Appendix G

Hydraulic Report

Progres Report for
MoDOT Review
Hydrology and Hydraulics
Existing Conditions

I-44 Flood Study

Jerome, MO
J5I3182
Phelps County, Missouri

Prepared for: Missouri Department of Transportation

January 31, 2018

HANSON
Engineering | Planning | Allied Services

Table of Contents

1. Executive Summary

Little Piney Creek passes under I-44 and merges into the Gasconade River near Jerome, Missouri. Short-term flooding issues have impacted I-44 in this vicinity since its original construction. In the last 10 years, the frequency and duration of the flooding issues have been increasing. In 2013, a storm resulted in recording flooding, up to five feet in depth, along a one-half mile section of I-44, closing the interstate. In 2015, a new record flood event eclipsed the 2013 flood, inundating the interstate by six feet, forcing a three day closure. In 2017, a new record flood overtopped the interstate by up to eight feet in depth, forcing a longer closure. With I-44 being the second most used corridor in the state, the Department selected Hanson Professional Services (Hanson) to analyze the current hydraulic conditions and evaluate alternatives to minimize the chance of future I-44 closures at this site.

Stream gage analysis was performed for two critical gages in the study area. The first gage is located on Little Piney Creek located in Newburg, Missouri, approximately 3.7 miles upstream of I-44. The second gage is located on the Gasconade River in Jerome, Missouri, approximately 1.0 mile downstream of I-44. The gage analyses of the record 2017 flood event found that peak flows on Little Piney Creek were near the magnitude of a 15-year flood event and on Gasconade River were near a 150-year flood event. The timing of the two peaks were offset by 22 hours, with the Little Piney Creek peak occurring at 4 PM on 4/30/17, and the Gasconade River peak occurring at 2 PM on 5/1/17. Model analysis confirmed that Little Piney Creek had little impact on the 2017 peak stages at I-44. The Gasconade River tailwater is the controlling source for extreme floods.

An interesting aspect of the gage analysis identified a significant change in trend regarding flood frequencies along the Gasconade River. With the three largest floods of record, and five of the top eleven, occurring since 2008, there has been a rapid shift in the statistical exceedance probability. The 2017 flood currently is shown to be near a 150-year flood frequency. Had this flood occurred prior to the other recent events, say in year 2000, the flood frequency would have been greater than a 500-year event. The number of large flood events in recent years has dramatically altered the anticipated flood frequencies and corresponding design discharges.

USGS regression equations were used to define the discharge-frequency relationship used in the evaluation of Little Piney Creek and its tributaries. Both Little Piney Creek and Tater Hollow, a 9 square mile tributary along I-44, have potential to be impacted by the proposed flood mitigation alternatives. A HEC-HMS model was developed to define design hydrographs for analysis. The hydrographs allow evaluation of peak flows, velocities, timing and volumes. The HEC-HMS model was calibrated to the 2017 flood event with favorable results. A slight curve number adjustment from 62 to 67.5 was required to match the peak magnitudes as derived from USGS regression equations.

HEC-RAS models were also developed from MoDOT project surveys, project LiDAR and supplemental hydraulic surveys. For this study, modeling was confined to Little Piney Creek upstream and downstream of I-44, and Tater Hollow along I-44 to its confluence with Smith Hollow. This defines the limits of anticipated impacts due to the proposed flood mitigation alternatives. Three separate models were developed in HEC-RAS: (1) a 2D model of the LiDAR terrain without hydraulic structures, (2) a 1D steady flow model, and (3) a 1D unsteady flow model. The 1D unsteady flow model was used for simulation of the 2017 flood event with favorable results. This model was also used to define the baseline conditions 50-, 100- and 500-year flood events, and will be used to evaluate hydraulic impacts of the proposed alternative flood mitigation plans.

Based on survey of the I-44 road profile, the lowest asphalt elevation is 689.90 feet, which represents the edge of pavement elevation for the right shoulder on the west bound lanes. For purposes of this study, elevation 689.90 represents the overtopping elevation of I-44. Based on the current gage analysis for the Gasconade River at Jerome, this correlates to a **20-year flood frequency event**.

2. Introduction

Little Piney Creek passes under I-44 and merges into the Gasconade River near Jerome, Missouri. Short-term flooding issues have impacted I-44 in this vicinity since its original construction. In the last 10 years, the frequency and duration of the flooding issues have been increasing. In 2013, a storm resulted in record flooding, up to five feet in depth, along a one-half mile section of I-44, closing the interstate. In 2015, a new record flood event eclipsed the 2013 flood, inundating the interstate by six feet, forcing a three day closure. In 2017, a new record flood overtopped the interstate by up to eight feet in depth, forcing a longer closure. With I-44 being the second most used corridor in the state, the Department selected Hanson Professional Services (Hanson) to analyze the current hydraulic conditions and evaluate alternatives to minimize the chance of future I-44 closures at this site. A project location map is located in **Appendix A.**

The purpose of this progress report is to provide a progress update on the existing conditions hydraulic modeling.

3. Data Collection

Site specific data used for engineering analysis, includes but is not limited to:

- project photogrammetry surface provided by MoDOT
- I-44 construction drawings: road profile, bridges A6671 and A1635 and other drainage culverts
- publically available topographic data (DEM or contour mapping)
- NRCS soils mapping
- historic aerial imagery
- USGS Stream gage #06933500 Gasconade River at Jerome, MO
- USGS Stream gage #06932000 Little Piney Creek at Newburg, MO
- NOAA rainfall data
- Specific purpose survey at requested channel cross sections

4. Existing Site Description

The *Gasconade River* (2840 sq.mi. drainage area) is the source of recent flooding that has overtopped I-44 and forced several closures. The Gasconade parallels I-44 to the west passing through the community of Jerome. Two bridges cross the river near the confluence with Little Piney Creek, Route D and BNSF Railway. Both of these crossings, especially the BNSF Railway, potentially impact backwater elevations projected on I-44.

Little Piney Creek (266 sq.mi. drainage area) crosses beneath I-44 only ¼-mile upstream of the Gasconade. While the I-44 bridge is elevated high above all historical flood events, its in-water features, such as, piers, abutments and embankments influence hydraulics both from Little Piney Creek as well as Gasconade River backwater. The road profile has a sag on the west side of the bridge making a one-half mile section of interstate prone to flood inundation during extreme floods, see Figure 1.

Tater Hollow (9 sq.mi. drainage area), a tributary to Little Piney Creek travels along the west side of I-44 before entering Little Piney Creek. This tributary collects upstream runoff from Tater Hollow, Smith Hollow and an Unnamed Tributary which pass beneath I-44 through a bridge, box culvert and pipe culvert. All of these structures have the potential to influence the design of the recommended solution, along with the potential to be impacted by the flood reduction plan.

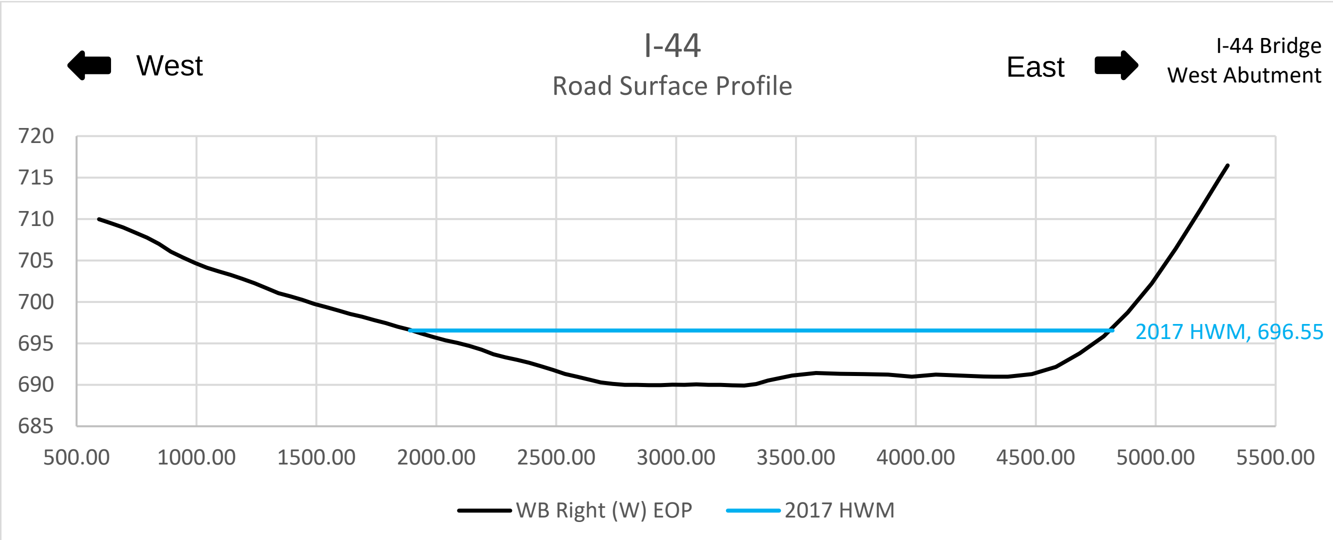


Figure 1: I-44 Road Surface Profile

5. Hydrology

Little Piney Creek has a drainage area of 266-mi^2 at the Interstate 44 crossing, just prior to its outfall into the Gasconade River. Refer to the Basin Map included in Appendix A. There is a USGS stream gage #06932000 located on Little Piney Creek 3.7 miles upstream in Newburg with an upstream drainage area of 199-mi^2. This gage has a 90 year record, dating back to 1915. Peak flow estimates for flood frequencies ranging from 10-year to 500-year were estimated using (1) stream gage data, (2) USGS regression equations, and (3) HEC-HMS models, as shown in **Tables 1-3**. For the purposes of the I-44 overtopping analysis the USGS regression equation discharges will be utilized.

Table 1: Peak Flows – Stream Gage Data

Location	Drainage Area (mi^2)	Flow Rates (cfs)					
		10-YR	25-YR	50-YR	100-YR	500-YR	May '17-Event
Little Piney Creek at Newburg Gage	199	19,804	27,383	33,320	39,414	54,059	21,000
Little Piney Creek at I-44 *	266	23,830	32,900	39,990	47,270	64,770	25,260

***** Gage data was projected to I-44 using the transposition of discharges methodology as outlined in MoDOT EPG 749.7.2 Ungaged Sites Near Stream Gage

Table 1 presents the results of the Bulletin 17B statistical analysis. The Discharge-Frequency curve is presented in Figure 2. The gage record provides 90 years of data with the record event occurring in 1946 at 32,500 cfs. The December 2015 event was the seventh highest record at 24,000 cfs and the 2017 flood was the tenth highest at 21,000 cfs. Interestingly, the 90-year record flood of 32,500 cfs results in a statistical frequency near a 50-year (33,319 cfs) event. The 2017 flood is estimated near a 15-year frequency and the 2015 flood is near a 25-year event. According to this analysis the watershed has not yet experienced the magnitude of a 100-year event (39,414 cfs). The most recent flood events and their associated frequency are summarized in Table 4.

Table 2: Summary of Recent Flood Events on Little Piney Creek

Flood Event	Rank	Year	Peak Flow	Frequency
Flood of Record	1st	1946	32,500 cfs	50-year
2015 Flood	7th	2015	24,000 cfs	25-year
2017 Flood	10th	2017	21,000 cfs	15-year
2013 Flood	13th	2013	20,100 cfs	10-year
2008 Flood	14th	2008	17,800 cfs	9-year
2010 Flood	15th	2010	15,800 cfs	7-year

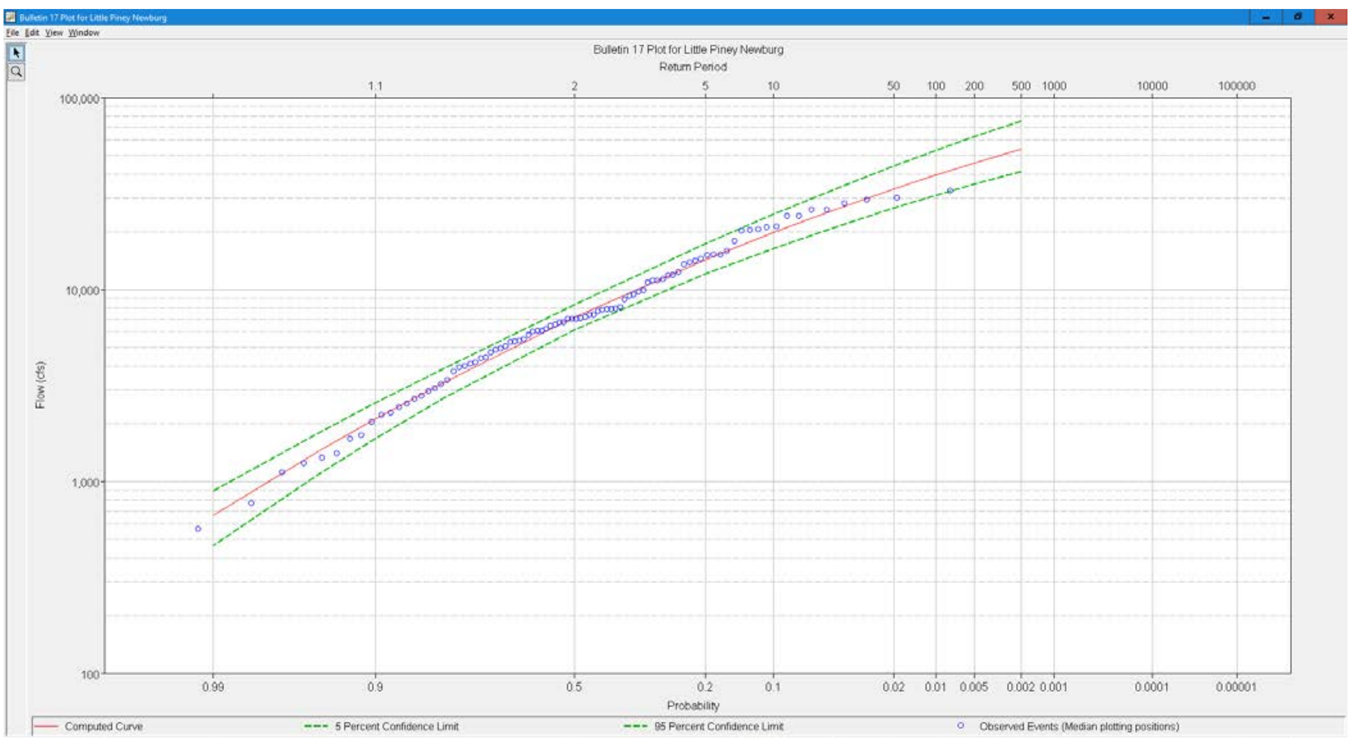


Figure 2: Discharge-Frequency Curve, Little Piney Creek at Newburg

Table 3: Peak Flows – USGS Regression Data

Location	Drainage Area (mi²)	Flow Rates (cfs)					
		10-YR	25-YR	50-YR	100-YR	500-YR	May '17-Event
Little Piney Creek at Newburg Gage	199	18,470	25,140	30,170	35,200	47,190	n/a
Little Piney Creek at I-44	266	23,040	31,390	37,680	43,960	58,950	n/a
Tater Hollow Tributary	9.32	2,890	4,030	4,900	5,770	7,840	n/a

Table 4: Peak Flows – HEC-HMS Model Data

Location	Drainage Area (mi²)	Flow Rates (cfs)					
		10-YR	25-YR	50-YR	100-YR	500-YR	May '17-Event
Little Piney Creek at Newburg Gage	199				29,980		20,490
Little Piney Creek at I-44	266				37,480		27,330
Tater Hollow Tributary	9.32				2,660		1,860

Table 3 presents the results of USGS regression equation calculations. These equations were taken from *USGS Methods for Estimating Annual Exceedance-Probability Discharges and Largest Recorded Floods for Unregulated Streams in Rural Missouri (SIR 2014-5165)*, as recommended in the MoDOT Engineering Policy Guide. Results are comparable to the gage analysis and will be used for analysis of existing and proposed conditions.

Table 4 presents the results of the HEC-HMS models. These models were developed from measured hydrologic parameters and calibrated to the most recent 2017 flood event. In order to maintain valid data, not only to the gage but in other areas downstream, model adjustments used in calibration were applied uniformly throughout the entire model. Only two parameters were adjusted for calibration – SCS curve number (CN) and Clark's Unit Hydrograph time of concentration (Tc) and storage coefficient (R). Both parameters were adjusted modestly to match the gage reading. Curve Numbers were adjusted from the calculated value of 58 to the calibrated value of 62, an adjustment of 7%. Tc and R were adjusted uniformly by 10% to better match gage hydrograph peak timing and shape.

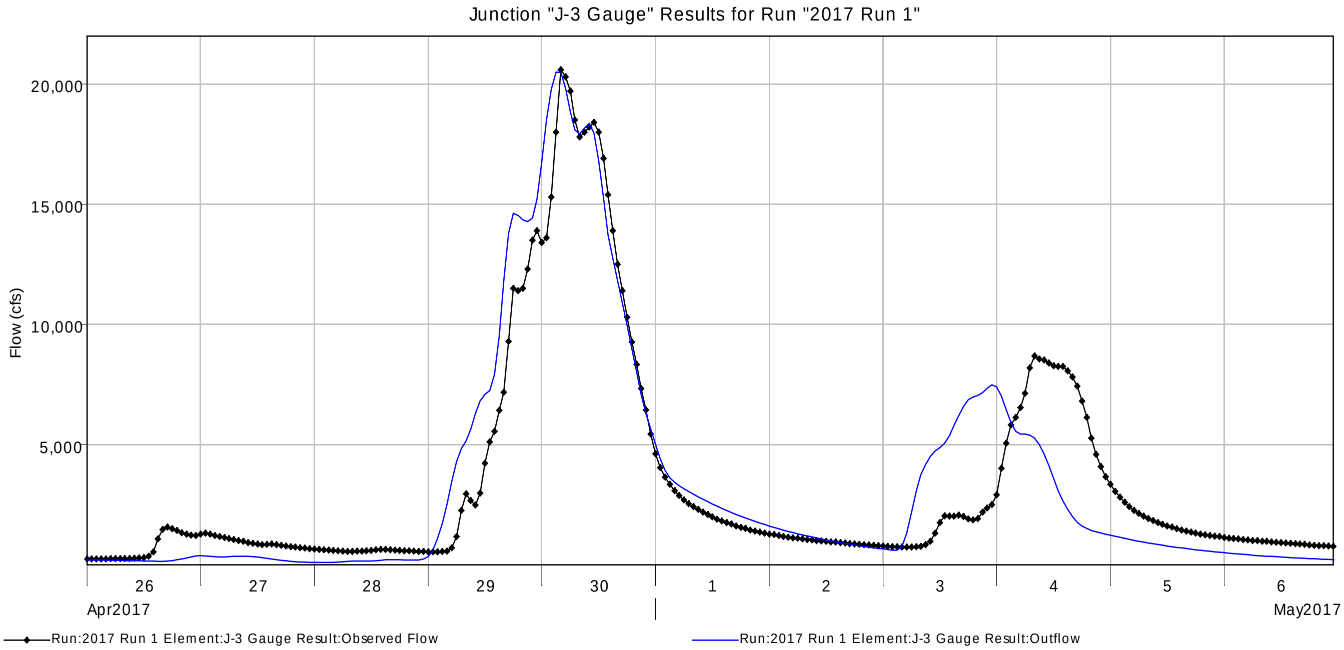
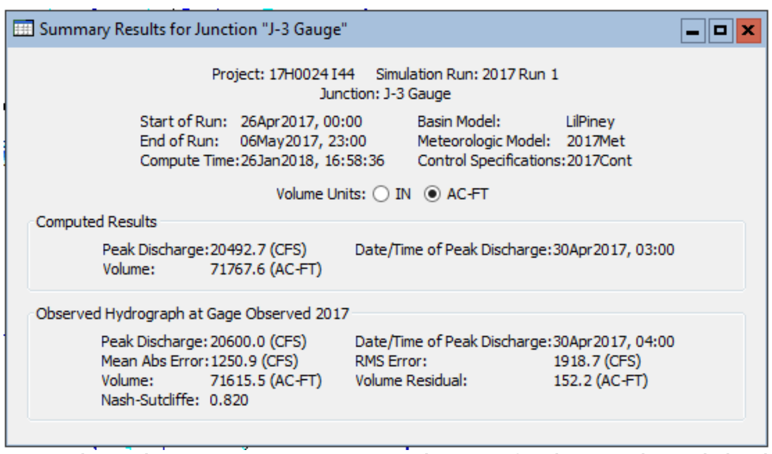


Figure 3: HEC-HMS Model Calibration



The calibrated HEC-HMS model produces a favorable match of the recorded 2017 flood event. In Figure 3, the black line represents the recorded gage data and the blue line represents the HEC-HMS calibrated model output. The model agrees with the gage in both peak (-0.5%) and volume (+0.2%).

There are three rainfall gages (Salem, Waynesville, Rolla) in the area that recorded hourly rainfall data during this event. All three have similar rainfall data records. The Salem gage was chosen for input since it is the closest in proximity to the watershed as shown in Figure 4.

Using the favorable calibration model, HEC-HMS was compared to the design frequency discharges provided by USGS regression equations. As shown by comparing Tables 2 and 3, the HEC-HMS peak flow rates are less than the USGS regression equations. In order to match the peak magnitudes, the HEC-HMS model Curve Numbers were adjusted higher from 62 to 67.5. This adjustment brought the 100-year model peak within 0.1% of the regression equations. The HEC-HMS model provides hydrograph (flow vs. time) data for use in HEC-RAS to evaluate not only flood peaks, but also flood timing and flood volumes. All of these hydrologic parameters will be evaluated in the design and comparison of the flood mitigation alternatives.

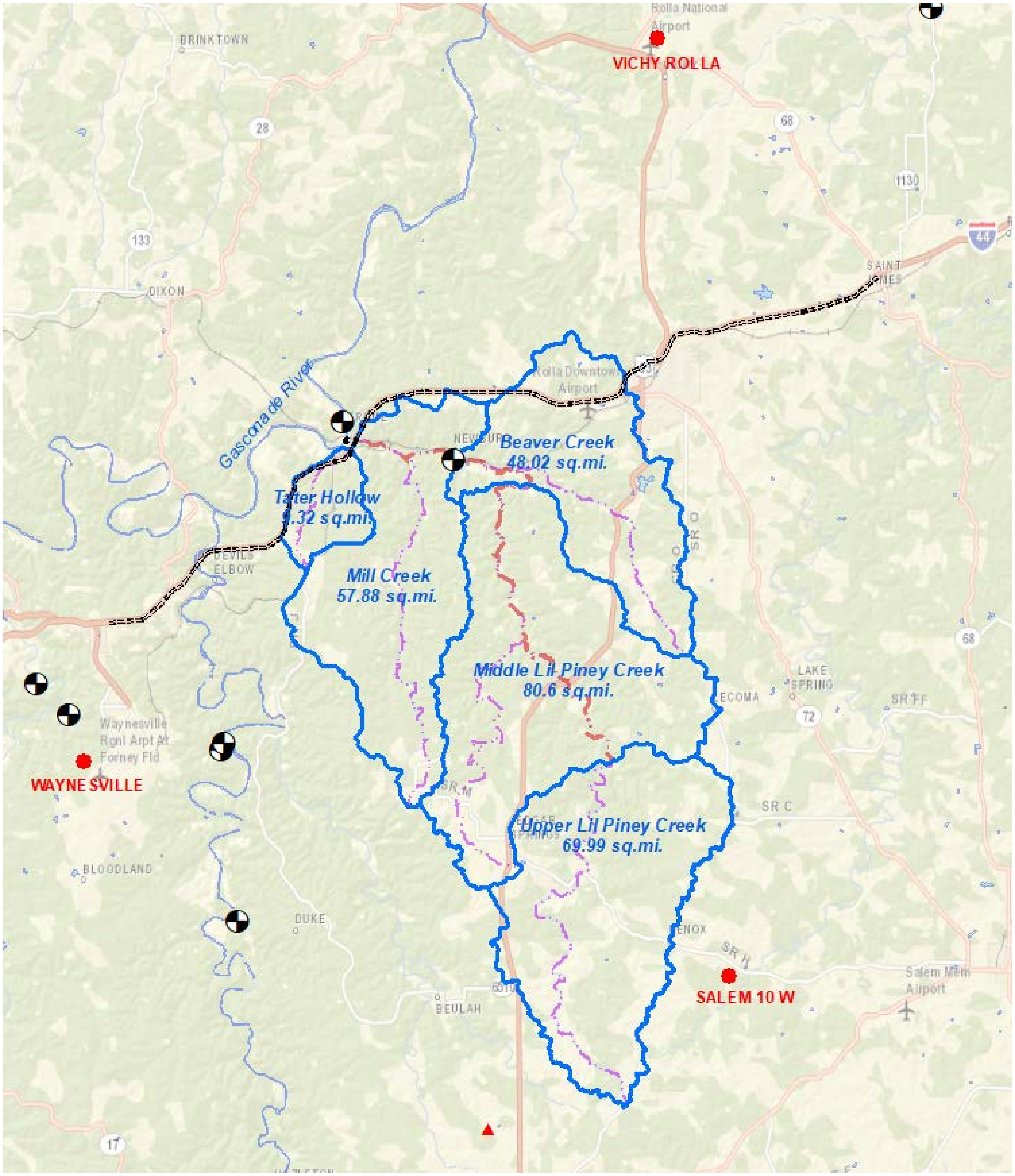


Figure 4: Rainfall Gage and Stream Gage Locations

The Gasconade River provides a vital component to hydraulics within the project study area. The tailwater produced by the Gasconade River is the most critical component in the system. USGS stream gage #06933500 provides 99 years of record dating back to 1897. The three highest recorded flood events have occurred in the past four years. The third largest flood of record occurred on August 7, 2013 producing a peak discharge of 138,000 cfs. The second largest flood of record occurred on December 29, 2015 producing a peak discharge of 140,000 cfs. The highest flood of record occurred on May 1, 2017 producing a peak discharge of 197,000 cfs. All of these events overtopped I-44 and forced road closure for several days. It is clear that modifications need to be implemented to reduce the likelihood of future road closures.

Table 5: Gasconade River Stream Gage Data

Location	Drainage Area (mi^2)	Gage Analysis					
		10-YR	25-YR	50-YR	100-YR	500-YR	May '17-Event
Gasconade River at Jerome Gage (Discharge in cfs)	2,840	85,878	118,366	144,964	173,487	247,725	197,000
Gasconade River at Jerome Gage (Stage in ft)	2,840	26.08	29.82	32.22	34.35	38.49	35.06

Table 6: Summary of Recent Flood Events on Gasconade River

Flood Event	Rank	Year	Stage	Peak Flow	Frequency
Flood of Record	1st	2017	35.06 ft	197,000 cfs	150-year
2015 Flood	2nd	2015	31.92 ft	140,000 cfs	50-year
2013 Flood	3rd	2013	31.81 ft	138,000 cfs	50-year
2008 Flood	6th	2008	30.43 ft	118,000 cfs	30-year
2011 Flood	11th	2001	26.58 ft	85,100 cfs	10-year

It should be noted that frequency information is an evolving number that changes with each additional year of gage data input. An interesting footnote to the Gasconade gage analysis is developed by eliminating recent data from 2000-2017. Doing so still provides 82 years of prior record but significantly shifts the discharge-frequency relationship. The 500-yr stage becomes 34.07 (one foot below the 2017 flood event). While this is not the most current statistical analysis, it does show how significantly the recent extreme events have shifted the expected probability.

Part of the Gasconade River gage analysis involved applying data from the gage to the confluence with Little Piney Creek, and consequently onto I-44. Converting data from stage to elevation was accomplished by applying the gage datum elevation of 657.64 feet. Two factors were applied to correlate the data from the gage to I-44. First, the gage is read in NGVD29 datum. Updating those values to NAVD88 requires a shift of +0.187 feet. Second, transferring elevation data requires a factor of +3.66 feet. This is based on surveyed high water marks from the 2017 flood of record, which produced a high water mark on the interstate of 696.55 feet. At that time the gage recorded a peak elevation of 692.89 feet (NAVD88). Combining the datum shift and location shift produces a composite shift of +3.85 feet between gage and I-44. It should be noted that this was only valid and confirmed during the 2017 flood event. It is likely that this number varies during events with smaller magnitudes, especially those that do not reach the BNSF Railway bridge deck. However, for the purposes of this study, a constant +3.85 feet will be used to correlate gage elevations to I-44. Table 7 shows the final peak stages for the Gasconade River at the Little Piney Confluence at different return events including the May 2017 flood event.

Table 7: Elevation-Frequency at I-44

	Peak Stage - Gasconade @ Little Piney Confluence (Gage + 3.85) (NAVD 88 = NGVD 29 + .187)					
River	10 Year Peak	25 Year Peak	50 Year Peak	100 Year Peak	500 Year Peak	May 2017
Gasconade	687.57	691.31	693.71	695.84	699.98	696.55

Based on surveys of the road profile, the lowest asphalt elevation on I-44 is 689.90, which represents the edge of pavement elevation for the right shoulder on the west bound lanes. For purposes of this study, elevation 689.90 represents the overtopping elevation of I-44. Based on the current gage analysis for the Gasconade River at Jerome, this correlates to **a 20-year flood frequency event**.

6. Hydraulics

Using the collected data, HEC-RAS 1D and 2D models have been constructed in order to develop understanding of the existing condition hydraulics. The 2D model was run using the stage and discharge data associated with the May 2017 flood. This model utilized the LiDAR based terrain and did not include any bridge or other hydraulic structures. Results of the 2D model indicated that flow overtopped the interstate in an east to west direction following the flow direction of Little Piney Creek. Figure 5 is a screen capture of the 2D model results showing the flow direction during the peak of the flood event. This information was used to confirm the results of the 1D modeling approach.

HEC-RAS unsteady flow 1D modeling has been developed to define area hydraulics. It incorporates the specific purpose survey of the channels with the LiDAR to create an accurate terrain. Structure information was entered for the I-44 bridges over the Little Piney along with the three bridges over the tributary. Additionally, the embankment for I-44 was included in the model as a lateral structure which included the three culvert crossings that allow flow from the south side of the alignment to enter the main tributary channel. The highest alignment profile of I-44 between the tributary bridges and the Little Piney bridges was used to define the weir that separates the tributary channel from the adjacent storage area. A lateral structure was also defined along the left bank of the portion of the Little Piney channel that is upstream of the bridges. This structure allows flow from the Little Piney overbank area to flow into a storage area, similar in concept to the tributary structure and storage area. These two storage areas were linked together allowing the model the capability to route water in either direction over the I-44 embankment as flooding occurs. The results of the 1D and 2D modeling are generally in very good agreement regarding the magnitude and extents of the flooding associated with the May 2017 event.

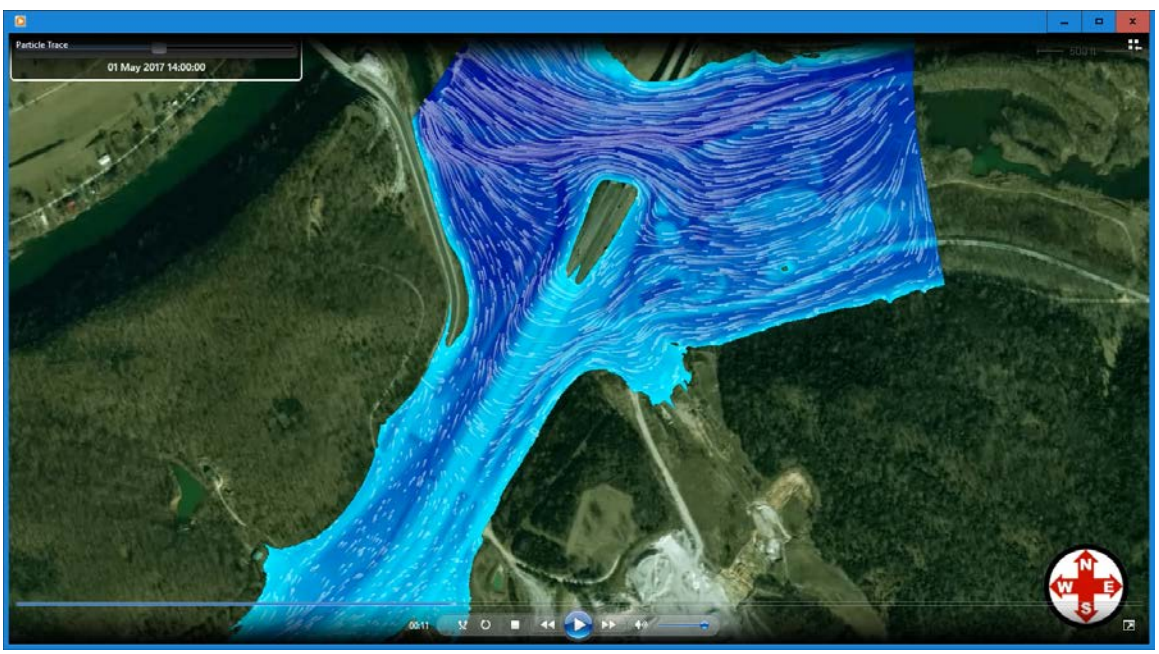
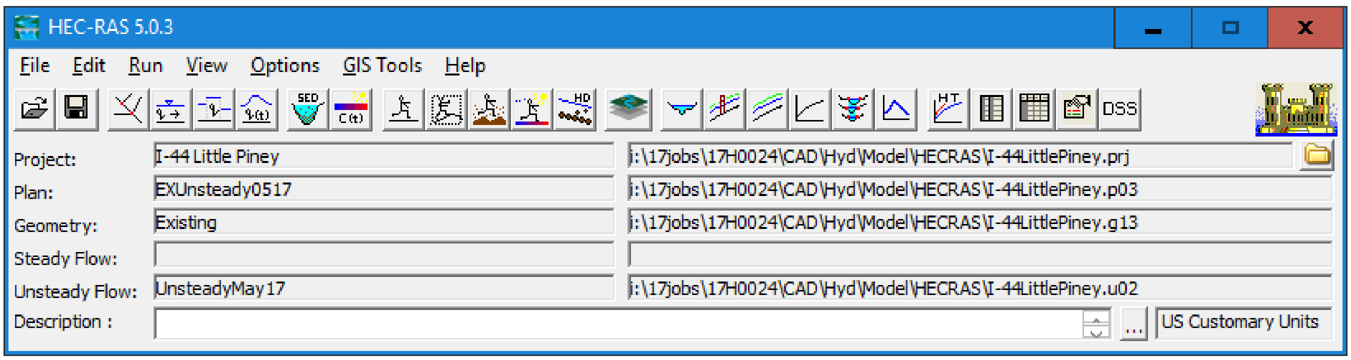


Figure 5: 2D Model with Velocity Trace

Hanson has placed a few different videos of the 2D HEC-RAS model simulation for the 2017 flood event at the following (non-searchable) YouTube address (*address will be emailed upon request*):
https://www.youtube.com/watch?v=uhIyzw2a6L0&list=PL4JahDA0go8rwc4lJXfVPme1-hYe7GTdO
Review of the velocity trace video best demonstrates the difference in timing between Little Piney and Tater Hollow versus the Gasconade River. During the actual peak, velocities are minimal since this was a backwater driven vent.

Several existing condition unsteady state 1D model scenarios were run in order to gain an understanding of the effects of the system response. Those are:

6.1 Existing Condition May 2017 stages and discharges (.p03)



The Existing conditions were subjected to the stage data for the Gasconade corresponding to the May 2017 flood event along with the computed hydrographs for the discharge in the tributary and Little Piney reaches. A high water elevation of 696.55 was collected for the May event. This elevation is essentially the same as what was indicated by the Gasconade stream gage. This condition and overtopping is a result of the stage in the Gasconade and the model reflects this by the “level pool” condition that exists at the Little Pine crossing.

Figure 6, is a screen capture of the maximum modeled water surface elevation for this scenario.

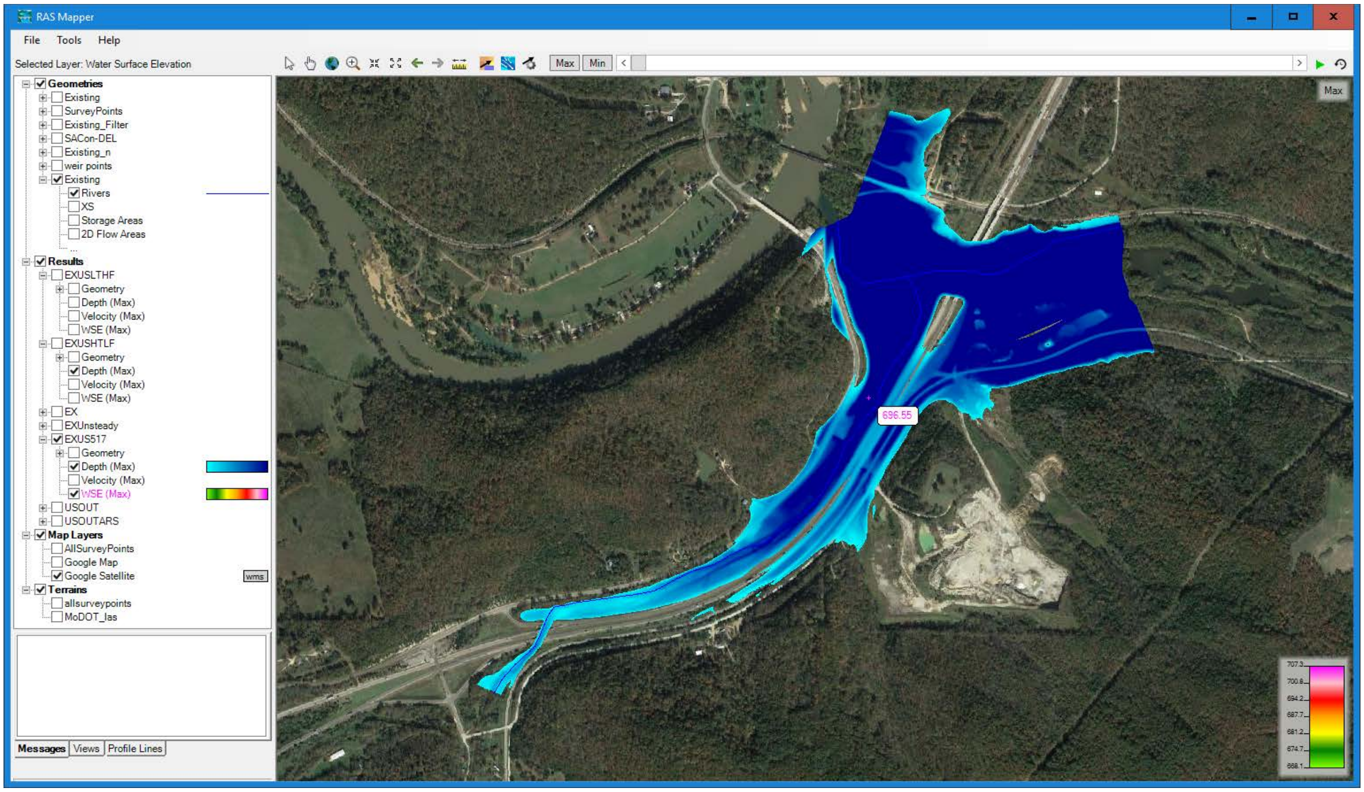


Figure 6: Screen Capture of the Maximum Modeled Water Surface Elevation Existing Condition May 2017 stages and discharges

Figure 7, shows a profile view of the water surface in the tributary channel and the lateral structure that represents the I-44 embankment.

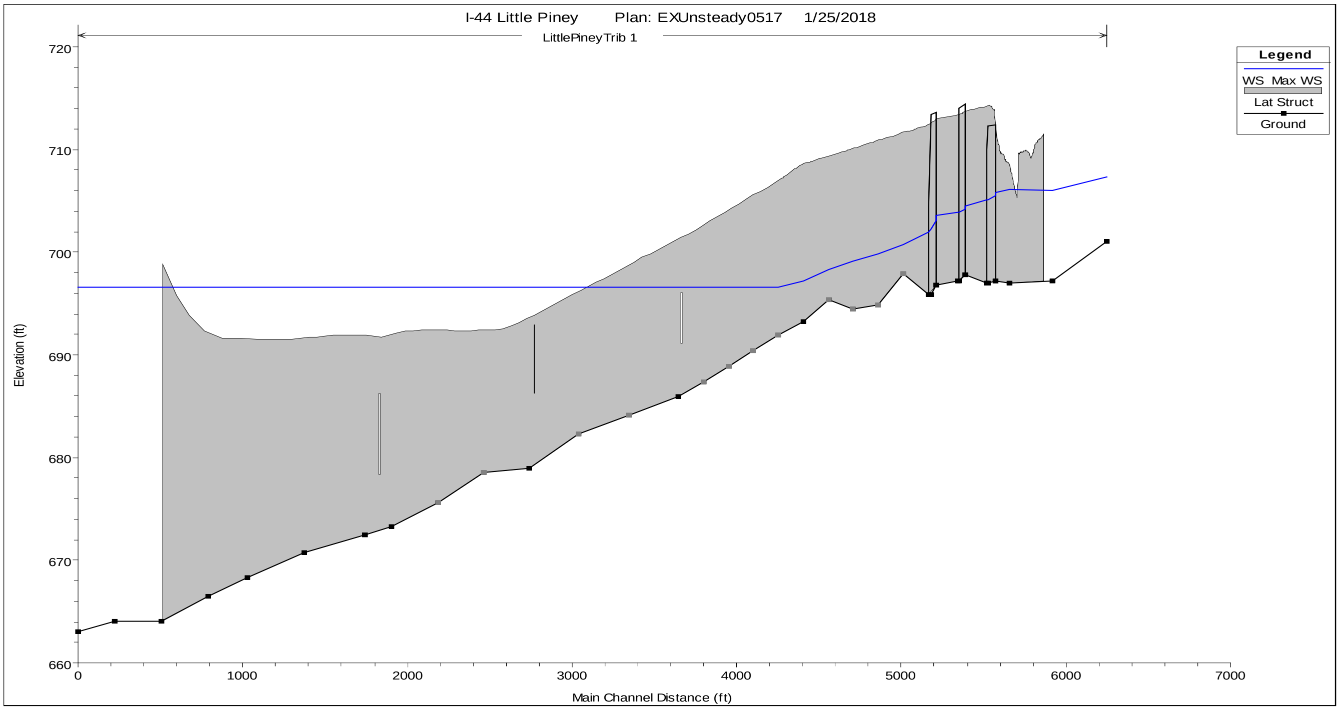
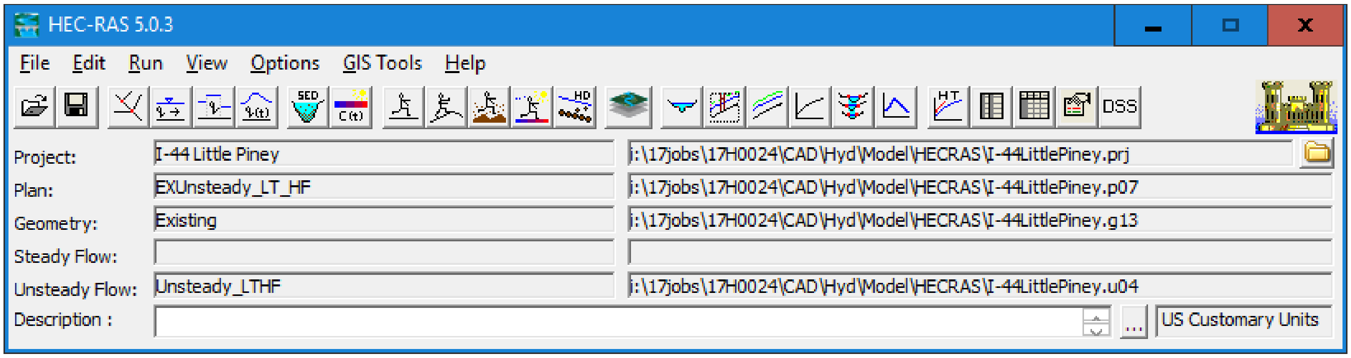


Figure 7: Profile View of Tributary Channel Water Surface Existing Condition May 2017 stages and discharges

6.2 Existing Condition normal depth tailwater and 100 year discharge (.p07)



The Existing condition was modeled using 100 year discharges calculated for the contributing watersheds. Normal depth of flow was calculated at the downstream cross section to represent a low stage condition in the Gasconade during a large discharge event from the basins. This condition does not create an overtopping condition for I-44.

Figure 8, is a screen capture of the maximum modeled water surface elevation for this scenario.

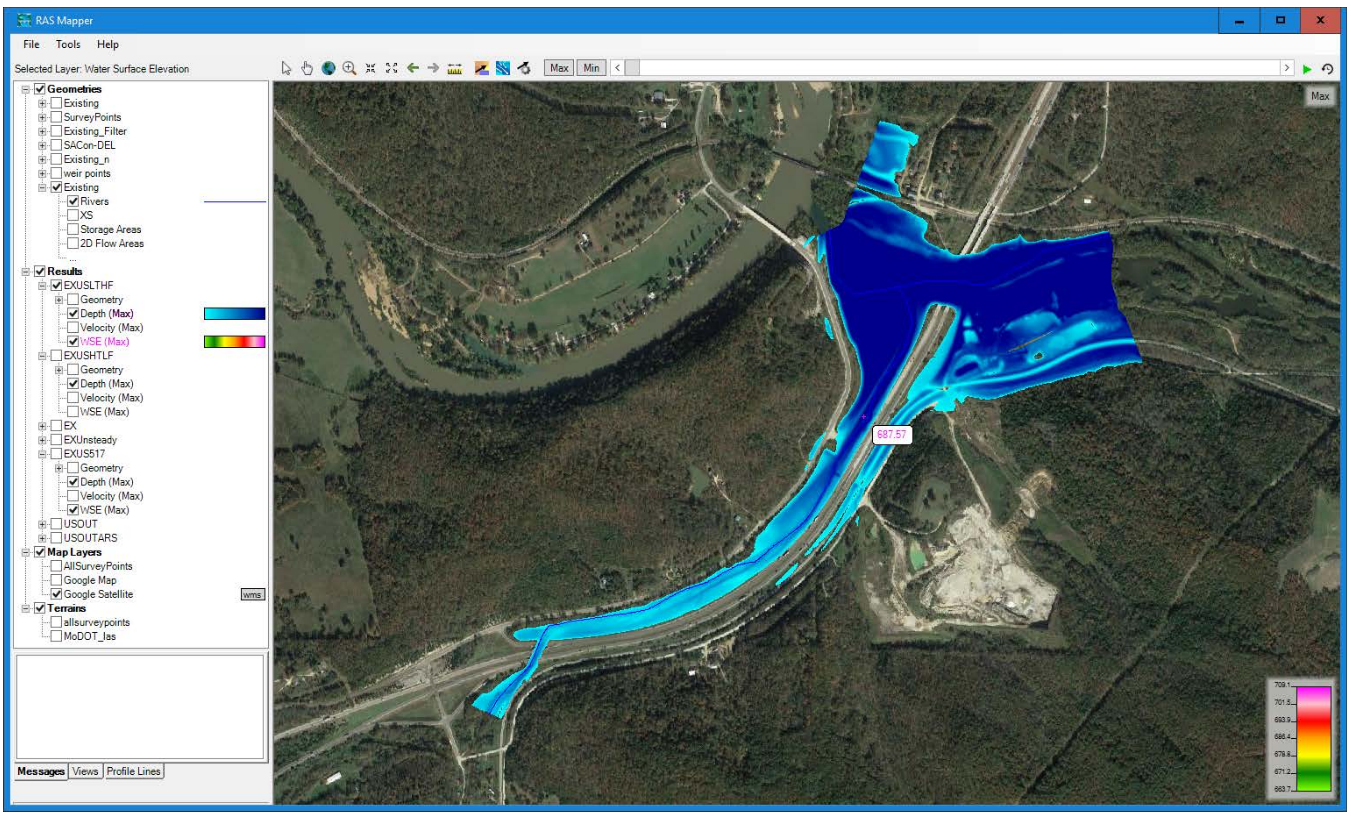


Figure 8: Screen Capture of the Maximum Modeled Water Surface Elevation Existing Condition normal depth tailwater and 100 year discharge

Figure 9, shows a profile view of the water surface in the tributary channel and the lateral structure that represents the I-44 embankment.

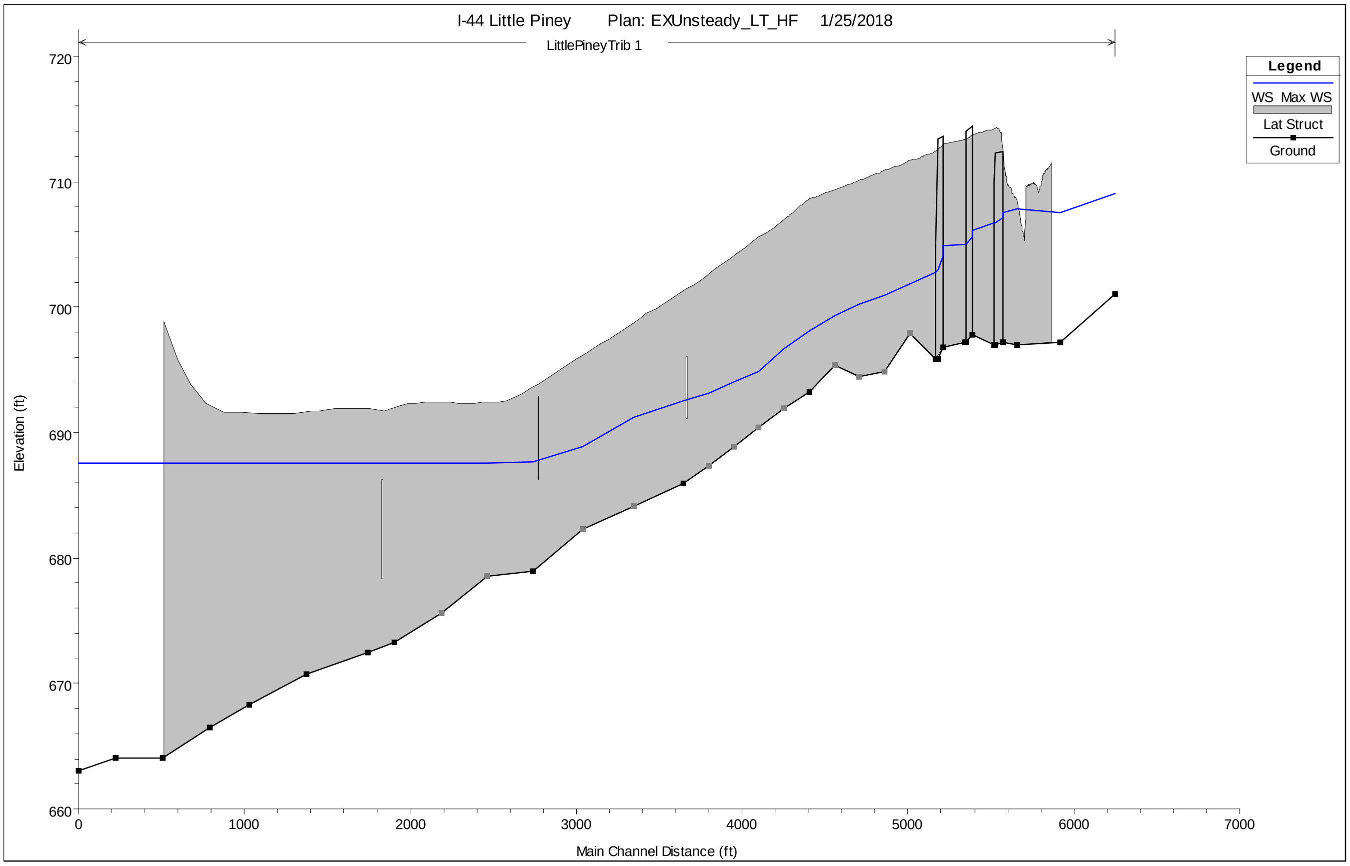
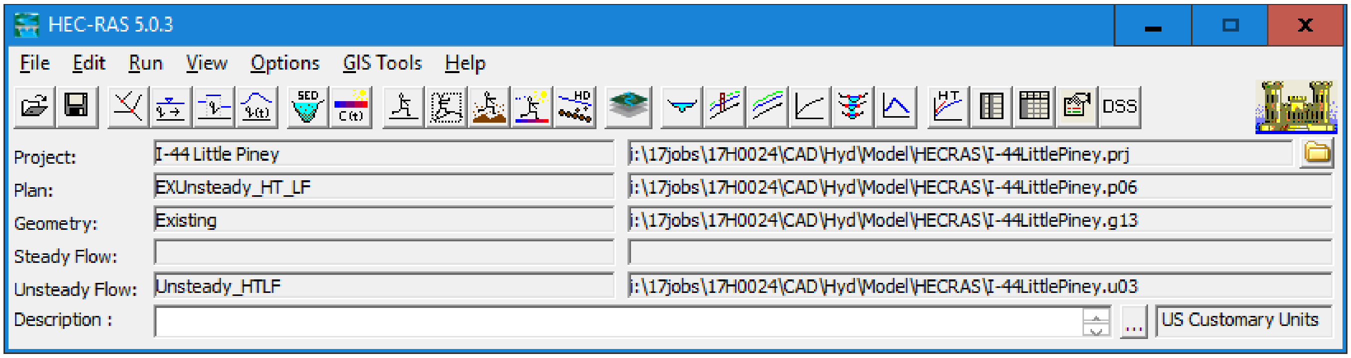


Figure 9: Profile View of Tributary Channel Water Surface
Existing Conditions normal depth tailwater and 100 year discharge

6.3 Existing Condition with May 2017 tailwater and small discharge (.p06)



The Existing condition was modeled using low discharges in the contributing watersheds and the 2017 stages in the Gasconade as the tailwater condition. This condition does create an overtopping condition for I-44. Flooding extents are very similar to the model results for the May 2017 event. This indicates that the tailwater from the Gasconade alone can cause overtopping of I-44 in this area.

Figure 10, is a screen capture of the maximum modeled water surface elevation for this scenario.

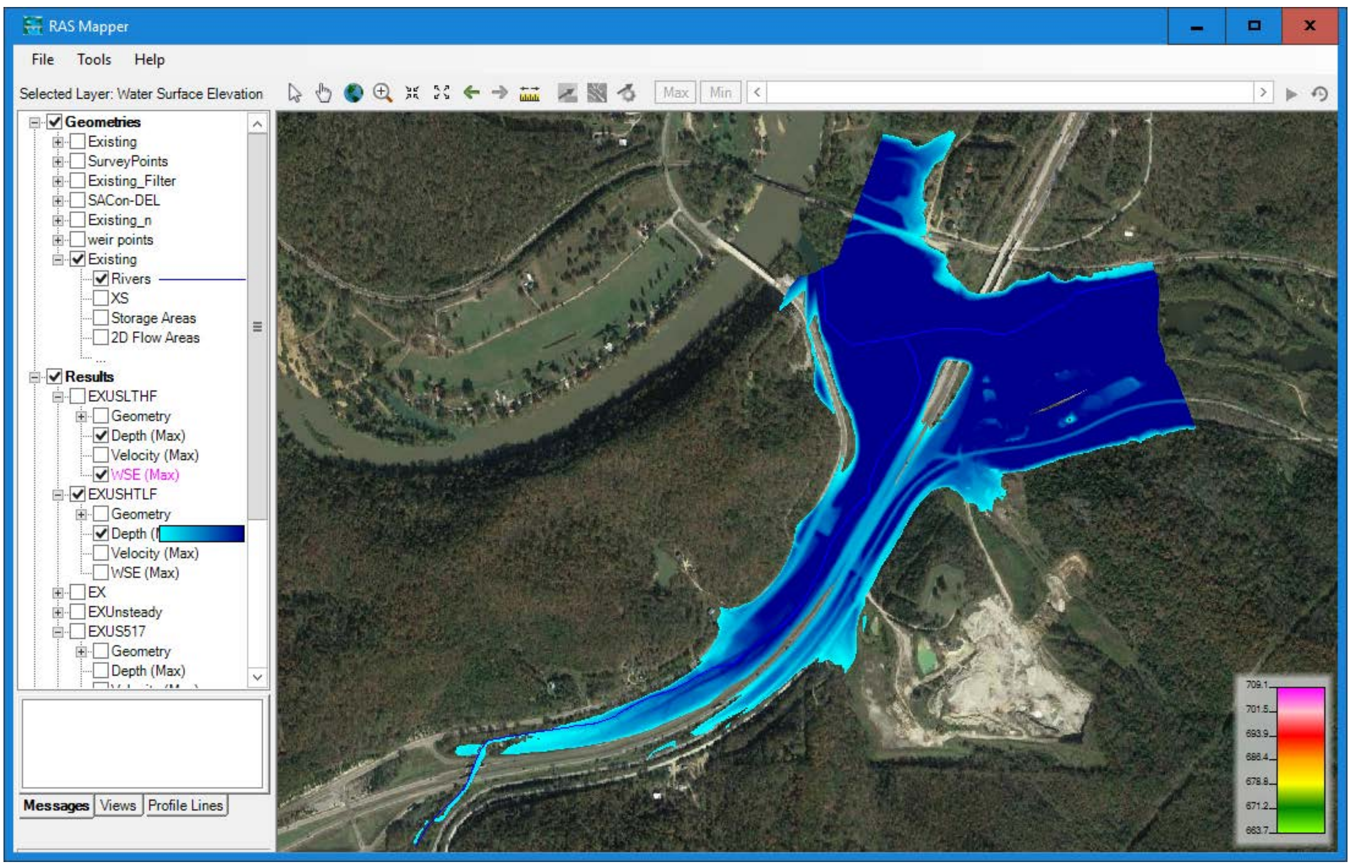


Figure 10: Screen Capture of the Maximum Modeled Water Surface Elevation Existing Condition with May 2017 tailwater and small discharge

Figure 11, shows a profile view of the water surface in the tributary channel and the lateral structure that represents the I-44 embankment.

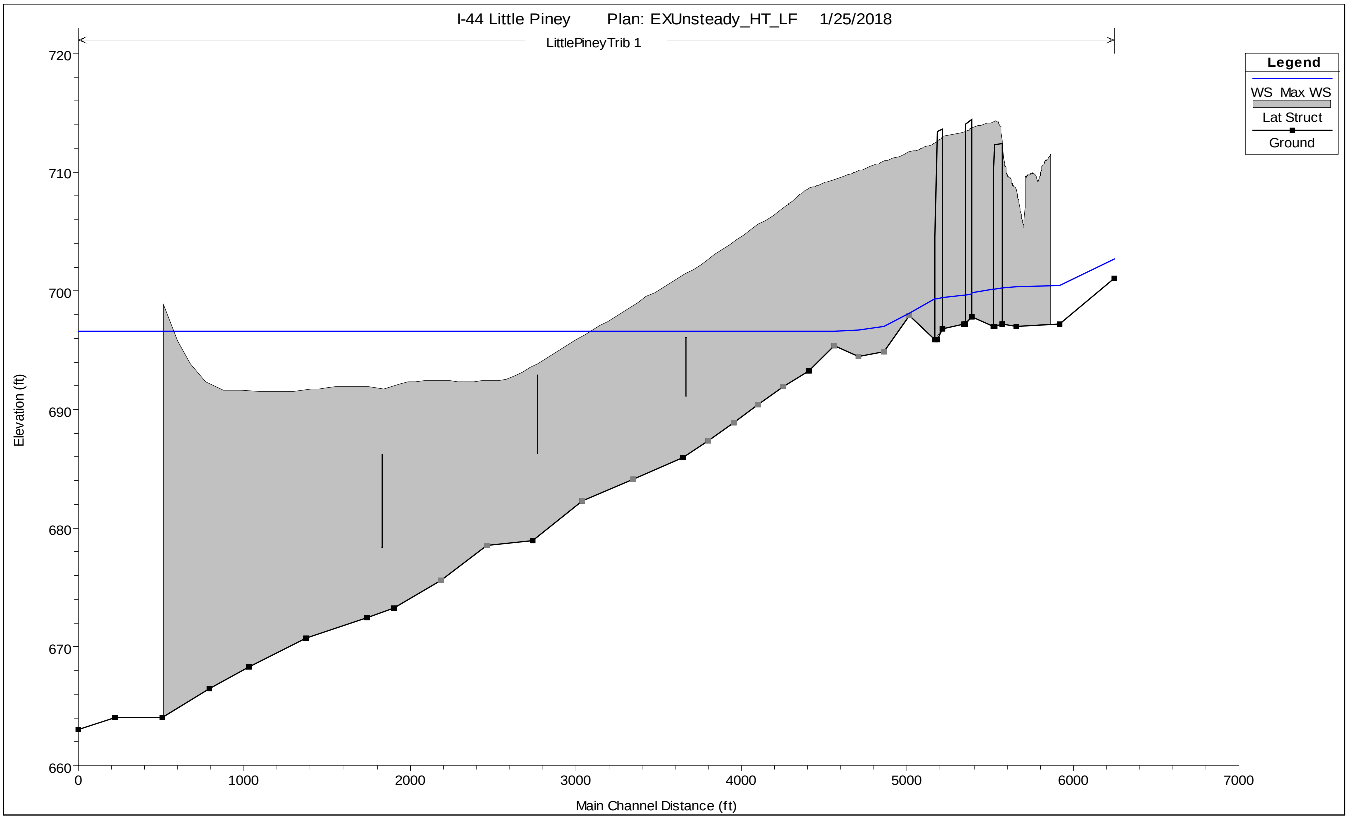


Figure 11: Profile View of Tributary Channel Water Surface Existing Condition with May 2017 tailwater and small discharge

Figure 12 is a comparison profile that shows the results of all scenarios in the tributary channel.

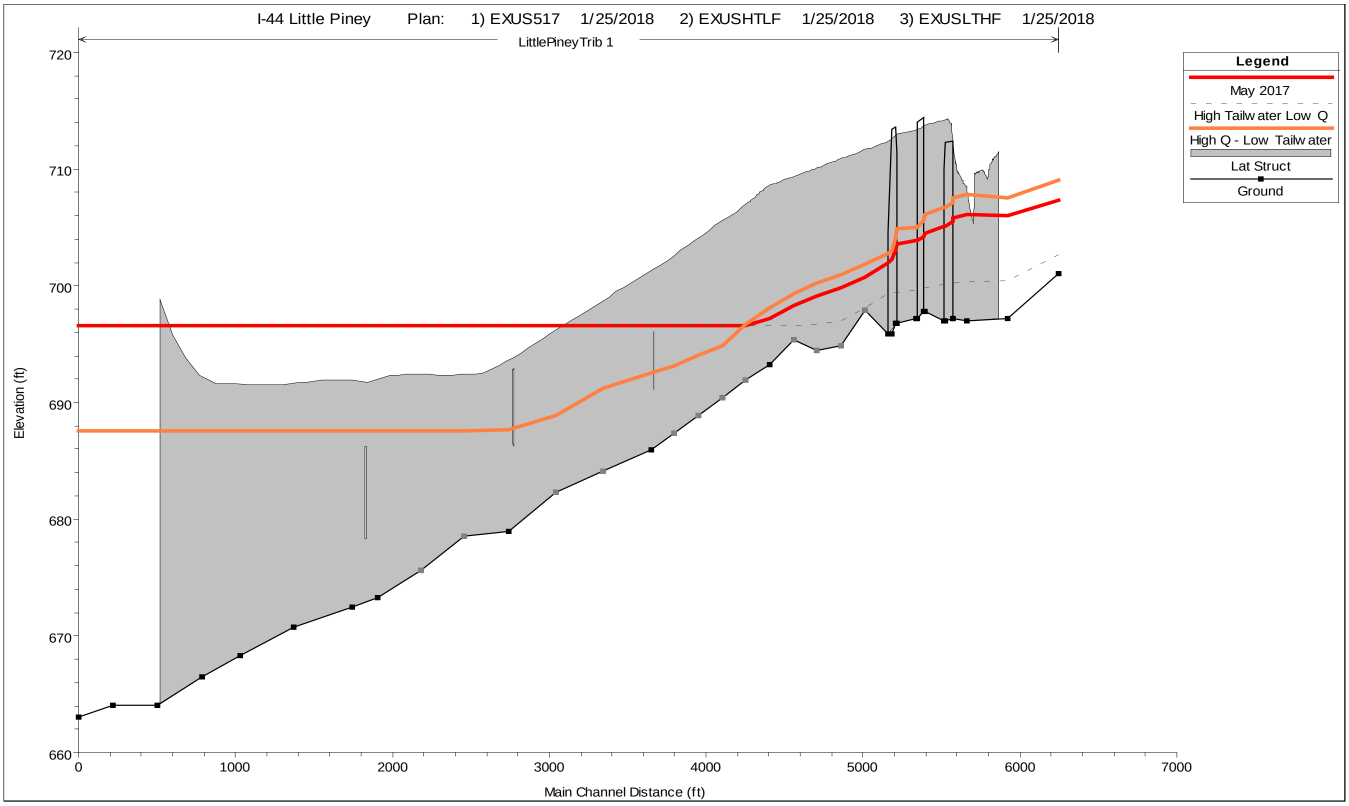


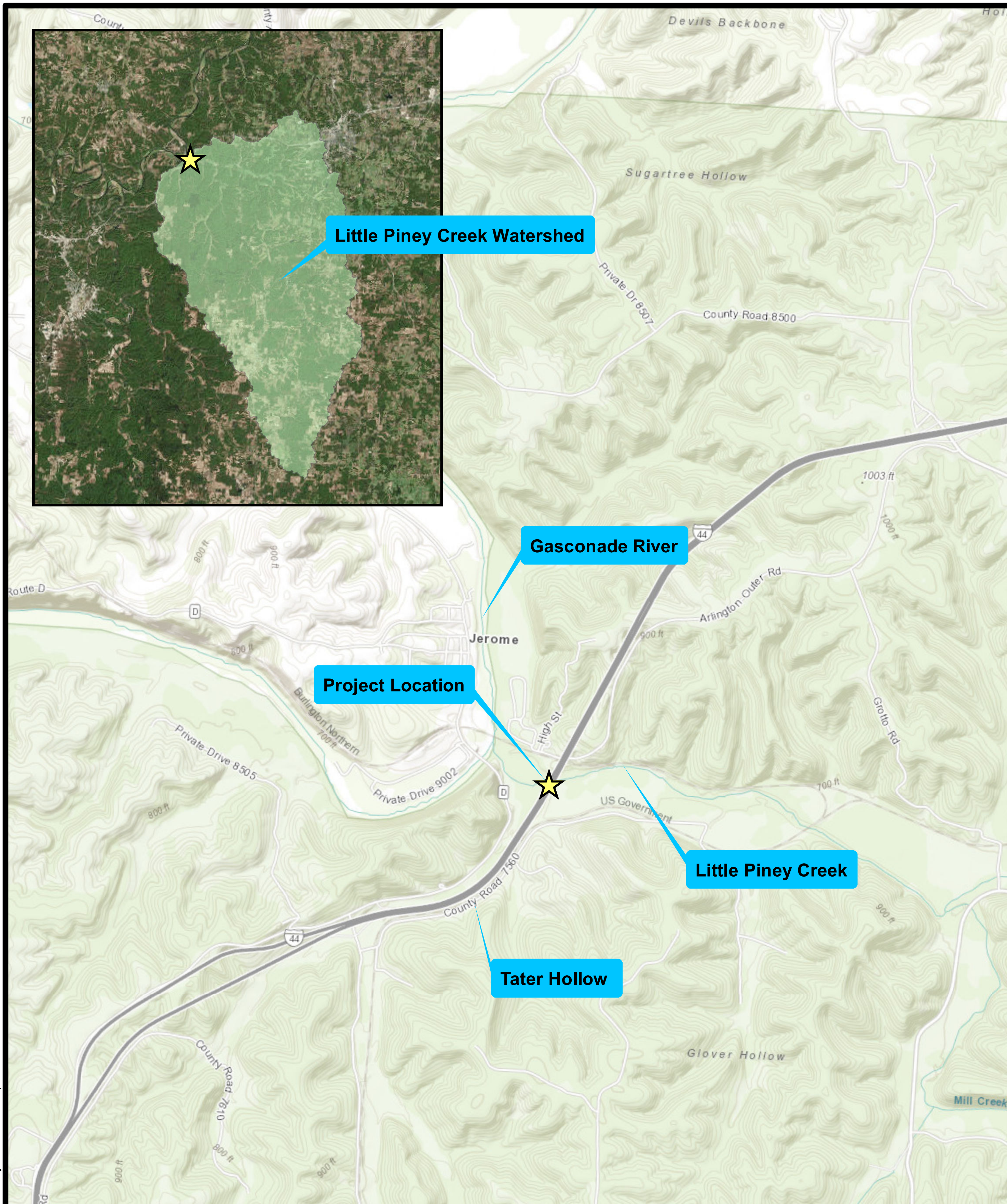
Figure 12: Comparison Profile of Tributary Channel

7. Next Steps

Proposed condition model scenarios will be developed to determine the impacts and feasibility of the alternatives proposed. Results and recommendations will be documented in a final report.
It is expected that the proposed alternatives will have no effect on the Gasconade River. However, protecting I-44 from the Gasconade backwater may have significant impacts on Tater Hollow and Little Piney Creek. Hydraulic analysis of the alternatives will define these impacts and provide mitigation plans to minimize impacts as needed.

Appendix A

Exhibits



0 1,750 3,500 Feet

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HANSON
Hanson Professional Services Inc.

Project Location Map

Missouri Department of Transportation
I-44 Flood Reduction Analysis
Phelps County, MO

MoDOT Project No. J5I3182

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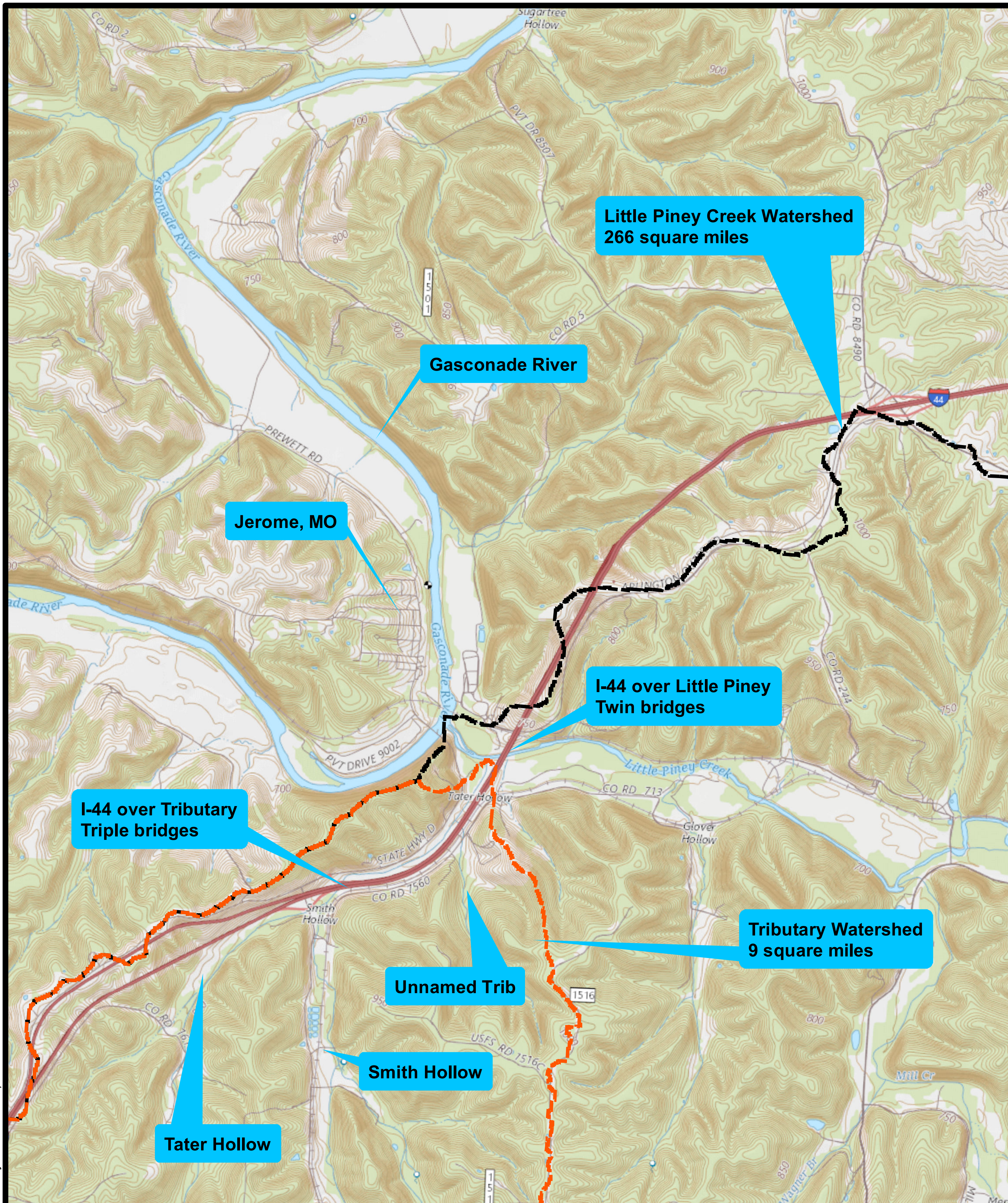

0 1,750 3,500
Feet

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HANSON
Hanson Professional Services Inc.

Basin Map

Missouri Department of Transportation
I-44 Flood Reduction Analysis
Phelps County, MO

MoDOT Project No. J5I3182

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