MoDOT Job J5S3162

Overtopping Study for
I-44 over Gasconade River near Hazelgreen, Mo

Prepared for

Missouri Department of Transportation

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HNTB Corporation

715 Kirk Drive

Kansas City, MO 64105

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Section 1 - Executive Summary

The I-44 crossing of the Gasconade River near Hazelgreen, Missouri has been overtopped by floodwaters during several storms in the 2000's and 2010's. Hydrologic analysis of the USGS stream gauge records at this site indicate that the interstate is overtopped in approximately a 20 year event, which is more frequent than MoDOT's 100-year design frequency for interstates and FHWA's 50-year design frequency for interstates. Hydraulic analysis indicates that the Gasconade River tailwater (floodwaters downstream of the site) is above the current roadway low point for a 50-year design event.

Several alternatives to reduce the frequency of overtopping of I-44 were developed and evaluated, and all alternatives require raising I-44 through the project site, including changing the profile through the river bridges. The three alternatives included in this report include:

1. Raising I-44 without substantially lengthening either river or relief bridges
2. Raising I-44 and constructing a new 350-ft relief bridge between the existing sets of bridges
3. Raising I-44 and lengthening the I-44 Gasconade River bridge 300 ft

The first alternative creates a significant rise / backwater of water surface relative to the existing conditions, while the second two alternatives provide variable options for raising the interstate above a 100-year design flood with acceptable backwater.

In order to not preclude the construction of these future improvements, it is recommended to construct the new 2018 outer road bridge replacement on a parallel alignment to I-44, offset such that I-44 can be raised in the future without a retaining wall. The vertical profile of the outer road should match I-44, but the east end should be raised so 0 ft of freeboard is provided on the proposed girders. The outer road bridge should be constructed of steel for future debris repair considerations and to provide the ability for the bridge to be raised in the future to either clear the 100-year storm or provide 50-year freeboard if desired. The outer road bridge should also be constructed with an east abutment that can be converted to an intermediate pier to provide for potential future lengthening to match the potential length of future I-44 bridges.

Section 2 - Introduction

2.1 Study Location

The project study location is the crossing of I-44 over the Gasconade River near Hazelgreen, in Laclede County, Missouri as shown in Figure 1. The I-44 crossing consists of 680-ft span steel girder bridges in each direction (eastbound and westbound) as well as a pair of 125-ft relief bridges located approximately 1300 ft east of the main river bridges. The superstructure of the I-44 westbound structure was recently replaced (2013) in a bridge slide-in that reused the original substructure. I-44 is paralleled by a MoDOT maintained outer road, which was originally constructed and signed as US Route 66. The outer road has bridges over both the main Gasconade River as well as a relief bridge paralleling the I-44 relief bridges. The existing outer road Gasconade River bridge is a truss bridge with historic significance as original Route 66 construction.

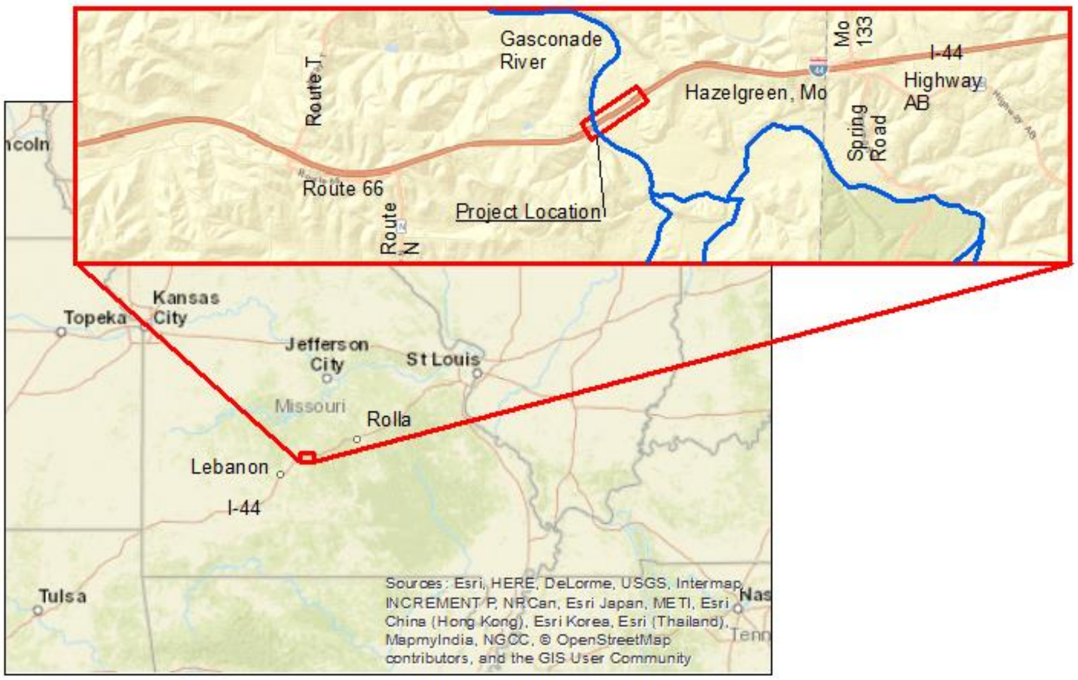


Figure 1: Project Location Map

2.2 Purpose of Study

The purpose of this study is to determine the frequency of overtopping for I-44 and provide recommendations to reduce the I-44 overtopping and provide hydraulic impacts of the recommendation. I-44 has experienced multiple overtopping events in the 2000's and 2010's. Overtopping events have required at least four closures of I-44 and a resulting extensive detour as well as repairs to pavement and bridges. Three alternatives are analyzed in the study. The outer road Gasconade River bridge is being replaced (construction scheduled for 2018), and this report was developed as part of the design phase of that project. Due to the historical significance of the existing outer road truss bridge, the original bridge will be left in place and the new outer road bridge will be constructed on a new alignment between the existing I-44 bridges and the historic truss structure. While the overtopping frequency of I-44 is not being addressed as part of the outer road bridge replacement project, the new bridge will be constructed so as to not interfere with the potential future implementation of the alternatives to reduce overtopping frequency presented in this report.

Section 3 - Hydrology

3.1 Watershed Characteristics

The drainage area is 1,253 sq. miles. The drainage area is predominantly rural and farmed. Approximately a mile upstream and downstream are confluences with tributaries of significant size relative to the main channel.

3.2 USGS Gage

There is a USGS Stream Gauge located at the project site, on the existing outer road crossing of the Gasconade River, a historic Route 66 bridge. Gauge record includes annual peaks from 1929 to 1917, with a major data gap from 1984 through 2000. Gauge record also includes historic peaks from Water Years 1915 and 1916. Additionally, flood of record peak from April/May 2017 is also available. The USGS performed a field measurement at the gauge site very near the peak discharge.

Prior to 2017, the largest reported discharges at the site were a gauged discharge of 89,500 cfs in March 2008 and a historic peak of 90,000 cfs from December 1915. On April 30th/May 1st 2017, the flood of record occurred, with a peak flow of 119,000 cfs listed by the USGS on their website.

3.3 Results

USACE software HEC-SSP, Version 2.1, July 12, 2016 was used for analysis of the gauge data. USGS Bulletin 17b was used as the calculation basis. The program has Bulletin17c methodology capability, but 17c is still in a draft revision, undergoing reviews.

Regional skew was taken from "Methods for Estimating Annual Exceed and-Probability Discharges and Largest Recorded Floods for Unregulated Floods in Rural Missouri", Scientific Investigations Report 2014-5165, a much more recent source than the map exhibit from Bulletin 17b. That report presented a regional skew value of -0.30 and a region skew MSE of 0.14 for the entire state.

Table 1 shows the influence of recent highwater events, including the 2017 flood of record, on the projected discharges. The period ending in 2010 was used because that was when MoDOT performed hydrology for the potential impacts of piers added downstream of I-44 for the recent slide-in bridge replacement. The period ending in 2016 (prior to the flood of record) was used, to show the impact of the 2017 flood of record. The final period shown includes the most recent 2017 flood of record.

Period of Record	Return Frequency Event, Weighted Skew, Flows in cfs							
	2-yr	5-yr	10-yr	20-yr	50-yr	100-yr	200-yr	500-yr
1915-2010	23,700	45,000	61,300	78,000	101,000	119,000	137,000	162,000
1915-2016	25,100	48,500	66,400	84,900	110,000	130,000	150,000	178,000
1915-2017	***25,600***	***50,200***	***69,400***	***89,500***	***117,000***	***139,000***	***162,000***	***194,000***

Table 1 Return Frequency Event (cfs) per Period of Record

Because it uses the most comprehensive data available, the 1915 to 2017 period of record Bulletin 17b results based on weighted skew (the final line of the table) were chosen as the discharges to be used for design of the outer road bridge and for the hydrologic basis of the I-44 overtopping study. It should be noted that the recent 2017 flood peak of 119,000 cfs was essentially a 50-year event.

Figure 2 shows the HEC-SSP summary and plot for the adopted hydrology results:

Frequency Curve for: gasconade-Hazelgreen, MO-FLOW-ANNUAL PEAK

Percent Chance Exceedance	Computed Curve Flow in cfs	Confidence Limits Flow in cfs	
		0.05	0.95
0.2	193838.5	281470.3	144527.6
0.5	162392.5	230066.0	123264.9
1.0	139484.8	193554.7	107468.3
2.0	117388.2	159198.2	91933.3
5.0	89493.8	117255.6	71796.2
10.0	69417.8	88274.1	56824.1
20.0	50189.8	61731.2	41952.4
50.0	25606.1	30220.8	21738.0
80.0	12163.9	14529.8	9916.2
90.0	8005.2	9827.1	6249.1
95.0	5579.3	7059.7	4167.5
99.0	2727.4	3701.4	1848.1

Statistics

Log Transform: Flow

Statistic	Value
Mean	4.386
Standard Dev	0.368
Station Skew	-0.396
Regional Skew	-0.300
Weighted Skew	-0.357
Adopted Skew	-0.357

Number of Events

Event	Number
Historic Events	0
High Outliers	0
Low Outliers	0
Zero Or Missing	0
Systematic Events	73
Historic Period	

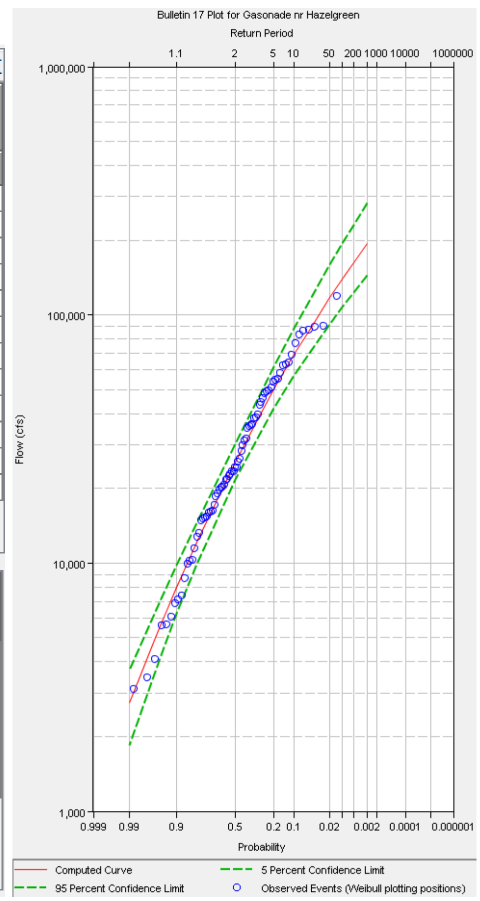


Figure 2 HEC-SSP Results

3.4 Analysis based on previous sets of records

Predicted streamflow peaks are dependent upon observed peak discharges. Wet and dry climate periods can greatly influence the magnitude of peak flows. The following table shows the variability of predicted peak flood flows as a function of the period of record at the USGS Gasconade River gauge. For the range of annual peaks, 15,000 cfs is an arbitrary flow, approximately 60% of a 2-year peak discharge, and 61,000 cfs is approximately a 10-year peak discharge for the 1915-2010 data range.

		# of	Computed Curve Discharges in cfs			# of Annual Peaks	
Period	Data Range	Peaks	50-Yr	100-Yr	500-Yr	< 15K cfs	> 61K cfs
1	1915 - 1950	24	138,000	168,000	242,000	6	4
2	1915 - 1960	34	120,000	145,000	209,000	9	4
3	1915 - 1970	44	103,000	122,000	167,000	12	4
4	1915 - 1980	53	98,900	117,000	161,000	15	4
5	1915 - 1990	56	102,000	121,000	168,000	16	5
6	1915 - 2010	66	101,000	119,000	162,000	17	6
7	1915 - 2016	72	110,000	130,000	178,000	18	10
8	1915 - 2017	73	117,000	139,000	194,000	18	11

As can be seen from the number of small and large peak annual streamflow events, there were no 10-year events or greater that occurred between 1950 and 1980, but there were numerous years with relatively low annual peaks. As a result, predicted flood discharges decreased significantly in this period. From 1980 through 2010, the number of low and high annual peaks were balanced, and changes in predicted flood flows were minor. In the past 10 years, however, there have been 6 annual peaks of 10-year magnitude or higher, resulting in significant increases to predicted flows.

Section 4 - Existing Conditions Hydraulics

4.1 Hydraulic Model Approach

For this study, 1D and 2D HEC-RAS 5.03 models were created covering approximately a mile and a half of the Gasconade River, centered on the I-44 crossing. Due to the presence of the relief bridge, the 2D hydraulic model was considered as it was expected to give a more reliable and accurate result better accounting for the flow in the overbank and the conveyance through the relief bridge. Hydraulic models were completed for natural and existing conditions and compared to models for three future alternatives for reducing overtopping of I-44 as well as an interim model of the 2018 outer road bridge replacement. For the natural model, both the outer road and I-44 bridges along with the roadway embankment were removed. This was done because the purpose of the study is to improve the area as a whole and not just by the new outer road bridge.

For both 1D and 2D models, the hydraulic results in this report represent the status of the design of the 2018 Outer Road bridge at preliminary design phase. No changes to roadway profile are anticipated after that phase, but pier sizes and guardrail layouts were not finalized at that stage. Further changes of those components are expected to have minimal impact on the results, and impacts would be limited to the interim 2018 construction project with no impact on the future alternatives to reduce overtopping.

4.1.1 HEC-RAS 1D

The HEC-RAS 1D model utilizes the multiple opening analysis functionality to represent flow through the overflow bridge. Eastbound and Westbound I-44 are modeled together as one bridge, due to their proximity and connection to a common embankment across the floodplain. The I-44 bridge model is widened along the river to account for the piers left in place from the westbound bridge slide-in replacement. The existing outer road is modeled as a separate bridge structure in HEC-RAS with its own multiple opening analysis. The two bridge groups are separated by two cross sections. Eight cross sections downstream and four sections upstream are used to determine tailwater and backwater effects. A schematic of the model is shown in Figure 3.

Ineffective flow areas were horizontally set in the 1D model based on contraction into and out of the bridges and vertically based on the overtopping elevations of I-44 and the outer road. In several sections “permanent” ineffective areas were used to model the wet area that would be blocked at lower elevations by contraction into the bridges but would be effective flow for flood depths overtopping the roadway, for consistency in flow distributions across the floodplain.

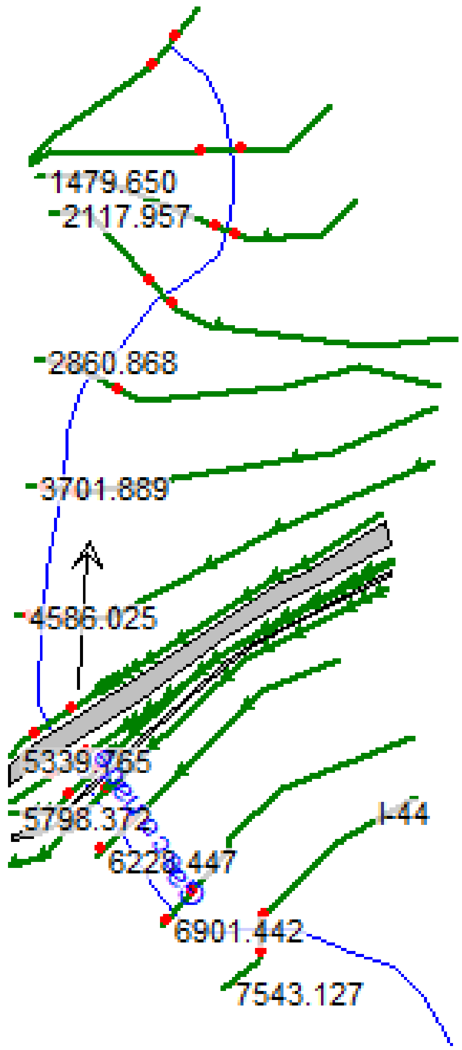


Figure 3 1D HEC-RAS Model Schematic

Limitations were found in the 1D model both with the sensitivity of large result changes to relatively small input changes as well as software feature limitations on how and where physical inputs are represented in the model. Specifically:

(1) When utilizing the multiple opening analysis, fatal model errors could be created or eliminated by adding or subtracting as few as two groundline points in the weir.
(2) While HEC-RAS ineffective flow areas can physically describe the areas where water is expanding out of the bridge openings of the Gasconade and Relief bridges, the 1D calculations are not sophisticated enough to track the lateral flow distribution in front of the main channel bridge vs. in front of the relief bridge between sections. This can be observed by an experienced modeler within the model output, but the modeler is forced to modify these ineffective areas to produce a flow distribution reasonable for one discharge at the expense of a direct correlation with the physical geometry and calibration to other discharges.
(3) Modeling the 2018 outer road bridge replacement physical configuration is awkward with 1D cross section layouts. Model changes between the proposed conditions and existing conditions

should be limited to physical changes and not change modeling approach. The existing outer road embankment and truss bridge are remaining in place, connected to the relief bridge the same as in the existing conditions. The proposed outer road is expected to mirror I-44 near the main channel before tying back into the existing relief bridge as well. Adding the new outer road bridge to the model by replacing the upstream face of the I-44 main channel bridge (and increasing the length along the stream in the bridge routine) was reasonable as the bridge is expected to perform hydraulically similarly to the existing I-44 bridges. The compromise is that the low chord of the existing eastbound I-44 bridge is no longer explicitly represented (although its length along the channel is still represented in the total for the composite of proposed outer road bridge, the eastbound bridge, the westbound bridge, and the downstream extension of the westbound bridge piers). The portion of the outer road with a higher profile than I-44 must be projected onto the I-44 profile in the bridge routine, which does not physically represent the fact that water can still overtop the outer road and then overtop I-44 behind the outer road.

4.1.2 HEC-RAS 2D

HEC-RAS 2D was expected to produce more reliable results for the flow distribution in the main channel vs. the overbank and the flow distribution between the main channel vs. relief bridge. Observation of video from the April 2017 event indicated areas where flow was not directly downstream. The 2D model was also expected to better depict the flow pattern of water overtopping the outer road but flowing through either the main channel or relief bridges.

A key limitation of the current version (5.0.3, September 2016) of HEC-RAS's 2D component is that open span bridges with piers cannot be directly represented in the 2D grid. Weirs, culverts, and orifices through embankments can be placed between cells on the grid, and piers can be represented by either editing the groundline in the 2D grid or a locally increased roughness factor, but neither method can accurately model both flow through the opening and flow overtopping the structure. In the 50-year event, water flows against the low chord of the I-44 Gasconade River bridge and overtops the relief bridges and existing truss bridge. Additionally, the spans of the I-44 Gasconade River bridge are long enough such that velocity is expected to vary through the opening. Due to these multiple variations in water surface and velocity across the channel sections, it was desired to find a way to represent the structures in the model as bridges as opposed to culverts or orifices.

As a compromise, the 2D grid functionality was used to represent flow upstream and downstream of the I-44 and outer road embankments. 1D reaches were used to represent flow from the upstream toe of the outer road to the downstream toe of I-44. One reach was used to model the main river channel and a second reach was used to model the overflow channel. Separate grids were used upstream and downstream of I-44 as the grid cannot contain a "hole" nor can the 1D reach be attached to the same grid upstream and downstream. In addition to transferring flow between the 2D grid and the 1D cross sections at the upstream and downstream ends of the 1D reaches, lateral weirs are placed along the edges of the 1D cross sections between the I-44 and outer road embankments to allow flow from the 2D grid to enter into the 1D reaches and pass through the I-44 bridges. This allows a portion of flow to overtop the outer road (represented in the 2D grid) but still pass through the 1D I-44 bridges.

The upstream grid was terminated at the centerline of I-44's westbound lanes and connected to the downstream grid with a 2D area connection. This 2D area connection is a weir, modeling the overtopping elevation and accounting for the hydraulic shadow of guardrail (which generally clogged with debris during the 2017 event). Breaklines within the 2D grid are used to capture the crowns of eastbound I-44 and the outer road with the grid mesh. Breaklines are also placed along land use boundaries in order to limit the compositing of Manning's n values within cells, specifically to avoid overestimating friction in the main channel. Cell size for the 2D grid was set at 40 ft by 40 ft. This, combined with breaklines at key physical and land use features was found to be sufficient for this size of floodplain. A schematic of the model is shown in Figure 4.

For the natural conditions 2D model, one 2D grid was utilized with the same overall footprint as the model with bridges, however the existing embankments were cut down to surrounding ground in the natural conditions ground terrain model, and this area incorporated into the 2D grid. All Breaklines, cell sizes, and manning's n values (with the exception of roadway, which was modified to match overbanks) were kept consistent with the models with bridges.

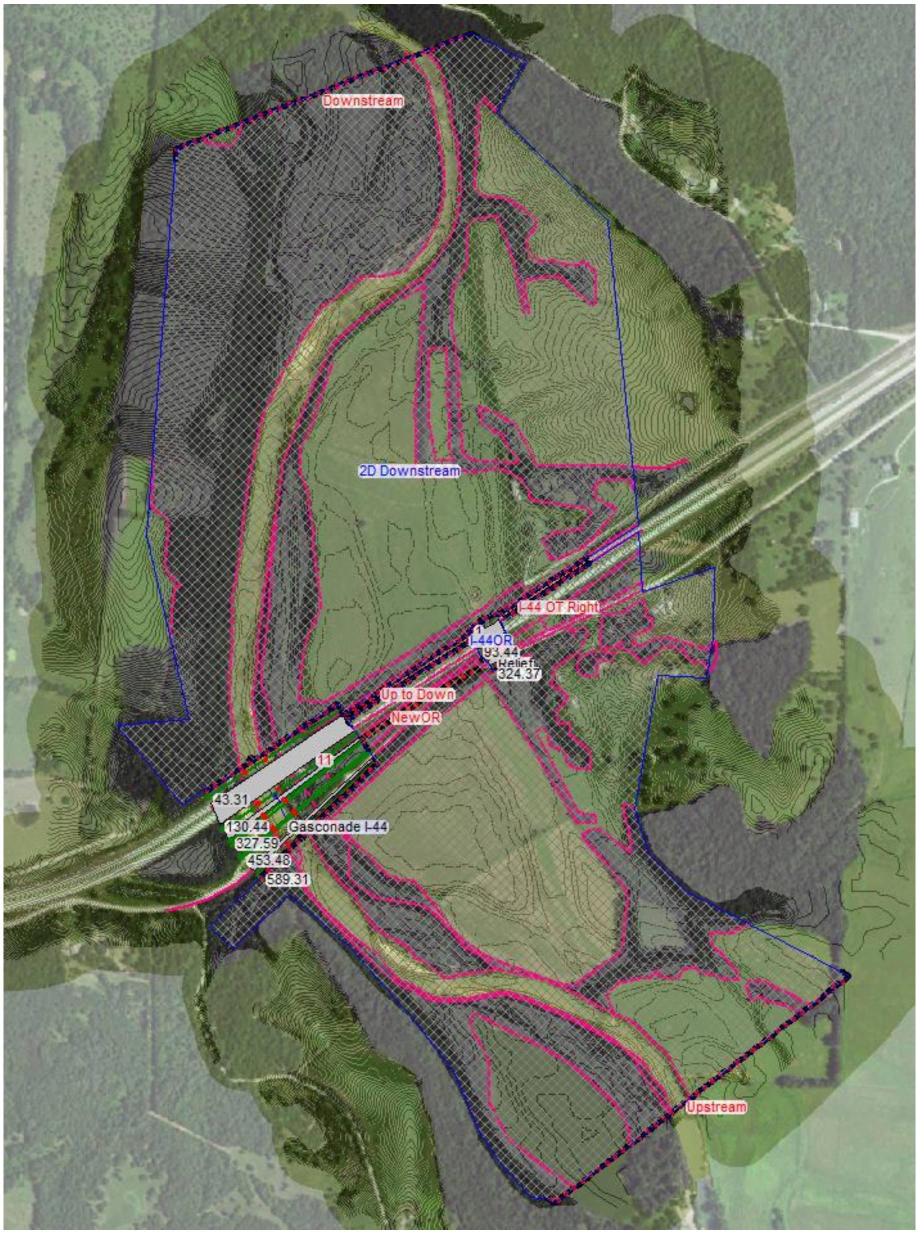


Figure 4 2D HEC-RAS Model Schematic

Lessons learned from the 2D model include:

(1) Manning's n values for the 2D grid may need to be higher than a 1D model of a comparable area.
(2) Breaklines should be placed along key physical features (top of bank or roadway crown) as well as at land use boundaries in order to capture the changes in these features within the 2D grid.
(3) The interface between 1D and 2D components can be unstable. Raising 1D weirs artificially high may be required in order to prevent fatal model errors (The lateral weirs interfacing the 2D grid

downstream of the outer road needed to be set at approximately half the outer road embankment height for a stable model).

(4) Model instability is sometimes, although not always, caused by model inputs error or model features that can oscillate between wet and dry.

(5) Where possible, the model should be extended far enough downstream that sensitivity to starting water surface slope can be reduced or eliminated (easier / more cost effective in counties with LiDAR available).

4.2 Results and Calibration

Both hydraulic models were calibrated to data from the USGS gage records. For the May 2017 flood event, the USGS obtained field measurements of velocity and depth which they used to calculate a discharge. Field measurements were taken by the project surveyor of high water marks. The highest highwater mark recorded by the team was a marking made on the outer road pavement by a resident. This mark (885.43) was considered the most reliable, and is found to be approximately 0.65 ft higher than the measurement noted by the USGS (884.78). It should be noted that the water surface is not expected to be truly flat across the floodplain, due to the velocity gradient across the river valley. This measured mark was at the extreme edge of the floodplain, where velocity is expected to be nearly zero. Highwater mark locations are shown below in Figure 5.

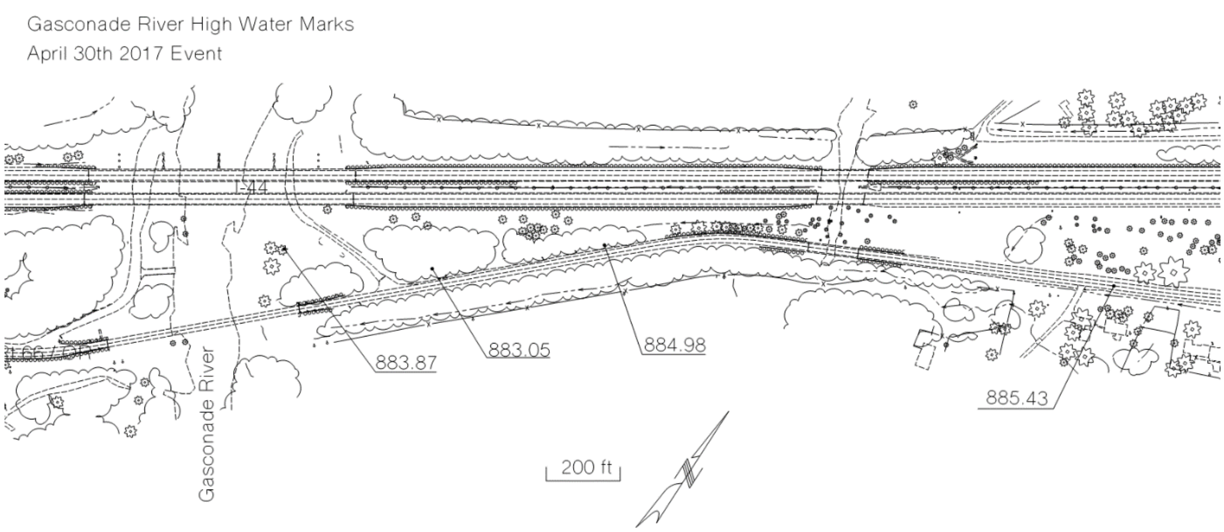


Figure 5 April 30th, 2017 High Water Marks

For the 2D model, care was taken to calibrate based on the water surface at the recorded location of the water mark, while the water surface in front of the bridge openings was found to be lower. For the 1D model, calibrating with this mark at the extreme edge of the floodplain is considered to be overly conservative since the 1D model will not accurately calculate the near zero velocity at the edge of the floodplain. The 1D model was matched within 6 inches to the highest tree marker, just downstream of the outer road, between the main channel and the relief bridge.

For both the 1D and the 2D models, a starting energy gradient of 0.0006 ft/ft was used. This is the approximate slope along the channel through and downstream of the project site. The starting energy slope was initially used as a calibration measure, however it was found to be undesirable. Based on the Hazelgreen Gage and the downstream Jerome Gage, an overall slope to the river's water surface was found to be approximately 0.0005 in the April 2017 flood event likely subject to localized increases and decreases as the bed slope varies. Varying the starting energy slope in the model was found to have an unexpectedly large impact on water surfaces and energy slope through the rest of the reach. Varying between 0.0006 and 0.0005 was found to yield nearly a foot difference in water surface elevation at the upstream face of the outer road. For both of these values, the energy slope throughout the project reach was found to vary between 0.0001 and 0.0004. with the flatter starting slope yielding flatter slopes upstream. Ultimately, 0.0006 was selected as the starting slope to match standard practice of assuming the bed slope is equal to the energy slope, as well as to keep a higher energy slope through the project reach better matching the observed slope across the river.

For both the 1D and 2D models, calibration was accomplished by consistently varying Manning's roughness "n" values throughout the project reach. Manning's n values were taken from Chow for the 1D model and from Australian Rainfall & Runoff Revision projects for the 2D model and shown in Table 2 and Table 3. It was desired to utilize Manning's n values within or as close to the documented ranges for each land use. For both the 1D and 2D models, land uses were delineated based on 2017 aerial photography. Manning's n values were initially set consistently between the models, however it was found that the 2D model would return lower water surfaces for the same roughness factor and slightly higher values were therefore used for the 2D model. This is consistent with documented literature regarding 2D modeling. Setting the values for channel, forest and cropland overbanks to the maximum of the accepted ranges still yielded water surfaces lower than the range of observed high water marks. For both models, the decision was therefore made to set the channel and cropland overbanks near the top of the accepted ranges, and vary the forest "n" value above the commonly accepted range. The physical rational behind this selection is that in the 25 ft to 45 ft water depths for the 50-year design storm, the floodwaters would not only be impeded by the tree trunks and thick undergrowth, but friction would also occur against the lower levels of tree canopies as well.

Landuse	**Mannings "n"**
Channel	0.030
Cropland	0.040
Overbank / Vegetated	0.050
Overbank / Trees	0.100
Forest (Heavy)	0.200

Table 2 Selected 1D model Manning's "n" values

Landuse	**Manning's "n"**
Channel	0.035
Cropland	0.070
Trees	0.185
Pavement	0.013

Table 3 Selected 2D model Manning's "n" values

In addition to calibrating to the observed highwater marks, USGS indicated recorded discharges through the main channel and overbank near the peak of the April 2017 event. For both the 1D and the 2D model, discharges are compared spatially with the observed event in Table 4, taken at the outer road crossing. Note that while the observations provided by USGS sum to 114,000 cfs, the posted peak by USGS is 119,000 cfs.

Location	USGS Observation	HEC-RAS 1D	HEC-RAS 2D
Main Channel	81,000	79,031	82,689
Total Overbank(1)	32,880	39,969	36,311
Relief Bridge(2)	5,000	1,395	8,165

(1) This value includes the flow through the relief bridge

(2) This value is estimated specifically by the USGS as “1000 sq ft flowing at 5 fps mean velocity”

Table 4 HEC-RAS Model Flow Distribution Calibration for April 30th, 2017

Ultimately, the 1D and 2D models were found to generally agree within approximately 1 ft as shown in Table 5. The results are most similar for the 20-yr and 100-yr events with the existing and proposed outer road bridge replacement. The 2D natural model produced lower elevations than the 1D natural model, while the 2D models with bridges produced higher results than the 1D models with bridges. As the 1D model is the current industry standard, for this preliminary overtopping study the results and recommendations that follow are based on the 1D model.

#	HEC-RAS Plan	Face of Existing Rt 66 -5952.845								
		20-Yr			50-Yr			100-Yr		
		1D	2D	Δ_{2D-1D}	1D	2D	Δ_{2D-1D}	1D	2D	Δ2D-1D
1	1-Natural	879.25	878.30	-0.95	884.04	883.91	-0.13	887.52	886.85	-0.67
2	2-Existing	879.43	879.93	0.50	884.03	885.35	1.32	887.46	888.04	0.58
3	3-Proposed Outer Road	879.66	880.02	0.36	884.32	885.48	1.16	887.66	888.18	0.52

Table 5 1D/ 2D Hydraulics Results Comparison

As shown in Figure 6, the 2D model includes the capability for plotting water surface extents, velocities, and flow direction arrows. The 2D model was used as verification for the placement of ineffective flow areas within the 1D model. The 2D model also confirmed flow patterns within the model near the embankments, such as the ability for water to overtop the outer road, but turn and flow through the I-44 bridges rather than overtopping I-44. The 2D model was also used during the development of the alternatives to serve as a check model, particularly for the scenarios where the 1D model requires the modeler to make assumptions regarding flow patterns or where multiple structures needed to be composited together. The 2D model did confirm the feasibility of Alternative 3 (discussed in 5.3) which includes a new set of I-44 relief bridges but does not include a new outer road bridge. The 2D model also confirmed the feasibility of constructing a raised I-44 bridge without raising the outer road bridge to match.

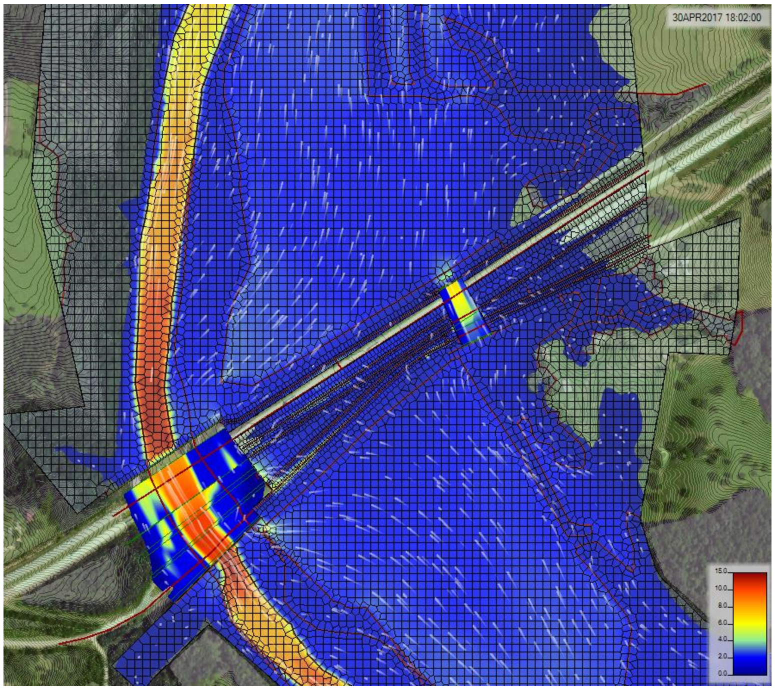


Figure 6 2D Model Velocity (feet per second) Results and Flow Direction (April 30th Event)

Section 5 - Alternatives to Reduce Overtopping Frequency

5.1 Introduction & Design Criteria

The three alternatives to reduce overtopping frequency are intended to follow MoDOT EPG guidelines, specifically for bridge and roadway freeboard, unless otherwise noted. Additionally, federal FEMA regulations will be followed. As the river crossing is located in a Zone A floodplain (shown on panel 29105C0175C, effective September 29, 2010) without a floodway, up to 1 ft of cumulative rise is allowed over the natural conditions.

Based on EPG criteria, the bridges should pass the 100-year storm and pass the 50-year storm with 2 feet of freeboard from the girders. The 100-year design flood elevation should also be 1 ft below the shoulder away from the bridge.

Three alternatives are considered in order to reduce the overtopping frequency of I-44. Based on the design discharge for the 50-yr event, the existing conditions hydraulic model indicates that the tailwater elevation of the Gasconade River downstream of the I-44 crossing is higher than the existing roadway low point elevation. This was also observed in video taken during the April 2017 overtopping event. While not directly investigated as part of this study, downstream improvements to lower this tailwater would require extensive channelization / grading outside of MoDOT's right-of-way and long term maintenance by MoDOT, and are not considered practical. Therefore, all alternatives will include raising the I-44 low point above the 100-year design flood elevation.

5.2 Alternative 1: I-44 Future Raise with Slightly Longer I-44 Bridges, New Outer Road Bridge Used as Constructed

For this alternative, I-44 would be raised in the future so that the edge of shoulder in the future is 1 ft above the 100-year flood elevation. The I-44 Gasconade River bridges would be raised or reconstructed at this time at the higher profile, with a profile set so that 2 ft of 50-year event freeboard is obtained to the girders. The bridges would be slightly lengthened, corresponding to increased length of 2H : 1V abutment spill slope to reach the new profile. The I-44 relief bridges would be reconstructed to the new profile, with at least 2 ft of 50-year freeboard to the low steel. The relief bridges would be lengthened corresponding to increased length of 2H : 1V abutment spill slope to reach the new profile. For this alternative, the 2018 outer road bridge would remain in place as constructed with no modifications. No modifications would be made to the existing outer road relief bridge. A conceptual plan and profile is shown in the appendix.

This alternative is found to produce a 0.44 ft rise in the 100-year event relative to the existing conditions and 1.14 ft of backwater relative to the natural conditions.

5.3 Alternative 2: I-44 Future Raise with Additional I-44 Relief Bridges in Between Existing Bridges, New Outer Road Bridge Used as Constructed

For this alternative, I-44 would be raised in the future so that the edge of shoulder in the future is 1 ft above the 100-year flood elevation. A new set of eastbound / westbound relief bridges would be constructed (approximately 350-ft total span) between the Gasconade River bridges and the existing relief bridges. The I-44 Gasconade River bridges would be raised or reconstructed at this time at the higher profile, with a profile set so that 2 ft of 50-year event freeboard is obtained to the girders. The bridges would be slightly lengthened, corresponding to increased length of 2H : 1V abutment spill slope to reach the new profile. The I-44 relief bridges would be reconstructed to the new profile, with at least 2 ft of 50-year freeboard to the low steel. The existing relief bridges would be lengthened corresponding to increased length of 2H : 1V abutment spill slope to reach the new profile. For this alternative, the 2018 outer road bridge would remain in place as constructed with no modifications. No new relief bridge would be constructed along the outer road; flow through the new I-44 relief bridges would first overtop the outer road, as it does in the existing conditions. No modifications would be made to the existing outer road relief bridge. A conceptual plan and profile is shown in the appendix.

This alternative is found to drop the water surface 0.08 ft in the 100-year event relative to the existing conditions. Backwater relative to the natural conditions would be 0.61 ft.

5.4 Alternative 3: I-44 Future Raise and Main Span Bridges Extended 300 feet, Future Raise and Lengthening of Outer Road Bridge Matching I-44

For this alternative, I-44 would be raised in the future so that the edge of shoulder in the future is 1 ft above the 100-year flood elevation. The I-44 Gasconade River bridges would be raised or reconstructed at this time at the higher profile, with a profile set so that 2 ft of freeboard is obtained to the girders. The river bridges would be lengthened by approximately 300 ft. The I-44 relief bridges would be reconstructed to the new profile, with at least 2 ft of 50-year freeboard to the low steel. The relief bridges would be lengthened corresponding to increased length of 2H : 1V abutment spill slope to reach the new profile. For this alternative, the 2018 outer road bridge would be raised so that the girders have 2 ft of freeboard above the 100-year flood and the bridge would be lengthened approximately 300 feet beyond the length constructed in 2018 to match the future I-44 spans. No modifications would be made to the existing outer road relief bridge. No new relief bridge would be constructed along the outer road. A conceptual plan and profile is shown in the appendix.

This alternative is found to produce a 0.30 ft maximum rise in the 100-year event relative to the existing conditions. Backwater relative to the natural conditions would be 0.99 ft.

5.5 Hydraulic Results Matrix

A matrix summarizing the results for the various hydraulic scenarios and future structure alternatives are compiled in the following tables Table 6 and Table 7.

Hydraulic Options Matrix - 1D Modeling Results

				I-44 Gasconade Bridges		I-44 Relief Bridges		New Rt 66 / OR Gasconade Bridge		OR Relief Bridges		Low Point		Overtopping						Face of Existing Rt 66 -5952.845									Upstream (~1600 ft from bridge) Boundary -7543.127								
												I-44	OR	I-44			OR			20-Yr			50-Yr			100-Yr			20-Yr			50-Yr			100-Yr		
#		HEC-RAS Plan	Notes	Elevation	Span	Elevation	Span	Elevation	Span	Elevation	Span	ft	ft	20-Yr	50-Yr	100-Yr	20-Yr	50-Yr	100-Yr	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}
1	Natural	1-Natural	Same as Existing with no bridges or roadway embankment.	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	879.25	N/A	N/A	884.04	N/A	N/A	887.52	N/A	N/A	879.50	N/A	N/A	884.26	N/A	N/A	887.71	N/A	N/A
2	Existing	2-Existing	Existing configuration	Existing	Existing (680')	Existing	Existing	No New Bridge	No New Bridge	Existing	Existing	878.5	876.5	Yes	Yes	Yes	Yes	Yes	Yes	879.43	0.19	N/A	884.03	-0.01	N/A	887.46	-0.06	N/A	880.64	1.14	N/A	885.07	0.81	N/A	888.40	0.69	N/A
3	Proposed	3-Proposed Outer Road	New Outer Road bridge elevation set to have ~0' of 50yr freeboard. No grading under the new bridge or the I-44 bridges, and no change of n-values.	Existing	Existing (680')	Existing	Existing	+4.5	+20 (700' total)	Existing	Existing	878.5	881.9	Yes	Yes	Yes	No	Yes	Yes	879.66	0.41	0.22	884.32	0.28	0.29	887.66	0.15	0.20	880.82	1.32	0.18	885.32	1.06	0.25	888.58	0.87	0.18
4	Alternative 1	4-Future I-44 raise	I-44 raised to prevent 100yr overtopping and Proposed Outer Road remians as is for #3 above; I-44 having ~1' of freeboard for the 100 yr event and Outer Road ~0' of freeboard for the 50 yr event.	+8 ft	+16 ft	+8 ft	+24 ft	+4.5	+20 (700' total)	Existing	Existing	889+	881.9	No	No	No	Yes	Yes	Yes	879.36	0.11	-0.08	884.22	0.18	0.19	887.46	-0.06	0.00	880.54	1.03	-0.10	885.48	1.22	0.41	888.85	1.14	0.44
5	Alternative 2	5-Future I-44 raise and new 350 relief	I-44 raised to prevent 100yr overtopping and Proposed Outer Road remians as is for #3 above; I-44 having ~1' of freeboard for the 100 yr event and Outer Road ~0' of freeboard for the 50 yr event; with I-44 additional intermediate 350' relief bridges	+8 ft	+16 ft	+8 ft	+24 ft	+4.5	+20 (700' total)	Existing	Existing	889+	881.9	No	No	No	Yes	Yes	Yes	879.33	0.09	-0.10	884.20	0.15	0.17	887.57	0.05	0.11	880.05	0.55	-0.59	884.91	0.65	-0.16	888.32	0.61	-0.08
6	Alternative 3	6-Future I-44 raise ext 300 75 and OR raise	I-44 raised and main span bridges extended 300' and relief bridges extended 75' to prevent 100yr overtopping, having ~4.5' 50yr of freeboard (~1' for the 100yr). Also raise Outer Road additional ~4' (8-9' total) on east end to nearly match raised I-44 with ~0' 50yr of freeboard.	+13	+300	+8 ft	+75 ft	+8.5	+320 (1,000 total)	Existing	Existing	889+	877	No	No	No	Yes	Yes	Yes	879.23	-0.01	-0.20	884.06	0.02	0.03	887.29	-0.23	-0.17	880.43	0.93	-0.21	885.33	1.08	0.27	888.70	0.99	0.30

Table 6 Hydraulic Options Matrix - 1D Modeling Results

Hydraulic Options Matrix - 2D Modeling Results

				I-44 Gasconade Bridges		I-44 Relief Bridges		New Rt 66 / OR Gasconade Bridge		OR Relief Bridges		Low Point		Overtopping						Face of Existing Rt 66 -5952.845									Upstream (~1600 ft from bridge) Boundary -7543.127								
												I-44	OR	I-44			OR			20-Yr			50-Yr			100-Yr			20-Yr			50-Yr			100-Yr		
#		HEC-RAS Plan	Notes	Elevation	Span	Elevation	Span	Elevation	Span	Elevation	Span	ft	ft	20-Yr	50-Yr	100-Yr	20-Yr	50-Yr	100-Yr	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}	W.S.	Δ_{Nat}	Δ_{Exist}
1	Natural	1-Natural	Same as Existing with no bridges or roadway embankment.	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	878.30	N/A	N/A	883.91	N/A	N/A	886.85	N/A	N/A	879.29	N/A	N/A	884.74	N/A	N/A	887.64	N/A	N/A
2	Existing	2-Existing	Existing configuration	Existing	Existing (680')	Existing	Existing	No New Bridge	No New Bridge	Existing	Existing	878.5	876.5	Yes	Yes	Yes	Yes	Yes	Yes	879.93	1.63	N/A	885.35	1.44	N/A	888.04	1.19	N/A	880.91	1.62	N/A	886.18	1.44	N/A	888.79	1.15	N/A
3	Proposed	3-Proposed Outer Road	New Outer Road bridge elevation set to have ~0' of 50yr freeboard. No grading under the new bridge or the I-44 bridges, and no change of n-values.	Existing	Existing (680')	Existing	Existing	+4.5	+20 (700' total)	Existing	Existing	878.5	881.9	Yes	Yes	Yes	No	Yes	Yes	880.02	1.72	0.09	885.48	1.57	0.13	888.18	1.33	0.14	881.00	1.71	0.09	886.31	1.57	0.13	888.91	1.27	0.12
4	Alternative 1	4-Future I-44 raise	I-44 raised to prevent 100yr overtopping and Proposed Outer Road remians as is for #3 above; I-44 having ~1' of freeboard for the 100 yr event and Outer Road ~0' of freeboard for the 50 yr event.	+8 ft	+16 ft	+8 ft	+24 ft	+4.5	+20 (700' total)	Existing	Existing	889+	881.9	No	No	No	Yes	Yes	Yes	880.05	1.75	0.12	886.04	2.13	0.69	889.30	2.45	1.26	881.03	1.74	0.12	886.88	2.14	0.70	890.08	2.44	1.29
5	Alternative 2	5-Future I-44 raise and new 350 relief	I-44 raised to prevent 100yr overtopping and Proposed Outer Road remians as is for #3 above; I-44 having ~1' of freeboard for the 100 yr event and Outer Road ~0' of freeboard for the 50 yr event; with I-44 additional intermediate 350' relief bridges	+8 ft	+16 ft	+8 ft	+24 ft	+4.5	+20 (700' total)	Existing	Existing	889+	881.9	No	No	No	Yes	Yes	Yes	879.97	1.67	0.04	885.20	1.29	-0.15	888.12	1.27	0.08	880.93	1.64	0.02	885.99	1.25	-0.19	888.86	1.22	0.07
6	Alternative 3	6-Future I-44 raise ext 300 75 and OR raise	extended 300' and relief bridges extended 75' to prevent 100yr overtopping, having ~4.5' 50yr of freeboard (~1' for the 100yr). Also raise Outer Road additional ~4' (8-9' total) on east end to nearly match raised I-44 with ~0' 50yr of freeboard.	+13	+300	+8 ft	+75 ft	+8.5	+320 (1,000 total)	Existing	Existing	889+	877	No	No	No	Yes	Yes	Yes	879.81	1.51	-0.12	885.74	1.83	0.39	888.81	1.96	0.77	880.65	1.36	-0.26	886.43	1.69	0.25	889.46	1.82	0.67

Table 7 Hydraulic Options Matrix -2D Modeling Results

Section 6 - Conclusions

6.1 Future

The alternative with the least future backwater to reduce overtopping frequency of I-44 is Alternative 2, consisting of raising I-44 and constructing a new set of I-44 relief bridges between the existing Gasconade River spans and the existing relief bridges. Based on the 1D model this alternative has under 1 ft of backwater over the natural conditions, with a minimal decrease from the existing conditions. The feasibility of this model was confirmed with the 2D model. This alternative does require two additional bridges on MoDOT's system, which can be avoided with Alternative 3. It is recommended that the 2018 outer road bridge replacement be constructed in a manner to not preclude either option based on MoDOT's future preferences. The table below shows estimated costs, for comparison purposes, of the three alternatives assessed.

	Notes	**Additional Cost of Improvement (Bridge and Roadway)**
Proposed	New Outer Road bridge elevation set to have ~0' of 50yr freeboard. No grading under the new bridge or the I-44 bridges, and no change of n-values.	Base Cost
Alternative 1	I-44 raised to prevent 100yr overtopping and Proposed Outer Road remains as is for the Proposed; I-44 having ~1' of freeboard for the 100 yr event and Outer Road ~0' of freeboard for the 50 yr event.	$19,700,000
Alternative 2	I-44 raised to prevent 100yr overtopping and Proposed Outer Road remains as is for the Proposed; I-44 having ~1' of freeboard for the 100 yr event and Outer Road ~0' of freeboard for the 50 yr event; with I-44 additional intermediate 350' relief bridges	$22,900,000
Alternative 3	I-44 raised and main span bridges extended 300' and relief bridges extended 75' to prevent 100yr overtopping, having ~4.5' of 50yr freeboard (~1' for the 100yr). Also raise Outer Road additional ~4' (8-9' total) on east end to nearly match raised I-44 with ~0' of 50yr freeboard. Lengthen Outer Road bridge 300' to match I-44.	$24,200,000

Table 8 Relative Costs for Alternatives to Reduce Overtopping of I-44, 2017 dollars

Assumptions:

- EB/WB I-44 roadway typical section assumed three-12' lanes, a 4' inside shoulder and a 10' outside shoulder for each direction of travel.
- Bridge widths of 52'-8" assumed for future EB/WB I-44 bridges, overflow bridges and additional relief bridges where applicable.

- Cost of existing bridges removal not included.
- Future escalation of costs not included.
- All costs shown are in addition to the base cost.
- Cost of improvements does not include Right of Way, Permitting, Utility Relocation, or Design/Construction Engineering costs.

The costs shown above represent an estimate of probable construction cost prepared in good faith and with reasonable care. HNTB has no control over the costs of construction labor, materials or equipment or any control over competitive bidding or negotiating methods and does not make any commitment or assume any duty to assure that bids or negotiated price will not vary from this estimate.

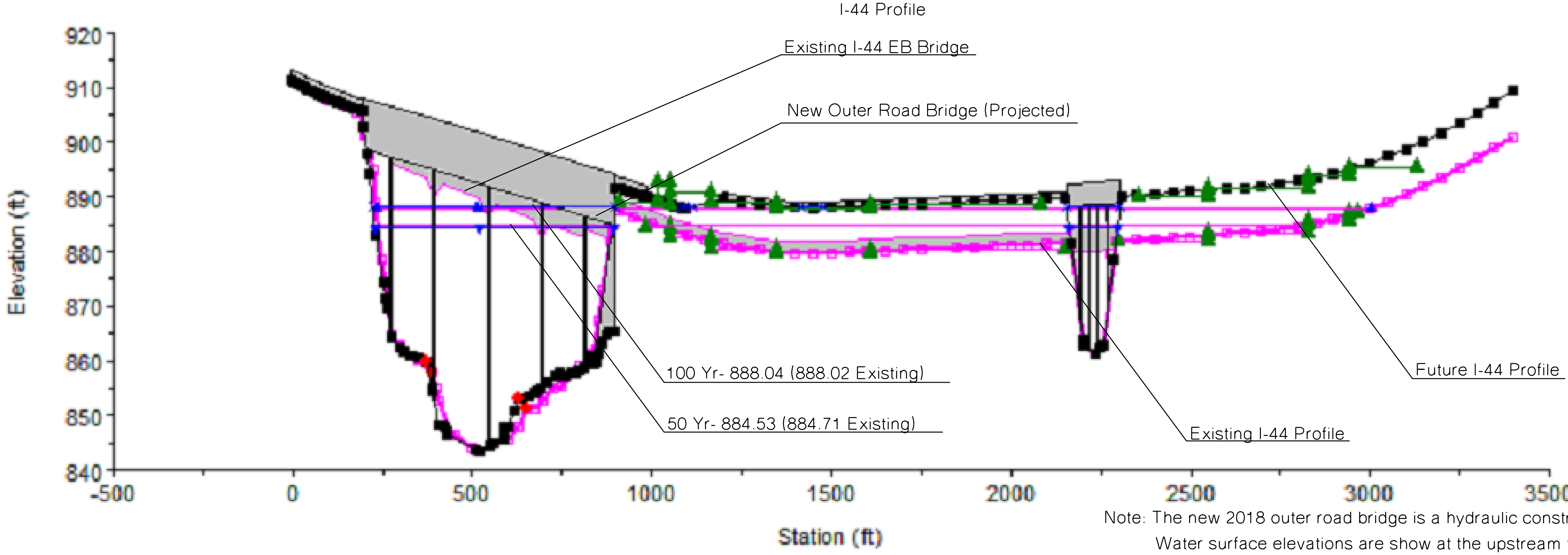
6.2 Outer Road Bridge Replacement in 2018

To allow for maximum flexibility for future construction projects to reduce the overtopping frequency of I-44, after discussions with MoDOT, the following recommendations are made for the construction of the 2018 outer road bridge replacement:

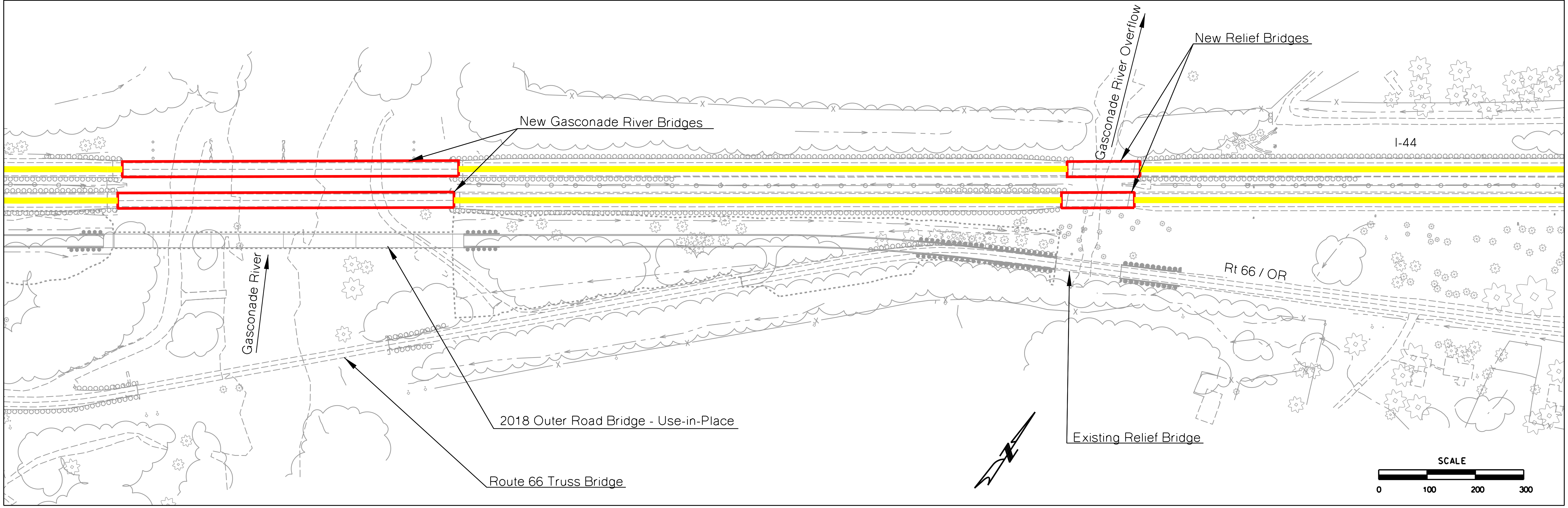
- Set the outer road alignment parallel to I-44 a sufficient offset such that I-44 could be raised in the future likely eliminating a retaining wall along the outer road for the new embankment. This is necessary to accommodate all future alternatives.
- Set the vertical profile of the new outer road bridge such that 0 ft of 50-year freeboard from girders is provided at the east abutment to minimize potential for damage from flood debris while also minimizing the increase in backwater. Note that most debris carried by floodwater is expected to be near the center of the stream thalweg, where additional vertical clearance will be provided due to the roadway profile.
- Construct the new outer road bridge with a steel superstructure, to potentially allow the bridge to be raised in the future either to obtain 50-year freeboard or pass the 100-year flood.
- Construct the new outer road bridge so that it may be lengthened in the future by constructing the east abutment on drilled shafts, with a larger beam seat, so that the abutment can be converted in the future to an intermediate pier. This recommendation specifically accommodates Alternative 3.

Appendix – Display of Future Alternatives to Reduce Overtopping

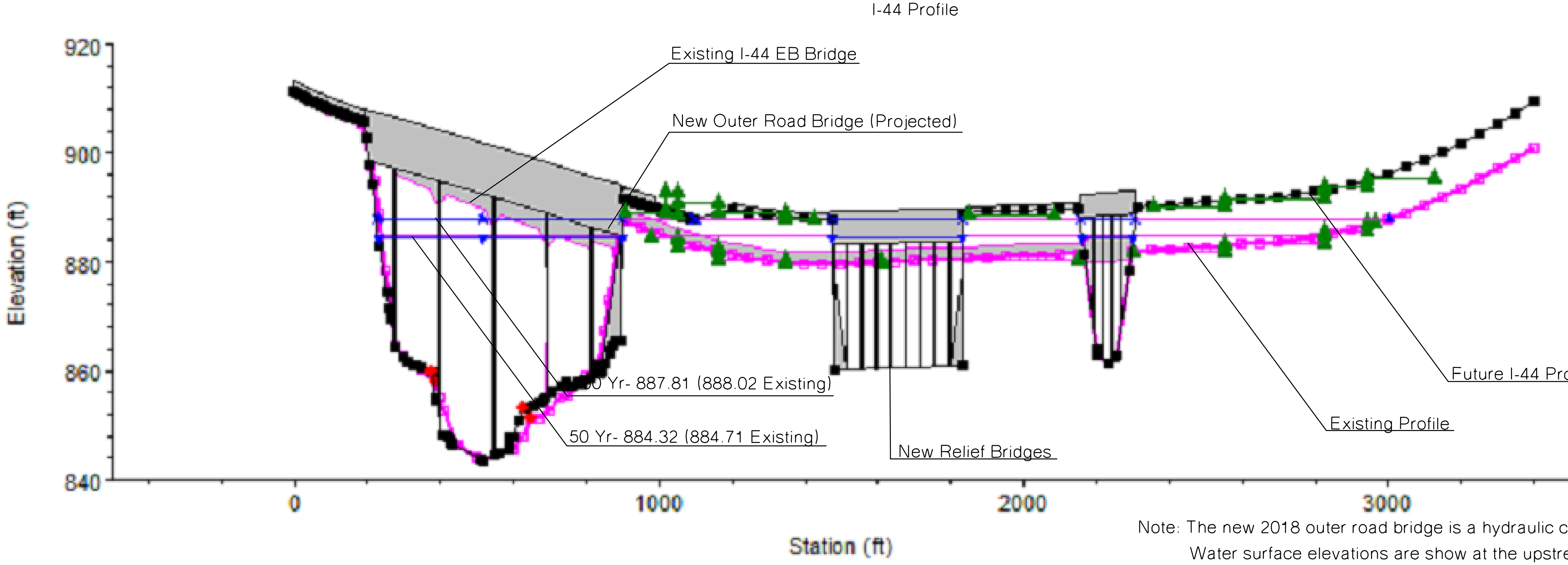
Overtopping Study for I-44 over Gasconade River near Hazelgreen, Mo | Alternative 1: Raise I-44 with Lower Outer Road Bridge



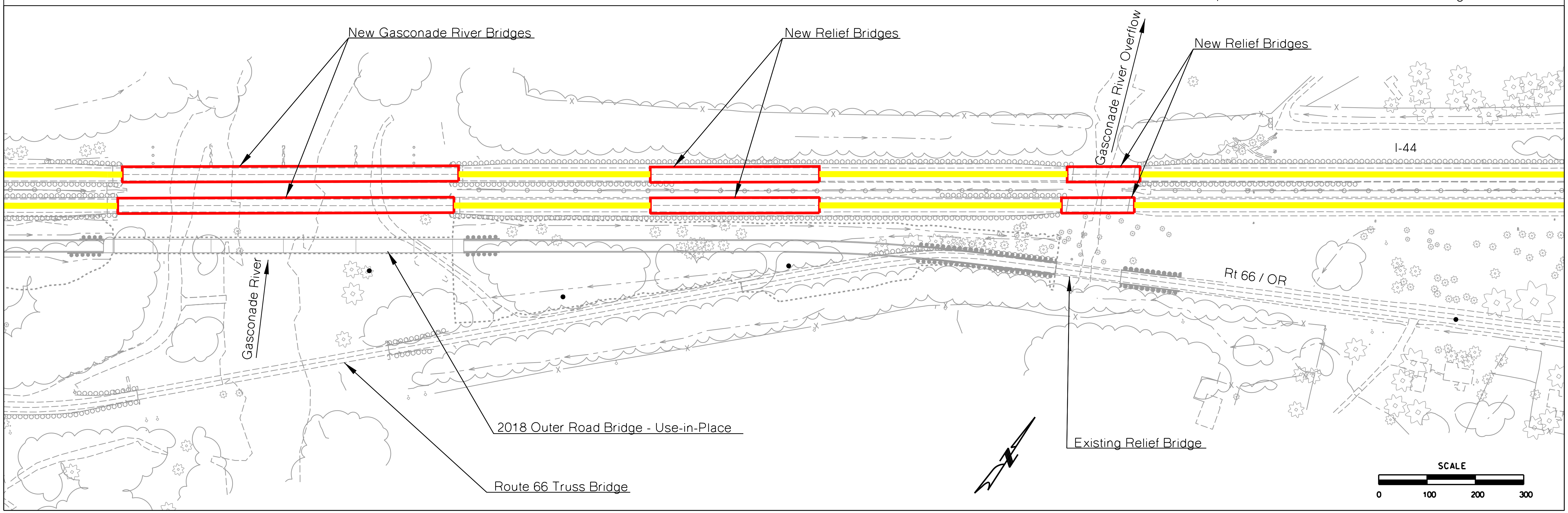
Note: The new 2018 outer road bridge is a hydraulic constriction and is therefore projected onto this profile.
Water surface elevations are show at the upstream face of the 2018 outer road bridge.



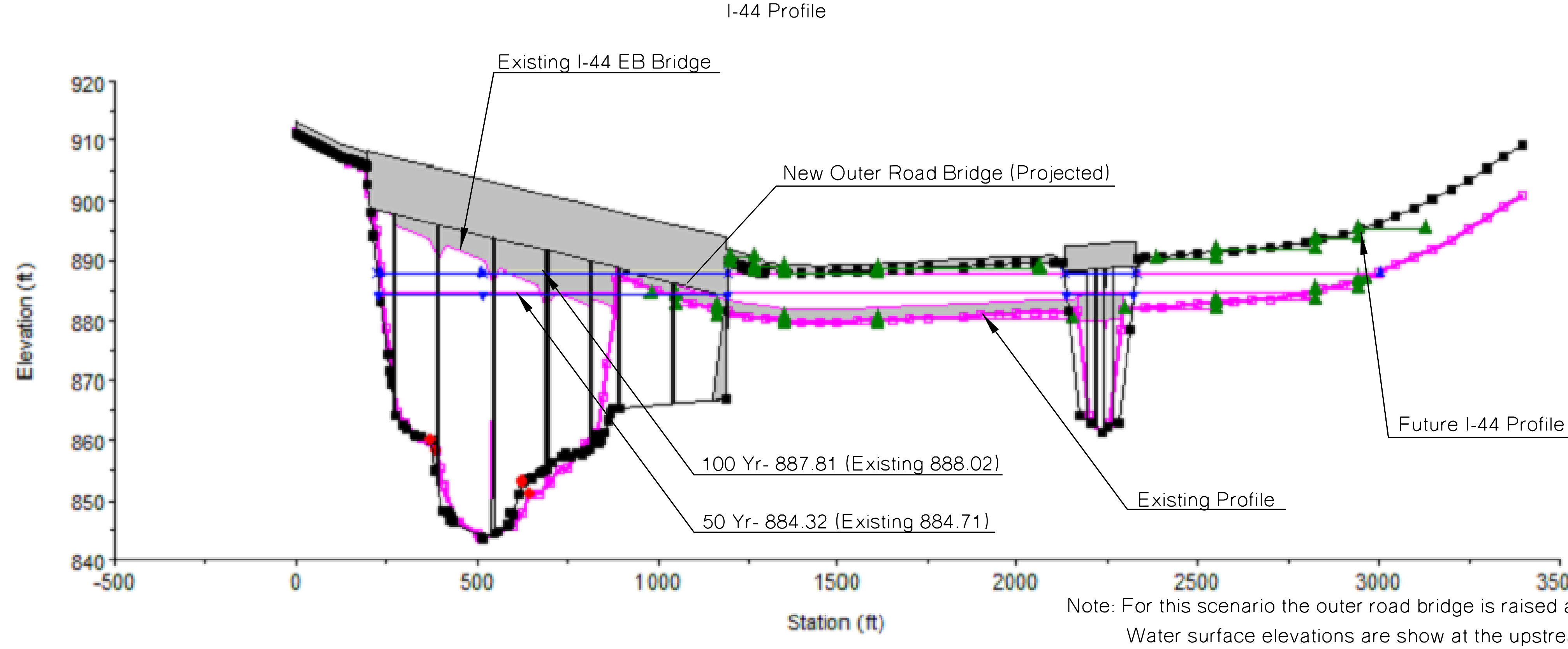
Overtopping Study for I-44 over Gasconade River near Hazelgreen, Mo | Alternative 2: Raise I-44 with New Relief Bridge



Note: The new 2018 outer road bridge is a hydraulic constriction and is therefore projected onto this profile. Water surface elevations are show at the upstream face of the 2018 outer road bridge.



Overtopping Study for I-44 over Gasconade River near Hazelgreen, Mo	Alternative 3: Raise I-44 with 300' Longer Bridges



Note: For this scenario the outer road bridge is raised and matches the profile of the new I-44 bridges. Water surface elevations are show at the upstream face of the 2018 outer road bridge.