00	$ 5,000
	SUBTOTAL				**$ 233,500**
	Design Fee (15%)				**$ 35,025**
	30% CONTINGENCY				**$ 70,050**
	TOTAL				**$ 338,575**
REFERENCE: Prices based on TXDoT Austin District Construction Average Low Bid Unit Price					

Table B16: Phase 2 –Downtown Connections

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
531-2029	Concrete sidewalk (8' wide)	1,540	SY	$ 65.00	$ 100,100
531-2054	Pedestrian ADA curb ramps	14	EA	$ 2,000.00	$ 28,000
666-2001	Painted Crosswalks	8	EA	$ 500.00	$ 4,000
	Regulatory Signage	1	LS	$ 5,000.00	$ 5,000
	SUBTOTAL				**$ 137,100**
	Design Fee (15%)				**$ 20,565**
	30% CONTINGENCY				**$ 41,130**
	TOTAL				**$ 198,795**
REFERENCE: Prices based on TXDoT Austin District Construction Average Low Bid Unit Price					

Table B17: Phase 3 – Johnson and Lakeside Park Connections

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
531-2029	Concrete Trail (10' wide)	1,460	SY	$ 70.00	$ 102,200
531-2054	Pedestrian ADA curb ramps	6	EA	$ 2,000.00	$ 12,000
666-2001	Painted Crosswalks	3	EA	$ 500.00	$ 1,500
	Regulatory Signage	1	LS	$ 5,000.00	$ 5,000
	SUBTOTAL				**$ 120,700**
	Design Fee (15%)				**$ 18,105**
	30% CONTINGENCY				**$ 36,210**
	TOTAL				**$ 175,015**
REFERENCE: Prices based on TXDoT Austin District Construction Average Low Bid Unit Price					

Benefit Cost Ratio

Since the Creek Walk would be constructed in conjunction with the downtown channel improvements, it would see the same flood mitigation benefits as the downtown channelization project. The benefit cost ratio for the Creek Walk alternative was assumed to be similar to Alternative #5.

Summary of Scoring

Alternative #6 Scoring Summary - Creek Walk		
Criteria	**Description**	**Score**
Flood Mitigation Benefit/Cost Ratio	When considered in conjunction with Downtown Channel Improvement Alternatives A-C, the overall cost is remains significant. However, adding considerable aesthetic, environmental, and potential future economic benefits through incorporating the creek walk option improve the cost benefit ratio.	3
Community Beautification	The proposed improvement would yield significant aesthetic benefits.	10
Future Economic Impacts	Although there are potential future costs associated with operation maintenance and upkeep, these are balanced by the potential economic benefit of the corridor's connectivity to city areas offering community incentive to frequent and develop these areas.	9
Operation and Maintenance Upkeep	The proposed improvements would require short and long term maintenance of the landscape improvements.	4
Grant Availability	This alternative is a potential candidate for grants from TPWD as well as TxDOT enhancement grants.	5
Project Longevity	The proposed trails, sidewalks, rest areas and overlooks are associated with longevity and performance provided necessary upkeep is maintained.	8
Community Buy-in	The community is extremely interested and wants to pursue this alternative	10
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Tree clearing will be minimal and likely a significant amount of trees will be added. As discussed in Alternative 4, it is likely that the waters of the U.S. could be affected by the significant channel modifications. This would be avoided at all costs.	5

B.8 Alternative # 7 - Unnamed Tributary Bypass Channel

Although the unnamed tributary south of FM 1431 that flows into Backbone Creek at the railroad crossing was not included in the scope of this study, it was apparent that this small tributary was a significant flooding hazard. The current capacity of this unnamed tributary is very low. In order to produce a significant flood reduction impact, it was determined that the 100-year discharge from this tributary's upstream sub-basin would need to be diverted to Backbone Creek instead of flowing through the unnamed tributary. In order to reduce the frequency of flooding along this tributary, two options were analyzed. The first option (A) involved a culvert and open channel required to convey flow from the upstream subbasin north, along the fault, into Backbone Creek. The second option (B) involved channel modifications to convey flow from the upstream sub-basin along FM 1431 to Backbone Creek near Arbor Lane. The diversion to Backbone Creek is possible because additional water from the unnamed tributary will flow through Backbone Creek before the peak flow from Backbone Creek flows through the City of Marble Falls. This timing difference allows for a diversion of water without increasing flooding along Backbone Creek.

A. Channelization to Backbone Creek Upstream of the Fault

This option analyzed the potential culvert and channel option to convey flow from the unnamed tributary's upstream sub-basin, north along the fault, to Backbone Creek. To divert this sub-basin's flow, it is recommended that three 8 ft. X 7 ft. concrete boxes be constructed under FM 1431 in combination with an excavated open channel that would convey water to Backbone Creek. Multiple HEC-RAS models were developed to minimize the distance and excavation for the diversion channel. Unfortunately, a large hill exists along the diversion route. The existence of this hill resulted in significant excavation in all potential diversion routes. Through citizen input during a public meeting, it was discovered that most of the excavation in this region would be rock and granite. These factors significantly increased the cost for this option.

A comparison of existing and "Channelization to Backbone Creek" 100-year floodplains for the unnamed tributary can be seen in Figure B10. The comparisons reveal that channelizing and adding the culvert openings under FM1431 will greatly reduce the impact of flooding through the residential neighborhood, removing 23 habitable structures from the newly developed 100-year floodplain for a total approximate appraised value of $1,100,074. A preliminary estimate of probable cost for the design and construction of the channel is shown in Table B11.

B. Channelization to Backbone Creek along FM 1431

Due to the expenses associated with Option A, an alternate route was considered that channelized water within the southern right of way of FM 1431. The hydraulic modeling analysis for this option quickly revealed that the multiple driveway crossings would be impacted by this route. Initial runs also indicated that the right of way did not have capacity to carry such a large volume of flow. A channel of this magnitude would be very expensive to construct which would likely outweigh the benefits it could provide. A detailed cost analysis was not conducted for Option B as it is not considered economically beneficial.

Table B18: Preliminary Probable Cost Estimate for Unnamed Tributary Diversion

TxDOT ITEM NO.	DESCRIPTION OF ITEM	TOTAL QUANTITY	UNIT	UNIT PRICE	COST
110-2003	Channel Excavation (Cut + Removal of Granite)	137,033	CY	$ 40.00	$5,481,320
462-2032	Concrete Box Culvert (10' x 7') x 3	210	LF	$ 700.00	$147,000
	Cut and Restore Paving	311	SY	$ 60.00	$18,660
502-2001	Barricades, Signs, and Traffic Handling	1	LS	$ 5,000.00	$5,000
500-2001	Mobilization (10%)	1	LS	$ 565,198.00	$565,198
	Engineering Fees (10%)	1	LS	$ 621,717.80	$621,718
	SUBTOTAL				**$6,838,896**
	30% CONTINGENCY				**$2,051,669**
	TOTAL				**$8,890,565**
REFERENCE: Prices not based on TxDOT Construction Average Low Bid Unit Price When Available					
NOTE: Excludes cost of land acquisition for necessary drainage easements and environmental permitting					

Benefit Cost Ratio

To conduct a benefit cost analysis, it was necessary to determine the value of the structures being removed from the 100-year floodplain. The Burnet County tax database was utilized to obtain the improvement value for each structure. The summation of these values was then multiplied by the annual probability of a 100-year event (1%, or 0.01) to calculate an annual flood damage benefit. The analysis period for the benefit cost analysis was chosen to be 50 years, the estimated effective lifetime of the proposed alternative. Annual inflation was assumed to be 7% over the 50 years of the project. To bring the annual benefits to a present dollar value, the following equation was applied:

$$\text{Present Value} = \frac{A * (1 + i)^n - 1}{i(1 + i)^n}$$

Where A = *Annual Benefit in dollars*
i = *Inflation (7%)*
n = *Period of Analysis (50 years)*

Results of the benefit cost analysis are provided in Table B19.

Table B19: Benefit Cost Results for Unnamed Tributary Bypass

Mitigation Alternative 3: UNT to Backbone Creek Diversion	
50 Yr Projected Annual Benefit	$151,810
Project Cost	$8,890,565
Benefit Cost Ratio Value	0.017

Summary of Scoring

Alternative #7 Scoring Summary - Unnamed Bypass		
Criteria	**Description**	**Score**
Flood Mitigation Benefit/Cost Ratio	Benefit Cost Ratio = 0.017 (high project cost due to excavation of granite)	2
Community Beautification	The proposed improvements will not offer aesthetic benefit to the area.	1
Future Economic Impacts	The proposed improvements will significantly decrease the 100-year floodplain in the area, opening up more land to be developable in the future	9
Operation and Maintenance Upkeep	The two options for this alternative are associated with minimal operation and maintenance upkeep to sustain integrity.	9
Grant Availability	This alternative is a potential candidate for hazard mitigation grants from FEMA, USACE, TDEM, and TWDB, however a more favorable B/C ratio would be needed.	3
Project Longevity	The proposed modifications are both associated with longevity and performance.	9
Community Buy-in	The community was open to this alternative.	7
Environmental Constraints	As discussed in Appendix C, while there are federally listed and endangered species within Burnet County, there are no critical habitat areas identified within this study area. Tree removal will be minimal with this alternative. No Impacts to waters of the U.S.	7

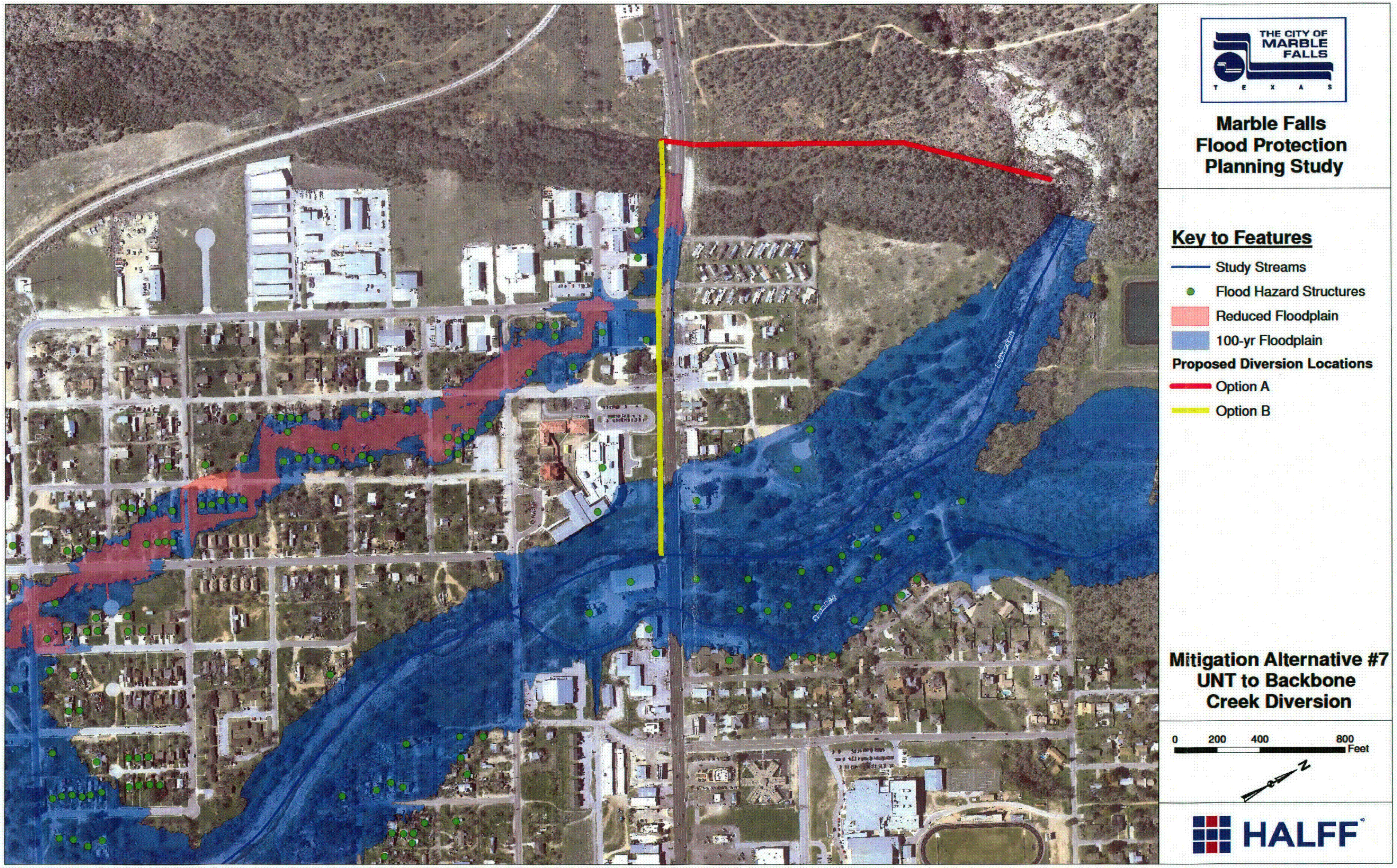


Figure B10: Unnamed Tributary Diversion Flood Reduction

B.9 Alternative # 8 - Voluntary Property Acquisition

The newly developed hydrologic and hydraulic models resulted in floodplains that indicate several properties are at risk of frequently flooding. The table below indicates the number of structures and the appraised property values associated with these more frequent flooding events. It should be noted that a majority of these frequently flooded structures are located near the unnamed tributary, which has not been studied or surveyed in detail.

Table B20 – Structures at Risk for Frequent Flooding

Frequency Event	Number of Structures	Appraised Property Values
2-year	14	$802,000
5-year	27	$1,907,484
10-year	46	$4,109,045

Due to the frequent risk of flooding, voluntary property acquisition should be considered. To maximize acquisition funding, potential federal funds are available through the following programs: Pre-Disaster Mitigation grants (PDM), Flood Mitigation Assistance grants (FMA), and through the Hazard Mitigation Grant Program (HMGP). With funding assistance, it may be more cost effective to acquire properties in the floodplain versus implementing a structural flood mitigation solution. If the surrounding undeveloped lots are also obtained by the City of Marble Falls, the city could consider creating a community park or greenbelt that would enhance the their amenities and surrounding neighborhood appeal, as well as reduce risk during the frequent flood events.

Benefit Cost Ratio

The Burnet County tax database was utilized to obtain the market value for each structure. The actual cost to acquire the proposed properties will likely be higher than just the market value for the property. For this analysis, it was assumed that the acquisition cost of the properties would be 1.5 times the market value of the structure.

To determine the benefit for this alternative, summation of the structures being removed from each flood frequency (2-yr, 5-yr, and 10-yr) was multiplied by the representative annual probability of the event (0.5, 0.25, and 0.1) to calculate an annual flood damage benefit. The analysis period for the benefit cost analysis was chosen to be 50 years, the estimated effective lifetime of the proposed alternative. Annual inflation was assumed to be 7% over the 50 years of the project. To bring the annual benefits to a present dollar value, the following equation was applied:

$$\text{Present Value} = \frac{A * (1 + i)^n - 1}{i(1 + i)^n}$$

Where A = Annual Benefit in dollars
i = Inflation (7%)
n = Period of Analysis (50 years)

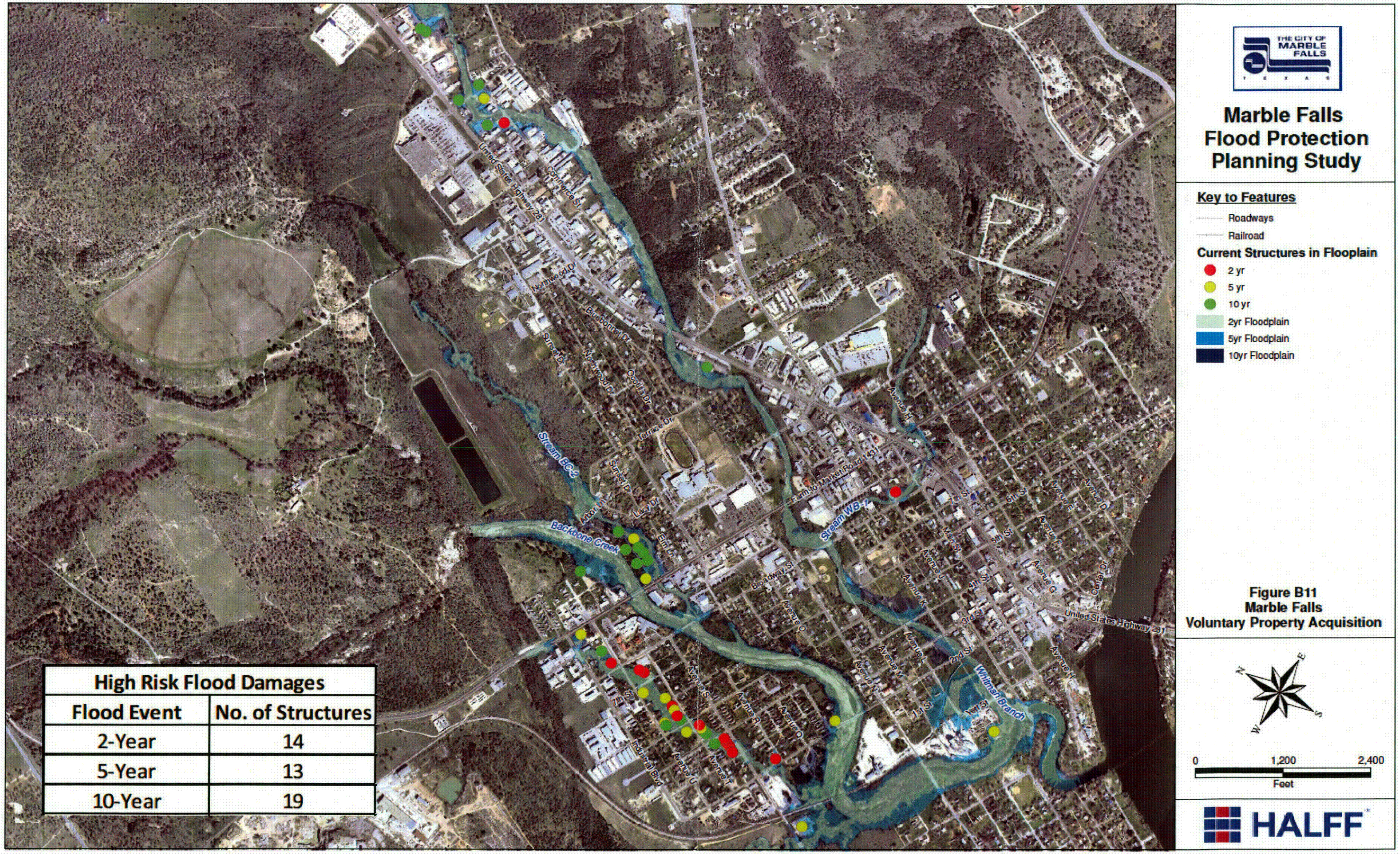
Results of the benefit cost analysis are provided in Table B21.

Table B21: Benefit Cost Results for Voluntary Property Acquisition

Mitigation Alternative 5: Voluntary Property Acquisition		
50 Yr Projected Annual Benefit	2-year Frequency Event	$5,533,800
	5-year Frequency Event	$3,813,920
	10-year Frequency Event	$3,038,154
Total 50 Yr Projected Annual Benefit		$12,385,874
Property Acquisition Cost		$6,163,568
Benefit Cost Ratio Value		2.010

Summary of Scoring

Alternative #8 Scoring Summary - Voluntary Property Acquisition		
Criteria	**Description**	**Score**
Flood Mitigation Benefit/Cost Ratio	Benefit Cost Ratio = 2.010	10
Community Beautification	The proposed improvements will not offer aesthetic benefit to the area.	1
Future Economic Impacts	Decreased flooding repair costs during future rainfall events.	3
Operation and Maintenance Upkeep	No continual maintenance or upkeep required.	9
Grant Availability	This alternative is a potential candidate for federal funds through PDM, FMA, and HMGP.	7
Project Longevity	Due to the fact that the many of the buyouts are near the Unnamed Tributary which does not have a FEMA floodplain, there may be no regulation in place restricting redevelopment of the acquired areas.	3
Community Buy-in	The community would likely not readily support this alternative	2
Environmental Constraints	Environmental issue outlined in section C.3 have the potential to arise with this alternative	3



High Risk Flood Damages

Flood Event	No. of Structures
2-Year	14
5-Year	13
10-Year	19

Table B12 – Voluntary Property Acquisition

B.10 Implementation and Phasing Plan

Based on input from City staff and the scoring table for each alternative, projects have been prioritized with the ranking matrix seen in Table B22. Recommendations and details about potential funding sources for the top three alternatives are described below.

Table B22: Ranking Matrix Results

Alternative	Flood Mitigation Benefit/Cost Ratio	Community Beautification	Future Economic Impacts	O&M Costs + Upkeep	Grant Availability	Project Longevity	Community Buy-in	Environmental Contraints	*Total Score*	*Final Ranking*
# 6 - Creekwalk	3	10	9	4	5	8	10	5	*54*	***1***
# 4 - Crossing Improvements	5	1	5	9	8	8	9	7	*52*	***2***
# 7 - Unnamed Tributary Bypass	2	1	9	9	3	9	7	7	*47*	***3***
# 1 - Whitman Bypass	3	1	8	7	7	9	4	7	*46*	***4***
# 8 - Voluntary Property Acquisition	10	1	3	9	7	3	2	3	*38*	***5***
# 5 - Downtown Channel Improvements	1	3	3	7	3	8	3	5	*33*	***6***
# 2 - Whitman Detention	2	5	9	2	5	6	1	1	*31*	***7***
# 3 - Backbone Detention	1	5	4	2	5	6	1	1	*25*	***8***

Creek Walk

The City of Marble Falls is extremely interested in pursuing the Creek Walk alternative in conjunction with downtown channelization and creek improvements along Whitman Branch and Backbone Creek. The project fits in with the City's master plan for development, and scored extremely well in the criteria for Community Beautification, Future Economic Benefits, and Community Buy-in. While the alternative is expensive as a standalone flood mitigation project, the combination of channelization and improved landscape design provides a range of significant benefits.

Due to the community's high level of interest in this alternative, it is recommended that it be pursued with the application for funding immediately.

The most likely funding source for this project would be TxDOT's Transportation Enhancement Program. Application for the funding requires significant upfront planning and design. The analysis and recommendations provided in section B.7 provide much of the information required for the grant application. TxDOT administers the federal funded program and is looking for projects that integrate the surrounding environment in a sensitive and creative manner that contributes to the livelihood of the communities, promotes the quality of the environment, and enhances the aesthetics of roadways. Funded projects are eligible for reimbursement of up to 80 percent of allowable project costs.

Bridge Crossing Improvements

As discussed in section B.5, modifications to the crossings at US 281 at Whitman Branch and Whitman Branch Tributary 1 will allow the vehicles to safely pass during larger flooding events. Due to the fact that these structures are frequently flooding and requiring repair or rebuilding, it is recommended that the City pursue funding to upsize these structures immediately.

TxDOT is the most likely funding source for this alternative. The City could also fund improvements for the crossings and receive reimbursement from TxDOT through a "pass through" funding mechanism commonly used by communities.

In the event that TxDOT is not interested in funding the upsizing of these creek crossings immediately, the analysis conducted in section B.5 should be readily available when damages occur or result in future rainfall events. The detailed hydraulic modeling conducted as part of this study will be valuable in the future rebuilding or repair of these structures as analysis indicates that they are likely to be damaged during the next significant flooding event.

Unnamed Tributary Bypass

The community was interested in the unnamed tributary bypass channel to reduce flooding through the residential area along the manmade creek. However, the benefit cost analysis indicated that the construction of the diversion channel outweighed the benefits. This was primarily due to the fact that the excavation to build the channel would require excavation through granite that exists in the area. If local quarries were willing to extract the granite in this location for a reduced, or zero cost than the alternative becomes feasible.

It is recommended that City staff pursue this alternative with the local quarries to gage the potential for a reduced cost flood mitigation alternative.

It is also highly recommended that a detailed hydraulic study be conducted on the unnamed tributary to better quantify the flood risk to this residential area such that additional development does not occur in flood prone areas. The analysis done for this study could be used to apply for funding under the FEMA Risk Map Program to include the unnamed tributary as part of a FEMA studied stream. This would expand other funding opportunities through the FEMA Hazard Mitigation Grant program, which would provide 75% funding for the project improvements.

Mitigation alternatives identified by this study could be eligible for funding under the Texas Water Development Board's financial assistance programs. Applications requirements and eligibility criteria is identified by Board rules specified in Section 363 of the Texas Administration Code. Recommended alternatives outlined in this report can be used in support of an application to the Board for financing the proposed improvements.

C

APPENDIX C: Environmental Constraints Summary

C.1 Introduction

For the purposes of the preliminary environmental constraints review, the study area includes the Backbone Creek and Whitman Branch Watershed in Burnet County, north of Lake Buchanan. Additionally, within the watersheds, a more focused review was placed on the City of Marble Falls near potential flood hazard reduction areas. The outer limits of this area are loosely defined by existing roadways. These limits are: Resource Parkway (northern extent), Mormon Mill Road (eastern extent), Johnson Street (southern extent), and County Road 122 (western extent).

C.2 Methods

Numerous sources were reviewed to identify potential environmental constraints in the study area. These sources and data include:

- U.S. Census Bureau 2010 (USCB) socio-economic data.
- Texas Parks & Wildlife Department (TPWD) threatened and endangered species by county.
- Texas Natural Diversity Database (TXNDD) element of occurrence and managed area records.
- United States Fish & Wildlife Service (USFWS) critical habitat and threatened and endangered species by county.
- USFWS National Wetland Inventory (NWI) data.
- Texas Commission on Environmental Quality (TCEQ) hazardous materials data.
- Cultural resources information from the Texas Historical Commission (THC) online atlas.
- Texas Natural Resources Information System (TNRIS) data including hydrology, roads and railroads.
- Texas Water Development Board (TWDB) water well locations.
- United States Geological Survey (USGS) topographic quadrangle maps.

C.3 Socio-Economics/Environmental Justice

The study area is located in Census Tracts 9604, 9606, and 9607, as defined by the United States Census Bureau's (USCB) 2010 Census. These census tracts have a total population of 15,783 while Burnet County has a total population of 42,606. According to the Texas Almanac, the primary industries in Burnet County include agribusiness, mineral extraction, and tourism. Demographic data was reviewed to determine if minority or low-income persons have the potential to be adversely affected by the proposed project. The data was retrieved from the USCB on September 26, 2013. Block group data from the 2010 Census indicates that approximately 21 percent of the population in the project area is comprised of minorities. Although income data is not available in the 2010 Census, the American Community Survey (ACS) provides a 5 year average of income and poverty information for the investigated geographies. The ACS is an ongoing nationwide survey that provides social, economic, and housing data every year. All ACS data are estimates; therefore, the USCB provides a margin of error (MOE) for every ACS estimate. The 2013 United States Department of Health and Human Services (USDHHS) poverty guideline for a family or household of four is $23,550. The ACS data for 2007-2011 indicate that the median household income for Burnet County is $48,291 (MOE +/-$1,980). The average median household income for the study area census tracts is $51,684 with an average MOE of +/-$6,945. Therefore, the county and census tract data show that the median household income in 2011 for all investigated geographies is greater than the USDHHS poverty guideline; however, the 2007-2011 ACS data indicates that low-income individuals live in the project area.

Although minority and low-income persons are located within the project area, the proposed action is not expected to have adverse or disproportionate impacts on minority or low-income populations. The benefits of the flood control project are expected to equally benefit all residents in Burnet County. Public outreach planning for any future public involvement activities should take into consideration low-income and minority populations.

C.4 Biological Resources

The USFWS lists three federally threatened or endangered species in Burnet County. TPWD lists 14 species as either threatened or endangered. This data was retrieved from the USFWS and TPWD annotated county lists of rare species for Burnet County on September 3, 2013. The USFWS also maintains a database of critical habitat for threatened and endangered species. No critical habitat areas were identified within the study area.

In addition, a database search for federal and state listed or tracked threatened, endangered, and rare species was conducted using the Texas Natural Diversity Database (TXNDD) on September 10, 2013. The search also included managed areas. The search revealed 16 Element Occurrence Records (records of sightings of rare or threatened/endangered species) and one managed area within 1.5 miles of the study area. **Given the small proportion of public versus private land in Texas, the TXNDD does not include a representative inventory of rare resources in the state. Although it is based on the best data available to TPWD regarding rare species, the data cannot provide a definitive statement as to the presence, absence, or condition of special species, natural communities, or other significant features in any area. The data cannot substitute for on-site evaluation by a qualified biologist. The TXNDD information is intended to assist users in avoiding harm to rare species or significant ecological features.**

A field visit by a qualified biologist is recommended prior to construction to determine the presence or absence of suitable habitat for federal and state listed protected species.

C.5 Surface Waters, Including Wetlands

According to hydrologic data including USGS topographic maps, there are numerous water features (streams, drainages, ponds, lakes, etc.) within the study area. It is recommended that a site survey be conducted to identify the location of any potential waters of the United States (WOUS). Figure C1 shows mapped stream locations within the Backbone Creek and Whitman Branch Watershed.

Wetlands are identified as those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. A search of the USFWS National Wetlands Inventory database indicates that there are numerous wetlands in the study area. These wetlands may be jurisdictional under Section 404 of the Clean Water Act and may require a permit prior to filling or dredging. It is recommended that a jurisdictional determination be performed in the field prior to construction in order to determine potential impacts to WOUS.

C.6 Potential Hazardous Materials

The TCEQ's known hazardous materials database was reviewed for the study area. The data includes superfund sites, municipal solid waste sites, permitted industrial hazardous waste sites, and radioactive material locations. No known sites were identified within the study area.

Once the perimeters of the project are established during the design phase, a comprehensive database review and site visit are recommended to determine the level of assessment necessary. A Phase I Environmental Site Assessment may be needed prior to construction.

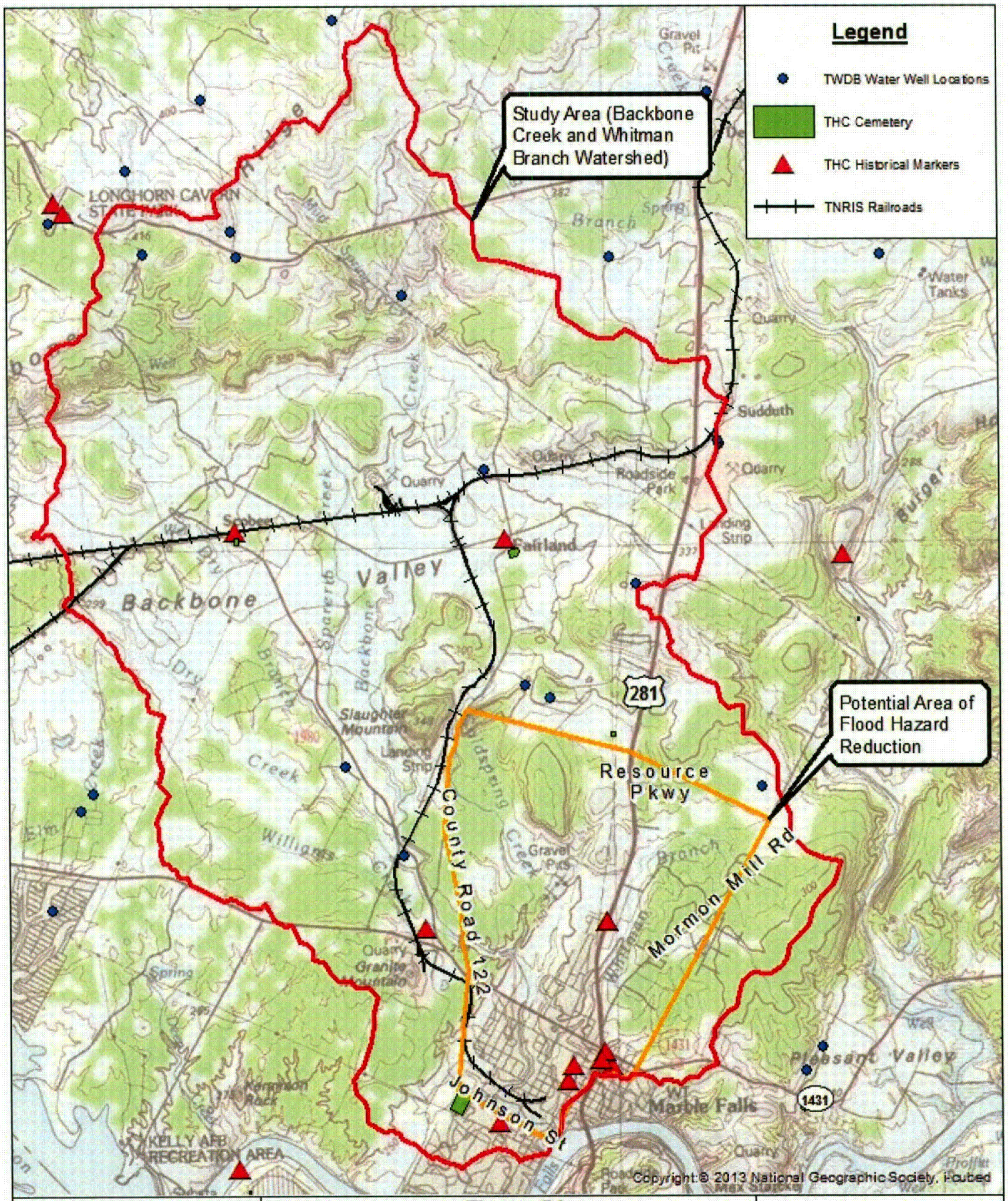
C.7 Physical Constraints

Physical constraints data (roads and railroads) from TNRIS are depicted in Figure C1. Other constraints, such as water wells, are also shown. A field reconnaissance is recommended prior to construction to determine any conflicts with existing infrastructure.

C.8 Cultural Resources

Cultural resources are structures, buildings, archeological sites, districts (a collection of related structures, buildings, and/or archeological sites), cemeteries, and objects. Both federal and state laws require consideration of cultural resources during project planning. At the federal level, the National Environmental Policy Act (NEPA) and the National Historic Preservation Act of 1966 (NHPA), as amended, among others, are applicable for federal actions. In addition, state laws such as the Antiquities Code of Texas are applicable. Compliance with these laws can require consultation with the Texas Historical Commission (THC), a Texas State Historic Preservation Officer (SHPO), and federally recognized tribes to determine the project's effects on cultural resources. Previously identified cultural resources such as cemeteries, properties listed on the National Register of Historic Places (NRHP), state historic sites, and historical makers were reviewed from the THC online atlas on September 4, 2013, and are shown in Figure C1. According to the online data extracted from the THC, there are four cemeteries and ten historical markers within the study area. No NRHP listed properties or state historic sites were identified.

To comply with federal and state laws regarding review and coordination, a site visit and additional research by an architectural historian and an archeologist to determine the likelihood of impacts on significant cultural resources is recommended prior to construction.



Study Area (Backbone Creek and Whitman Branch Watershed)

Potential Area of Flood Hazard Reduction

Copyright:© 2013 National Geographic Society, i-cubed

Figure C1
Environmental Constraints
Flood Protection Planning Study
Marble Falls, Texas

Note: This map is not to scale.

Sept. 2013

HALFF

AVO: 28545

THE CITY OF MARBLE FALLS TEXAS

List of References

Americans with Disabilities Act (ADA). 1990). 42 U.S.C. §§12101 et seq.

Asquith, William H. 1998. Depth-Duration Frequency of Precipitation for Texas, USGS Water Resources Investigations Report 98-4044

Federal Emergency Management Agency (FEMA). 2007. Flood Insurance Study #48053CV000B, Burnet County, Texas and Incorporated Areas, Washington, D.C., November 16, 2007

Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J. 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.

National Weather Service (NWS). 1961. Rainfall Frequency Atlas of the United States, 30-Minute to 24-Hour Durations, 1- to 100-Year Return Periods. Technical Paper No. 40. U.S. Department of Commerce.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed February, 2012.

U.S. Army Corps of Engineers (USACE). 2010. Institute for Water Resources, Hydrologic Engineering Center, Hydrologic Modeling System, Version 3.5

United States Department of Agriculture (USDA). 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55). Natural Resources Conservation Service, Conservation Engineering Division.

D

APPENDIX D: Large Maps

M 2/18/14

Texas Water
Development Board

P.O. Box 13231, 1700 N. Congress Ave.
Austin, TX 78711-3231, www.twdb.texas.gov
Phone (512) 463-7847, Fax (512) 475-2053

February 18, 2014

Ralph Hendricks
City Manager
City of Marble Falls
800 Third Street
Marble Falls, Texas 78654

RE: Flood Protection Planning Grant Contract between the Texas Water Development Board (TWDB) and the City of Marble Falls (City); TWDB Contract No. 1148321284, Amendment No. 2; Draft Report Comments for Flood Protection Planning Study

Dear Mr. Hendricks:

Staff members of the TWDB have completed a review of the draft report prepared under the above-referenced contract. ATTACHMENT I provides the comments resulting from this review. As stated in the TWDB contract, the City will consider revising the final report in response to comments from the Executive Administrator and other reviewers. In addition, the City will include a copy of the Executive Administrator's draft report comments in the Final Report.

The TWDB looks forward to receiving one (1) electronic copy of the entire Final Report in Portable Document Format (PDF) and six (6) bound double-sided copies. **Please further note, that in compliance with Texas Administrative Code Chapters 206 and 213 (related to Accessibility and Usability of State Web Sites), the digital copy of the final report must comply with the requirements and standards specified in statute. For more information, visit http://www.sos.state.tx.us/tac/index.shtml.** If you have any questions on accessibility, please contact David Carter with the Contract Administration Division at (512) 936-6079 or David.Carter@twdb.texas.gov

The City shall also submit one (1) electronic copy of any computer programs or models, and, if applicable, an operations manual developed under the terms of this Contract.

If you have any questions concerning the contract, please contact Gilbert Ward, the TWDB's designated Contract Manager for this project at (512) 463-6418.

Sincerely,

Lisa Glenn

Lisa Glenn
Deputy Executive Administrator
Operations & Administration

Enclosures

c: Gilbert Ward, TWDB

ATTACHMENT I

Review of Draft Report for TWDB Contract No. 1148321284
City of Marble Falls Flood Protection Planning Study

1. Please perform a final edit for typos, grammar, and inconsistent usage of acronyms and abbreviations. In addition, there were several references that appeared in the text as being used but were not cited properly (for example as in Appendix A, Section A.1 and A.2). Please ensure that prescribed citation standards are followed. Also, please include a list of References in the Final report.

Document was thoroughly proof read and check for consistencies. Properly cited all references, and added a list of references to end of document.

2. Section 2.0, Page 5; please provide the date of the Current Effective Flood Insurance Study listed by the initial bulleted item, and reference properly.

Date and reference added to the Current Effective Flood Insurance Study. Also added to list of references.

3. Section 3.0, Page 7; referral is made to Figure 4 as the watershed boundary delineation map; however this should be Figure 5. Please correct in the Final report.

Reference to watershed boundary delineation map was revised to be Figure 5.

4. Section 5.0, Page 9; the 2nd paragraph references the "previous Flood Insurance Study" results. Please date and reference properly. Also, if this is the same report as referenced in Section 2.0 (Comment 2 above) please ensure that similar citations are used.

Date and reference added to the Current Effective Flood Insurance Study. Also added to list of references

5. Section 7.0, Page 14; within the 2nd paragraph the acronym ADA is used several times but not properly identified or spelled out the initial time. Please correct.

The first use of ADA was spelled out to read American with Disabilities Act (ADA, 1990). Also added to list of references.

6. Section 7.0, Page 14; please consider amending Table 2 to also include the alternative number (as identified in Section 6.0) to go along with the alternative name, in order to avoid possible confusion by the readers. In addition, please also include the alternative numbers in the subtitle headings of Appendix B for the alternatives detailed descriptions.

Alternative numbers were added to both Table 2, and the headings of Appendix B.

7. Section 7.0, Page 14; please include a more detailed discussion of the ranking matrix developed to quantify, evaluate and rank the flood mitigation alternatives. Each of the criterion

used in the matrix (Table 2) should be discussed and should include; a general description of each of the criteria, where or how the information used for the criteria was derived or obtained, and the general process for scoring, or weighting of scores, for the ranking of the alternatives. Also, please include as a criterion, the environmental information developed by the study and described in Appendix C (or describe where in the matrix this information is utilized). Consider providing this discussion as part of Appendix B (the first subsection of B) and then summarize in Section 7.0 as additional information describing Table 2.

Section B.1 was added that gives a description of each criterion. Also, a description of how each alternative was scored was added to each of the alternative descriptions in appendix B.

8. Appendix A, Section A.2; the report references a United States Geological Survey report by William Asquith (98-4044) and states that it was "developed in November 2001" when this report was published in 1998. Please correct and properly cite.

Date corrected, and proper citation added.

9. Appendix B, Sections B.1 and B.2. Both of these sub-sections conclude with the statement that a detailed cost analysis was not conducted because the alternative is considered to not be economically beneficial. Please provide additional information to support that decision. In addition, referring to Table 2 in Section 7.0, a score is given for both of these alternatives under Flood Mitigation Benefits to Cost Ratio criteria thereby indicating that some form of a cost analysis was performed for these two alternatives. Please provide additional explanation.

Detailed benefit cost analyses were conducted for all alternatives and a section was added to each alternative description in Appendix B detailing the methods and results.

10. Appendix B, Section B.6. The report indicates that there had been considerable effort into the development of the Creek Walk alternative; however there is no discussion of this alternative as mitigating a flood hazard. If there is no flood mitigation benefits from this alternative, than it should be removed from the report. If the Creek Walk is intended to be used in conjunction with a flood mitigation alternative, such as channelization, then it should be presented with that particular alternative. Please amend as necessary. As a suggestion, the discussion of the flood mitigation alternative could be developed as a "with the Creek Walk" and "without the Creek Walk", however be aware that this may also require amending Table 2 in Section 7.0.

The Creek Walk Alternative would go in combination with the Downtown Channel Improvements described in Appendix B.5. This will be better described and include descriptions of how the 2 alternatives benefit each other. Your suggestion of a "with Creek Walk" and Without Creek Walk" are in effect appendix B.6 and B.5. More detail was added to both the Creek Walk and Downtown Channel Improvements alternatives to discuss how they are to be used in conjunction with one another.

11. Appendix B, Section B.8. This discussion of the Voluntary Property Acquisition mitigation alternative contains an estimate of appraised Property Values for properties impacted by a 2-year, 5-year and 10-year flood frequency event. However, there is no discussion of how this

information is utilized in a benefit/cost analysis. In addition, although Table 2 in Section 7.0 seems to indicate that a Benefit/Cost Ratio was determined, there is no discussion of that analysis or calculation in this section (also see Comment 12 below). Please include this discussion in the final report.

Detailed benefit cost analyses were conducted for all alternatives and a section was added to each alternative description in Appendix B detailing the methods and results.

12. The Study Scope of Work, Task 9, included the performance of a Benefit/Cost Analysis and provided a limited description of how that analysis may be performed. Although the report indicates that a benefit/cost analysis was conducted as part of the study (Section 7.0, Table 2), there is no discussion of the analyses in the report. Please provide and ensure that the response to this comment is consistent and in conjunction with the information and discussion to the responses to Comment 7, Comment 9 and Comment 11 above.

Detailed benefit cost analyses were conducted for all alternatives and a section was added to each alternative description in Appendix B detailing the methods and results. Also, in section B.1 of Appendix B there is a writeup of how the benefit cost results were used to score the alternatives in the ranking matrix.

13. The Study Scope of Work, Task 10, includes the development of an Implementation and Phasing Plan. Although the report does provide recommendations to the City for the alternatives that appear the most feasible and effective to pursue, it does not go so far as to propose an Implementation and Phasing Plan. Please address in the Final report (see also Comment 15).

Section B.10 was added to the final report that specifically addresses Task 10 in the Scope of Work.

14. The Scope of Work for Task 10 also indicated that the Implementation Plan would include identification of potential funding sources. Although the final sentence of Section 7.0 does list three federal agencies that offer "grant funding programs" as do several of the subsections to Appendix B, no real discussion of the programs are provided. Please provide additional detail of the possible funding options available to the City, and indicate which alternatives could take advantage of specific grants available (see also Comment 15). Also, note that Table 2 identifies Grant Availability as one of the criterion evaluated. The additional discussion to satisfy this comment should be relevant to the response provided to Comment 7 above.

A more thorough discussion of funding sources was added to each alternative summary, and in section B.10.

15. Relative to Comment 13 and Comment 14, although some of the subsections of Appendix B briefly mention some of the objectives determined by performing the Task 10 Scope of Work, it is not clearly stated or consistently provided through each of the subsections. Please consider the addition of a final section of the report which could include a description of the final recommendations, along with the Implementation Plan and funding alternatives discussion.

Section B.10 was added to the final report that specifically addresses Task 10 in the Scope of Work.

16. As a final comment, please review and make any necessary changes to the Executive Summary which may be as a result of responses to the above comments.

Changes were incorporated into the executive summary.

17. The study follows standard methodologies and practice utilizing acceptable HEC modeling in the engineering aspects of hydrologic and hydraulic techniques. The hydrologic modeling parameters were determined based on the calculation and engineering judgments for the existing and ultimate conditions. Mitigation alternatives identified by the study are eligible for funding under the Board's financial assistance programs. Application requirements and eligibility criteria is identified by Board rules specified in Section 363 of the Texas Administrative Code. The report would be appropriate for use in support of an application to the Board for financing the proposed improvements. All additional information required by Board rules, 31 TAC 363.401-404, as well as necessary information to make legal findings as required by Texas Water Code Chapter 17.771-776, would be required at the time of loan application.