LJA Engineering, Inc. LJA

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Final

City of Conroe

Flood Protection Plan

For Stewart's Creek

Prepared for:

City of Conroe
Texas Water Development Board

STATE OF TEXAS
CHAD A. JOHNSON
91009
LICENSED
PROFESSIONAL ENGINEER
9-22-2016

CITY OF CONROE
Est. 1904

September 2016

Prepared by:

LJA Engineering, Inc. LJA

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Prepared by:

Planners ♦ Consulting Engineers ♦ Surveyors

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EXECUTIVE SUMMARY

Stewarts Creek runs from southwest of Willis through the City of Conroe, to its confluence with the West Fork of the San Jacinto River just south of Conroe with a drainage area of approximately 19.3 square miles. The City of Conroe has experienced significant flooding along Stewarts Creek in past years. Based on Federal Emergency Management Agency information, there are six repetitive loss structures within the City of Conroe. Additionally, the City has issued permits for renovation after flooding to 37 properties between 1994 and 2002.

In 2015, the City of Conroe received a grant from the Texas Water Development to pay 50% of the costs for a Flood Protection Plan for the City of Conroe. For the development of the Flood Protection Plan, this study was performed to determine the major causes of flooding and develop cost effective alternatives to prevent future flooding along Stewarts Creek within the City of Conroe.

The previous models of Stewarts Creek were developed over thirty years ago as part of the Flood Insurance Study. Since that time the watershed has experienced significant development. A number of Letters of Map Revisions since that time has resulted in fragmented modelling of the stream with no single model now accurately depicting the conditions along the stream. Therefore in order to accurately assess the causes of flooding we developed a new set of hydrologic and hydraulic models to account for the development within the watershed since the original FIS study. This model was used to determine the Expected Annual Damages for the existing condition in order to determine the cost effectiveness of the alternatives we examined.

We then examined detention, channel modification, and crossing modification alternatives to reduce the flooding on Stewarts Creek. We determined appropriate areas for detention and channel modification sites, and determined four roadway and rail crossings which showed excessive loss and analyzed a total of eleven alternatives. We also determined structures appropriate for buyout.

Based on this analysis, none of the structural alternatives examined were cost-efficient methods for reducing existing flooding, but eleven properties were identified as possible candidates for buyouts.

Based on the results of the analysis, the following items are recommended for the Stewarts Creek Flood Protection Plan.

- Continued enforcement of Floodplain Development regulations.
- Investigation of possible buyouts for the 11 properties identified as candidates.
- Preparation of a Letter of Map Revision to update the Flood Insurance Study for Stewarts Creek.
- Development of a system of gages within the Stewarts Creek watershed.

1.0 INTRODUCTION

1.1. Background

Flooding which hinders transportation and inundates residential and commercial structures has occurred frequently in the past twenty years in certain areas within the Stewart's Creek watershed in the City of Conroe.

The Federal Emergency Management Agency's (FEMA) Flood Insurance program statistics show that there are six repetitive loss properties in the Stewart's Creek watershed within the City of Conroe. A better measure of the problems is that from 1994 to 2002, the City of Conroe issued 37 permits for flood repairs in the Stewart's Creek watershed.

As the first step in reducing flooding in certain areas of repetitive flooding in the city, the City of Conroe requested planning grant assistance from the Texas Water Development Board (TWDB) in December 2013. The grant assistance was to develop a Flood Protection Plan for the Stewart's Creek watershed within the city. This plan is the subject of this report and consists of the following goals.

- Identify the causes of the flooding,
- Develop a plan for the orderly implementation of cost-effective solutions to the flooding problems.
- Reduce the frequency of flooding conditions, resulting flood damages, safety and access problems, and health hazards.

1.2. Description of Study Area

The study area consists of the Stewart's Creek watershed in Montgomery County, Texas as shown in **Exhibit 1.1**. The headwaters of the stream lie north of the City of Conroe near Willis, Texas. The stream flows generally southward through Panorama Village Lake, then under Interstate Highway 45 (IH 45). The creek outfalls into Shadow Lake within the Agnes Arnold Girl Scout Camp approximately one mile downstream of IH 45. The creek then continues south through the City of Conroe to its confluence with the San Jacinto River.

The Stewarts Creek watershed is approximately 19 square miles in area. The topography within the watershed is gently rolling with elevations from approximately 120 feet near the San Jacinto River to approximately 360 feet near the headwaters of the stream. The upper reaches of the watershed have sparse areas of residential development, with undeveloped wooded property the dominant land use. As mentioned above, two dams have been constructed along the middle portion of the stream. The middle portion of the watershed is approximately seventy-five percent developed with mixed residential, commercial and light industrial development. The lower third of the watershed is approximately forty percent developed with the remainder primarily undeveloped wooded property. There is currently significant development occurring within the watershed.

The majority of the middle and lower portions of the watershed lie within the city limits of the City of Conroe, with the remainder of the watershed primarily being within unincorporated Montgomery County.

The San Jacinto River Authority and Montgomery County provided letters of Support for the study. These letters can be found in **Appendix A**.

1.3. Previous Studies

The only comprehensive study of the watershed performed previously is the Flood Insurance Study (FIS) completed by FEMA in 1984. The hydraulic analysis for north Stewart's Creek was updated by the City of Conroe in 1988. Since that time, there have been numerous studies which examine a small segment of the Stewart's Creek watershed for which Letters of Map Revision (LOMR) have been issued. As a result, there is no single comprehensive model of Stewart's Creek.

The peak-discharge values for the FIS were determined using NRCS "Computer Program for Project Formulation" (TR-20). The U.S. Weather Bureau Technical Paper 49 (TP 49) was used to determine the point rainfall amounts for each frequency used in the study.

The hydraulic analysis used for the FIS utilized the SCS computer hydraulic program WSP2. This particular program is no longer accepted by FEMA for new studies, and is no longer supported by the National Resources Conservation Service.

The backup data for these original studies is not available from the FEMA Map Service Center, which makes reconstruction of the original study problematic. Additionally, there has been significant growth in the Conroe area over the past 30 years which has resulted in changes in the drainage characteristics within the watershed from the level of development at the time of the FIS studies.

1.4. Scope of Services

In March of 2015, the TWDB contracted with the City of Conroe to perform the Flood Protection Planning Study for the Stewart's Creek watershed and to develop a Flood Protection Plan for this area. The City of Conroe subcontracted with LJA Engineering (referred to as "the Engineer") to perform the required engineering studies. The scope of engineering services summarized below was performed to identify the causes of flooding and recommend appropriate solutions to the flooding problems.

Phase A Data Compilation

The Engineer met with the staff at the City of Conroe to identify areas of historical flooding and to compile sources of drainage information. The Engineer also obtained data regarding property ownership, property values, utility information, information on pipelines, previous studies in the study area, and topographic information for the study area. A map was developed to show this information for use in developing the Flood Protection Plan.

Phase B Stewart's Creek Watershed

Using information gathered as part of Phase A, the Engineer developed existing condition hydrologic and hydraulic models for the Stewart's Creek Watershed. These models were used as a base for the analysis of the various flood protection alternatives examined. The benefits of each alternative were compared to the estimated construction cost to help in determination of the recommended alternative. These benefits included the mitigation of flood impacts resulting from future development, as well as the potential recreational, cultural, and environmental uses of each alternative.

Phase C Final Report and Deliverables

The process used in the formulation of the Flood Protection Plan, the study results, and the recommended Flood Protection Plan have been compiled in this report. Hydrologic and hydraulic models are being provided with the Final Report.

1.5. Study Funding

The funding for the study was provided by the TWDB and the City of Conroe. Each provided fifty-percent of the study cost.

1.6. Project Data Compilation

The planning study area encompasses the portion of the Stewart's Creek watershed within the City of Conroe corporate limits as shown in **Exhibit 1.2**. Information about the study area and watershed was collected for use in the study. The types of information gathered include;

- Information on Repetitive Loss properties and permits issued after flooding within the study area from the City of Conroe.
- Property ownership and property value information from the Montgomery County Appraisal District.
- Publicly available information on pipeline locations in the area from the Texas Railroad Commission.
- LiDAR topographic information obtained by the Houston-Galveston Area Council (HGAC) in 2008 which covered the Stewart's Creek watershed.
- Bridge Inspection reports and as-built plans for applicable road crossings of Stewart's Creek.
- Survey of cross sections and crossing structures along the length of Stewart's Creek.

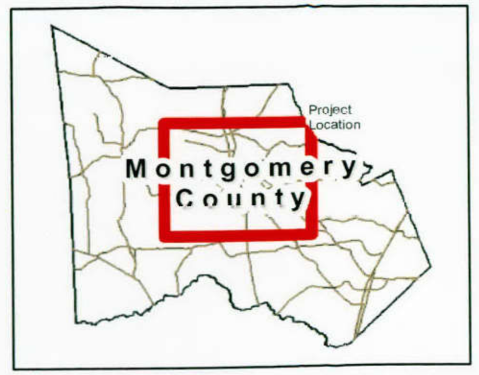
1.7. Public Input

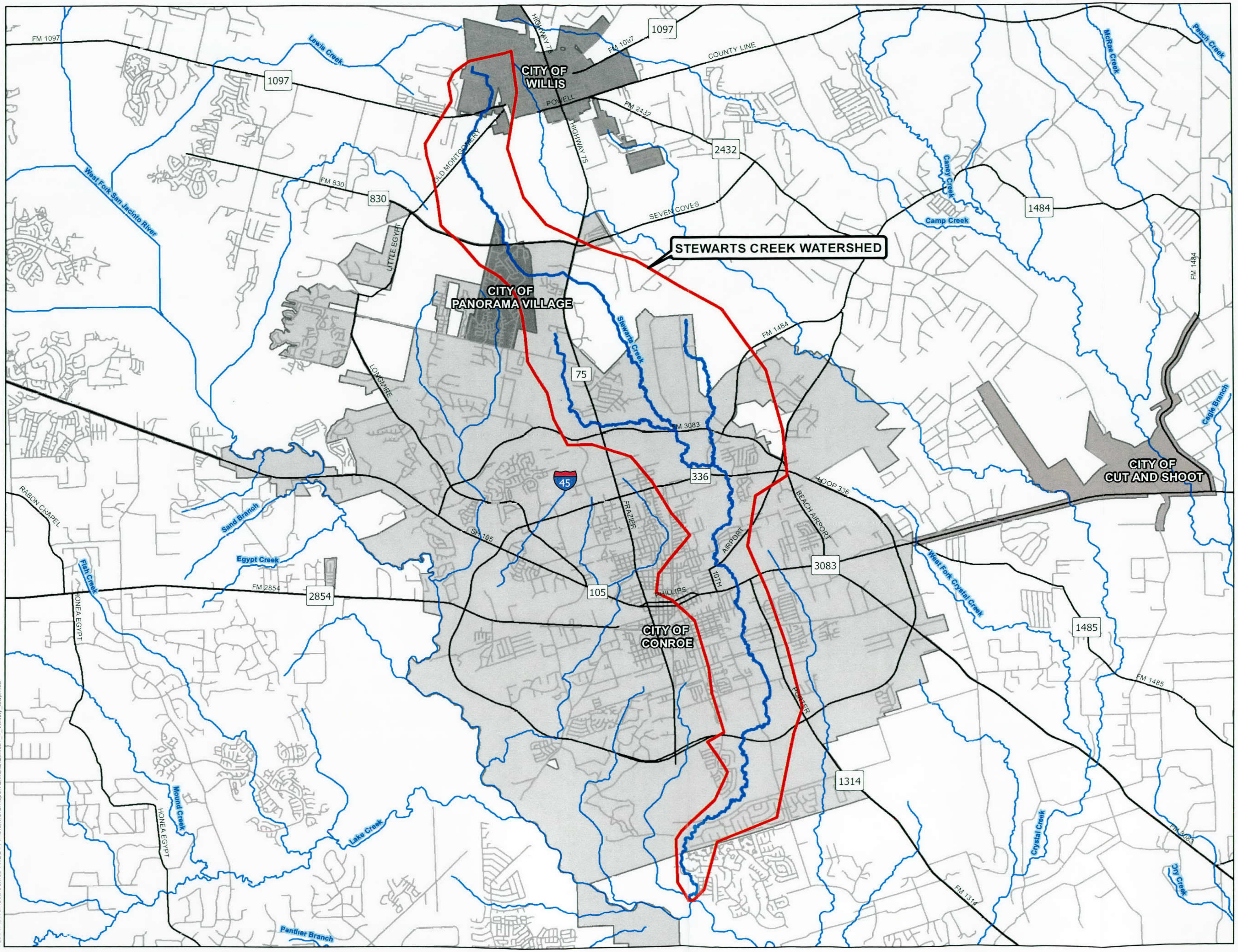
A public meeting was conducted during the data acquisition phase in March 2015. At this meeting, the public was informed of the City's intent to examine the flooding problems in the area and develop plans to alleviate the severity and frequency of the flooding. The public was also asked to provide input regarding the flooding in these areas, and possible solutions they saw to the problems they were experiencing. Input forms were supplied to the residents at the public meeting, and an internet website (https://gis.ljaengineering.com/conroe-flood-reduction/) was set up to provide another avenue to receive public input. Copies of the public meeting sign in sheets and returned public input forms are provided in **Appendix B**.

Overall, four residents attended the initial public meeting and two public input forms were received from residents. This information was used during the mapping process as a check on results of the analysis.

After the completion of the existing condition analysis, a second public meeting was held in September of 2015. The purpose of this meeting was to present the results to date to the public and receive input regarding the alternatives to be analyzed. Copies of the public meeting sign-in sheets are provided in **Appendix B**.

Upon completion of the analysis of the alternatives and determination of the costs and benefits, a final public meeting was held on April 5th of 2016 to present the results of the analysis of alternatives, and seek input regarding the final recommended plan. Copies of the public meeting sign-in sheets are included in **Appendix B.**





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0 3,500 7,000 14,000 Feet

One Inch Equals 7,000 Feet

Note:
This exhibit shows pertinent items necessary to illustrate the information described in the text and is not intended to include all physical characteristics of the area.

Data Source:
FEMA S_POL_AR
NHD Stream
TxDot OnSystem

Legend

- MONTGOMERY STREAMS
- STEWARTS CREEK WATERSHED

CITY LIMITS

- CITY OF CONROE
- CITY OF CUT AND SHOOT
- CITY OF WILLIS
- CITY OF PANORAMA VILLAGE

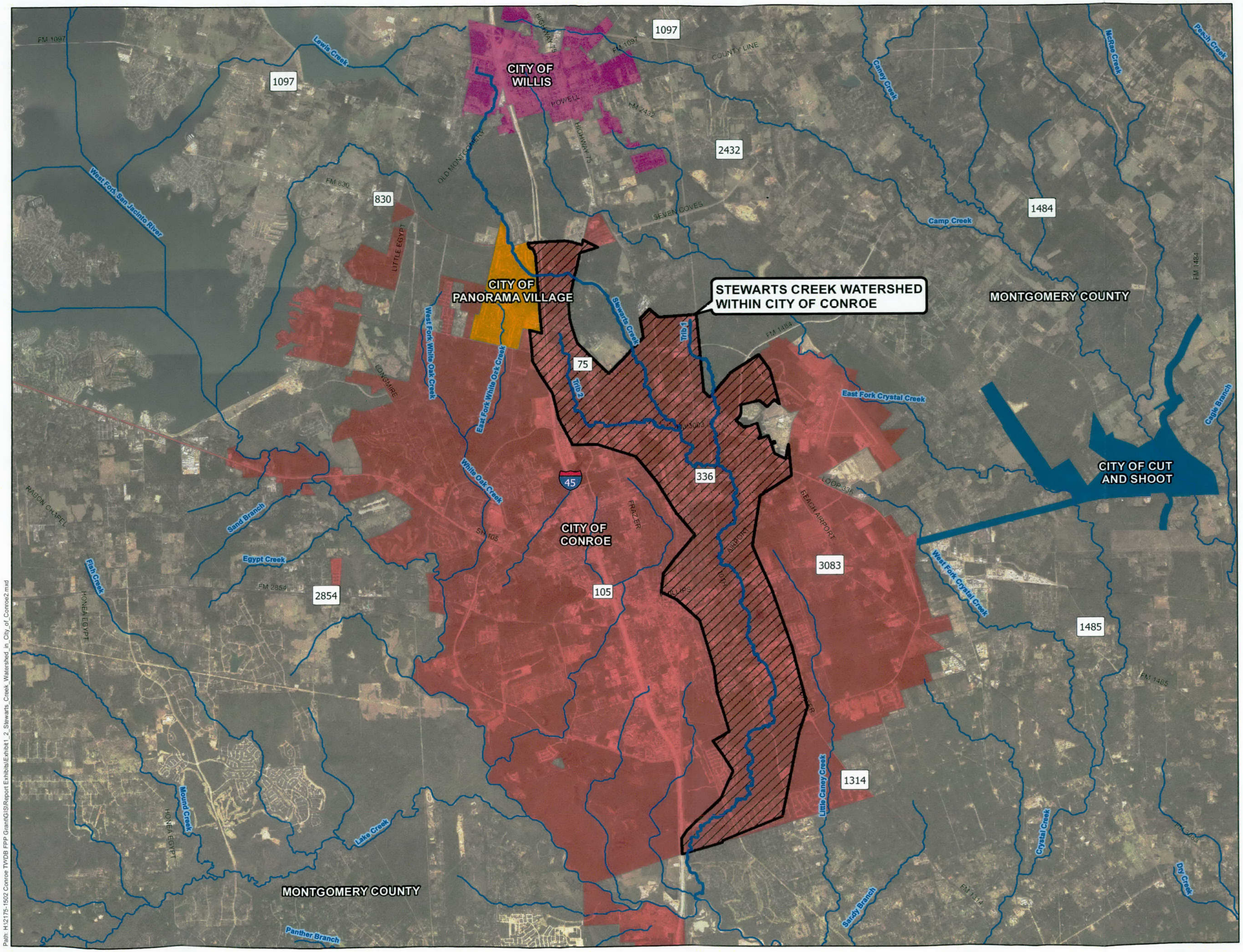
Exhibit 1.1

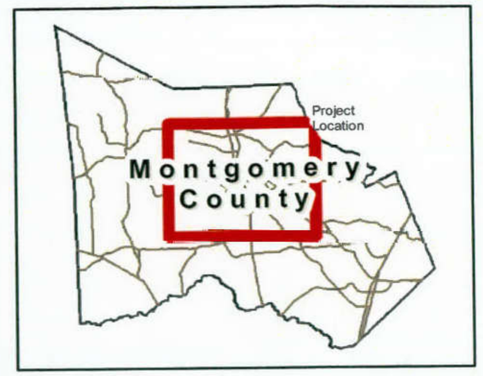
STEWART'S CREEK FLOOD PROTECTION PLAN

VICINITY MAP

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502





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One Inch Equals 7,000 Feet

Note:
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Data Source:
Aerial Photography 2014
FEMA S_POL_AR
NHD Stream
TxDot OnSystem

Legend

- MONTGOMERY STREAMS
- STEWARTS CREEK WATERSHED WITHIN CITY OF CONROE

CITY LIMITS

- CITY OF CONROE
- CITY OF CUT AND SHOOT
- CITY OF WILLIS
- CITY OF PANORAMA VILLAGE

Exhibit 1.2

STEWART'S CREEK FLOOD PROTECTION PLAN

STEWART'S CREEK WATERSHED IN CITY OF CONROE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

Path: H:\2175-1502 Conroe TWDB FPP Grant\GIS\Report Exhibits\Exhibit1_2_Stewarts_Creek_Watershed_in_City_of_Conroe2.mxd

2.0 ANALYSIS METHODOLOGY

No comprehensive study of the watershed has been performed since 1989. The current FEMA Effective models are a mixture of WSP2, HEC-2, and HEC-RAS models, with some segments of the models only a few thousand feet in length. It was decided that a restudy of the watershed using the current City of Conroe criteria would be the best approach for the Flood Protection Plan as it would easily allow for the changes in criteria, and changes in development within the watershed that have occurred since the previous studies. While this project was being performed for the City of Conroe, a significant portion of the watershed lies outside of the Conroe city limits and is the jurisdiction of Montgomery County. Therefore we compared the drainage criteria of both entities to make a determination as to the methodology to be used for the analysis. This comparison is further discussed in the following sections.

2.1. Hydrology

The Hydrologic Engineering Centers Hydrologic Modeling System Version 3.4 (HEC-HMS) was used to develop the runoff hydrographs for the subareas within each sub-basin. HEC-HMS is a computer program developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center to simulate the precipitation-runoff process and compute flood hydrographs at desired locations within a watershed. The physical characteristics of the watershed are represented by an interconnected system of geographic and hydrologic components described below.

The Stewart's Creek watershed was redelineated based on LiDAR information obtained in 2008 and land use within the watershed was determined based on aerial photographs obtained in 2014. The delineated watershed and subbasins are shown in **Exhibit 2.1**.

2.1.1. Hypothetical Storm Events

The City of Conroe drainage criteria specifies the use of the SCS Type III Curve for the rainfall distribution. The SCS storm method implements the design storm developed by the Natural Resources Conservation Service. With this methodology, the same hyetograph is calculated for all of the subbasins in the model, and each storm has the same total precipitation for each subbasin in the meteorological model. The only information required for this method is the 24-hour rainfall depth for each storm.

The City of Conroe criteria refers to the Texas Department of Transportation (TxDOT) Hydraulic Manual for the rainfall depths. Montgomery County is also preparing an addendum to their criteria which updates the rainfall amounts to be used. The updated rainfall amounts are based on the TxDOT rainfall rates which were determined based on *Depth-Duration Frequency of Precipitation for Texas* (USGS 98-1044) published by the U.S. Geological Survey. These rainfall rates were chosen to be used for this study as they fit the City of Conroe and Montgomery County drainage criteria, and are based on more years of data of rainfall information. The rainfall depths for the various exceedance probabilities used for this study are shown in **Table 2.1**.

Table 2.1 - Depth Duration Frequency (inches)

Duration	Exceedance Probability						
	50%	20%	10%	4%	2%	1%	0.2%
24-Hour	4 in.	5.8 in.	7.2 in.	9.3 in.	11.2 in.	13.5 in.	20.4 in.

2.1.2. Hydrograph Development

The City of Conroe drainage criteria calls for the SCS Unit Hydrograph methodology to be used for the calculation of flows. The current Montgomery County criteria calls for the use of the Clark Unit hydrograph to be used, and details the methods to be used for the parameters for this methodology. From previous experience in this area, this would result in lower peak flow rates than the City of Conroe criteria. The County is also preparing an addendum to the criteria which allows for the use of the SCS Unit Hydrograph methodology. Therefore it was decided to use the SCS methodology with the updated rainfall amounts.

With the SCS methodology, the standard lag is defined as the length of time between the centroid of precipitation mass and the peak flow of the resulting hydrograph. Studies have found that the lag time is approximately 60% of the time of concentration. Due to the scope of this study, it was determined that the NRCS Watershed Lag methodology would be the most appropriate way of determining the time of concentration for use in the approximation of the standard lag to be used in the HEC-HMS model. The form of the methodology used for this study is;

$$T_c = \frac{l^{0.8}(\frac{1000}{CN} - 9)^{0.7}}{1{,}140Y^{0.5}}$$

Where:

T_c = time of concentration (hours)

l = hydraulic length from the outlet to the watershed's most hydraulically remote point (feet)

CN = curve number ($50 \leq CN \leq 95$)

Y = average slope of the land for the watershed (%)

Table 2.2 shows the watershed parameters and resulting time of concentration for each subarea.

Table 2.2 – Watershed Parameters				
Name	Hydraulic Length, *l* (ft)	Watershed Land Slope, *Y* (%)	CN	Time of Concentration, Tc (hrs)
DA-01	8895	2.07	66	3.14
DA-02	7991	2.22	49	4.29
DA-03	6909	1.96	47	4.27
DA-04	7399	1.61	69	2.84
DA-05	7243	2.30	55	3.34
DA-06	11132	2.26	62	3.98
DA-07	10609	1.95	72	3.17
DA-08	14515	2.33	62	4.85
DA-09	10333	2.90	64	3.15
DA-10	5525	0.92	72	2.74
DA-11	12357	2.53	66	3.69
DA-12	11907	2.85	59	4.04
DA-13	9549	1.33	78	2.97
DA-14	8182	1.95	73	2.50
DA-15	12347	1.49	60	5.60
DA-16	13221	0.87	84	3.94
DA-17	12028	2.18	61	4.42
DA-18	12033	0.89	75	4.76
DA-19	11673	4.34	53	3.75
DA-20	11147	1.80	61	4.59

2.1.3. Infiltration Loss Rates

The City of Conroe criteria calls for the use of the SCS Curve Number loss method. The Montgomery County Drainage criteria addendum allows for the use of this method as well and it was determined that this methodology would be most appropriate for this study. The required information for this methodology in HEC-HMS is the Curve Number for the subbasin, the Initial Abstraction and the percent of imperviousness of the subbasin. The initial abstraction is determined by;

$$I_a = 0.2S$$

Where:

S = Potential retention

The potential retention is determined by;

$$S = \frac{1000 - 10CN}{CN}$$

Table 2.3 shows the potential retention and initial abstraction calculated for each subbasin.

Table 2.3 – SCS Loss Parameters				
DA Name	**CN**	**Potential Retention, S**	**Initial Abstraction, I_a**	**% Impervious**
DA-1	66	5.15	1.03	30
DA-2	49	10.41	2.08	6
DA-3	47	11.28	2.26	5
DA-4	69	4.49	0.90	49
DA-5	55	8.18	1.64	19
DA-6	62	6.13	1.23	11
DA-7	72	3.89	0.78	31
DA-8	62	6.13	1.23	24
DA-9	64	5.63	1.13	31
DA-10	72	3.89	0.78	10
DA-11	66	5.15	1.03	16
DA-12	59	6.95	1.39	26
DA-13	78	2.82	0.56	43
DA-14	73	3.70	0.74	49
DA-15	60	6.67	1.33	33
DA-16	84	1.91	0.38	72
DA-17	61	6.39	1.28	22
DA-18	75	3.33	0.67	43
DA-19	53	8.87	1.77	21
DA-20	61	6.39	1.28	35

2.1.4. Reach Routing

Reach routing was used to account for the movement of water in each reach and the resulting impacts on the runoff hydrographs. The Montgomery County drainage criteria calls for the use of the Modified Puls method for both channel and reservoir routing. This method of hydrograph development is based on the assumption that the storage depends on outflow rate. Altering downstream conditions will not change the stage-storage-outflow relationship of upstream reaches. Iterations of the HEC-HMS and HEC RAS models were performed in order to determine the appropriate storage-outflow relationships for each reach.

2.1.5. Flow Distribution

A log interpolation was used to distribute flows between the HMS calculation points to be used in HEC-RAS. A HEC-RAS calculation point was created where the flows had changed by five-percent. **Table 2.4** shows the flow rates for each frequency at representative points on the stream.

Table 2.4 Discharges at Major Crossings (cfs)

Reach	River Station	Crossing	Exceedance Probability						
			50%	20%	10%	4%	2%	1%	0.20%
Main Stem	84525	FM 830	714	1135	1554	2197	2396	3129	6398
	81024	IH-45 South	793	1260	1743	2466	2687	3494	7284
	80799	IH-45 North	793	1260	1743	2466	2687	3494	7284
	78186	SH 75	899	1435	1996	2830	3083	3992	8264
	63780	UP Rail Road 1	1307	2080	2892	4081	4435	5662	11424
	59153	FM 3083	1529	2416	3325	4647	5030	6331	12724
	52558	FM 1484	1800	2777	3806	5243	5669	7112	14544
	50317	Loop 336 N	2151	3030	4100	5607	6057	7607	15455
	40022	Airport Rd	2779	3909	5047	6808	7319	9038	18574
	37282	SH 105	2779	3909	5047	6808	7319	9038	18574
	37160	BNSF Rail Road	2779	3909	5047	6808	7319	9038	18574
	30632	Silverdale	2762	3892	5071	6826	7343	9030	18619
	27486	Foster Dr	2762	3892	5071	6826	7343	9030	18619
	22560	Ed Kharbar Dr	2762	3892	5071	6826	7343	9030	18619
	20456	Loop 336 S	2734	3883	5085	6862	7381	9090	18384
	9045	Crighton Rd	2704	3874	5101	6901	7422	9154	18136
	3558	River Plantation Dr	2704	3874	5101	6901	7422	9154	18136
	2742	Mosswood Dr	2704	3874	5101	6901	7422	9154	18136
Trib 1	4043	FM 3083	272	410	550	735	790	987	1844
	2421	FM 1484	309	469	631	849	914	1144	2129
Trib 2	15761	League Line Rd	256	380	502	671	720	891	1554
	7954	SH 75	433	639	835	1118	1198	1473	2575
	1843	UP Rail Road 2	547	794	1025	1355	1448	1767	3039

2.2. Hydraulics

HEC-RAS was developed as a part of the Hydrologic Engineering Center's Next Generation of hydrologic engineering software. The current version of HEC-RAS (Version 4.1) supports one-dimensional, steady and unsteady flow, water surface profile calculations. The unsteady flow component of HEC-RAS is capable of simulating one-dimensional unsteady flow through a full network of open channels. The unsteady flow component was developed for subcritical flow regime calculations. The hydraulic calculations for cross-sections and other hydraulic structures used in the steady flow component were incorporated into the unsteady flow component.

Due to various idiosyncrasies with the reach routing methodologies available in HEC-HMS, it was decided to use the unsteady flow module of HEC-RAS as a check on the reasonableness of the hydrologic results for the alternatives analysis. The geometric information requirements for unsteady flow analysis are the same as for steady flow analysis in HEC-RAS

The LiDAR information obtained in 2008 was used as the primary source of topographic information for the models. Survey information for the various structures located on Stewart's Creek was obtained for use in the creation of the models, as well as TxDOT Bridge Inspection reports for the various highway crossings. Survey of cross sections of the stream was also performed approximately every 5000 feet along the stream from high bank to high bank to verify the LiDAR elevations within the channel.

The hydraulic model for the stream was created from the confluence with the West Fork of the San Jacinto River to approximately 1000 feet upstream of Old Montgomery Road near Willis, TX. As stated above, LiDAR information was the primary topographic information used for the cross sections, with checks on the accuracy of the LiDAR at applicable locations based on comparison with the surveyed cross sections. The road crossing structures were input to the model based on information from the survey data. **Exhibit 2.2** shows the locations of cross-sections and structures used in the study.

We were unable to obtain plans for the dams or permission to enter the properties to perform surveys for the two dams on Stewart's Creek. Based on review of aerial photographs and the LiDAR information of the structures it was determined that the Panorama Village dam consisted of an overflow weir spillway with an emergency spillway located on the north side of the lake. The LiDAR and aerial information was used to determine the dimensions and elevations of the dam and spillway to be used in the hydraulic model. The dam outfall on the Agnes Arnold Girl Scout Camp Lake was determined to consist of a single culvert with a morning glory type inlet. An overflow spillway leads from the north side of the lake around the dam and back into Stewarts Creek downstream of the outlet structure. Based on the estimated dimensions of the outlet structure, it appeared that the outlet would be overwhelmed with a significant rainfall, and the primary outlet would be the spillway. For this reason only the overflow spillway was used in the hydraulic model as it is assumed the outlet structure would convey a very small portion of the flow and would not significantly lower the water surface upstream of the dam. For both lakes, there is no information regarding the underwater topography. However as this area would provide reduced conveyance through the lake and no storage to attenuate flows, it was decided to use the normal pool elevation as the flowline of the Stewarts Creek channel through the lakes.

2.3. Calculation of Economic Damages and Benefits

Because flooding in a watershed can occur in events other than the one-percent exceedance probability event, lowering the water surface elevation for events of greater frequency than the 100-year event can provide a large benefit. It was decided that only looking at the number of homes removed from the 100-year floodplain would not be the best method of determining the benefits of the various alternatives. Calculating Expected Annual Damages (EAD) was used to estimate current damages and the possible benefits of the various alternatives. This approach is used by the U.S. Army Corps of Engineers in determining what flood control projects should be enacted at the federal level. For the purposes of this Flood Protection Plan, the calculation of damages and benefits was used as a tool in determining what alternatives would work best for the citizens of Conroe. In order to obtain an estimate of the EAD for existing conditions and for the various alternatives, a GIS based method was developed to integrate the available information and determine the damages expected for each of six different frequency events. These damages were then used to estimate the EAD for the existing condition and for each alternative. The economic benefits of each alternative were then estimated by subtracting the EAD of each alternative from the existing condition EAD.

The method developed correlates available information for each structure in the study area with the water surface elevations determined in our study of the area, to determine the damage for each individual structure. This method estimates flood damage to structures and contents. The information used to develop the damage estimates include the 2008 HGAC LiDAR and property value information obtained from the Montgomery County Appraisal District (MCAD).

The total damage for each frequency event was multiplied by the exceedance probability to determine that event's contribution to the EAD. For example; If the total damages for the 50-percent flood are $1,000,000, the contribution of that event to the EAD is $1,000,000 x 0.50 = $500,000. The total EAD value is the sum of the EAD contributions of the six different frequency events.

The following sections describe the method used in calculating the damages for each category that comprise the total damage for each event, as well as the source of the amounts used for the different damage categories in the methodology.

2.3.1. Water Surface Elevations

As discussed previously, HEC-HMS and HEC-RAS hydrologic and hydraulic models were used to determine the flood elevations. Using the HEC-HMS and HEC-RAS hydrologic and hydraulic models, the water surface elevations for the 50-percent, 20-percent, 10-percent, 4-percent, 2-percent, 1-percent, and 0.2-percent exceedance probability flood events were determined. These floods were mapped based on the LiDAR topographic information using GIS.

2.3.2. Finished Floor Elevation and Depth of Flooding

Because of the large number of structures, rather than surveying the finished floor elevation of each structure, the finished floor elevation was estimated based on the LiDAR topographic information. Because the structures generally occupy the centroid of each lot, the centroid of the lot was calculated and the elevation determined at that point from the LiDAR data. This elevation was then compared in GIS to the water surface elevation for each event at that point as determined through the HEC-RAS analysis. This provided the depth of flooding for each frequency flood event for that structure.

2.3.3. Structural Damage

The structure value for each structure was determined using the MCAD database. This value was then used in the determination of structural damages based on the depth of flooding at the tract and selected depth-damage functions. In this study, depth-damage functions developed by the New Orleans District Corps of Engineers were used due to the similarities in topography and construction methods of structures in the study areas. Because the MCAD data did not include information regarding type of construction or number of stories for the structures, all residential structure damage was estimated based on the depth-damage curves for One-Story on Slab structures. Commercial Structure damages were based on the Masonry Bearing structure depth-damage curves. The GIS program uses the structure value for each tract, and calculates the percent damage based on the depth of flooding determined from the LiDAR data and the floodplain developed through the hydraulic analysis. It multiplies the structure value by the percent damage to estimate the structural damage for each tract for each flood frequency event. Further information on the depth-damage relationships used is included in **Appendix C**.

2.3.4. Contents Damage

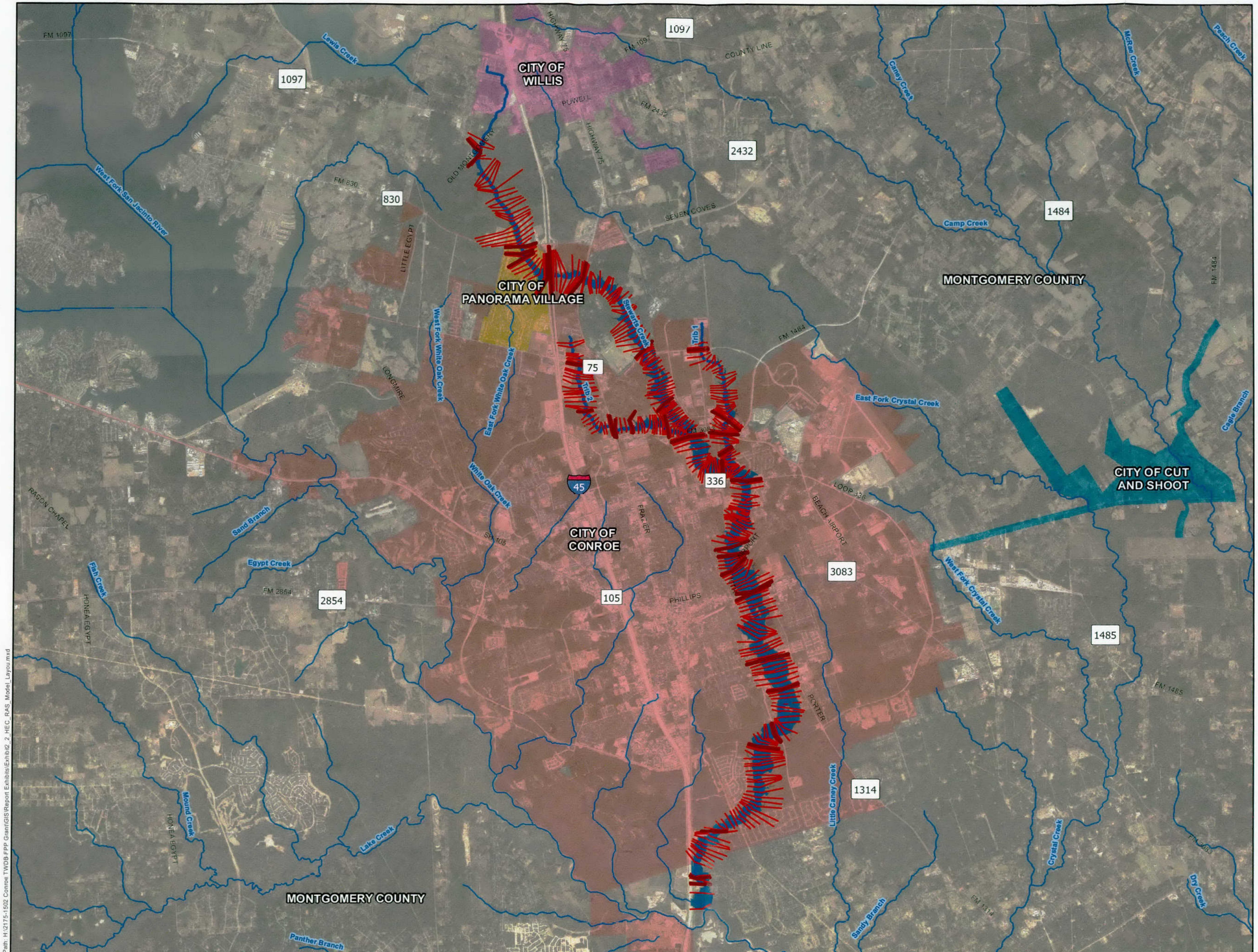
The New Orleans District depth-damage curves also relate contents damage to the depth of flooding of a structure. The depth-damage curves use a Contents-to-Structure Value Ratio (CSVR) to estimate the value of contents in a structure. Each type of structure has a separate CSVR. This ratio value is applied to the structure value to estimate the value of the contents to use with the depth-damage functions. This value is used with the contents depth-damage functions. The contents damage for each tract is then calculated in the same manner as the structural damage. Further information on the depth-damage relationships used is included in **Appendix C**.

2.3.5. Cost Estimates

Recent tabulations of bids for private and public construction projects in the Harris and Montgomery County areas were used to develop unit prices for the various construction components for the alternatives analyzed to develop cost estimates for each structural alternative to be analyzed. Quantities for each of the major components were based on a preliminary layout of the alternative.

2.3.6. Cost-Benefit Ratios

In order to eliminate some of the variables related to projecting overall construction costs to a future date, such as inflation, timing of bond issues, etc., it was decided to convert the benefits for each alternative to a present value. In order to calculate this, the reduction in EAD for each alternative was considered to be an annuity over the fifty year project life assumed for the alternatives. The factor to convert the annuity to a present value was calculated using the 2015 Federal Discount Rate of 3.5%. This factor was determined to be 23.606.



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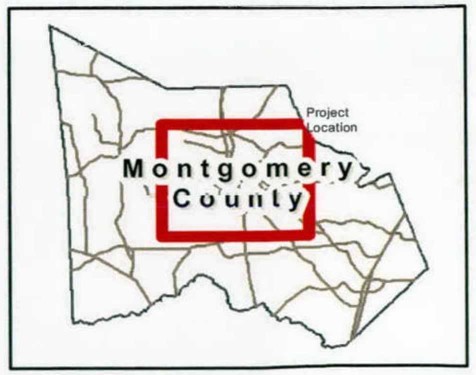

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One Inch Equals 7,000 Feet

Note:
This exhibit shows pertinent items necessary to illustrate the information described in the text and is not intended to include all physical characteristics of the area.

Data Source:
Aerial Photography 2014
FEMA S_POL_AR
NHD Stream
TxDot OnSystem

Legend

- MONTGOMERY STREAMS
- Roadway Crossings
- HEC-RAS CROSS-SECTIONS
- STEWARTS CREEK WATERSHED
- 1% FLOODPLAIN

CITY LIMITS

- CITY OF CONROE
- CITY OF CUT AND SHOOT
- CITY OF WILLIS
- CITY OF PANORAMA VILLAGE

Exhibit 2.2

STEWART'S CREEK FLOOD PROTECTION PLAN

STEWART'S CREEK HEC-RAS MODEL LAYOUT

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

3.0 FLOOD REDUCTION ANALYSIS

3.1. Sources of Flooding

This study only examined riverine flooding along Stewarts Creek and Tributaries 1 and 2. This type of flooding is caused by the water surface elevation in a stream rising to the same level as structures around it as runoff enters the stream. Other potential flooding issues such as inadequate secondary drainage systems not allowing runoff to reach Stewarts Creek in a timely manner were not addressed with this study.

Based on the hydraulic analysis, in the existing condition, during the 1-percent event runoff, approximately sixty structures could be flooded. In order to be able to reduce the flooding problems, the water surface elevation in Stewart's Creek must be lowered. Four roadway and railroad crossings were identified as contributing excessive head loss, with flooded structures immediately upstream of the crossings, and modification of these crossings were identified as possible alternatives to be examined. The other factors involved in structural flooding in the watershed were not attributable to a structure or other constriction, but are due to the large upstream watershed and the resulting water surface elevations as the runoff proceeds downstream. Therefore the other alternatives to be examined would need to reduce the water surface in Stewarts Creek by increasing the conveyance or reducing the flow within Stewarts Creek. Increasing conveyance could be accomplished through channel modifications and reduction of flow could be accomplished through detention. The following paragraphs describe the process used to determine the alternatives to be analyzed and the results of the analysis.

3.2. Floodplain Areas and Damages

The resulting floodplains for each event were mapped based on the topographic information for the area as shown in **Exhibit 3.1.** Based on the results of the existing condition hydraulic analysis, 60 structures are inundated during the 1-percent probability event. Resulting damages are estimated to total approximately $2,000,000. The floodplains determined by the analysis were reviewed by City staff and compared to input from residents of the area to determine if the flooding patterns identified matched with previous flooding events. It was determined that the floodplain identified by the steady HEC-RAS hydraulic model correlated well with previous flooding events. Based on our analysis, structural flooding begins at the 50-percent probability event, with five structures inundated in this event. **Table 3.1** shows a breakdown of flooded structures for each frequency event. The number of structures shown in the table are the total structures for that event.

Table 3.1 - Existing Condition Flooded Structures

	Exceedance Probability						
	50%	20%	10%	4%	2%	1%	0.2%
Flooded Structures	5	8	14	22	29	60	140

Based on these flooded structures, the EAD within the City of Conroe along Stewarts Creek is $218,700.25 in the existing condition Based on this EAD value, and using the 2015 Federal Discount Rate of 3.5%, the present value of the damages over a project life of 50 years is $5,162,638.12 based on the six event frequencies analyzed. **Appendix D** provides more information regarding the number of structures affected and the breakdown of damages for each frequency

3.3. Non-Structural Alternatives

Non-structural alternatives do not affect the water surface elevation or the flow rates on the stream. This type of flood protection is aimed at individual structures within a flooding area. Common non-structural methods of flood protection include buyouts, structure raising and flood-proofing. The following paragraphs discuss the viability of the various non-structural methods in reducing the flood damage experienced in the watershed.

3.3.1. Buyouts

Buyouts involve the identification and purchase of buildings subject to repetitive damage from flooding. This removes the possibility of future damages for all events. Because of this, for the purposes of this study, the benefits of a buyout are fully equal to the damages which would be experienced by the structure, discounting other possible benefits such as recreational benefits from the open space area, etc.

The EAD for each structure were calculated using the methodology outlined in Section 2 of this report. For the analysis of buyouts, the purchase price was estimated using MCAD data on the value of the land and the improvements. For the estimate of buyout costs, a factor of 1.75 was applied to the appraised value of the property and improvements to account for the cost of the property, relocation and demolition costs.

The Present Value of the EAD over 50 years was calculated as described in Section 2 and used as the benefits for comparison with the estimated buyout cost to determine if a structure had a benefit-cost ratio greater than 1.0.

3.3.2. Structure Raising

Structure raising would elevate the affected structures in the area to above the one-percent exceedance event water surface elevation. Many of homes in this area have slab on grade foundations. The cost and technical issues of raising slab on grade structures typically make this type of flood protection impractical. While it would reduce the structural and contents damage experienced in the neighborhood, it would not have a sufficient reduction in the other damage categories to make it economically feasible. Structure raising would only remove the homes from the water, which would still leave an emergency response access problem in these areas. For these reasons, it was decided that structure raising was not a feasible option for this watershed.

3.3.3. Flood-Proofing

Flood-proofing helps to protect property inside structures by preventing floodwaters from entering the structure. Typical techniques include water-tight doors, window seals, seepage controls, check valves, and sandbagging. This non-structural option is not considered practical for residential homes in frequently flooded areas that are subjected to flooding depths in excess of the heights of window sills. In addition, the flood proofing of residences would require personal effort to protect the home from the rising water.

Flood-proofing was not considered a viable option for the watershed because of the rapid rise of water during a storm event.

3.4. Structural Alternatives

Structural alternatives achieve their objective by lowering the water surface on the stream rather than by affecting individual structures. These structural measures can lower the water surface by providing greater conveyance capacity at a lower elevation, or by decreasing the peak flow rates in the stream. As previously discussed, three types of structural alternatives were determined to be the most applicable to flood reduction within the Stewarts Creek watershed. These consisted of crossing structure modification, detention, and channel modifications.

Because of the diffuse location of impacted structures along the stream, no single location for reduction appeared to be significantly better than any along the stream. In order to minimize impacts to the City's tax base, the channel modification and detention locations were chosen in strategic areas of the City where there was a suitable amount of vacant property. The preliminary layouts for the alternatives were kept primarily within the existing floodplain in order to reduce the amount of excavation of overburden which would not provide additional storage volume, as well as having less impact on developable land available within the City. The proposed locations of the structural alternatives are shown in **Exhibit 3.2**. Cost estimate sheets are included in **Appendix E**.

3.4.1. Roadway Crossing Modifications

As stated previously, four roadway and railroad crossings were identified as high head loss structures. In order to reduce the water surface elevation upstream of the crossings, these structures were identified for analysis of modifications to improve their conveyance capacity as discussed in the following sections.

3.4.1.1. MSB1

The first structure modification analyzed was the FM 3083 roadway crossing of Stewart's Creek. Based on the existing condition analysis, this structure has approximately two feet of head loss in the one-percent exceedance probability event. The existing crossing consists of a three span bridge approximately 120-ft in length. In order to improve conveyance the bridge was extended to a length of approximately 200-ft consisting of 5 spans. Channel excavation through the bridge was also assumed to improve conveyance. The estimated construction cost for this alternative is $611,642.00.

3.4.1.2. MSB23

Because the BNSF railroad crossing is adjacent to the SH105 roadway crossing, it was decided to examine the both structures as a single alternative. In the existing condition, there was approximately 3.3 feet of headloss though the two structures in the one-percent exceedance probability event. The SH 105 crossing is a four span bridge approximately 120 feet in length. The existing BNSF crossing is a four span railroad bridge approximately 112 feet in length. The proposed SH 105 bridge was extended with a single span to approximately 150 feet in length. The BNSF crossing was extended to a six span bridge approximately 170 feet in length. The estimated construction cost for this alternative is $1,264,293.00.

3.4.1.3. T2B4A & T2B4B

The existing Union Pacific Railroad crossing of Tributary 2 consists of three 60-inch circular culverts and has approximately ten feet of head loss across the structure.

Full replacement of the crossing would typically be prohibitively expensive unless a very large number of structures would be impacted. The first option examined for this crossing, in order to minimize the cost, an additional 60-inch culvert was assumed to be bored and jacked adjacent to the existing culverts rather than replacement of the crossing to determine how much improvement would occur. The estimated construction cost for this option is approximately $120,500.00.

In order to determine the maximum benefit possible, a second option was examined where the crossing was replaced with a bridge. The proposed bridge consisted of four spans with an overall length of approximately 100 feet. The estimated construction cost for this option is approximately $1,301,000.00.

3.4.2. Detention and Channel Modification Alternatives

The purpose of the detention alternatives was to reduce the peak flow rates on Stewarts Creek to determine the impacts on flooding. In order to maximize the volume of detention available within the sites chosen, the detention alternatives were analyzed as in-line detention. For all of the detention and channel modification alternatives, excavation occurred approximately four feet above the flowline of the channel in order to avoid environmental impacts. This resulted in excavation of the overbank areas, with the natural channel remaining as a low flow channel meandering through the detention area. The excavated area was graded to drain to the low flow channel as seen in **Figure 1**.

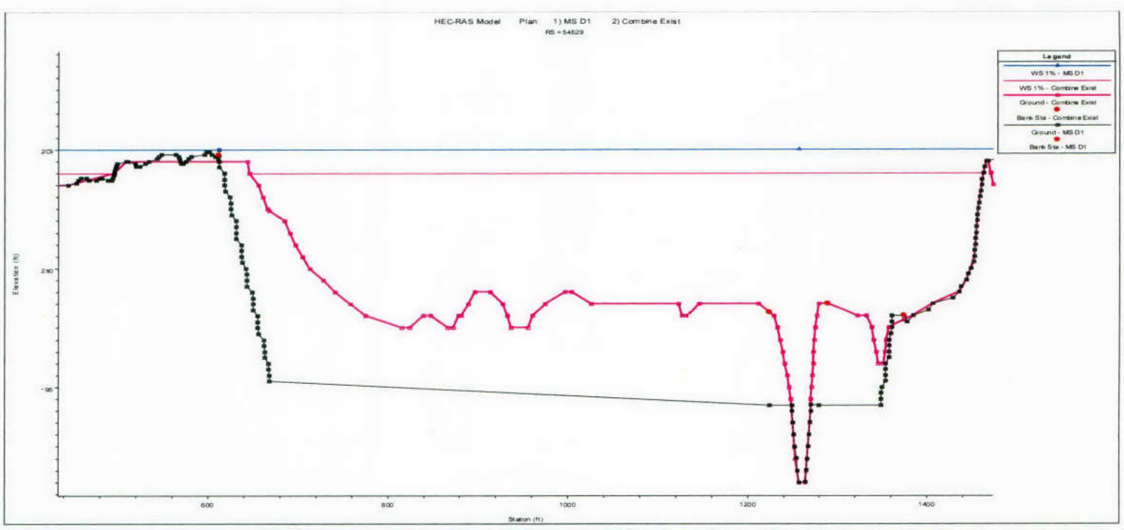


Figure 1 - Typical Channel/Detention Section

The purpose of the channel modification alternatives was to increase the conveyance of the streams in areas near where the flooding occurred to reduce the water surface elevation through these areas. Due to the locations used for the detention alternatives near areas of previous flooding and the availability of land for substantial channel modifications, the same locations and layouts were used for the channel modification alternatives. The difference between the detention and channel modification alternatives was the removal of the control structure.

3.4.2.1. MSD1 & MSC1

This proposed location is located between FM 1484 and FM 3083. The detention layout analyzed is shown in **Exhibit 3.3**. The control structure at the downstream outlet consisted of dual 6' x 6' reinforced concrete boxes. The area of the proposed detention is approximately 73 acres, with approximately 450,000 cubic yards of excavation

3.4.2.2. MSD2 & MSC2

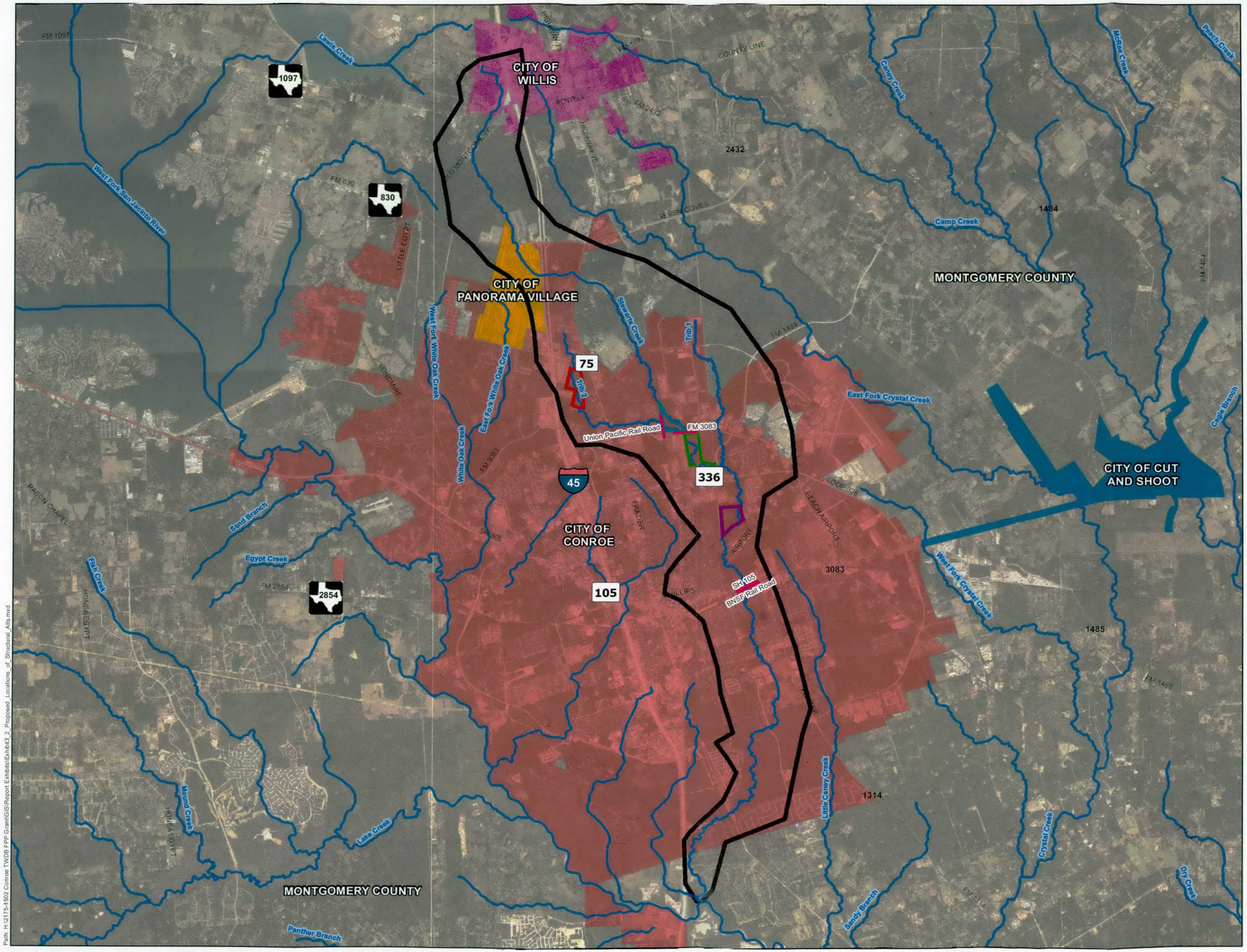
The proposed detention is located immediately upstream of FM 3083. The detention layout analyzed is shown in **Exhibit 3.4**. The control structure at the downstream outlet consists of dual 6' x 6' reinforced concrete boxes. The area of the proposed detention is approximately 34 acres, with approximately 271,000 cubic yards of excavation.

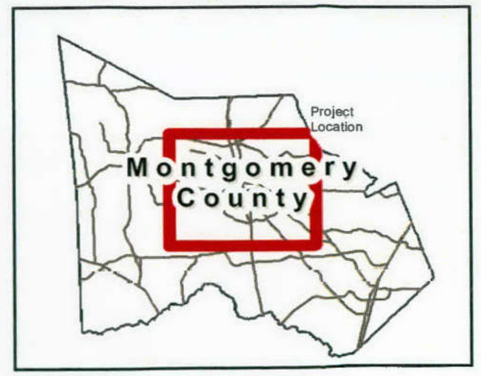
3.4.2.3. MSD3 &MSC3

The proposed detention is located upstream of E. Dallas St. The detention layout as analyzed is shown in **Exhibit 3.5**. The control structure at the downstream outlet consists of three 6' x 6' reinforced concrete boxes. The area of the proposed detention is approximately 63 acres, with approximately 688,000 cubic yards of excavation.

3.4.2.4. T2D4 &T2C4

The proposed detention facility is located on Tributary 2, upstream of N. Frazier St. The detention layout as analyzed is shown in **Exhibit 3.6**. The control structure at the downstream outlet consists of a 60-inch reinforced concrete pipe. The area of the proposed detention is approximately 66 acres, with approximately 350,000 cubic yards of excavation.





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One Inch Equals 7,000 Feet

Note:
This exhibit shows pertinent items necessary to illustrate the information described in the text and is not intended to include all physical characteristics of the area.

Data Source:
Aerial Photography 2010 (HGAC)

Legend

- MONTGOMERY STREAMS
- BRIDGE CHANGE LOCATIONS
- MSC1 & MSD1
- MSC2 & MSD2
- MSC3 & MSD3
- T2C4 & T2D4
- STEWARTS CREEK WATERSHED

CITY LIMITS

- CITY OF CONROE
- CITY OF CUT AND SHOOT
- CITY OF WILLIS
- CITY OF PANORAMA VILLAGE

Exhibit 3.2

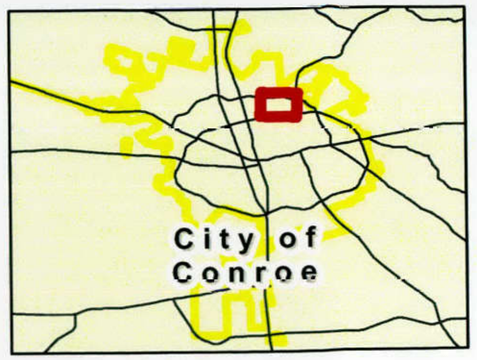
STEWART'S CREEK FLOOD PROTECTION PLAN

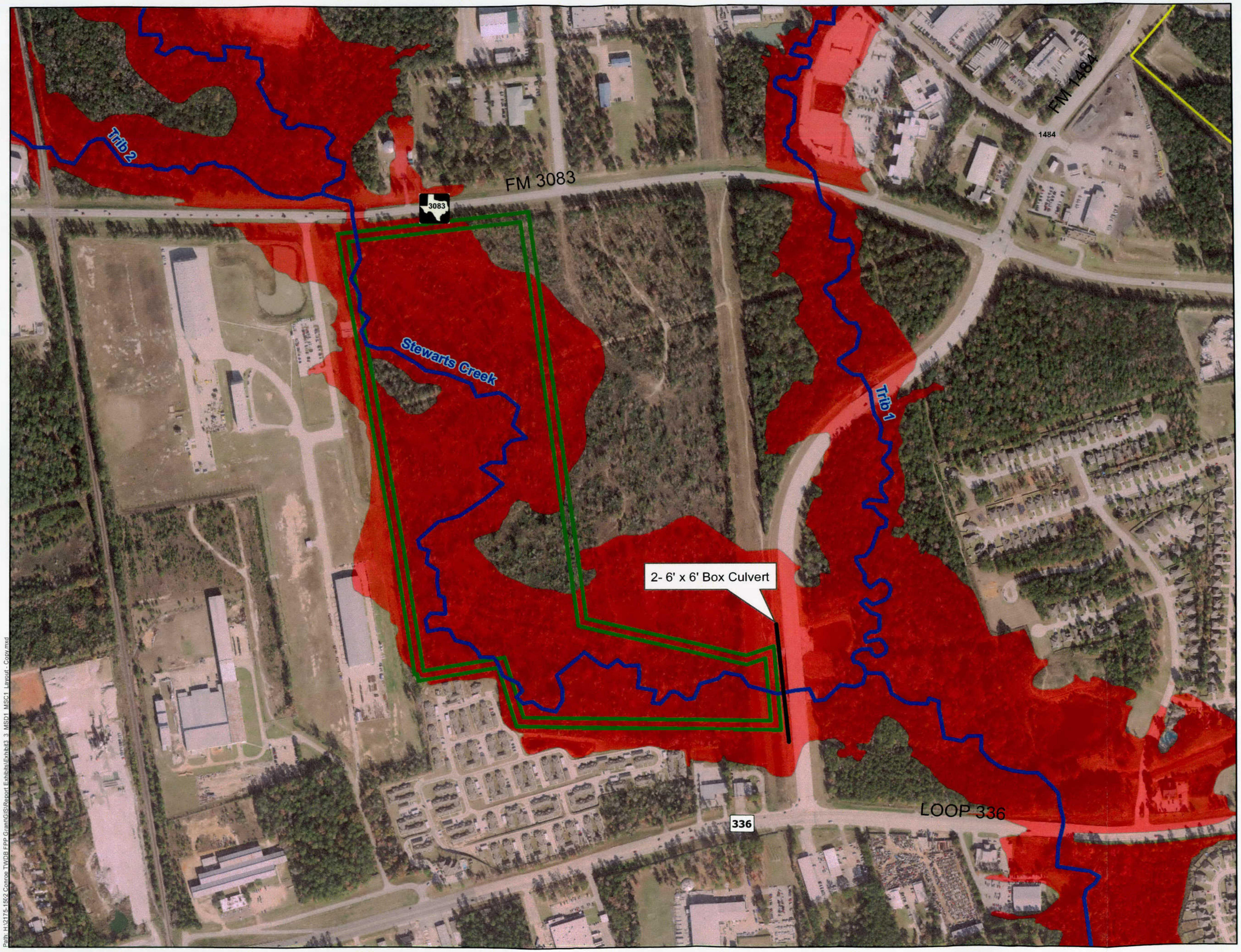
PROPOSED LOCATIONS OF STRUCTURAL ALTERNATIVES

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

Path: H:\2175-1502 Conroe TWDB FPP Grant\GIS\Report Exhibits\Exhibit3_2_Proposed_Locations_of_Structural_Alts.mxd





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Note.
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Data Source:
Aerial Photography 2010 (HGAC)

LEGEND

- Stewart's Creek
- MSC1 & MSD1
- 1% Floodplain
- Conroe City Limits
- Control Structure

Exhibit 3.3

STEWART'S CREEK FLOOD PROTECTION PLAN

MSC1 & MSD1 LAYOUT

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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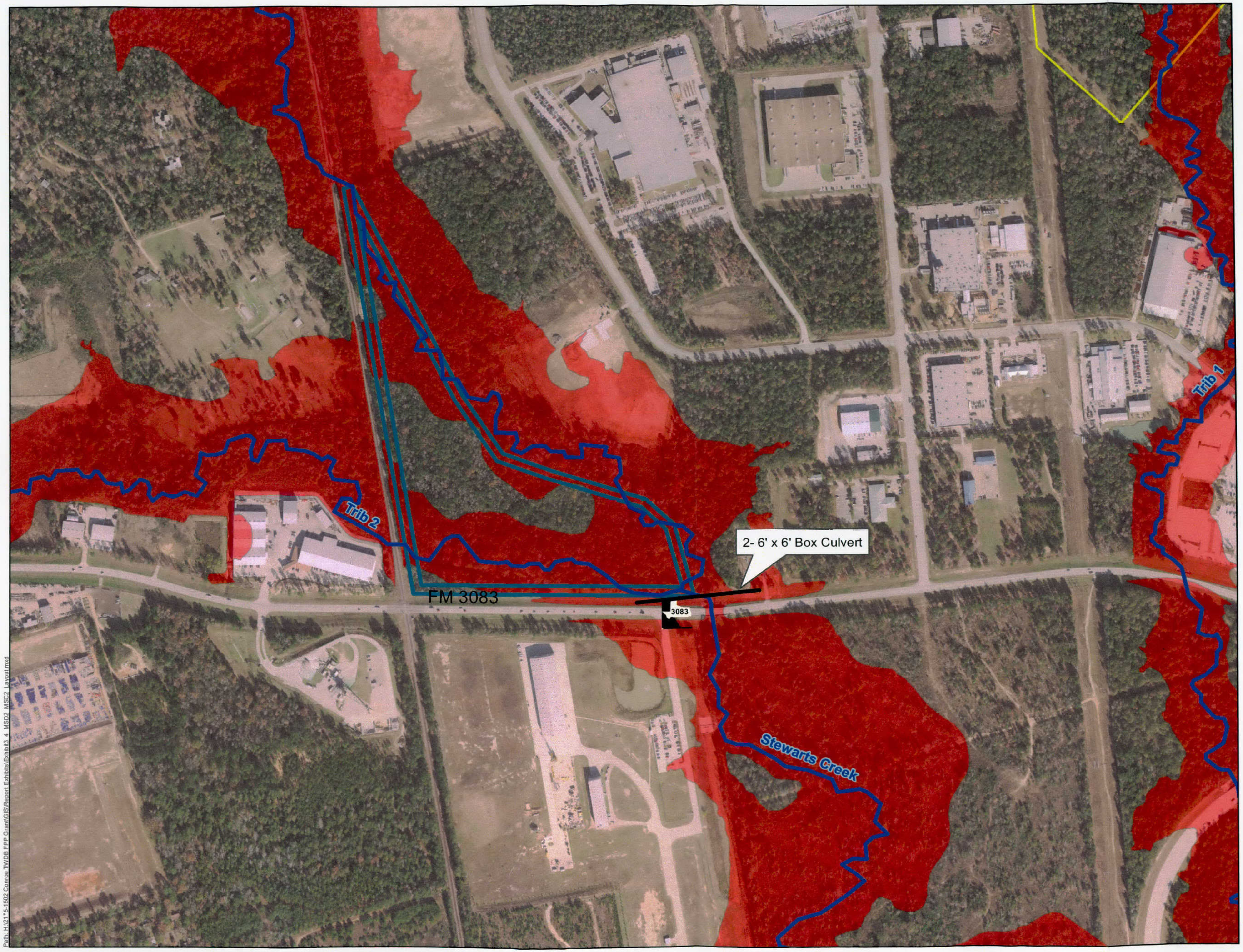

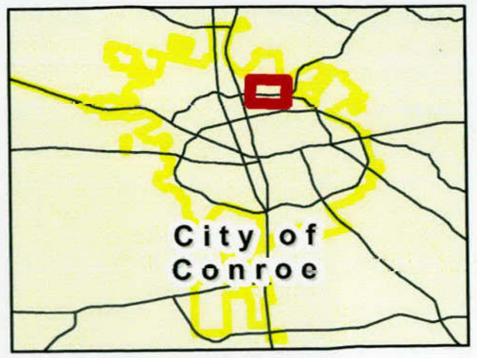

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One Inch Equals 500 Feet

Note:
This exhibit shows pertinent items necessary to illustrate the information described in the text and is not intended to include all physical characteristics of the area.

Data Source:
Aerial Photography 2010 (HGAC)

LEGEND

- Stewart's Creek
- MSC2 & MSD2
- 1% Floodplain
- Conroe City Limits
- Control Structure

Exhibit 3.4

STEWART'S CREEK FLOOD PROTECTION PLAN

MSC2 & MSD2 LAYOUT

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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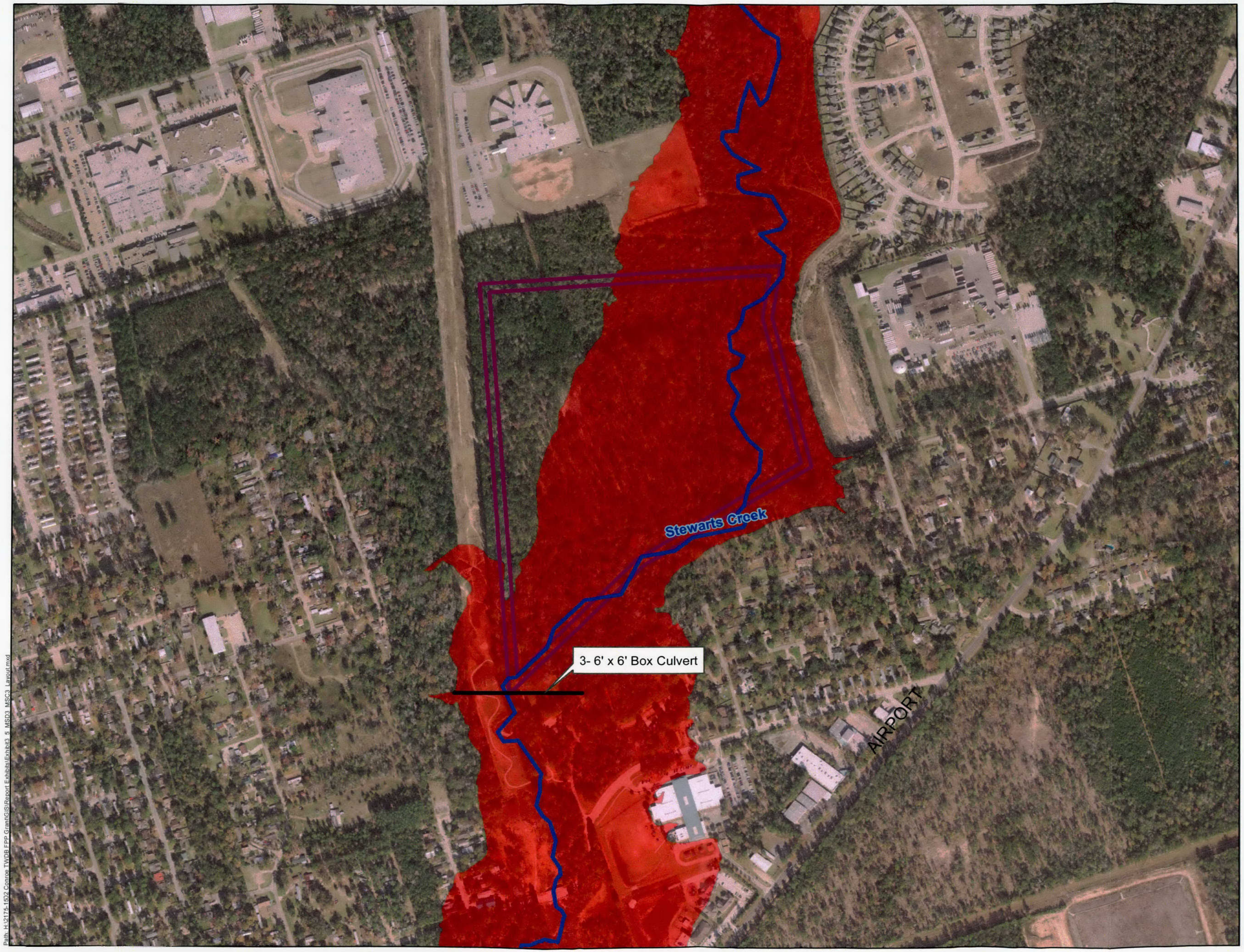

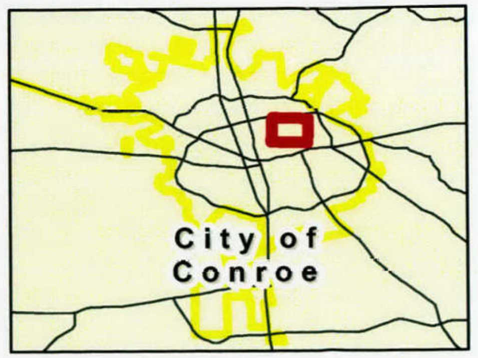

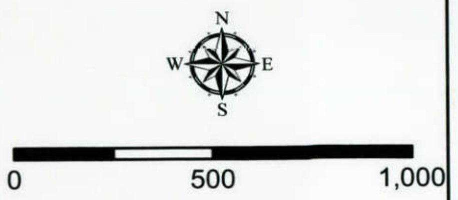

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Note:
This exhibit shows pertinent items necessary to illustrate the information described in the text and is not intended to include all physical characteristics of the area.

Data Source:
Aerial Photography 2010 (HGAC)

LEGEND

- Stewart's Creek
- MSC3 & MSD3
- 1% Floodplain
- Conroe City Limits
- Control Structure

Exhibit 3.5

STEWART'S CREEK FLOOD PROTECTION PLAN

MSC3 & MSD3 LAYOUT

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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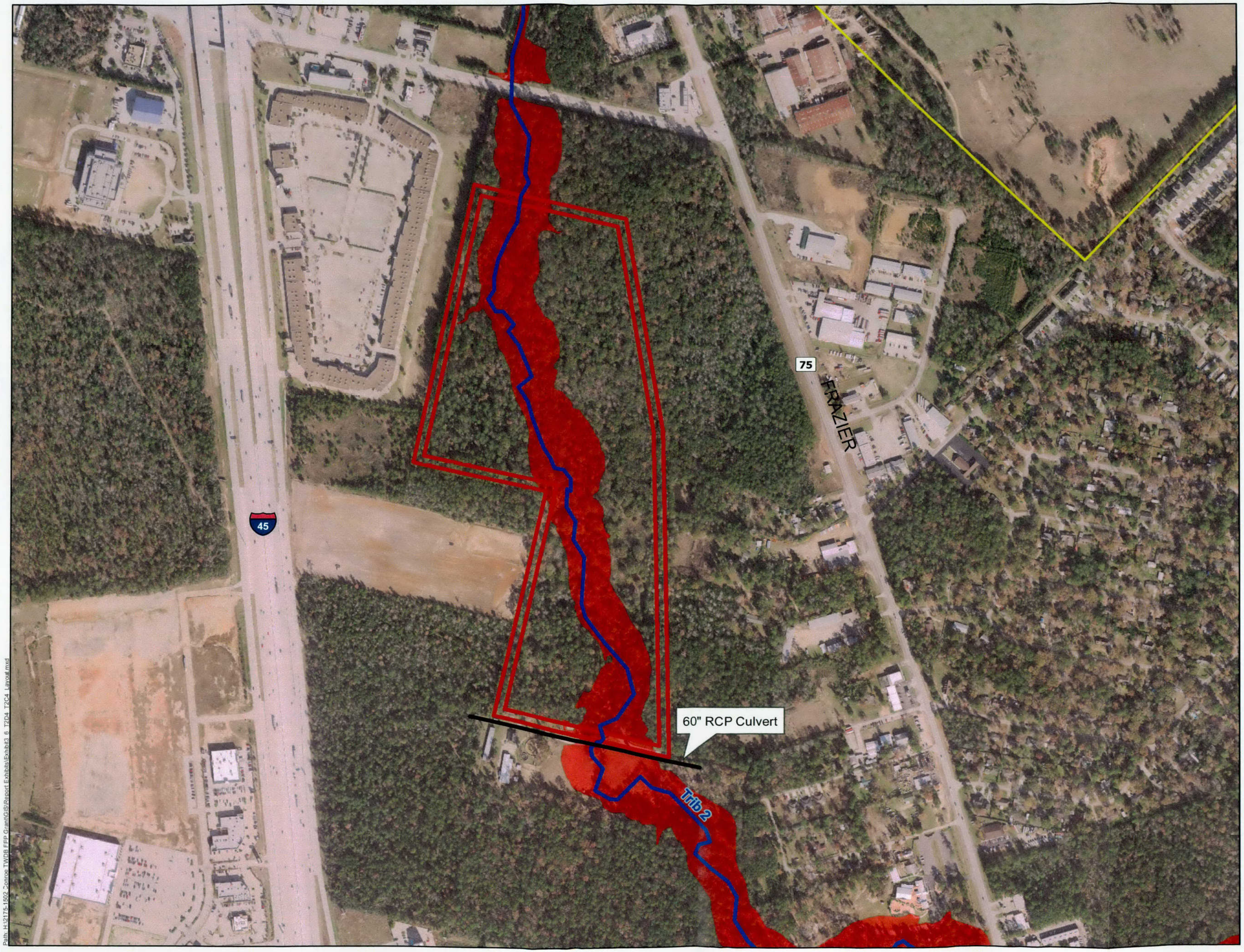

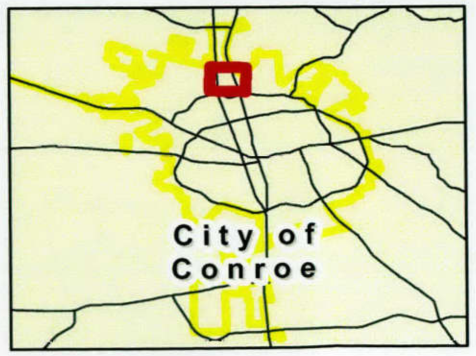

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One Inch Equals 500 Feet

Note:
This exhibit shows pertinent items necessary to illustrate the information described in the text and is not intended to include all physical characteristics of the area.

Data Source:
Aerial Photography 2010 (HGAC)

LEGEND

- Stewart's Creek
- T2C4 & T2D4
- 1% Floodplain
- Conroe City Limits
- Control Structure

Exhibit 3.6

STEWART'S CREEK FLOOD PROTECTION PLAN

T2C4 & T2D4 LAYOUT

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

Path: H:\2175-1502 Conroe TWDB FFP Grant\GIS\Report Exhibits\Exhibit3_6_T2D4_T2C4_Layout.mxd

4.0 RESULTS

4.1. Existing Condition

Due to the changes in methodology and information, there are differences between the models developed for this study and the current Effective Flood Insurance Study (FIS). The most significant differences include greatly increased flow rates and higher water surface elevations upstream of several crossings. With the increased development within the watershed, updated rainfall amounts and other differences in the methodologies, the peak flow rates are approximately double the discharges used for the FIS. **Table 4.1** shows the change in peak flow rates at selected locations.

Table 4.1 – Comparison of 1% Discharges

Reach	Cross Section	FEMA	FPP Study	Change
Main Stem	AI	1861	3349	1488
	AF	2250	3821	1571
	AB	2757	5663	2906
	X	3809	7486	3677
	H	4418	9199	4781
	G	4461	9199	4738
Trib 2	G	501	957	456
	E	853	1533	680
	B	936	1768	832

Exhibits 4.1a, 4.1b, 4.1c, 4.1d show a comparison of the water surface elevation from the model developed for this study and the water surface elevation in the Effective FIS. As seen, there are areas with up to a three foot increase in water surface elevation. **Table 4.2** shows a comparison of water surface elevations at selected points. All elevations shown are on the NAVD 1988 vertical datum.

Table 4.2 - Comparison of FIS and FPP Water Surface Elevations				
Reach	**Cross Section**	**FEMA**	**FPP Study**	**Change**
Main Stem	AI	270.1	267.2	-2.9
	AF	258.3	257.9	-0.4
	AB	219.6	221.1	1.5
	X	196.4	199.4	3
	H	147.8	148.7	0.9
	G	134.4	133.8	-0.6
Trib 2	G	252.8	251.9	-0.9
	E	229.2	231.8	2.6
	B	221.3	223.6	2.3

The areal extents of the floodplain do not differ significantly from the floodplain shown on the Effective Flood Insurance Rate Maps as shown in **Exhibit 4.2**.

When homes in the watershed experience flooding and receive permits to rebuild, current regulations call for them to build, floodproof, or elevate to above the Effective Base Flood Elevation. Because the FIS for Stewart's Creek is out of date, this could contribute to the problem of repetitive flooding. If rebuilt to the current Effective elevation, these structures could flood again in an event less than the one-percent exceedance event.

Based on the results of the existing conditions model, the water surface elevations along Stewarts Creek for the 50-, 20-, 10-, 4-, 2-, 1-, and 0.2-percent events were determined. The damages for each event were calculated using the GIS tool described in Section 2. These calculated damages were then used to calculate the existing condition EAD as shown in **Table 4.3**.

Table 4.3 - Existing Condition Expected Annual Damages					
Exceedance Probability	No. of flooded Structures	Structural Damages	Contents Damages	Total Damages	Freq x Damages
50%	5	$ 37,118.18	$ 49,217.75	$ 86,335.94	$ 43,167.97
20%	8	$ 106,302.10	$ 134,803.45	$ 241,105.56	$ 48,221.11
10%	14	$ 168,700.71	$ 224,696.74	$ 393,397.45	$ 39,339.75
4%	22	$ 349,983.29	$ 440,355.36	$ 790,343.65	$ 31,613.75
2%	29	$ 494,198.84	$ 611,622.11	$ 1,105,820.95	$ 22,116.42
1%	60	$ 910,335.09	$ 1,133,707.19	$ 2,044,042.28	$ 20,440.42
0.20%	140	$ 3,244,231.21	$ 3,656,188.04	$ 6,900,419.24	$ 13,800.84
				------------	------------
				EAD	$ 218,700.25

For this study the benefits for each of the alternatives were defined as the reduction in EAD with the proposed alternative in place. The impacts of each alternative are discussed in the following sections.

4.2. Flood Reduction Analysis

4.2.1. Non-Structural Alternatives

As stated in Section 3, buyouts were the only non-structural alternative which was considered feasible for analysis within the watershed for this study. The Benefit-Cost for the 140 properties within the study area which were calculated as suffering damage in the 0.2%-exceedance probability event was calculated. **Table 4.4** provides the appraised value of the property and structure, the EAD, the estimated Construction Cost, the Present Value of the benefits, and the Benefit-Cost ratio calculated for the eleven properties identified which had Benefit-Cost ratios equal to or greater than 1.0. Of the eleven properties identified, five are listed by the appraisal district as mobile homes.

Table 4.4 - Buyout Benefit Cost by Property					
	Appraised Value	EAD	Benefit	Cost	B/C
Structure 1	$ 85,720.00	$ 8,471.76	$ 199,984.47	$ 150,010.00	1.33
Structure 2	$ 25,820.00	$ 3,494.02	$ 82,479.82	$ 45,185.00	1.83
Structure 3	$ 17,860.00	$ 3,921.96	$ 92,581.82	$ 31,255.00	2.96
Structure 4	$ 121,780.00	$ 59,429.22	$ 1,402,886.23	$ 213,115.00	6.58
Structure 5	$ 26,220.00	$ 7,170.57	$ 169,268.44	$ 45,885.00	3.69
Structure 6	$ 13,550.00	$ 10,601.81	$ 250,266.32	$ 23,712.50	10.55
Structure 7	$ 50,370.00	$ 24,309.51	$ 573,850.31	$ 88,147.50	6.51
Structure 8	$ 3,210.00	$ 758.77	$ 17,911.48	$ 5,617.50	3.19
Structure 9	$ 22,170.00	$ 1,647.65	$ 38,894.52	$ 38,797.50	1.00
Structure 10	$ 52,280.00	$ 23,584.03	$ 556,724.66	$ 91,490.00	6.09

Table 4.4 - Buyout Benefit Cost by Property					
	Appraised Value	EAD	Benefit	Cost	B/C
Structure 11	$ 80,000.00	$ 6,914.15	$ 163,215.32	$ 140,000.00	1.17

The methodology used for this study provides an effective screening tool for determination of appropriate properties which may prove viable for buyouts. Because the methodology used for this analysis does not match FEMA criteria, further investigation of these properties would be needed in order to apply for FEMA grants for buyout purposes. Detailed calculations of the buyout analysis are provided in **Appendix F**.

4.2.2. Structural Alternatives

4.2.2.1. Roadway Crossing Modifications

Based on the results of the Roadway Crossing Modification alternatives, due to the relatively steep channel due to the topography, the effects of the reduced head loss do not extend a significant distance upstream of the modifications. With the exception of one area, the lack of a cluster of flooded structures minimizes the positive effects of these reductions. The results specific to each alternative are discussed in the following sections. **Table 4.5** shows the Benefit Summary for the Crossing Modification alternatives. As seen in the table, the increased conveyance of some of the crossings results in higher peak flows downstream leading to increased overall damages and a negative benefit-cost ratio.

Table 4.5 - Crossing Modification Benefit Summary					
	EAD	EAD Reduction	Benefits	Cost	B/C
Existing	$ 218,700.25				
MSB1	$ 218,930.85	$ - 230.60	$ - 5,443.57	$ 611,642.43	-0.01
MSB23	$ 214,510.88	$ 4,189.37	$ 98,894.33	$ 1,264,293.45	0.08
T2B4A	$ 218,893.01	$ - 192.76	$ - 4,550.23	$ 120,449.70	-0.04
T2B4B	$ 219,184.40	$ - 484.15	$ - 11,428.89	$ 1,301,355.09	-0.01
Negative correlation means increase in overall damages.					

4.2.2.1.1. MSB1

Based on the results of the analysis, the proposed bridge extension and excavation lowered the water surface immediately upstream of the bridge by approximately one-foot in the one-percent exceedance probability event. The lowering of the water surface lessened further upstream of the bridge with no reduction in the water surface elevation 2700 feet upstream of the crossing as shown in **Exhibit 4.3**.

No structures were fully removed from the inundation limits of any event with this alternative, and the lowered water surface only resulted in a reduction of the EAD of $230.26.

4.2.2.1.2. MSB23

Based on the results of the analysis, the proposed bridge extension and excavation lowered the water surface immediately upstream of the bridge by approximately one-foot in the one-percent exceedance probability event. The lowering of the water surface lessened further upstream of the bridge with no significant reduction in the water surface elevation 2800 feet upstream of the crossing as shown in **Exhibit 4.4**.

Table 4.6 provides a breakdown of the reduction in flooded structures by frequency with the bridge modifications.

Table 4.6 – MSB23 Reduction in Flooded Structures							
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	1	0	0	2	2	4	1

The EAD reduction with this alternative was $4,189.37 annually.

4.2.2.1.3. T2B4A & T2B4B

The addition of a single culvert only reduced the water surface upstream of the crossing by approximately 0.1 feet as shown in **Exhibit 4.5**, and did not remove any structures from flooding in any event. The EAD reduction with this option is $192.76.

For the option with replacement of the crossing with a bridge, there is approximately 6.7 feet of reduction of head loss across the structure. There is a decrease in water surface reduction such that approximately 4700 feet upstream there is no significant difference in water surface elevations as compared to the existing condition. With this option no structures are removed from flooding upstream of the crossing. The revised structure releases more water to the main stem of Stewarts Creek causing an increase in flood damages along the main stem resulting in an increase in the EAD of $484.15.

4.2.2.2. Detention Alternatives

Based on the results of the detention alternatives, the amount of storage volume available at these locations is relatively small as compared to the watershed drainage area upstream of the locations. With the combination of the large drainage areas and the inline detention, there is a relatively small effect on the peak flow rates downstream of the detention locations. In the steady state analysis, the impact on peak flow rates was typically less than 10-percent. The water surface decreases for the one-percent event downstream of the alternatives was typically approximately 0.5 feet. In order to verify the accuracy of the flow changes, an unsteady HEC-RAS analysis was performed of the one-percent event for each alternative. The unsteady analysis showed similar results in the impacts on the water surface elevations and flow reductions. The following sections discuss the results specific to each alternative. **Table 4.7** shows the Benefit Summary for the Detention Alternatives.

Table 4.7 - Detention Alternatives Benefit Summary					
	EAD	EAD Reduction	Benefits	Cost	B/C
Existing	$ 218,700.25				
MSD1	$ 178,828.21	$ 39,872.04	$ 941,219.47	$ 5,279,482.36	0.18
MSD2	$ 211,904.02	$ 6,796.23	$ 160,431.83	$ 2,851,325.30	0.06
MSD3	$ 204,366.69	$ 14,333.56	$ 338,358.13	$ 6,645,134.79	0.05
T2D4	$ 218,523.19	$ 177.06	$ 4,179.72	$ 3,709,614.17	0.00

4.2.2.2.1. MSD1

As shown in **Exhibit 4.6**, this alternative results in an increased water surface elevation immediately upstream of the control structure with a significant reduction at the upstream end of the detention. There was a small decrease in peak flow rates downstream of the detention resulting in approximately 0-0.5 foot reductions in the water surface elevation downstream of the detention. As seen in **Table 4.8**, overall this resulted in the removal of damages from seven structures in the one-percent event, but the addition of one structure in the 0.2-percent event.

Table 4.8 – MSD1 Reduction in Flooded Structures							
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	1	0	3	6	11	7	-1

This alternative had a reduction in EAD of $39,872.00.

4.2.2.2.2. MSD2

As with all of the detention alternatives, this analysis showed an increased water surface elevation immediately upstream of the control structure with a significant reduction at the upstream end of the detention as shown in **Exhibit 4.7**. This alternative had the smallest amount of storage and the flows downstream showed very small changes, with small changes in the water surface elevation downstream of the detention of typically less than 0.1 feet. As seen in **Table 4.9**, based on our analysis this resulted in damages being removed from two structures in the one-percent event.

Table 4.9 – MSD2 Reduction in Flooded Structures							
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	0	0	1	3	4	2	2

This alternative had a reduction in EAD of $6,796.23.

4.2.2.2.3. MSD3

This alternative was the location furthest downstream in the watershed of the detention alternatives. Again, there was increased water surface elevation immediately upstream of the control structure, with a significant water surface reduction at the upstream end of the facility as seen in **Exhibit 4.8**. There was very little change in flow downstream of the facility and water surface reductions downstream generally less than 0.1-foot. **Table 4.10** shows the reduction in flooded structures.

Table 4.10 – MSD3 Reduction in Flooded Structures							
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	2	1	1	1	3	5	1

This alternative had $14,333.60 reduction in the EAD.

4.2.2.2.4. T2D4

This was the only detention alternative not located on the main stem of Stewarts Creek. **Exhibit 4.9** shows the water surface profile through the proposed facility. As with the other detention alternative, the available storage is a small amount relative to the upstream drainage area and the reduction in peak flow rates downstream is approximately 50 cfs. This results in water surface reductions of approximately less than 0.1 feet. One structure is removed from the one-percent inundation, and none from any of the other frequency events. This alternative had and EAD reduction of $177.06.

4.2.2.3. Channel Modification Alternatives

Based on the results of the Channel Modification Alternatives, due to the relative steepness of the watershed, the positive effects of these alternatives do not extend much beyond the limits of the modifications. With there being relatively few houses in a specific area, these alternatives did not perform well from a cost-benefit standpoint. **Table 4.11** shows the Benefits Summary for the Channel Modification alternatives.

Table 4.11 - Channel Modification Benefit Summary					
	EAD	EAD Reduction	Benefits	Cost	B/C
Existing	$ 218,700.25				
MSC1	$ 206,379.74	$ 12,320.51	$ 290,838.04	$ 5,187,683.80	0.06
MSC2	$ 217,431.40	$ 1,268.85	$ 29,952.56	$ 2,662,463.90	0.01
MSC3	$ 199,138.11	$ 19,562.14	$ 461,783.88	$ 6,442,728.39	0.07
T2C4	$ 218,522.24	$ 178.01	$ 4,202.14	$ 3,665,892.17	0.00

4.2.2.3.1. MSC1

This detention alternative utilized the same location and preliminary layout as MSD1 and shown in **Exhibit 3.3**. This alternative did not utilize the control structure and only provided conveyance improvements. Based on the analysis, the one-percent water surface reductions range from approximately 0.5 feet to four feet through the channel modification area as shown in **Exhibit 4.10**. The reduction ends approximately 300 feet upstream of the facility as modeled. There was a reduction in EAD of $12,320.50 based on the results of all events. The breakdown of the reduction in the number of damaged structures is shown in **Table 4.12**.

Table 4.12 – MSC1 Reduction in Flooded Structures							
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	0	0	1	3	5	8	7

4.2.2.3.2. MSC2

This detention alternative utilized the same location and preliminary layout as MSD2 and shown in **Exhibit 3.4**. This alternative did not utilize the control structure and only provided conveyance improvements. As seen in **Exhibit 4.11**, there was 0.25 foot to approximately 2.75 feet of reduction in the one-percent water surface elevation through the proposed facility. Significant water surface reduction ends approximately 3000 feet upstream of the proposed facility. Based on the results of all of the studied events, there is a reduction in EAD of $1,268.85. The breakdown of the change in flooded structures is shown in **Table 4.13**.

Table 4.13 – MSC2 Reduction in Flooded Structures							
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	0	0	0	-1	0	1	6

4.2.2.3.3. MSC3

This detention alternative utilized the same location and preliminary layout as MSD3 and shown in **Exhibit 3.5**. This alternative did not utilize the control structure and only provided conveyance improvements. Based on the results, there was a reduction of 0.25 to five feet through the facility, shown in **Exhibit 4.12**. Significant water surface reduction ends approximately 3000 feet upstream of the proposed facility. Based on the results of all of the studied events, there is a reduction in EAD of $19,562.10. The breakdown of the change in flooded structures is shown in **Table 4.14**.

Table 4.14 – MSC3 Reduction in Flooded Structures

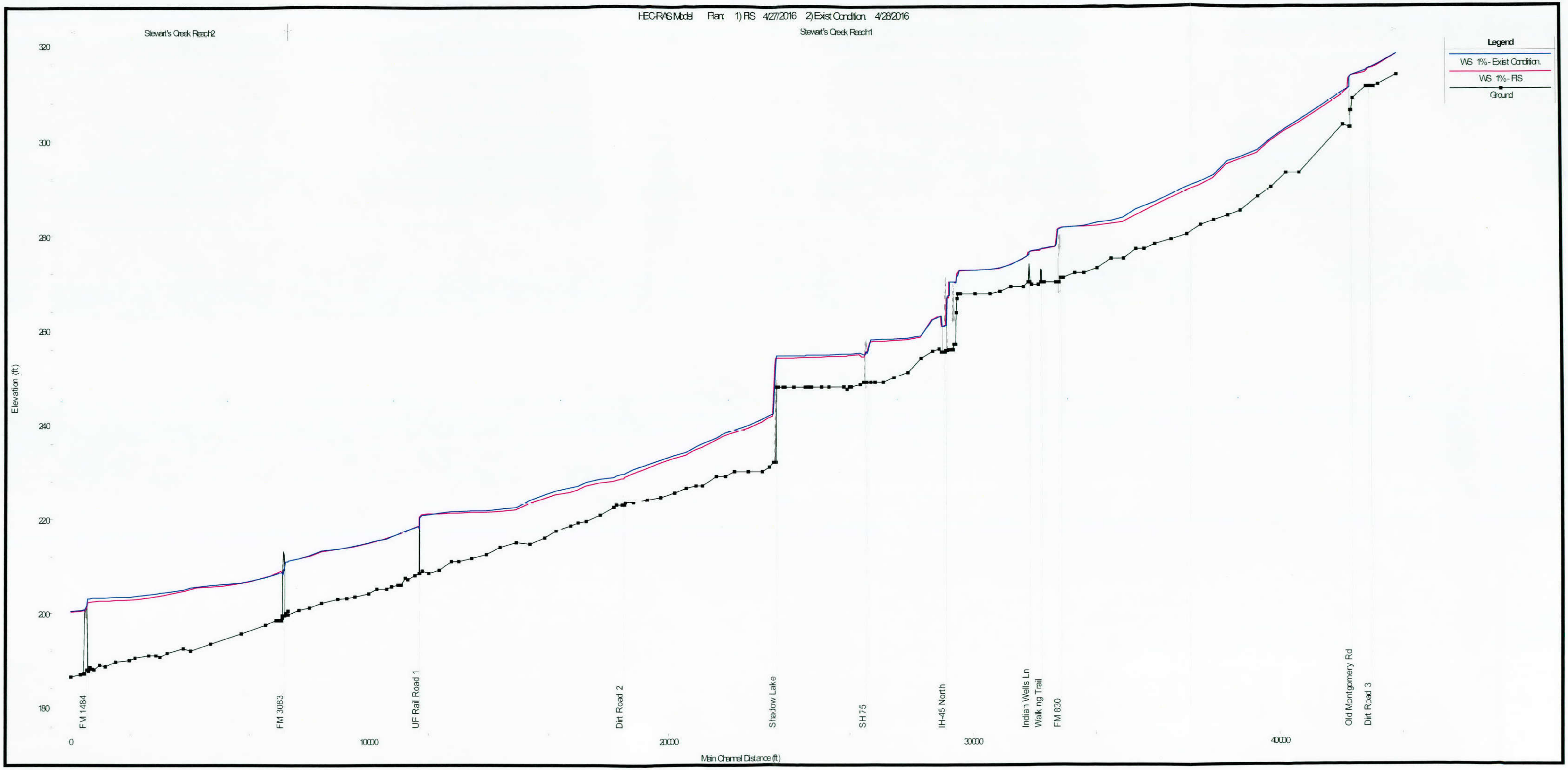
Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	2	0	0	3	4	6	1

4.2.2.3.4. T2C4

This detention alternative utilized the same location and preliminary layout as T2D4 and shown in **Exhibit 3.6**. This alternative did not utilize the control structure and only provided conveyance improvements. As seen in **Exhibit 4.13**, the results show zero to two and a half feet of water surface reduction through the facility. Significant water surface reduction ends approximately 3000 feet upstream of the proposed facility. Based on the results of all of the studied events, there is a reduction in EAD of $178.01. The breakdown of the change in flooded structures is shown in **Table 4.15**.

Table 4.15 – T2C4 Reduction in Flooded Structures

Probability Event	50%	20%	10%	4%	2%	1%	0.2%
Number of Structures Reduced	0	0	0	0	0	1	1



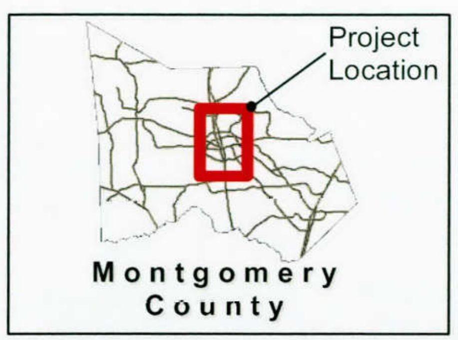


Exhibit 4.1a

STEWART'S CREEK FLOOD PROTECTION PLAN

FIS MAIN STEM WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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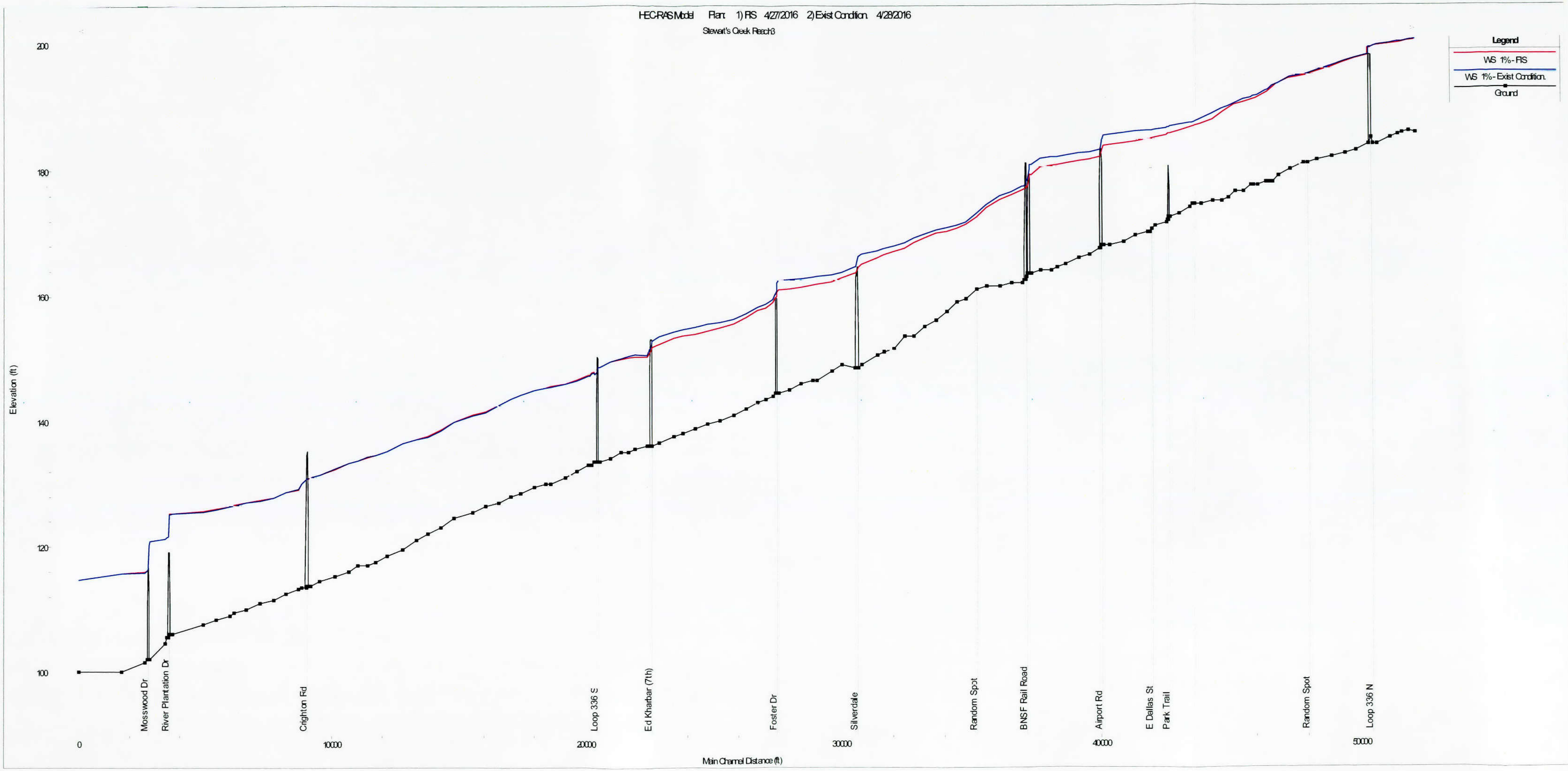

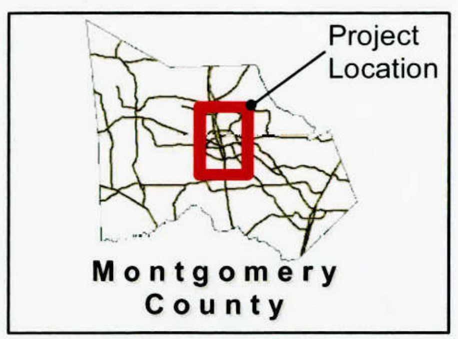

Exhibit 4.1b

STEWART'S CREEK FLOOD PROTECTION PLAN

FIS MAIN STEM WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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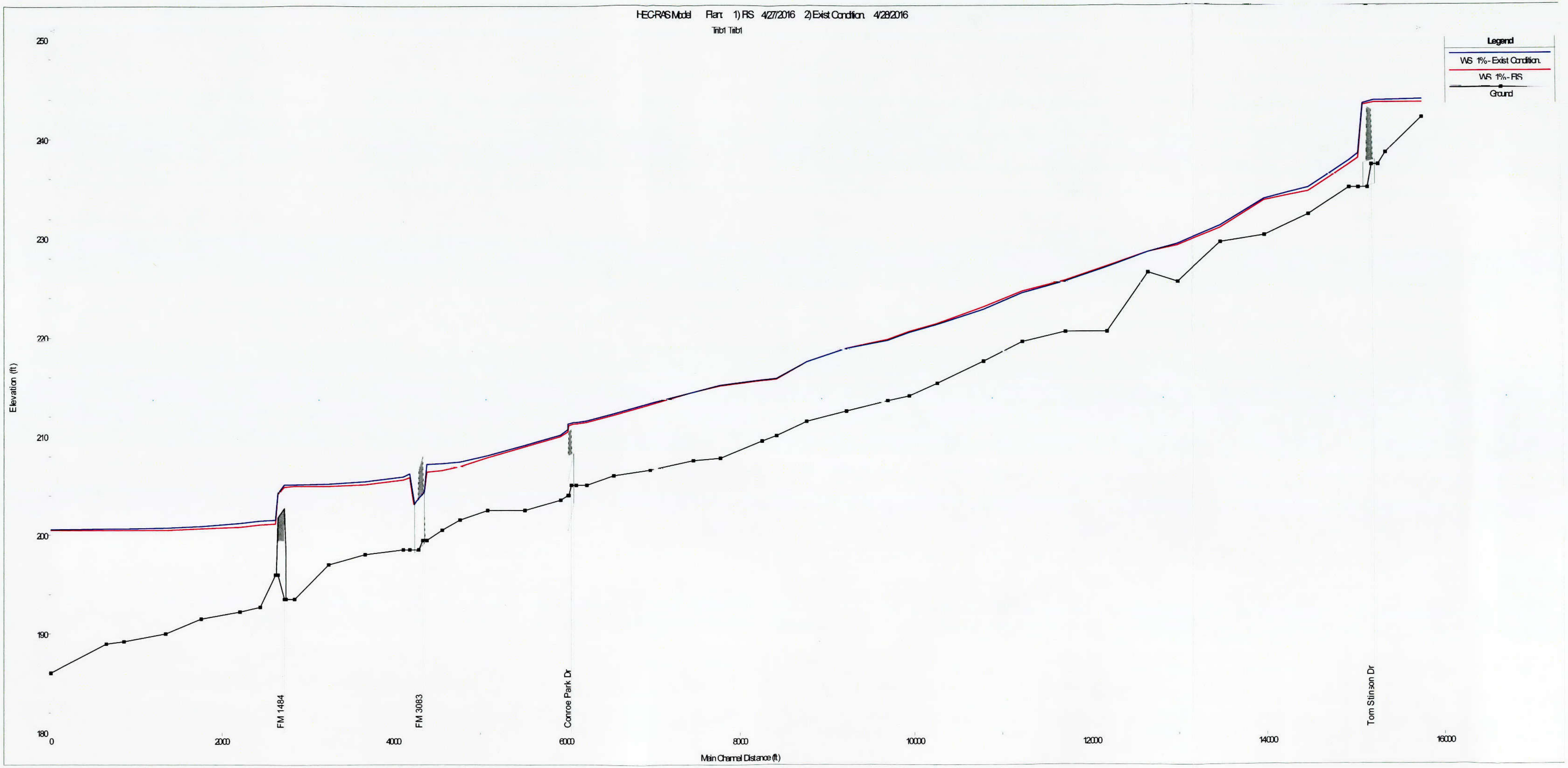

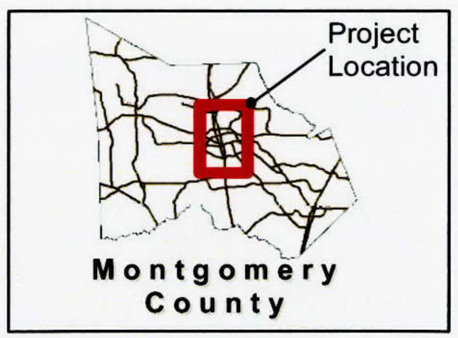

Exhibit 4.1c

STEWART'S CREEK FLOOD PROTECTION PLAN

FIS TRIB 1 WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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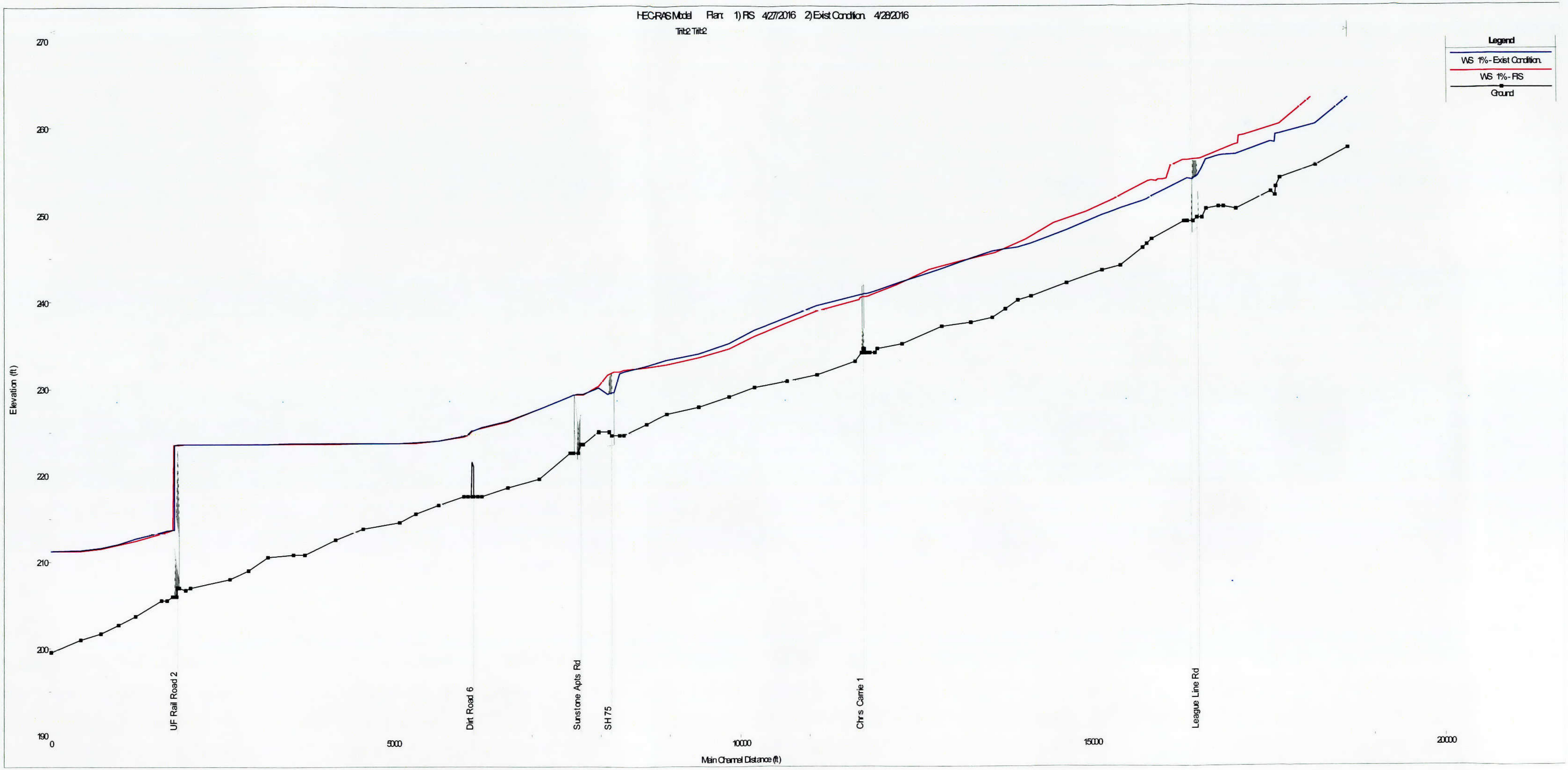

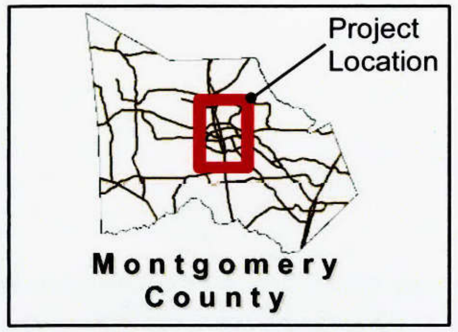

Exhibit 4.1d

STEWART'S CREEK FLOOD PROTECTION PLAN

FIS TRIB 2
WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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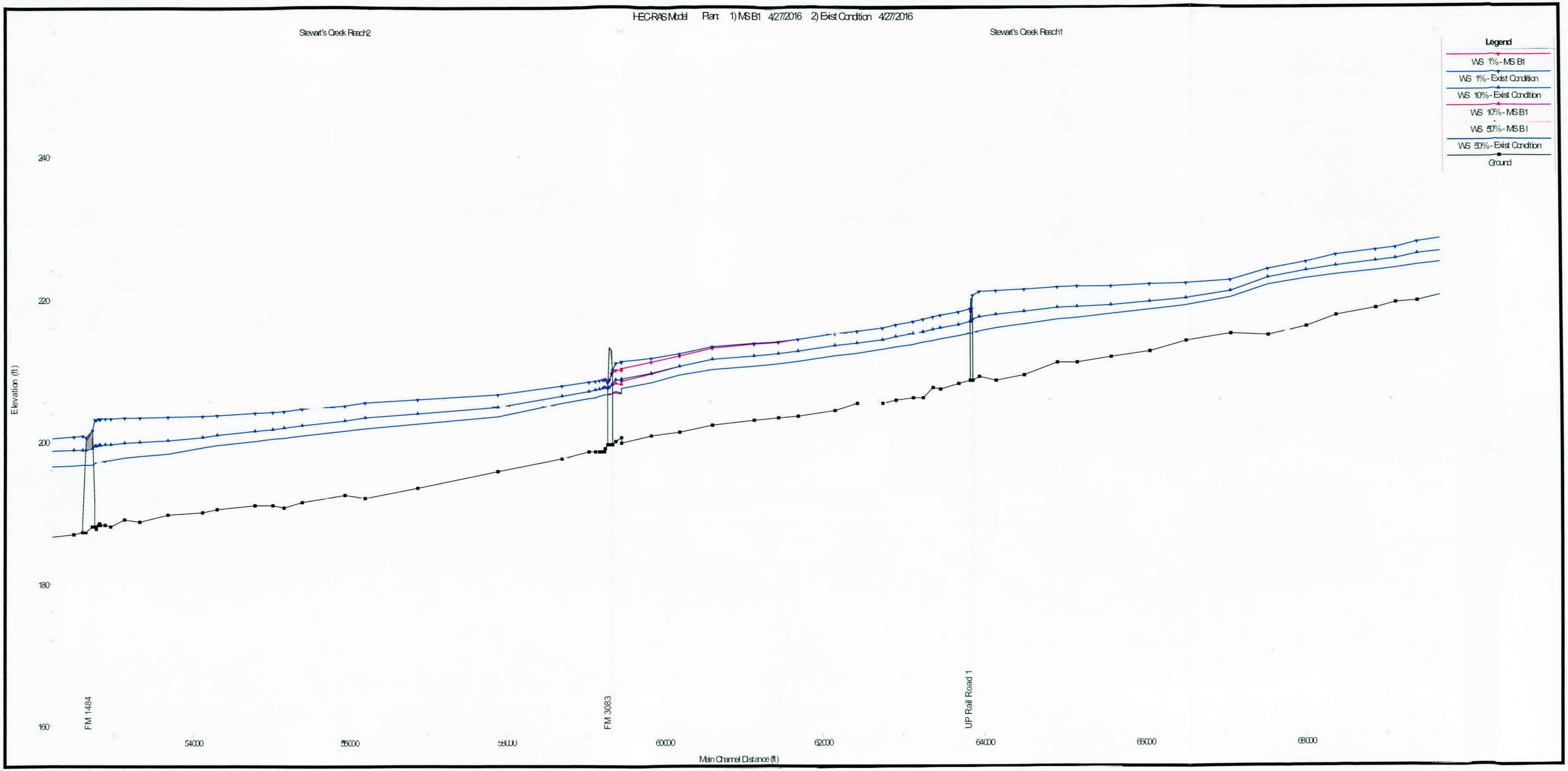

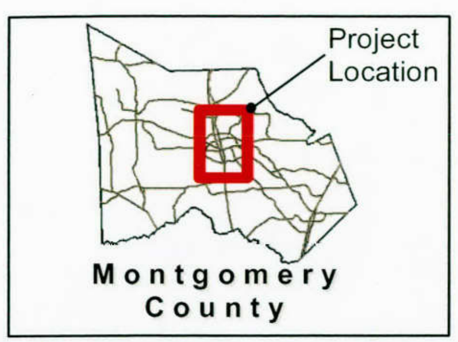

Exhibit 4.3

STEWART'S CREEK FLOOD PROTECTION PLAN

MSB1- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175 1502

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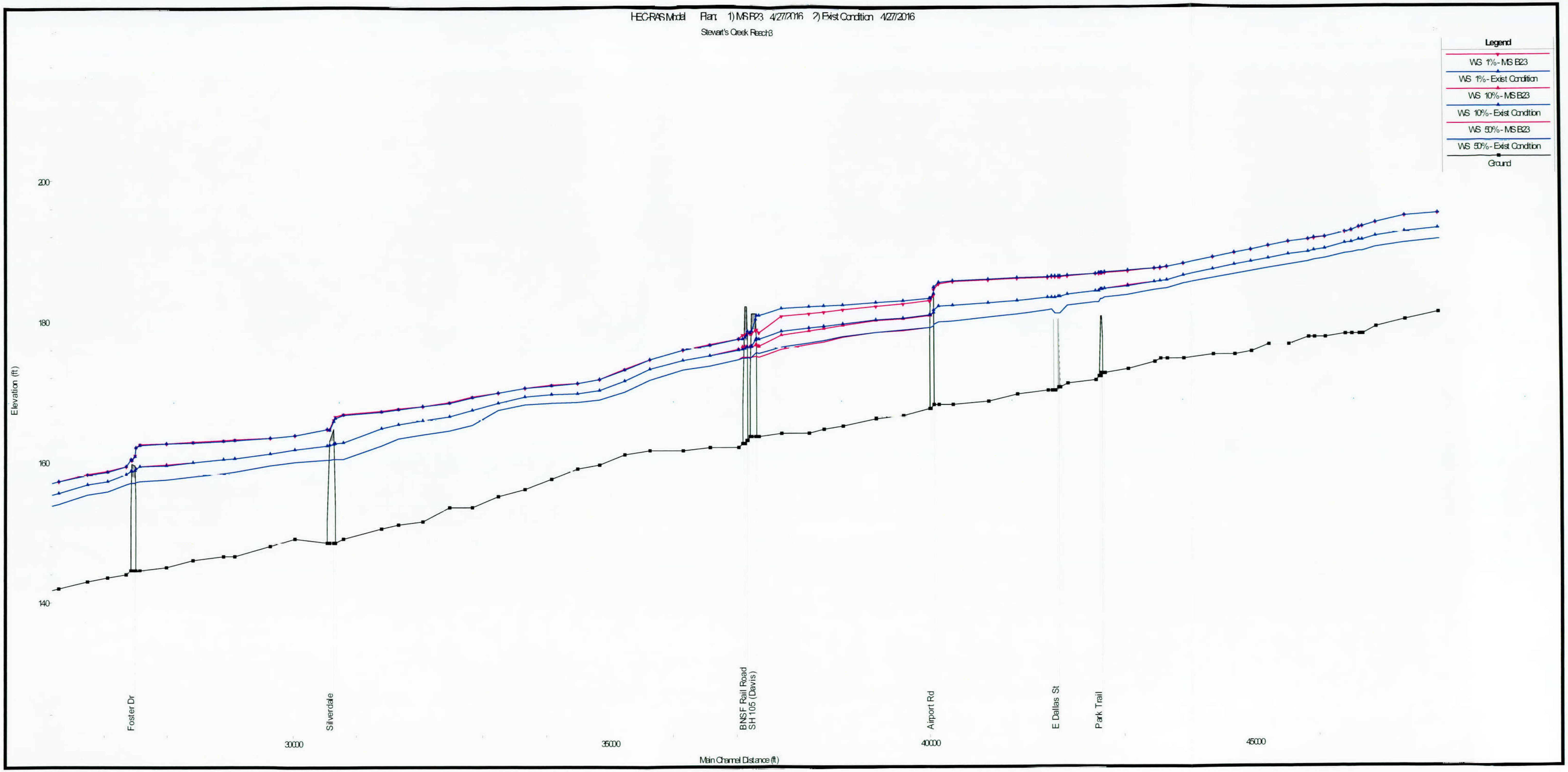

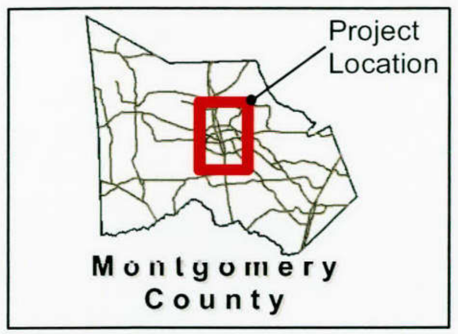

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Exhibit 4.4

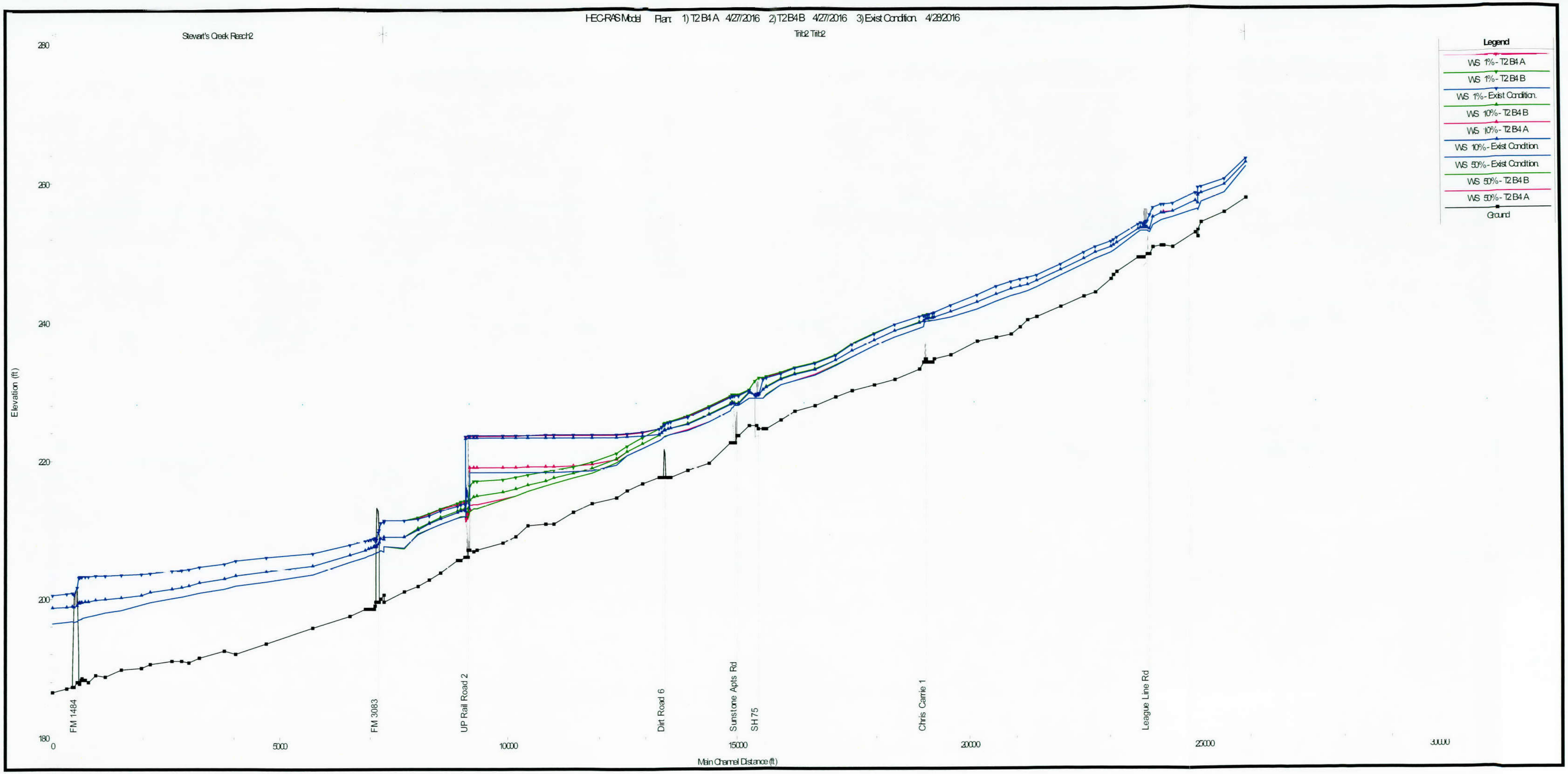
STEWART'S CREEK FLOOD PROTECTION PLAN

MSB23- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016

Job No. 2175-1502



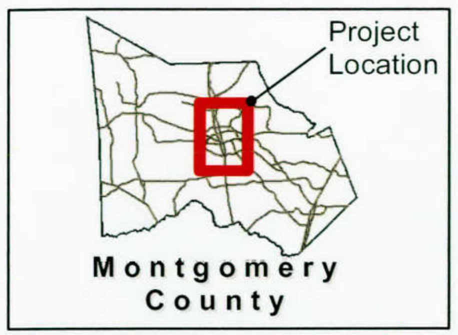


Exhibit 4.5

STEWART'S CREEK FLOOD PROTECTION PLAN

T2B4 A & B- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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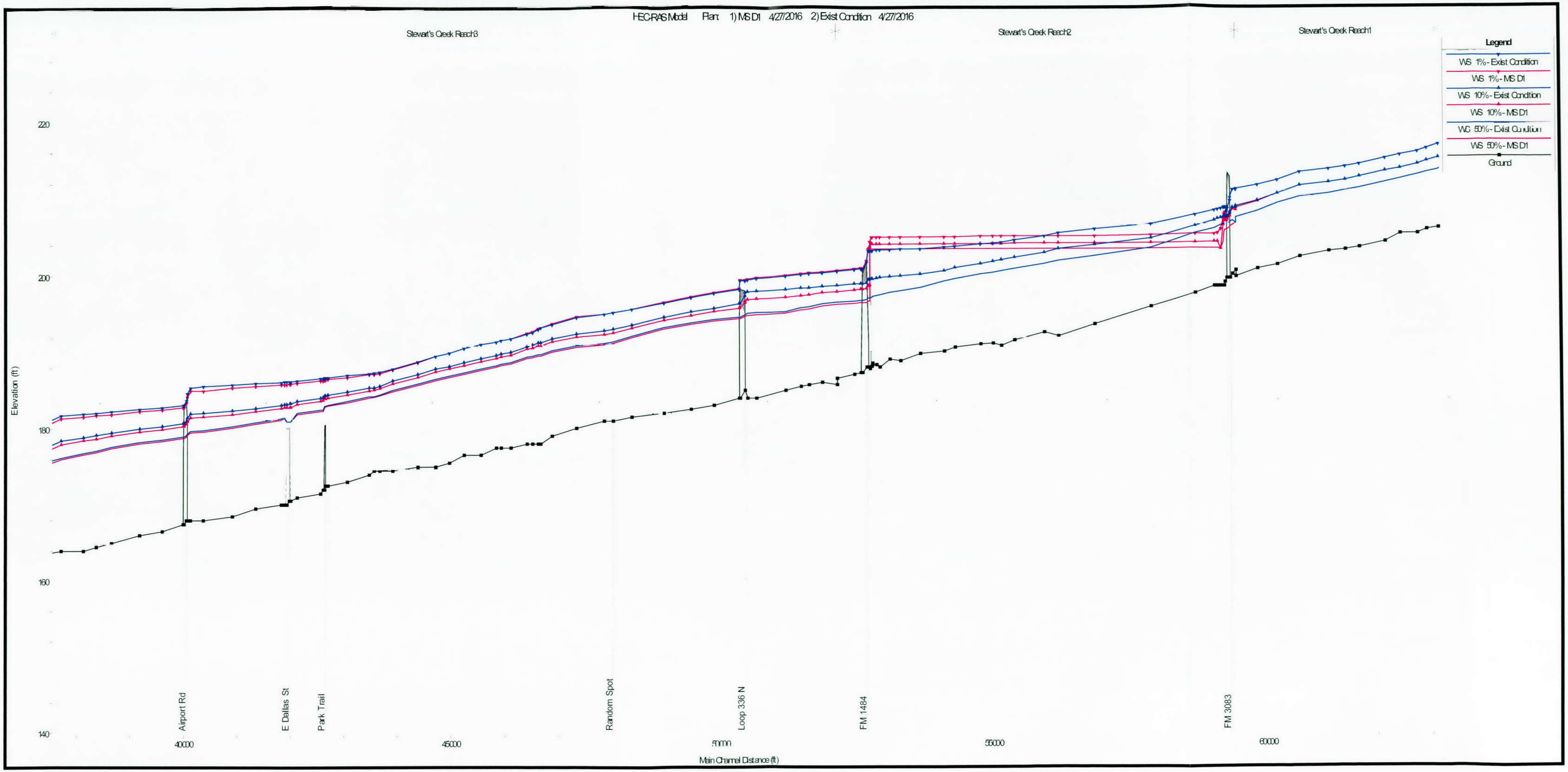

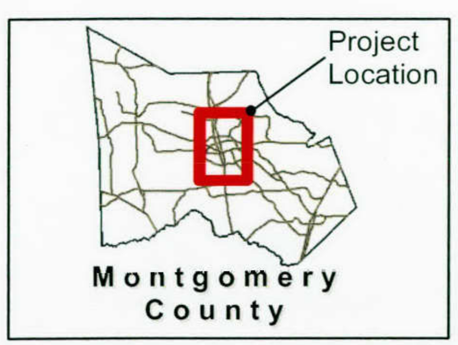

Exhibit 4.6

STEWART'S CREEK FLOOD PROTECTION PLAN

MSD1- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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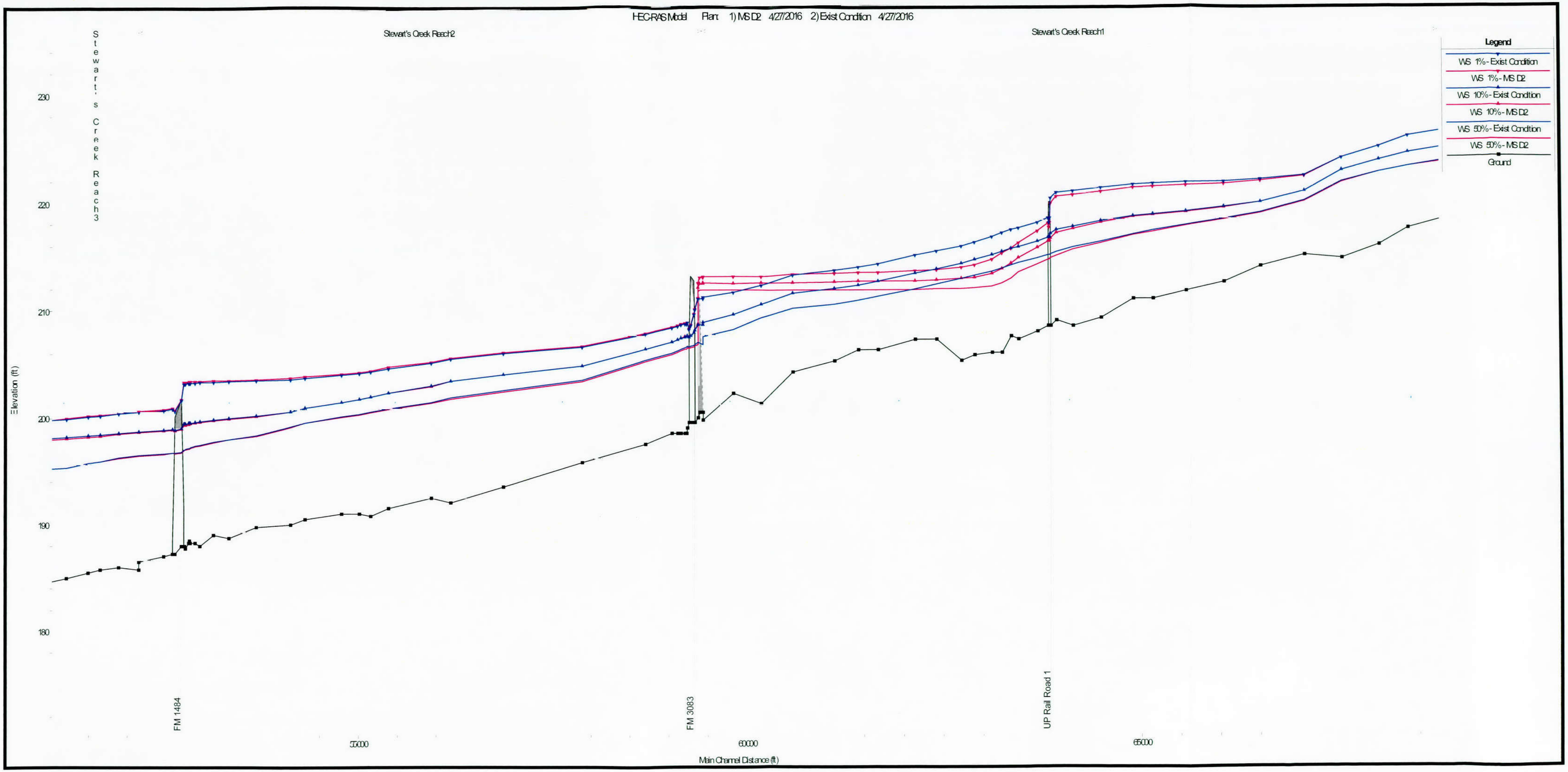

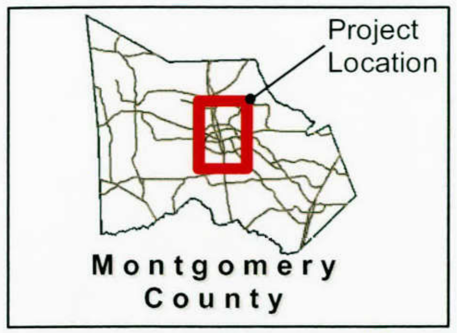

Exhibit 4.7

STEWART'S CREEK FLOOD PROTECTION PLAN

MSD2- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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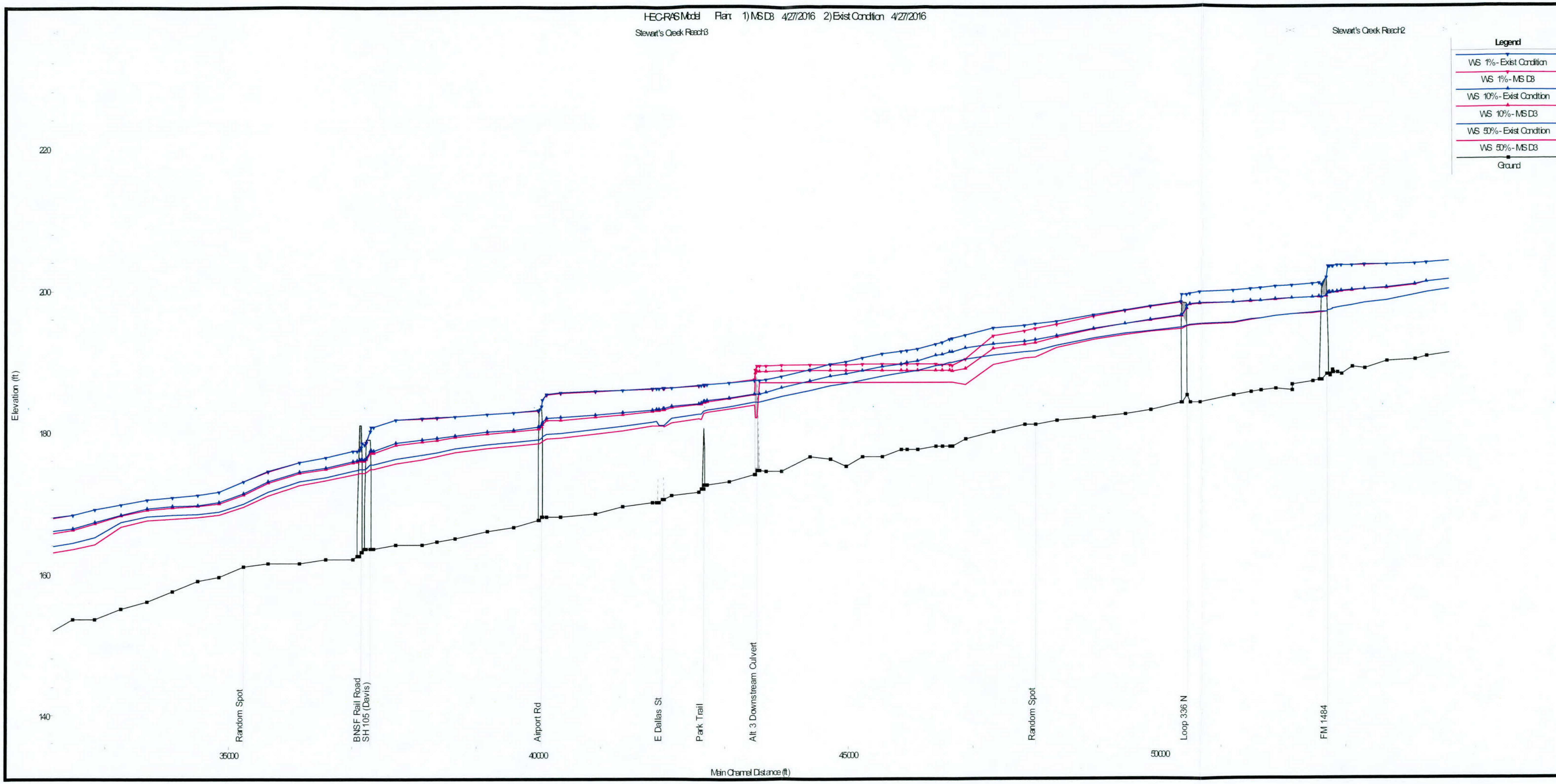

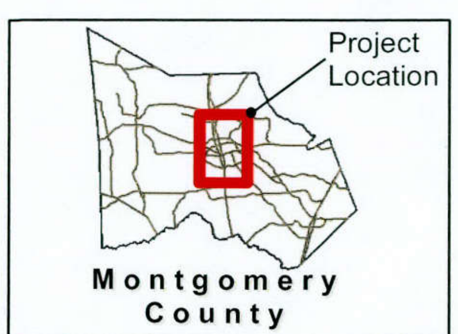

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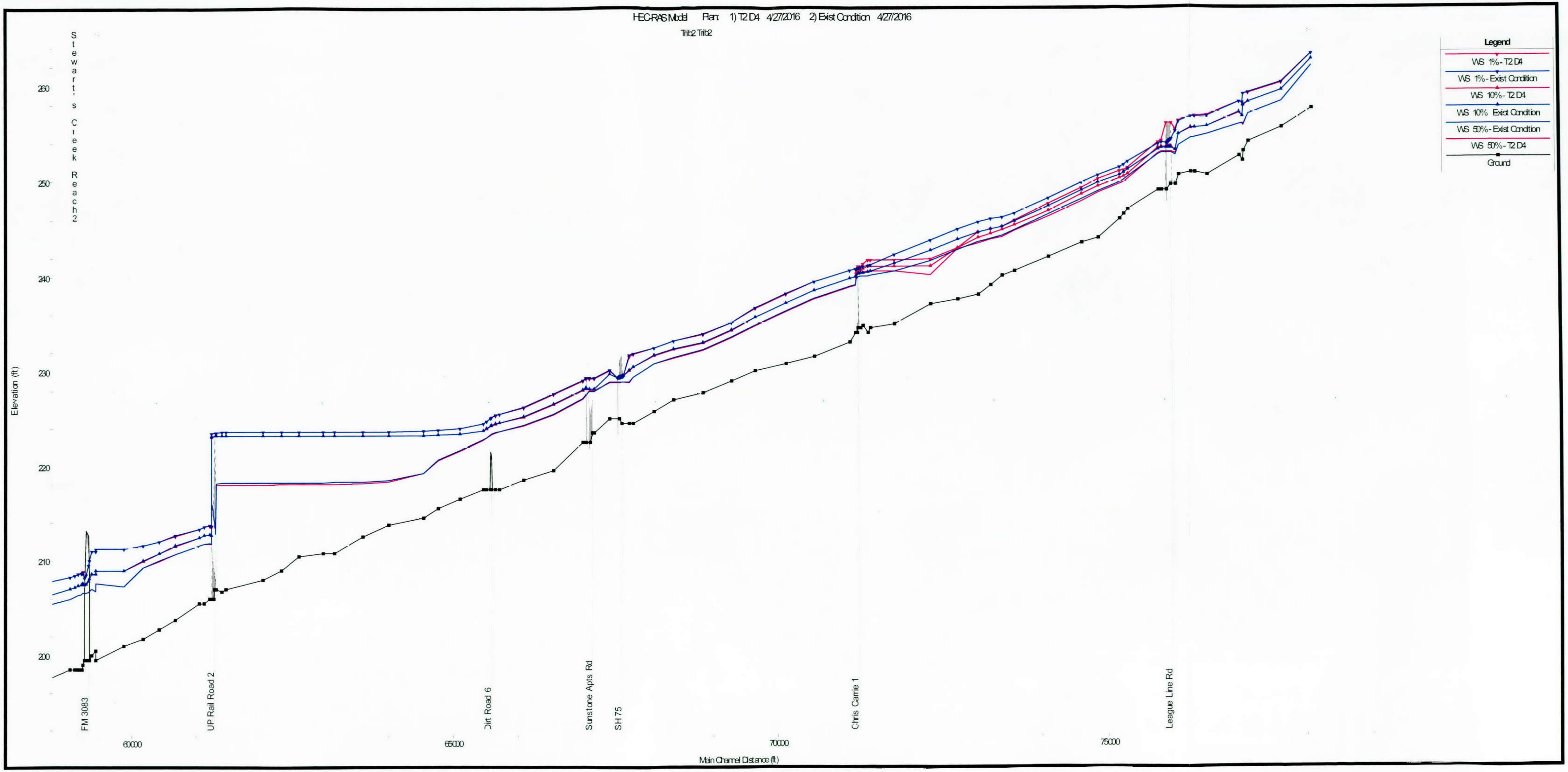
Exhibit 4.8

STEWART'S CREEK FLOOD PROTECTION PLAN

MSD3- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502



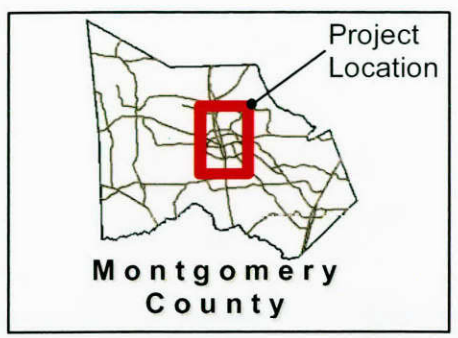


Exhibit 4.9

STEWART'S CREEK FLOOD PROTECTION PLAN

T2D4- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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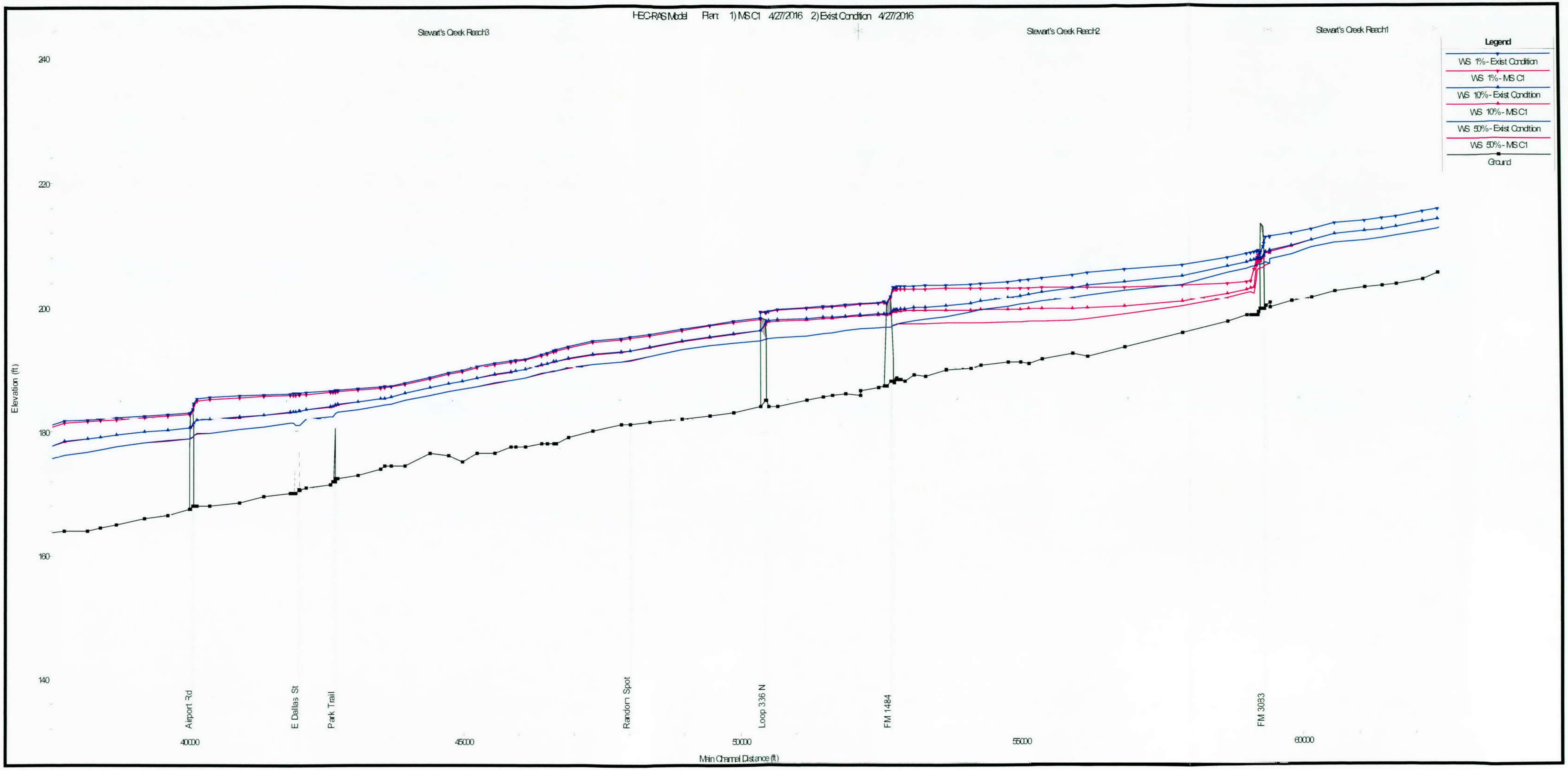

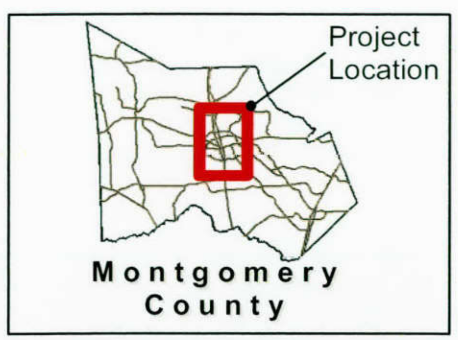

Exhibit 4.10

STEWART'S CREEK FLOOD PROTECTION PLAN

MSC1 WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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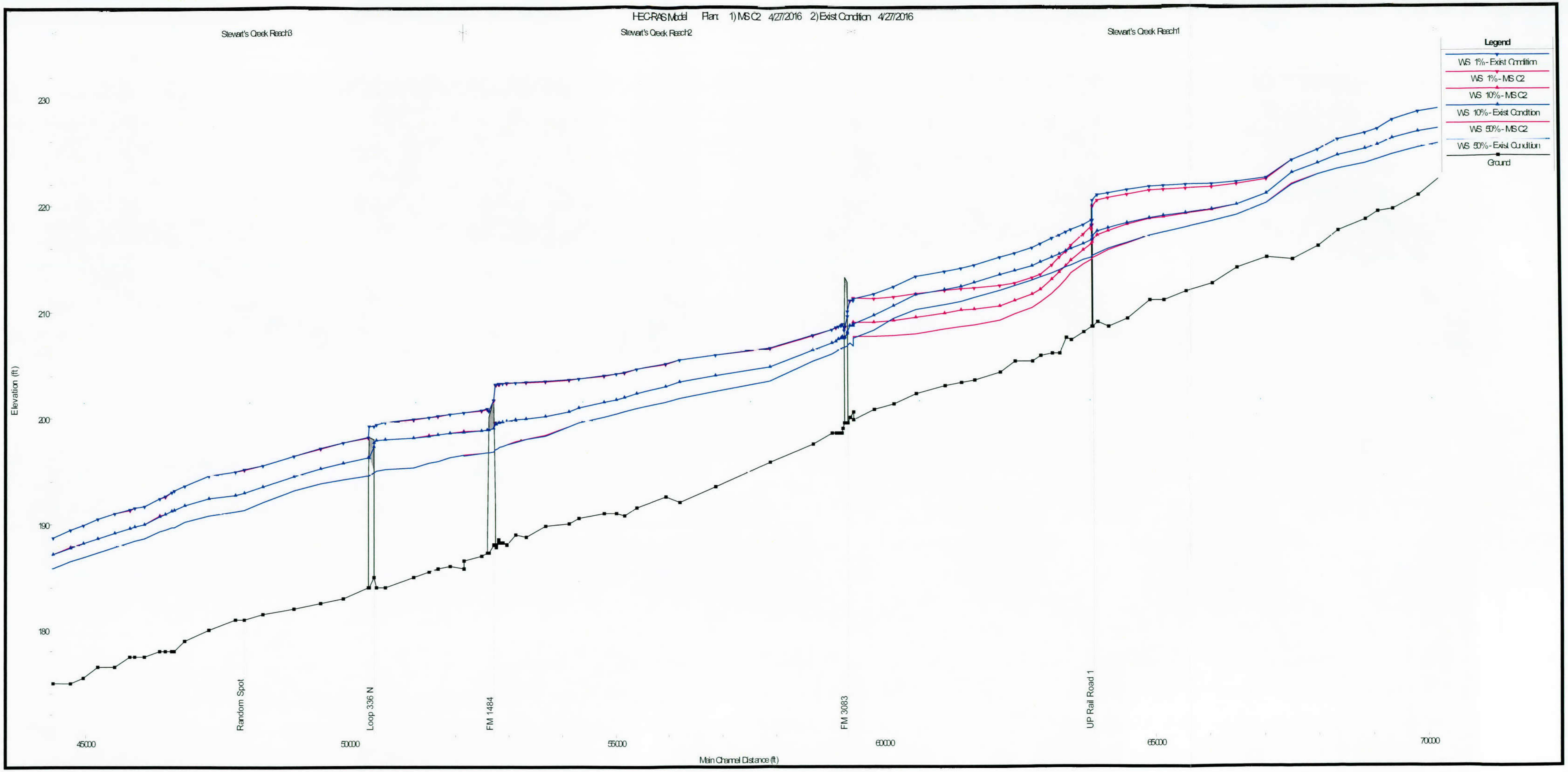


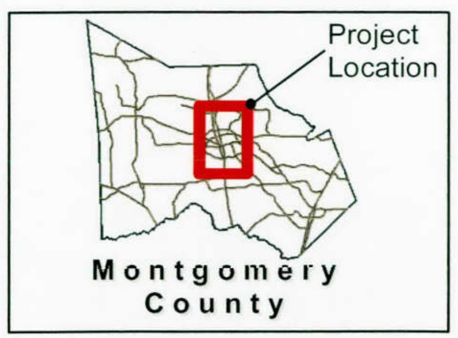


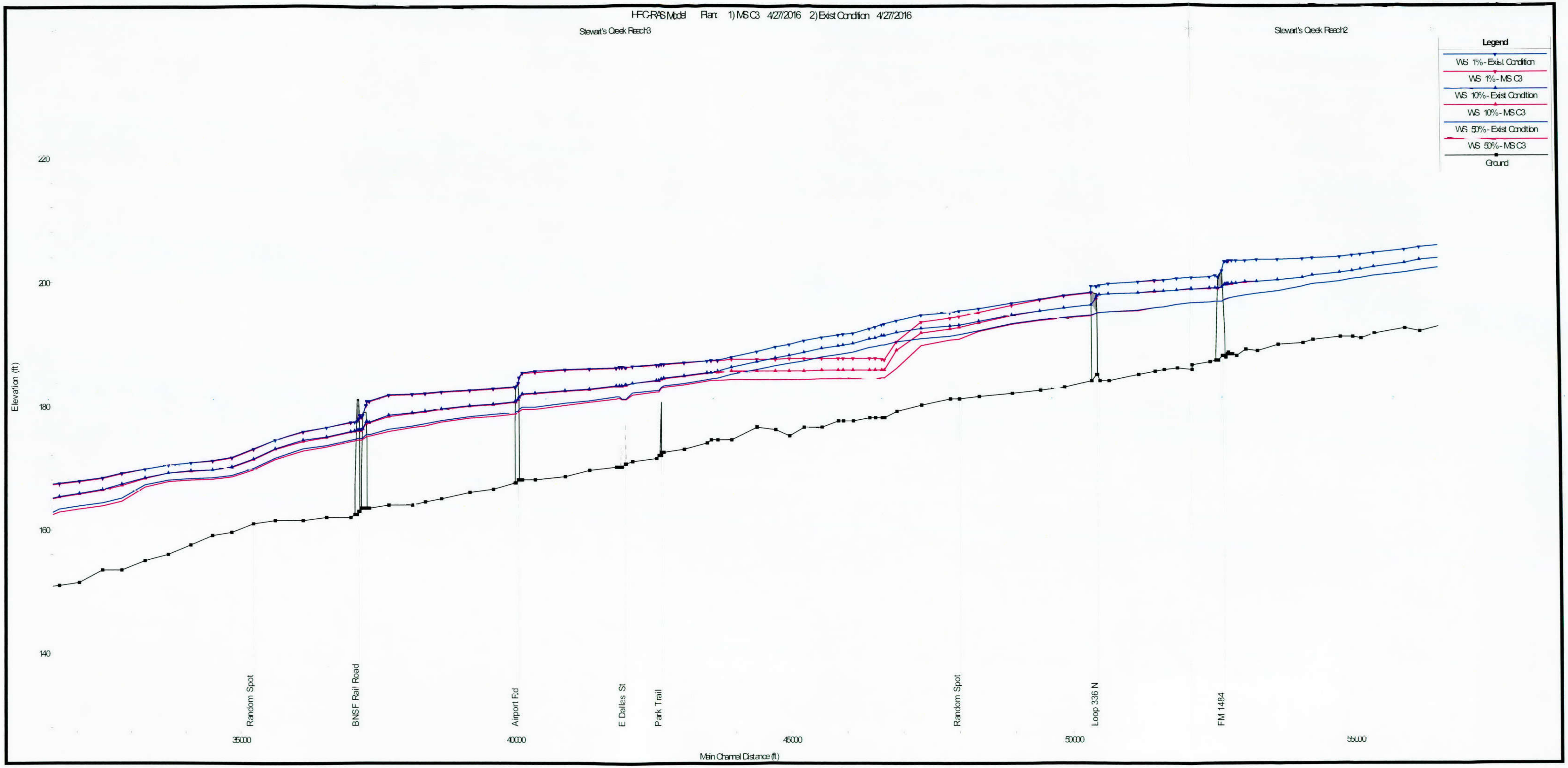
Exhibit 4.11

STEWART'S CREEK FLOOD PROTECTION PLAN

MSC2- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502



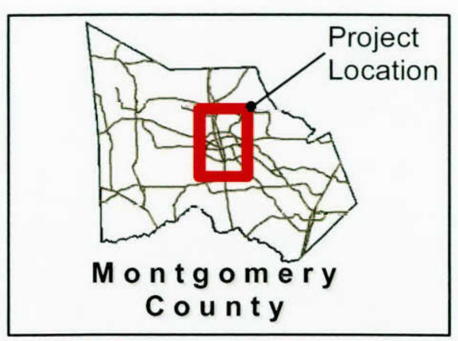


Exhibit 4.12

STEWART'S CREEK FLOOD PROTECTION PLAN

MSC3- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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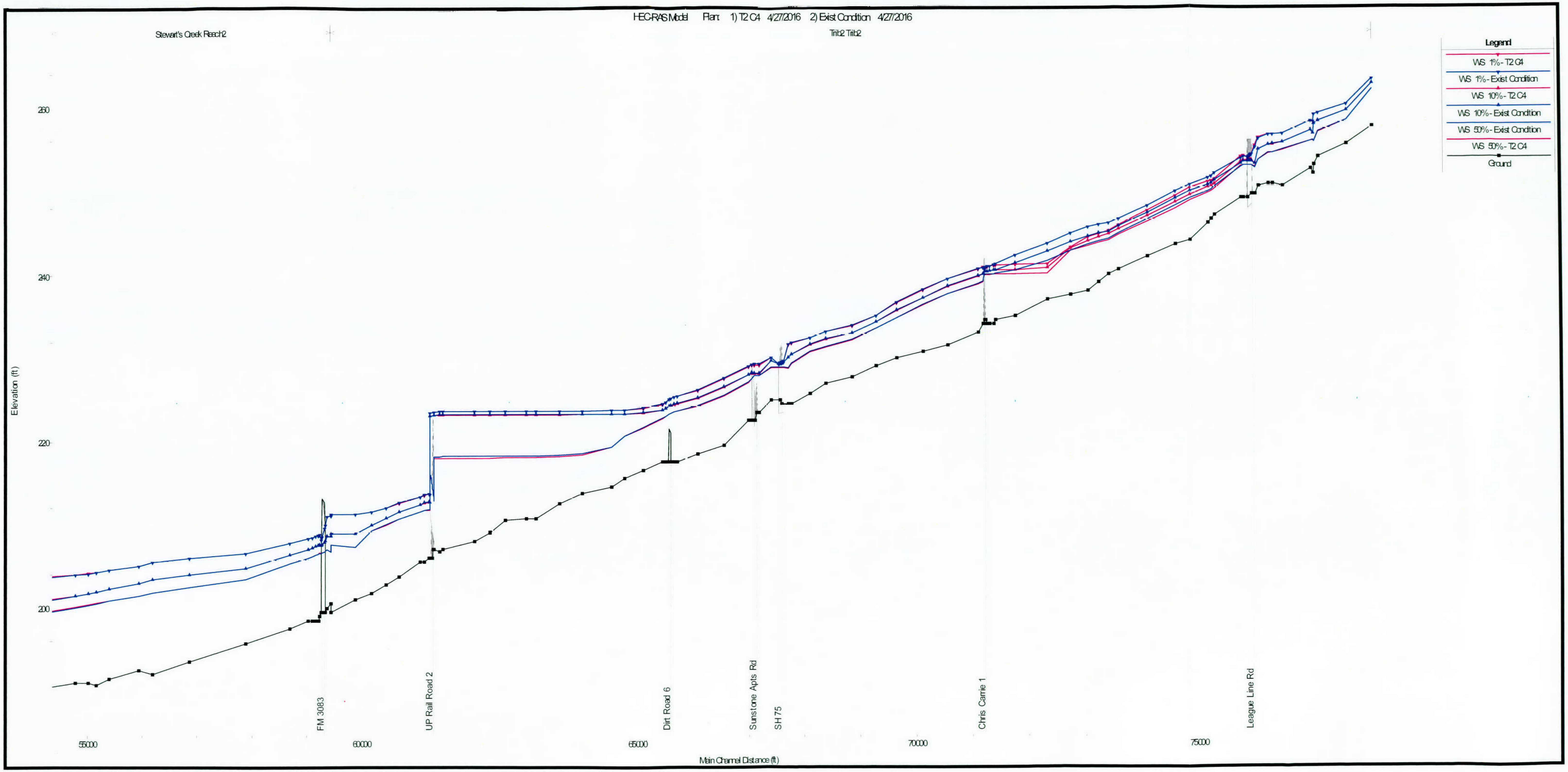

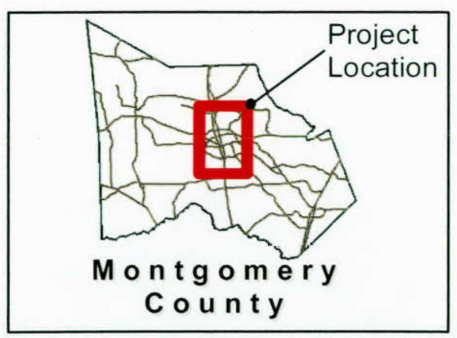

Exhibit 4.13

STEWART'S CREEK FLOOD PROTECTION PLAN

T2C4- WATER SURFACE PROFILE

LJA Engineering, Inc.

Date: September 2016 Job No. 2175-1502

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5.0 RECOMMENDATIONS

One of the conclusions based on our analysis is that the City's enforcement of floodplain development regulations has been successful at minimizing the flood risks within the watershed to date. There are relatively few clusters of structures with flooding problems, and many of the previously flooded structures are relatively isolated.

Based on the results of the channel modification alternatives, the effects of the modifications are localized due to the topography within the watershed. With the positive effects ending a relatively short distance upstream of the modifications, these types of structural alternatives would be best used adjacent to a cluster of structures which would provide sufficient benefits relative to the cost of the construction. At this time, there are no clusters of flooded structures which would provide sufficient benefits for these alternatives.

Due to the relative size of the watershed above the City, the detention sites evaluated do not provide enough storage to have a large enough effect on the flows within Stewart's Creek to provide a significant reduction in water surface elevations. While there is a definite possibility for these sites to be used as regional detention for future development, they do not provide sufficient benefit to be considered for reduction of the existing floodplain at this time.

Based on the results of the analysis, modification of roadway crossings can help reduce water surface elevations within a limited area. These modifications can also increase the peak flow rates downstream. In order to avoid causing adverse impacts downstream, mitigation of these increased flows would be required, making the overall cost of these options even higher. At this time, there are no areas with sufficient numbers of flooded structures to make these alternatives cost beneficial.

The current Effective FIS for Stewarts Creek is approximately thirty years old. Due to its age and the number of Letters of Map Revision over that time the current model is a combination of different models all using the original flow rates. Since that time, the rainfall data for Texas has been updated based on more years of data and represents a significantly better idea of rainfall probabilities in the area. There has also been development within the watershed which is not reflected in the Effective models. This results in the FIS not accurately representing the flood risks within the watershed. In turn this contributes to repetitive losses as previously flooded structures are rebuilt below the true one-percent exceedance event as well as allowing future development to be constructed below the one-percent event elevations.

There are currently no stream gages in the Stewarts Creek watershed. Lack of a gage system makes timely planning for potential flooding situations difficult for the City and its residents. Without adequate information regarding the speed and severity of flooding in the watershed, it is more difficult for the City to evaluate when and where to stage equipment, plan for evacuation, implement other Emergency Management procedures, or notify the residents of potential situations.

Based on these factors, at this time we have identified four items as part of the recommended plan for the Stewarts Creek watershed within the City of Conroe. These items are;

- Continued enforcement of Floodplain Development regulations.

- More detailed investigation of possible buyouts for the 11 properties identified as candidates.

- Preparation of a Letter of Map Revision based on current criteria and development levels to provide a clearer idea of flooding within the watershed for future development. This could also be accomplished by the City's adoption of the models developed as part of this study to be used as best available data.

- Development of a system of gages within the Stewarts Creek watershed to be used in developing a system to allow for timely notification of potential flooding situations. This will allow residents more time to take appropriate measures to safeguard their property or evacuate if needed. It will also provide the City with more timely information for enacting Emergency Management procedures.

There are possible funding sources for implementation of the plan. The Federal Emergency Management Agency has several grant programs such as Flood Mitigation Assistance (FMA), the Hazard Mitigation Grant Program (HMGP), and others which can be used to provide up to 75% of the funding for qualifying projects. Additionally, the FMA grant program includes acquisition of structures (buyouts) as an eligible project and can be used to provide up to 90% of the federal funding for Repetitive Loss structures and up to 100% for Severe Repetitive Loss structures. Additionally, the Texas Water Development Board has expanded the Flood Protection Grant program to include monies available for early warning systems, and the implementation of local strategies for alerting and responding to floods.

Appendices on Disk

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