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MODELING THE EFFECTS OF THE DEVELOPMENT OF FM 156 ON THE BIG FOSSIL CREEK - WEST TRINITY RIVER WATERSHED

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MODELING THE EFFECTS OF THE DEVELOPMENT OF FM 156 ON THE BIG FOSSIL CREEK - WEST TRINITY RIVER WATERSHED

by

VALERIE ARRUDA

Presented to the Faculty of the Honors College of
The University of Texas at Arlington in Partial Fulfillment
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for the Degree of

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First and foremost, I would like to thank my parents for their continual support during my college career. I am thankful for their warnings about taking on too much at once, but I am more thankful they stood by me and helped me cope when I did it anyway. As a first-generation college student, I owe so much to them for the opportunities I have.

I would like to thank my siblings for being such a solid support system. Thank you, Thomas, for setting the standard and setting it high. Your year of knowledge over me saved me more hours of stress than I care to admit. Thank you, Samantha, for always being the friend I needed, and for holding down the fort at home while Thomas and I were away.

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December 4, 2019

ABSTRACT

MODELING THE EFFECTS OF THE DEVELOPMENT OF FM 156 ON THE BIG FOSSIL CREEK - WEST TRINITY RIVER WATERSHED

Valerie Arruda, B.S. Civil Engineering

The University of Texas at Arlington, 2019

Faculty Mentor: Recep Birgul

Urban development increases the runoff created from a property, requiring analysis to ensure the watershed in question is not negatively affected, and adjacent properties are not adversely impacted. This study focuses on a project currently being done by the Texas Department of Transportation, including the widening and reconstruction of FM 156 in Saginaw, Texas, within the Big Fossil Creek Watershed. This project runs through a FEMA floodway, presenting challenges in the allowed scope of work. The focus of this study is to model the watershed using the hydraulic analysis software, HEC-RAS, and to design the proposed 4-lane roadway profile, including two bridges. This hydrologic and hydraulic analysis, along with economic and environmental consideration, show the proposed

roadway cannot be economically designed to pass the desirable design criteria but can be improved from its existing condition. With right-of-way acquisition being a major constraint, the roadway was designed for the 10-year storm as to follow FEMA regulations and TxDOT criteria.

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CHAPTER 1

INTRODUCTION

1.1 Project Overview

The purpose of this project is to reconstruct FM 156 in Saginaw and Fort Worth, Texas for the Texas Department of Transportation (TxDOT). FM 156 was constructed in 1947 as a rural two-lane highway. In the 70 years since its construction, development of the surrounding properties has caused serious congestion on the road. The goal of the reconstruction is to provide a safer, four-lane divided highway with improved infrastructure to meet federal and state design criteria. A vicinity map can be seen in Figure 1.1 below.

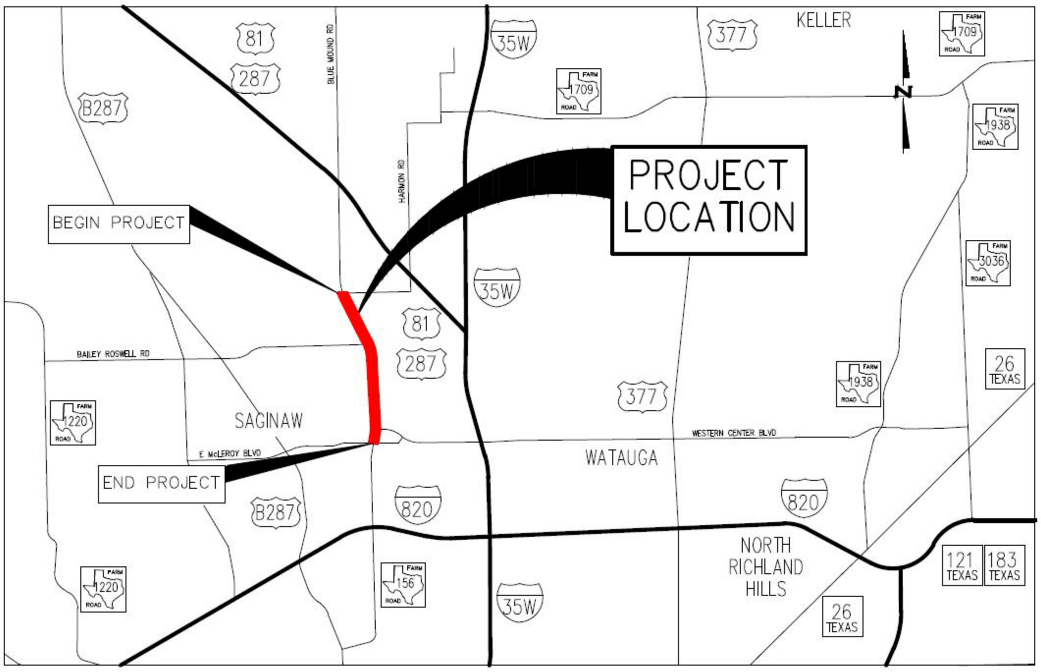


Figure 1.1: Vicinity Map of Project Extents (Not to Scale)

A major constraint for this project is that the roadway is in the middle of a FEMA Floodway. Big Fossil Creek and its tributary BFC-4 are documented in FEMA Flood Insurance Rate Map (FIRM) 48439C0065L [1]. Being in the floodway puts constraints on both the horizontal and vertical alignment of the road, as we cannot adversely impact the streams or the downstream properties.

1.1.1 Team Objectives

For context on the scope of the senior design project at hand, the overall project objectives will be discussed. This project was given to the University of Texas at Arlington's Department of Civil Engineering by the Texas Department of Transportation (TxDOT) to be used as a senior design project. The group members included in the design and reconstruction of FM 156 include the author, Valerie Arruda, and group members Blayne Champlin, Grayson Grzybowski, Armando Martinez, and Raul Orozco. The project director and TxDOT point of contact is professional engineer, Herman Doane Tarin.

The goal of the project was to produce a 30% schematic for the reconstruction of FM 156 from Watauga Road to Harmon Road. This includes the preliminary engineering to determine the geometry and infrastructure of the roadway. To determine the need for the road reconstruction, a traffic analysis was done of the road in the existing condition using TxDOT traffic movement counts. The level of service of the road was determined for the existing condition to prove that the congestion on the road makes it unserviceable. The horizontal and vertical alignment of the road was determined per TxDOT criteria in coordination with the hydrologic and hydraulic requirements determined. A pavement design was prepared comparing rigid and flexible pavement, as well as a life cycle cost analysis. Preliminary bridge design was done for the north bridge, consisting of detailed superstructure and bent cap design.

1.1.2 Individual Objectives

It was the author's responsibility to perform the hydrologic and hydraulic analysis of the site to meet federal and state regulations for development in the floodplain. The National Flood Insurance Program (NFIP) and Federal Emergency Management Agency (FEMA) are the governing agencies for floodplain development and were researched accordingly. Research was needed to fully understand the constraints and guidelines in place for urban development in these high-risk areas. For the fulfillment of this honors thesis, research on the federal regulations for flood mitigation was done, along with the extensive hydraulic modeling of the streams in question using HEC-RAS.

CHAPTER 2

DEVELOPMENT IN THE FLOODPLAIN

2.1 Site Description

To preface the federal and state level regulations associated with the development of FM 156, a site description is necessary to introduce the need for such regulation. FM 156 is located in Tarrant County, dividing the cities of Saginaw on the west and Fort Worth on the East. FM 156, or North Blue Mound Road within our project area, is a farm to market road being owned by the state. The roadway is in public right-of-way, meaning it is owned and funded by TxDOT.

Being a public farm to market road, the development of the road must adhere to state standards. A further constraint of this site in particular is that it is in a FEMA Floodway. Tarrant County is a participant in the National Flood Insurance Program (NFIP) and is therefore regulated by FEMA floodplain management requirements [2]. A FEMA Floodway is land consisting of a channel or waterway and the adjacent land reserved to discharge the base flood. The base flood is the 100-year flood event, defined as a 1% annual chance flood. Communities are required to set the standard for floodway development, while the NFIP defines where these areas are.

Our site, as defined by the NFIP, is in a Zone AE. Figure 2.1 below shows an excerpt from the Flood Insurance Rate Map (FIRM), Map Number 48439C0065L. The project area is shown in red. A Zone AE refers to a community with a mapped floodway with determined base flood elevations. The studied streams in the project include Big Fossil

Creek and its tributary, BFC-4. The crossings studied in the hydrologic and hydraulic analysis include a crossing of Big Fossil Creek south of Harmon Road, a crossing of BFC-4 south of Hidden Lake Road, and a culvert north of Bailey Boswell feeding to Big Fossil Creek.

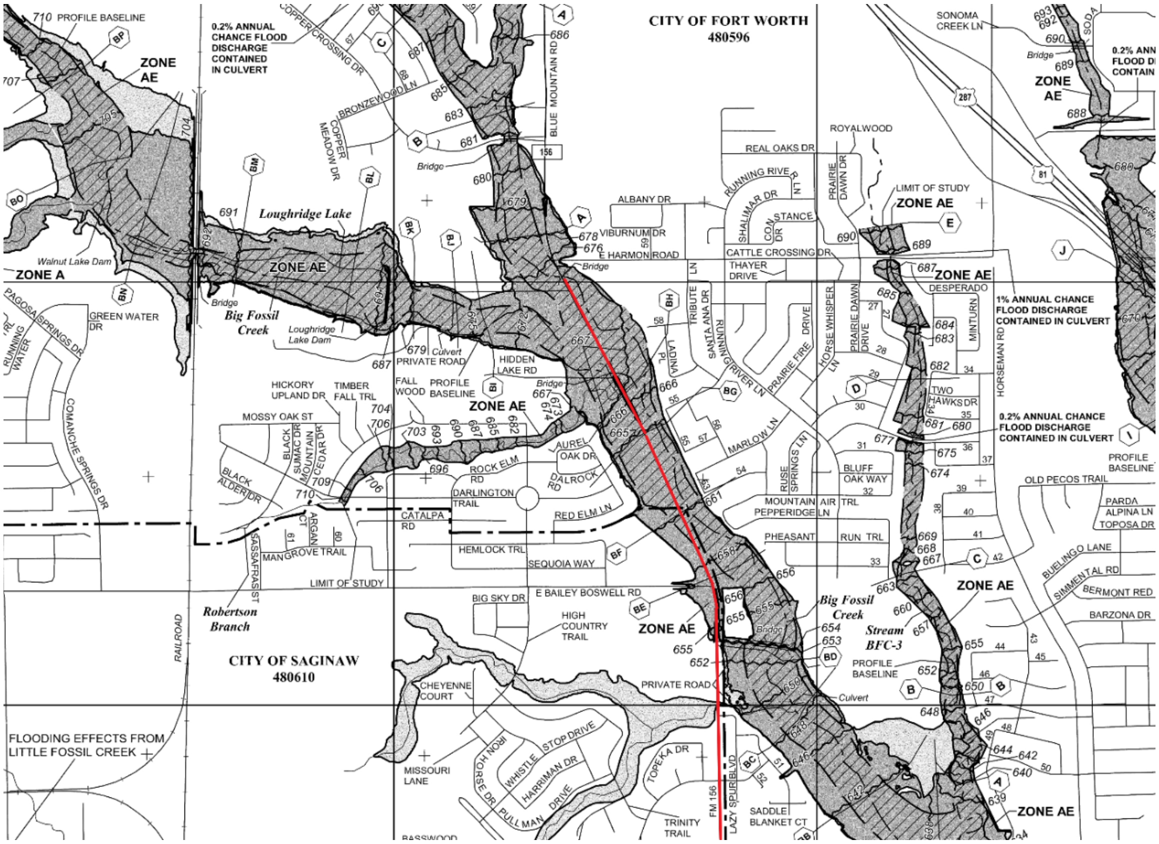


Figure 2.1: Excerpt from FEMA Flood Insurance Rate Map, Panel 0065L (Not to scale)

2.2 Federal Regulations

As mentioned above, the site is within a community participating in the NFIP. This means the minimum standard that developments in the floodplain must adhere to are set by FEMA, while they recommend states and communities should adopt higher standards. A Flood Insurance Study (FIS) has been done in the area of the development and determined the site to be in a Flood Zone AE.

The development is bound by Title 44 Section 60.3 of the Code of Federal Regulations, which sets forth the floodplain management criteria for special flood hazard areas [3]. The project area is in a 60.3(d) community, meaning base flood elevations have been determined, and a FIRM mapping the floodway is available. Some of the specific requirements for this community include adopting regulatory floodways for the passage of flood discharge and prohibiting development that will adversely impact the flood risk of affected properties.

The latter requirement will be the focus of the study performed. The hydraulic analysis will be performed to ensure the proposed improvements of FM 156 do not increase the flood hazard on other properties. This will be quantified by using the FEMA-approved HEC-RAS model of the project area to show the 100-year water surface elevation shows no increase from the existing to the proposed condition.

2.3 State Requirements

In the TxDOT Hydraulic Design Manual, the requirements reiterate and refine regulations set forth by the NFIP. TxDOT states that if the project is in a Zone AE floodway, a study must be performed to ensure no rise in the water surface [4]. TxDOT outlines that the FEMA effective hydraulic model must be verified and corrected for the existing condition, then updated for the proposed condition. In the scope of this project, the model received from TxDOT was assumed to be verified, and the proposed model was created.

In addition to the steps taken to manage the floodplain, TxDOT sets forth standards for roadway performance that will affect the design of the infrastructure of FM 156. The Hydraulic Design Manual defines the minimum and desirable design storms for various hydraulic structures in Table 4-2 of the manual. A summary of the information relevant to the development of FM 156, with the functional classification of a minor arterial, can be found in Table 2.1 below.

Table 2.1: Recommended Design Storms for a Minor Arterial

Structure	Minimum Design Storm	Desirable Design Storm
Culvert	5-year	10-year
Small bridge	10-year	25-year

These requirements are meant to ensure the serviceability of the road. In the design of FM 156, the desirable design-storms will be reached for the hydraulic structures, while the road itself will only need to be passing for the minimum design storm. As defined in the TxDOT Roadway Design Manual, a minor arterial must be serviceable in the minimum 10-year storm [5]. TxDOT defines that the freeboard of a roadway or structure is left to the discretion of the designer, and therefore must be defined before analysis. For the purpose of this project, the road will be deemed serviceable if the water surface of the 10-year storm is below the top of curb elevation.

CHAPTER 3

MODELING APPROACH

This chapter will present the steps taken to determine the design of the bridges, culverts, and road profile to meet the hydraulic requirements presented in the previous chapter. To sum up the goals of the design as stated in Chapter 2, the infrastructure of the roadway must be such that it does not raise the 100-year water surface elevation of Big Fossil Creek and BFC-4, the 25-year storm is contained under the proposed bridges, and the road profile is such that the 10-year storm does not overtop the top of curb elevation.

3.1 Existing FEMA Model

The existing FEMA model was received from TxDOT. Revisions were made to the FIRM in March of 2019, so the model used for that study was obtained. The existing model was assumed to be verified by TxDOT before analysis was done by the author.

In the project area from Harmon Road to McLeroy Boulevard, there are nine cross drainage structures, which are summarized in Table 3.1 below. A layout of the structures in relation to the overall project site can be seen in Appendix A, corresponding to the information in Table 3.1 Although there are nine existing structures, only three are modeled in the HEC-RAS model, which are bolded in Table 3.1. The model has been passed within the last year without the addition of these six culverts, implying that the sizing of the two bridges and single culvert north of Bailey Boswell is enough to mitigate the effects of development, meeting FEMA regulations. The culverts should be extended and resized for the proposed development of the roadway, but that was not within the scope of the project taken on by the author.

Table 3.1: Summary of FM 156 Cross Drainage Structures

No.	Project Station	HEC-RAS XS Station	HEC-RAS Stream Reach	Existing Size	Survey Length
1	**373+16**	**73468**	**BFC-4 X-ing; Modeled in BFC**	**2-Span Bridge**	**59.9' Opening; 30° Skew**
2	**386+11**	**72372.57**	**BFC**	**3-Span Bridge**	**74.5' Opening; 30° Skew**
3	393+91	n/a	n/a	2-30" RCP	61
4	**413+00**	**69855**	**No X-ing; Modeled in BFC**	**2-5'x3' RCB**	**118**
5	415+20	n/a	n/a	1-4x3' RCB	69
6	417+04	n/a	n/a	1-30" RCP	69
7	428+08	n/a	n/a	4-10.5'x4' RCB	48
8	442+04	n/a	n/a	6'x2' RCB	50
9	490+00	n/a	n/a	3-5'x2' RCB	116

Both Big Fossil Creek and BFC-4 affect the bridges because of where they come together in relation to the roadway. Because Big Fossil Creek runs parallel to the road, the cross sections chosen for the streams are unique in their geometry. When using HEC-RAS to analyze a stream, cross sections are taken perpendicular to the flow. In this model, the cross sections are perpendicular to the streams, but then are defined by the road geometry in places where hydraulic structures are present, as seen in Figure 3.1 below. In addition, it can be seen that several cross sections near the joining of the streams cross both Big Fossil Creek and BFC-4.

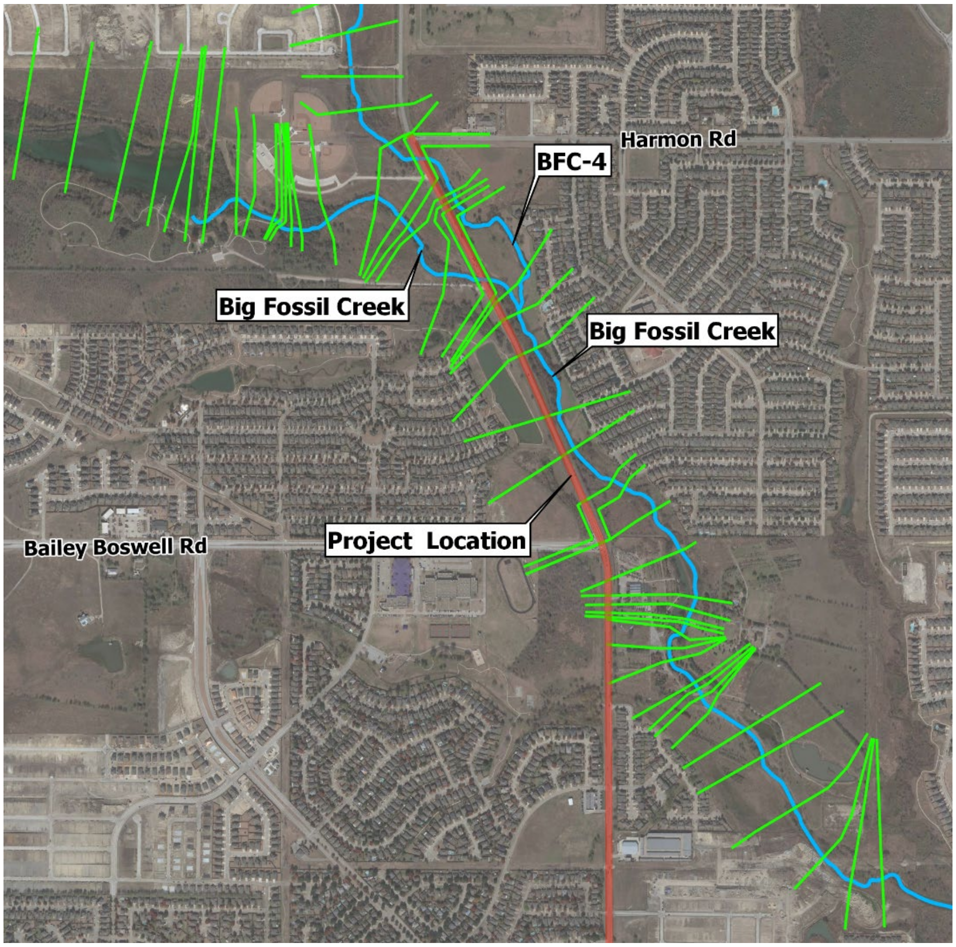


Figure 3.1: HEC-RAS River Cross Sections

It should be noted that both practices of abnormal cross section geometry and crossing multiple streams with a single cross section is bad practice, and therefore not recommended. This is due to the fact that in this format, HEC-RAS is a one-dimensional modeling software. It cannot consider the effect on the cross section due to both streams' discharge, and therefore does not realistically model the water surface and stream properties due to both streams. For the purpose of the existing model, this is considered to have negligible effects on the model, as it has been calibrated and verified by FEMA, and therefore accurately represents how the streams behave in reality.

The north bridge, referred to as Bridge 1, crosses BFC-4, but was modeled in the Big Fossil Creek reach in HEC-RAS. This was done because Big Fossil Creek has higher discharge and water surface elevations. The south bridge, referred to as Bridge 2, crosses Big Fossil Creek. The cross sections bounding both bridges were defined to cross both streams, so they were modeled as multiple opening structures as opposed to bridge structures.

3.2 Proposed Model

This section will outline the methodology taken by the author to determine the hydraulic infrastructure required for the reconstruction of FM 156. The determination of the structures was an extremely iterative process, using trial and error until all constraints were met.

3.2.1 Cross Section and Elevation Determination

To begin the analysis, a plan and profile of the existing alignment were provided by the group member in charge of the road geometry. Using AutoCAD Civil 3D, the cross section shapefiles were brought in from HEC-RAS and plotted in relation to the road stationing. Using the profile view provided, the elevations at the road station of each cross section was obtained. These elevations represent the initial centerline elevations that will be assumed for the initial analysis of the creeks due to the improvement. These centerline elevations were used to determine the corresponding elevations of key points along the road section, including the median extents, the 2% slope of the crowned road, the curb, and the sidewalks.

Using the determined criteria for an urban minor arterial from TxDOT's Roadway Design Manual, the sections seen in Figure 3.2 were produced. These sections do not reflect the final cross section throughout the entire roadway but are appropriate for editing the geometry file at each river cross section in HEC-RAS. The key section points are labeled

1-9 as seen below. Using the slopes indicated in Figure 3.2, a spreadsheet was created to determine the elevation at each point given the centerline elevation at point 5.

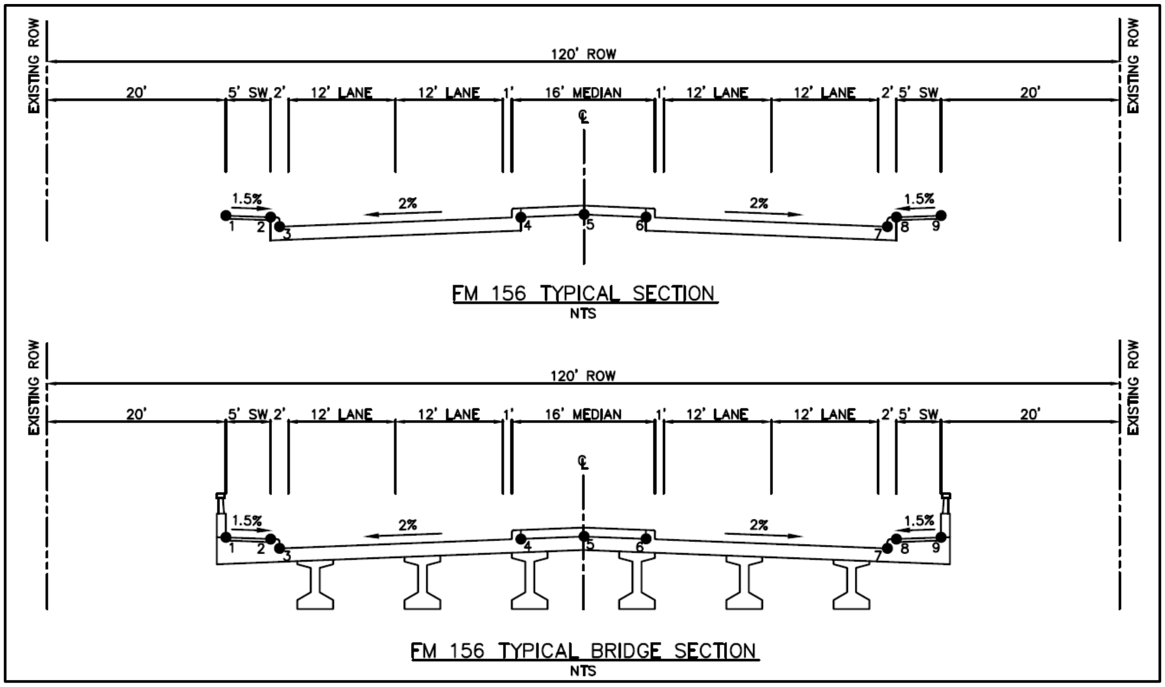


Figure 3.2: Assumed Cross Sections for HEC-RAS Analysis

In the HEC-RAS model, a copy of the existing geometry file was saved as the proposed improvements. Each cross section that crosses FM 156 was then edited to include the proposed road section with the existing centerline elevations. The steady flow analysis was run for the model for the improved road section, with no changes to the bridges or culverts. The results from the run were compiled in a spreadsheet to analyze the impact on the streams. This was used to determine the serviceability of the road. Another table was made to compare the 100-year water surface elevation of the existing condition versus the proposed condition. With these two constraints, the geometry file was changed to make the road serviceable and avoid negative impact to the creeks.

3.2.2 Bridge Opening Determination

The openings for each bridge needed to be updated in order not to raise the water surface elevations at the sections bounding the bridge structures, as well as keep the 25-year flood under the bridge. As previously mentioned, the existing bridge structures were modeled as multiple opening structures, so the proposed improvements were modeled in the same way. A spreadsheet was created to determine the opening of each bridge and elevations of the low chords of each bridge based on the profile of the road.

As the opening widened past the extents of the current channel, it became necessary to excavate underneath the channel as not to choke the flow. Channel improvements were necessary to meet the FEMA regulations. In the same spreadsheet, excavation geometry and pier location determination tables were created. For the excavation, 2:1 slopes were assumed for stability. The geometry of the proposed excavation was determined by assuming the same minimum channel elevation and having the excavation of the bottom of the channel run parallel to that of the road profile above. For the piers, the maximum spacing, as specified by TxDOT, is 80’ for TX Girders. Using these criteria, the appropriate amount of 3’ piers were modeled. After changing the bridge geometry, steady flow analysis was run again and put into the results table.

3.2.3 Culvert Sizing

The existing culvert is modeled in the HEC-RAS model, but the calculations presented in this section were done to understand the methodology of the program as opposed to relying on the guess and check approach of expanding the culverts in the model.

From the TxDOT Hydraulic Design Manual and Open Channel Hydraulics textbook, the culvert to be designed is a Type OC-1 outlet-controlled culvert [6]. This means that in the minimum 10-year design storm, the culvert will be in full flow, as shown in Figure 3.3 below.

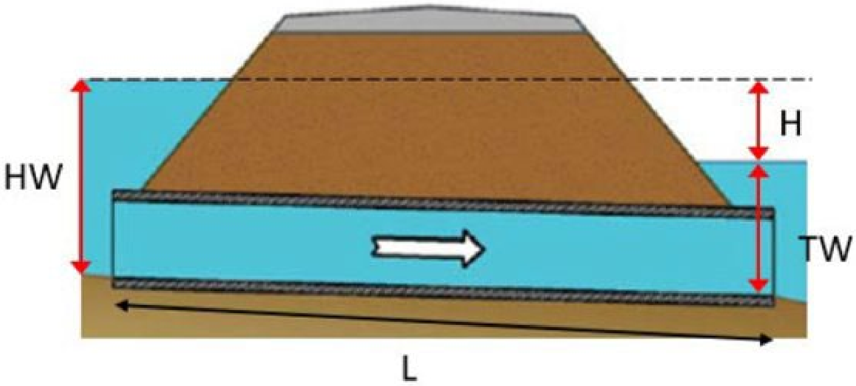


Figure 3.3: Type OC-1 Culvert

The discharge needed to be captured by the culvert was determined from the HEC-RAS model. The culvert is bounded by the Big Fossil Creek river stations 69923 and 69787.45. The flow of the channel between these stations was obtained from the model using the plot seen in Figure 3.4 below. The culvert was designed for roughly 1000 cfs flow.

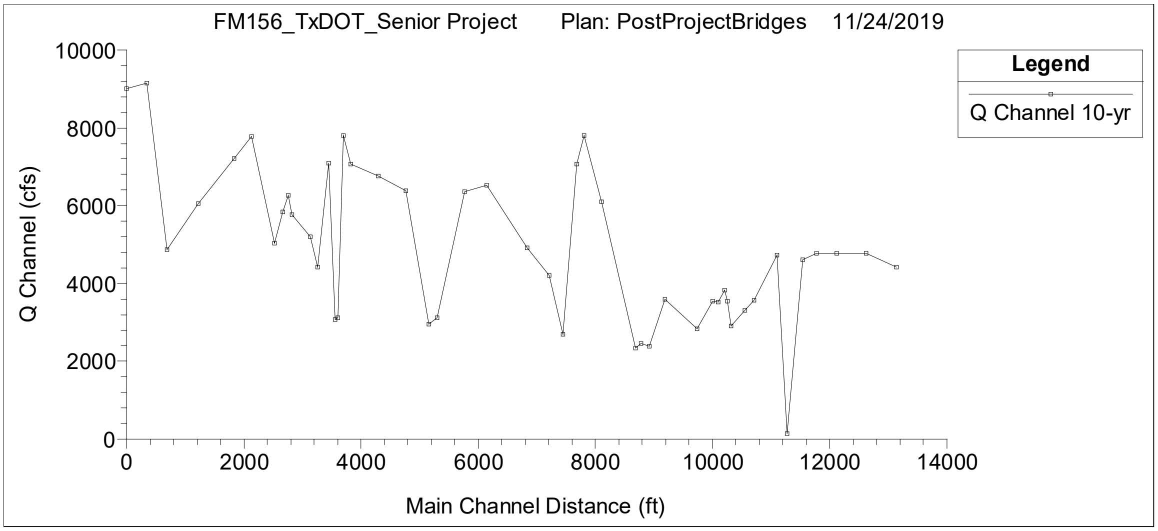
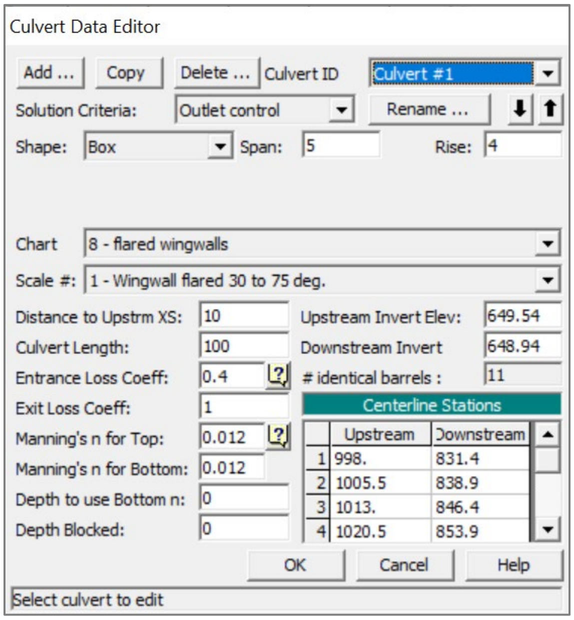


Figure 3.4: 10-Year Flow Through Big Fossil Creek

The allowable headwater is the overtop elevation of the road, defined as the top of curb elevation for this project. The tailwater is the 10-year water surface elevation of the downstream cross section. The slope of the channel is determined from the minimum channel elevations of the bounding cross sections. The length of the culvert is assumed to be 20 feet longer than the road section. The entrance loss coefficient is determined to be 0.4 for a culvert with wingwalls at 30º to 75º to barrel that is square edged at the crown, from Table 8-5: Entrance Loss Coefficients on page 8-34 of the TxDOT Hydraulic Design Manual.

A spreadsheet was created to find the capacity of the proposed culvert for a given size. The box size assumed is 4'x5' reinforced concrete box (RCB), as to keep standard box sizes, as well as keep the rise within the allowable cover of the existing roadway, assuming the profile of the road will not drastically change near this intersection. The number of barrels was increased until the capacity of the culvert exceeds the discharge in this area.

The culvert was then updated in the HEC-RAS model to ensure the results are as expected. The culvert was expanded from the existing structure in the model. The existing culverts are of the same span, so the centerline of the first culvert is assumed to stay in the same place. From there, the proposed culvert was modeled with the appropriate parameters, as shown in Figure 3.5 below. The steady flow analysis was run for the addition of the proposed culvert, and the results were checked to confirm the intersection is now serviceable in the 10-year storm.



Culvert ID: Culvert #1
Solution Criteria: Outlet control
Shape: Box
Span: 5
Rise: 4
Chart: 8 - flared wingwalls
Scale #: 1 - Wingwall flared 30 to 75 deg.
Distance to Upstrm XS: 10
Culvert Length: 100
Entrance Loss Coeff: 0.4
Exit Loss Coeff: 1
Manning's n for Top: 0.012
Manning's n for Bottom: 0.012
Depth to use Bottom n: 0
Depth Blocked: 0
Upstream Invert Elev: 649.54
Downstream Invert: 648.94
identical barrels : 11

Centerline Stations

	Upstream	Downstream
1	998.	831.4
2	1005.5	838.9
3	1013.	846.4
4	1020.5	853.9

Figure 3.5: Culvert Entry into HEC-RAS

3.2.4 Group Coordination and Iteration

A major constraint the group was faced with was to minimize the right-of-way acquisition as much as possible. To achieve this, we were not able to raise the profile of the road drastically due to the seven driveway accesses to FM 156 that occur in the floodway. Instead of raising the road profile so it is out of the 10-year water surface elevation, we were only able to extend the bridge openings and proposed channel improvements, as well as add culverts where bridges were not possible.

The model was adjusted to meet the appropriate criteria and a spreadsheet of key elevations was sent to the group member in charge of the road geometry to create a vertical profile that accommodates the changes. The profile would be updated and sent back to be reentered into the HEC-RAS model. Because of roadway constraints for vertical curves, the elevations provided from the H&H analysis are slightly altered and must be remodeled to ensure they still work with the hydraulics. Several bridge geometries were tested. Once the bridge geometry was solidified, it was sent to the group member doing the structural design of the bridges.

CHAPTER 4

HYDROLOGIC AND HYDRAULIC MODELING RESULTS

From the input described in Chapter 3, the results will be discussed in this section to quantify the effect of the proposed hydraulic structures on the flood risk and serviceability of FM 156. Refer to Appendix B for the HEC-RAS results tables referred to in this section.

4.1 Proposed Hydraulic Structures

The proposed hydraulic structures will be discussed in this section. Bridge 1 will be reconstructed from a 60’, 2-span bridge in the existing condition to a 100’, 3-span bridge. Channel improvements will also be required, excavating the entire length of the opening with 2:1 slopes on either side for channel stability. The bridge opening geometry is summarize in Table 4.1 below. These improvements can be seen as modeled in HEC-RAS in Figure 4.1 below.

Table 4.1: Bridge 1 Opening Geometry

Upstream Station 73529			Downstream Station 73408		
Station	High Chord Elevation (ft)	Low Chord Elevation (ft)	Station	High Chord Elevation (ft)	Low Chord Elevation (ft)
976.16	674.56	671.33	719.94	674.07	670.84
1076.16	673.83	670.60	819.94	673.55	670.32

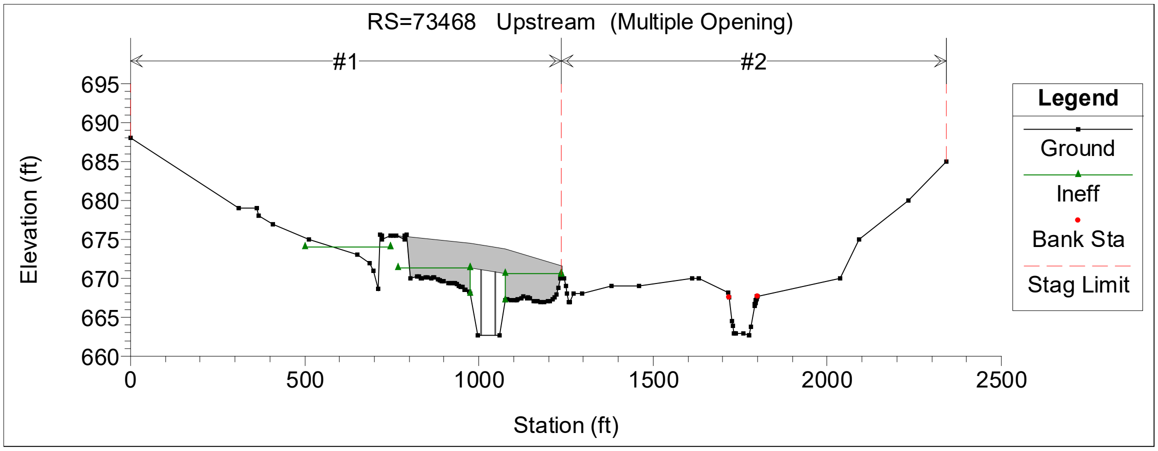


Figure 4.1: Proposed Bridge 1 Improvements

The bridges were modeled with 3’ piers and a span distribution of 30’-40’-30’ were used as not to have a pier splitting the flow. The 25-year water surface elevation of the downstream cross section is 670.86’, and the 10-year water surface elevation is 670.30’, as can be seen in Table B.3 of Appendix B. The 25-year water surface elevation is not contained under the bridge opening, but the 10-year flood is; therefore, it is only serviceable to the minimum design criteria.

Bridge 2 will be reconstructed from a 75’, 3-span bridge in the existing condition to a 750’, 10-span bridge. Similar to Bridge 1, channel improvements will be required, excavating the entire length of the opening. These improvements can be seen Figure 4.2 below, and the bridge opening geometry is summarized in Table 4.2 below.

Table 4.2: Bridge 2 Opening Geometry

Upstream Station 72419.74			Downstream Station 72310.21		
Station	High Chord Elevation (ft)	Low Chord Elevation (ft)	Station	High Chord Elevation (ft)	Low Chord Elevation (ft)
153.75	671.24	668.01	0.90	671.31	668.08
907.54	669.73	666.50	754.69	669.80	666.57

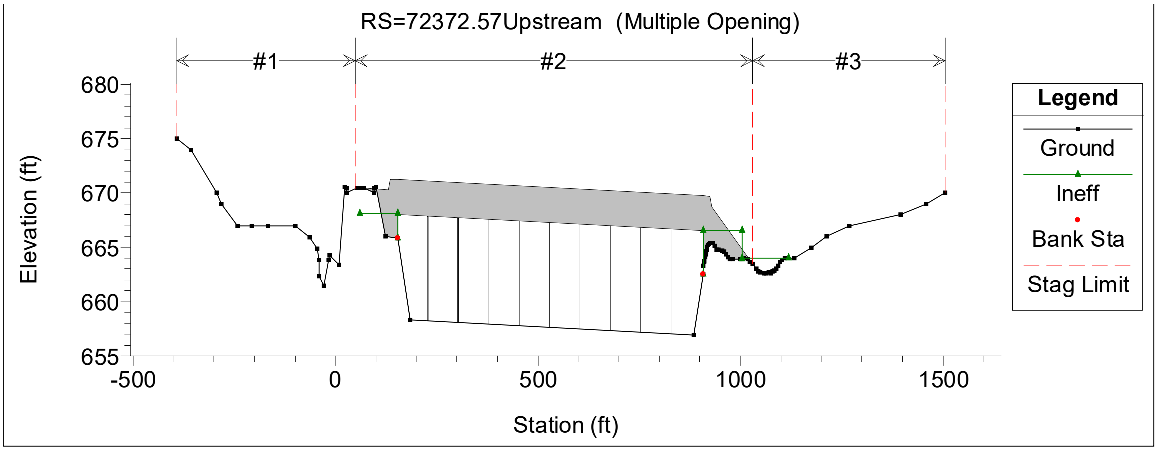


Figure 4.2: Proposed Bridge 2 Improvements

Bridge 2 consists of 10-75' spans. The 25-year water surface elevation of the downstream cross section is 666.38'. The 25-year water surface elevation is contained under the bridge opening; therefore, it is serviceable to desirable design criteria.

The culvert north of Bailey Boswell will be reconstructed from a 2-3'x5' RCB culvert to an 11-4'x5' RCB culvert. The culvert modeled in HEC-RAS can be seen in Figure 4.3 below.

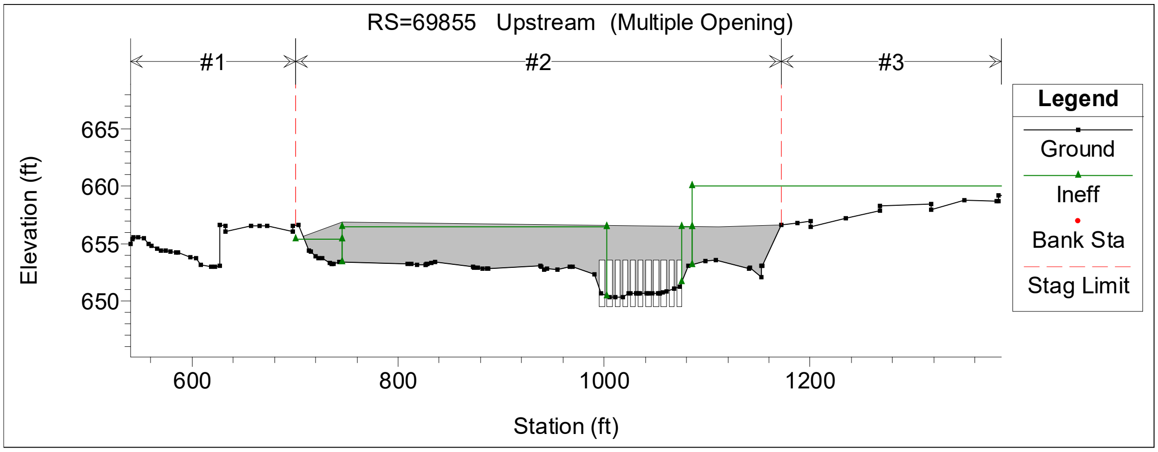


Figure 4.3: Proposed Culvert Improvements

4.2 Floodplain Impacts

The results tables for the effect of the proposed improvements on the 100-year water surface elevation can be seen in Tables B.1 and B.2 in Appendix B. The 100-year water surface elevation was slightly impacted for several cross sections, which will be discussed in Chapter 5. While it is not noticeable in a 100-year water surface comparison in Figure 4.4 below, the results table shows the water surface is raised due to the development.

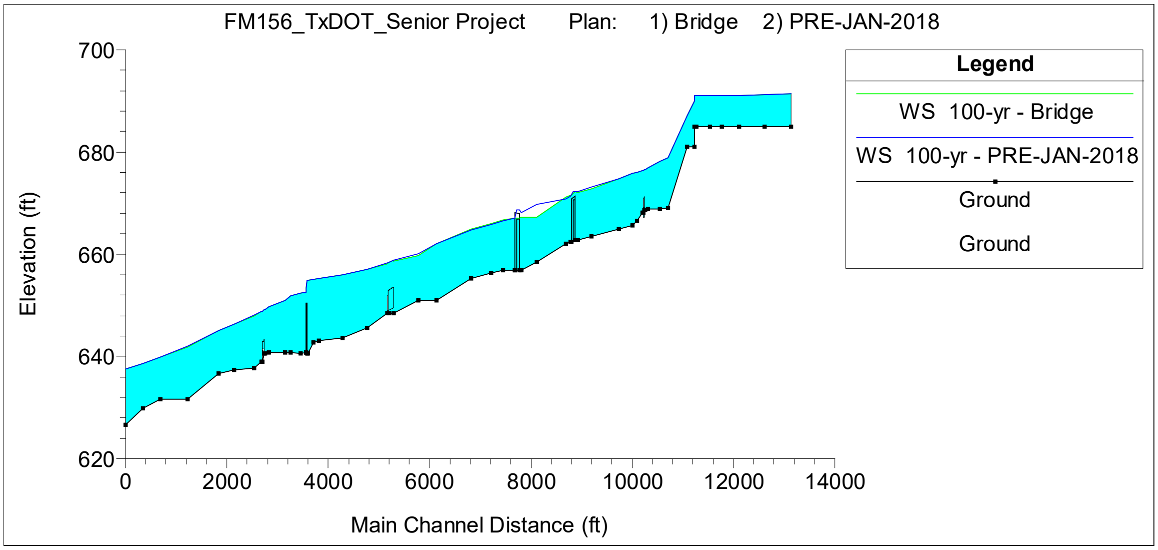


Figure 4.4: 100-Year Water Surface Elevation Comparison for Big Fossil Creek

4.3 Road Serviceability

A results table for the serviceability of the road for the 10-year and 25-year storm can be seen in Table B.3 in Appendix B. Figure 4.5 and 4.6 below show the development improves the flood risk in the 10-year and 25-year storms. Although the condition of the road is improved, the road is not considered serviceable near the proposed culvert because it overtops the curb. This will be further explored in Chapter 5.

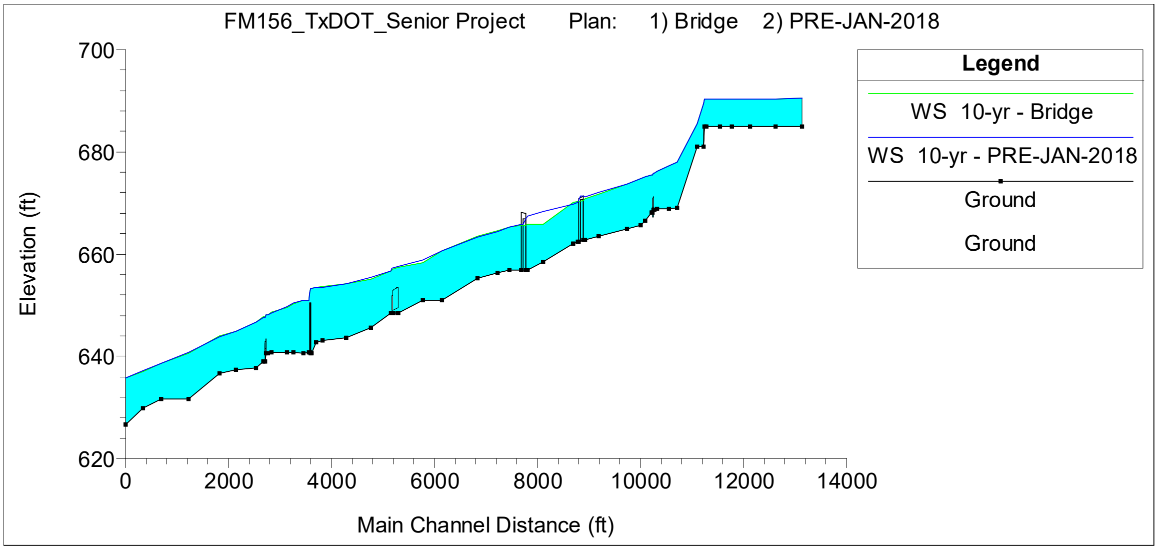


Figure 4.5: 10-Year Water Surface Elevation Comparison for Big Fossil Creek

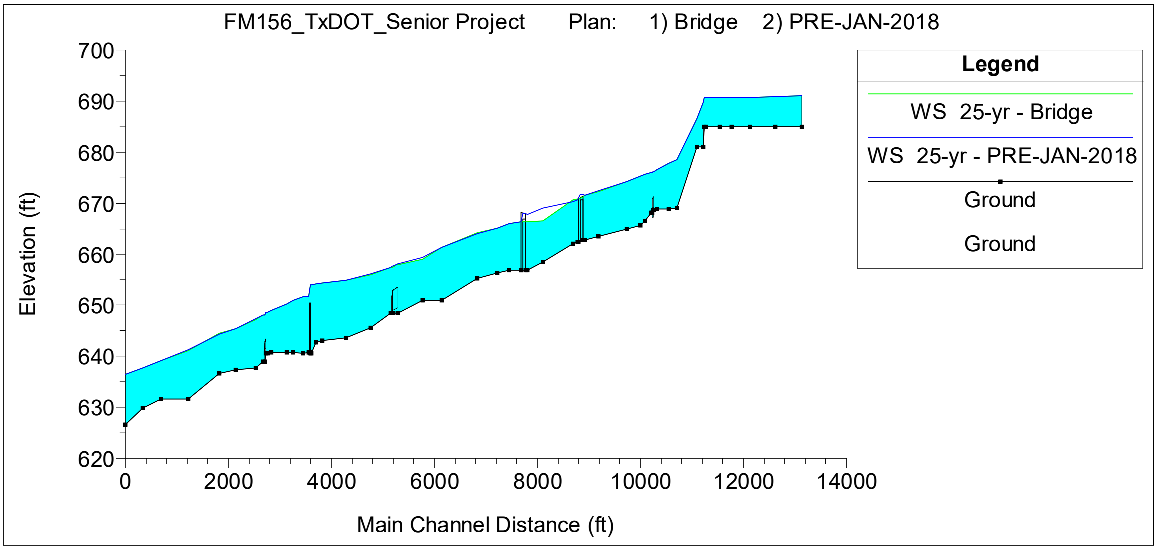


Figure 4.6: 25-Year Water Surface Elevation Comparison for Big Fossil Creek

CHAPTER 5

DISCUSSION AND CONCLUSION

From the HEC-RAS modeling, a road profile and infrastructure design were produced for the FM 156 improvements. Due to time constraints and the need for a final product for presentation, the design was unable to be finetuned to meet all requirements. In this section, a discussion of the effects of the design as it was left will be reviewed, and future steps necessary for the final analysis and design will be presented.

5.1 Effects of Improvement

The improvements proposed are a 750’ opening, 10-span bridge with the existing ground being excavated the entire length of the bridge opening, a 100’ opening, 3-span bridge with similar excavation, and an 11-4’x5’ RCB culvert. A layout of the proposed improvements can be seen in Appendix A, Figure A.2. While these hydraulic structures improve the condition of the road, they do not meet FEMA regulations or TxDOT criteria in all areas.

As seen in Tables B.1 and B.2, the 100-year water surface elevation was affected at a few cross sections. Depending on the jurisdiction, a rise in water surface that is less than a tenth of a foot is considered negligible. The majority of the differences in water surface elevation are less than this threshold and can be considered negligible. The two downstream cross sections of Bridge 1 have rises over a tenth of a foot. This is due to the dramatic lowering of the water surface elevation downstream at the bounding cross sections of Bridge 2.

As seen in Table B.3, the road is not considered serviceable in two locations. Near the culverts north of Bailey Boswell, the water service elevation of the 10-year event is still nearly a foot over the top of curb elevation. With the except of this location, the road is almost serviceable for the 25-year storm as well as the 10-year storm. This greatly improves the conditions of the road from the current condition, which still justifies the development. In addition, Bridge 1 does not meet the desirable design criteria. The bridge should be reanalyzed for the passage of the 25-year storm underneath the bridge.

In order to get the appropriate permits from FEMA to develop in the floodway, the adverse effects seen at Big Fossil Creek river stations 73408 and 73316.9 would need to be mitigated. To pass TxDOT design criteria, the road will need to be serviceable at the intersection of Bailey Boswell for the 10-year storm.

5.2 Future Work

To mitigate the flood effects of the development on the surrounding properties, further analysis will need to be done. Continued geometry iterations will have to be analyzed, comparing the effects of widening the opening of Bridge 1 on the downstream cross sections. Drastically lowering the water surface elevation at the bounding cross sections of Bridge 1 could have adverse effects on the upstream and downstream cross sections of Big Fossil Creek, so several alternatives will have to be done.

To make the road serviceable at the Bailey Boswell intersection, alternative analysis should be done. The alternatives that should be considered include raising the profile of the road at this intersection, adding more barrels to the proposed culvert, or adding a bridge north of the intersection and excavating under the road instead of adding culverts. Alternative analysis should be done comparing the cost, constructability, and right-of-way acquisition would be required for each possible solution.

APPENDIX A

LAYOUT OF CROSS DRAINAGE STRUCTURES

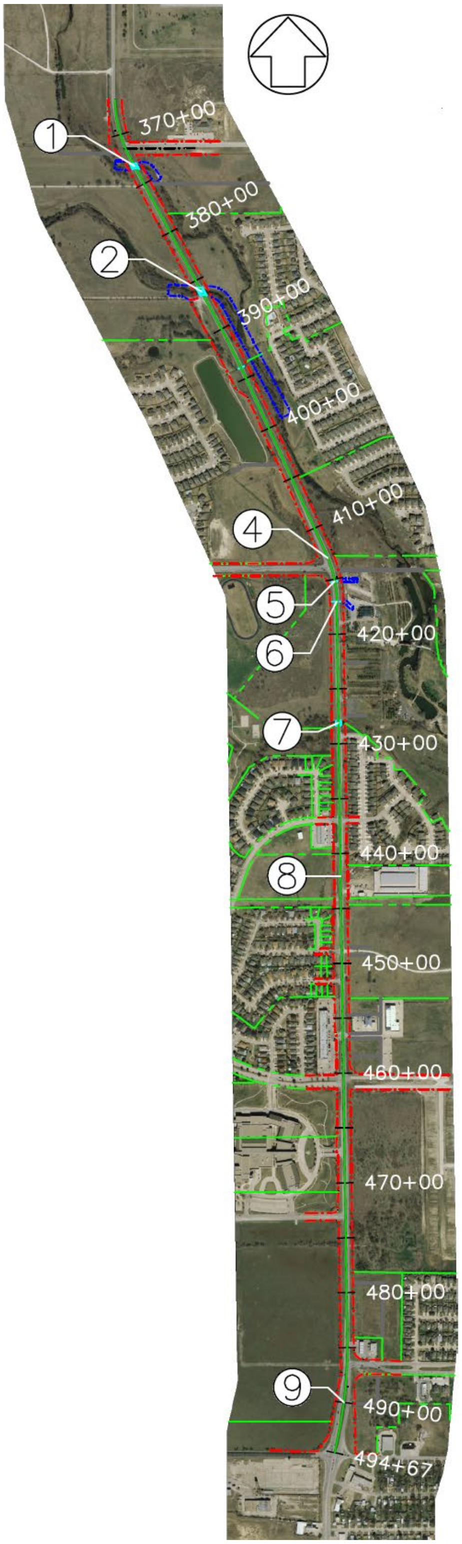


Figure A.1: Layout of Existing Cross Drainage Structures (Not to Scale)

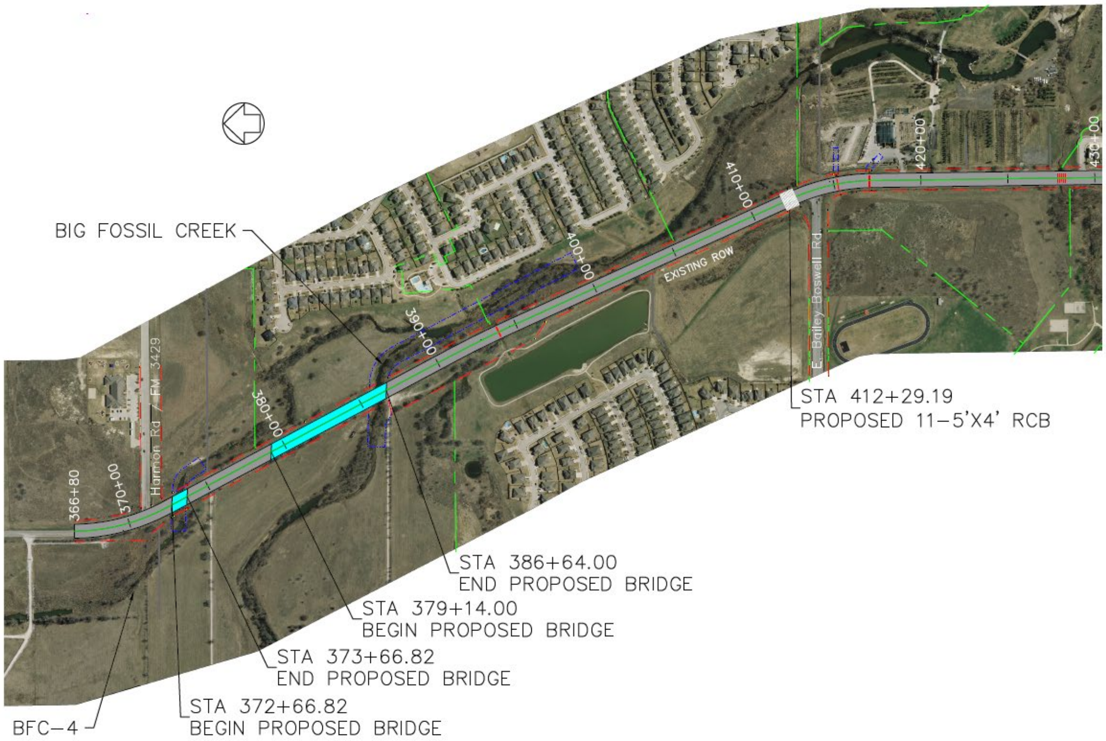


Figure A.2: Layout of Proposed Cross Drainage Structures (Not to Scale)

APPENDIX B

RESULTS TABLES

Table B.1: 100-Year Water Surface Elevations at River Stations 77763.36 to 72419.74

River Station	Ex 100-year WSE	100-year WSE	Difference
77763.36 BM	691.38	691.36	-0.02
77244.45	691.18	691.16	-0.02
76742.86	691.09	691.09	0
76401.46 BL	691.03	691.03	0
76162.57	691.01	691.01	0
75895.88	691	691	0
75860.03	Inl Struct	Inl Struct	
75717.45	687.16	687.16	0
75339.07 BK	678.88	678.88	0
75169.85	678.12	678.12	0
74936.51	676.92	676.92	0
74883.98	676.63	676.63	0
74861.66	Culvert	Culvert	
74835.59	676.45	676.45	0
74720.89 BJ	676.1	676.1	0
74631.84	675.83	675.83	0
74357.4	674.76	674.74	-0.02
73815.28 BI	673.11	672.87	-0.24
73529	672.2	672.09	-0.11
73468	Mult Open	Mult Open	
73408	671.28	671.52	0.24
73316.9	670.9	671.23	0.33
72735.99 BH	669.71	667.28	-2.43
72419.74	668.08	667.16	-0.92

Table B.2: 100-Year Water Surface Elevations at River Stations 72372.57 to 64629.55

River Station	Ex 100-year WSE	100-year WSE	Difference
72372.57	Mult Open	Mult Open	
72310.21	667.1	667.11	0.01
72076.41	666.61	666.71	0.1
71848.74	665.84	665.99	0.15
71457.44 BG	664.7	664.92	0.22
70774.01	661.99	662.07	0.08
70401.96 BF	660.09	659.69	-0.4
69923	658.8	658.68	-0.12
69855	Mult Open	Mult Open	
69787.45	658.25	658.18	-0.07
69394.02 BE	657.13	657.02	-0.11
68919.85	655.95	655.96	0.01
68453.06	655.21	655.25	0.04
68328.87	655.12	655.16	0.04
68231.45	654.88	654.92	0.04
68209.2	Mult Open	Mult Open	
68188.99	652.51	652.51	0
68077.58 BD	652.44	652.45	0.01
67885.4	651.85	651.83	-0.02
67769.72	651.01	650.94	-0.07
67454.67	649.77	649.77	0
67385.46	649.14	649.14	0
67345.88	Culvert	Culvert	
67302.11	648.84	648.83	-0.01
67160.49 BC	648.04	647.96	-0.08
66769.47	646.25	646.27	0.02
66458.47	645.06	645.12	0.06
65858.62 BB	641.98	641.86	-0.12
65314.46	639.95	639.95	0
64968.11	638.6	638.54	-0.06
64629.55 BA	637.47	637.47	0

Table B.3: 10-Year and 25-Year Road Serviceability Results

Road Station	River Station	Centerline Elevation	Top of Curb Elevation	10-year WSE	Feet below 10-year WS	25-year WSE	Feet below 25-year WS
420+74.99	68188.90	656.10	656.10	651.03	5.07	651.7	4.40
420+33.96	68231.45	655.98	655.98	653.25	2.73	654.01	1.97
419+55.58	68328.87	655.73	655.73	653.53	2.20	654.26	1.47
418+68.78	68453.06	655.48	655.48	653.59	1.89	654.33	1.15
417+24.58	68919.85	655.39	655.39	654.11	1.28	654.93	0.46
413+59.27	69394.02	655.72	655.72	655.07	0.65	655.97	-0.25
413+59.27	69787.45	655.72	655.72	656.65	-0.93	657.33	-1.61
409+30.00	69923.00	656.58	656.58	657.39	-0.81	657.97	-1.39
404+51.16	70401.96	659.19	659.19	658.35	0.84	658.97	0.22
400+51.95	70774.01	661.36	661.36	660.71	0.65	661.33	0.03
394+16.50	71457.44	664.13	664.13	663.46	0.67	664.14	-0.01
390+43.35	71848.74	667.26	667.26	664.52	2.74	665.19	2.07
388+68.06	72076.41	668.39	668.39	665.37	3.02	665.97	2.42
388+13.96	72310.21	668.48	668.48	665.7	2.78	666.34	2.14
378+79.89	72419.74	670.51	670.51	665.73	4.78	666.38	4.13
378+13.10	72735.99	670.95	670.95	665.84	5.11	666.56	4.39
377+43.57	73316.90	671.40	671.40	670.03	1.37	670.58	0.82
375+96.45	73408.00	672.35	672.35	670.3	2.05	670.86	1.49
370+79.24	73529.00	675.50	675.50	670.81	4.69	671.47	4.03
370+60.27	73815.28	675.60	675.60	671.65	3.95	672.25	3.35
367+79.41	2910.00	677.00	677.00	671.99	5.01	672.52	4.48

REFERENCES

[1] Federal Emergency Management Agency, “Flood Insurance Rate Map, Map No. 48439C0065L.” National Flood Insurance Program, 2019.

[2] “Unit 5: The NFIP Floodplain Management Requirements,” in *National Flood Insurance Program (NFIP) Floodplain Management Requirements: A Study Guide and Desk Reference for Local Officials*, Federal Emergency Management Agency, pp. 1–59.

[3] Flood plain management criteria for flood-prone areas, 44 C.F.R. § 60.3.

[4] Texas Department of Transportation, *Hydraulic Design Manual*. Texas Department of Transportation, 2019.

[5] Texas Department of Transportation, *Roadway Design Manual*, no. April. Texas Department of Transportation, 2018.

[6] T. W. Sturm, *Open Hydraulics Channel*, 1st ed. McGraw-Hill, 2001.

BIOGRAPHICAL INFORMATION

Valerie Arruda is a Civil Engineering major, and a member of the American civil engineering honor society, Chi Epsilon. She has been a member of the University of Texas at Arlington's Honors College since her first semester in Fall of 2016. She will be graduating in the Fall of 2019 *Summa Cum Laude.*

Valerie has had an internship with a local civil engineering consulting firm, MMA, Inc., since the summer of 2018. She passed the Fundamentals of Engineering Exam and will continue with MMA as an Engineer in Training in January of 2020. She plans to take her Professional Engineering Exam in 2020 and gain experience to become a licensed Professional Engineer in the coming years.

Valerie hopes to become a project manager in the civil engineering field. She also plans on applying to go back to school in the near future to earn a Master in Business Administration degree.