



**498 AVE BRIDGE HYDRAULICS INVESTIGATION
OF IMPACTS RELATED TO TOWN OF HIGH RIVER
FLOOD MITIGATION WORKS**

Submitted to:
M.D. of Foothills No. 31
High River, Alberta

Submitted by:
Amec Foster Wheeler Environment & Infrastructure
Calgary, Alberta

Funding for this Study was Provided by
Alberta Environment and Parks

March 2018

CW206706

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EXECUTIVE SUMMARY

Flood control dykes constructed within the Town of High River after the 2013 flood have previously been identified to increase discharge and water levels through the 498 Ave Bridge crossing of the Highwood River during future low-probability flood events.

This report contains a review of the 498 Ave bridge hydraulics and design criteria to assess the suitability of flow conveyance during future flood events. This assessment also considers the flood risks to adjacent areas and evaluates the structural integrity of the bridge to withstand a 2013 magnitude flood event. An option to mitigate the flood risks was evaluated.

This assessment is based on previous two-dimensional hydraulic modeling which is supplemented with additional 1D modeling that was undertaken for this study.

The discharges, water levels and velocities associated with the increased discharge were evaluated by Amec Foster Wheeler bridge engineers to determine the impacts on the bridge from a structure and stability perspective. The bridge engineering evaluation determined that increased discharge did not result in structural or stability issues associated with the bridge.

The main impact due to the increased discharge is flooding of adjacent areas. Specifically there is an increased flood hazard for the land on the west floodplain, north of 498th Avenue, due to a 183 m³/s increase in discharge. Due to the relatively high water levels at the downstream end of the bridge, the velocity through the bridge opening does not increase because of the increased headwater at the upstream side of the bridge. However, the flow situation under the bridge is hydraulically complex and the impact on the bridge erosion protection should be reviewed further.

The most feasible mitigation option available, to reduce the discharge and water levels at the bridge opening, consists of lowering the roadway west of the bridge to increase the proportion of discharge that overtops the road. This mitigation option marginally reduces water levels at the bridge by 0.16 m. Given that bridge stability is not impacted, there is no significant benefit from the lowering roadway mitigation scenario. Lowering the roadway increases the road topping overflow, further increasing flood hazards at the location discussed above.

In the event of a debris blockage at the bridge during a future large-probability flood, water levels upstream of the bridge would increase the flooding potential on the east floodplain south of 498th Avenue. There is an 80 m section of ground east of the channel and upstream of the bridge that would get overtopped. This would be a highly negative outcome given that 498 Ave east of the bridge was raised to prevent flooding of the east floodplain.

The following recommendations are based on this study:

- ▶ Future land-use and development of the west floodplain, north of 498th Avenue, should review the increased flood hazard noted herein.
- ▶ Further study is required to evaluate the feasibility of an 80 m long berm south of 498th Avenue on the east floodplain to reduce the flood hazard risk in the event of debris blockages at the bridge during floods. Additionally, the study should review the impact on the abutment erosion protection of the hydraulic complexities through the bridge waterway opening.

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1.0 INTRODUCTION

A previous study (Amec/Advisian, March 2017) identified that during future low-probability flood events, discharge and water levels would increase through the 498 Ave Bridge crossing of the Highwood River due to flood control dykes constructed within the Town of High River. Additionally, this previous study recommended that the bridge design and erosion protection should be reviewed due to these increased discharges.

This report contains a review of the 498 Ave bridge hydraulics. The report reviews the two-dimensional hydraulic modeling results in Amec/Advisian (March 2017) of the 498 Ave bridge crossing to assess flow conveyance during future flood events. Additional 1D modeling was undertaken to supplement the previous 2D modeling. This assessment also considers the flood risks present and evaluates the structural integrity of the bridge to withstand a 2013 magnitude flood event. Options to mitigate the flood risks are evaluated.

1.1 Scope of Work

The scope of work for this study is summarized below.

- ▶ Data Collection and Review – Review of the existing related documents including existing topographic information, engineering studies, reports, and designs. No additional engineering site investigations, such as geotechnical investigations or topographic surveys were undertaken. Previous studies contain estimates of the extreme flood discharges to be expected due to the upstream flood control dykes.
- ▶ Modelling – An existing two dimensional (2D) hydraulic model developed by Advisian was used to inform the 498 Ave crossing investigation. However, some additional 1D hydraulic modeling was undertaken to more accurately review the impacts on the bridge and mitigation options.
- ▶ Bridge and Adjacent Areas Assessment – The modeling results were evaluated to assess impacts on the bridge and adjacent areas. Bridge assessment considerations included structural stability of the bridge, available freeboard during low-probability flood events and suitability of erosion protection based on expected flow velocities adjacent to the piers and abutments. The assessment of impacts on adjacent areas included an evaluation of increased water levels, flows and inundation extents.

1.2 Information Sources

Information reviewed and used as part of this study included:

- ▶ Post-2013 flood LiDAR (obtained from the MD) which was used as the Digital Elevation Model (DEM) on which the channel and floodplain geometry was based for the hydraulic modeling and mapping of flood inundation extents.
- ▶ Recent orthorectified aerial imagery obtained from the MD.

- ▶ Bridge Design Drawings for the 498th Avenue Bridge (obtained from the bridge designers, ISL Engineering), which shows bridge design features such as the bridge deck and low chord elevations, location of the bridge piers, abutments, etc. These bridge features were used for the 1D hydraulic modeling undertaken for this study.
- ▶ 2D model results obtained from Advisian Worley Parsons Group for various scenarios including 2013 flood conditions and a 2013 magnitude flood based on existing conditions. The information obtained consisted of ASCII format GIS files for water depths and velocities. This information overlain on the LiDAR based DEM provided the water levels and distribution of discharge within the study area.

2.0 BACKGROUND AND 2D MODEL SCENARIOS

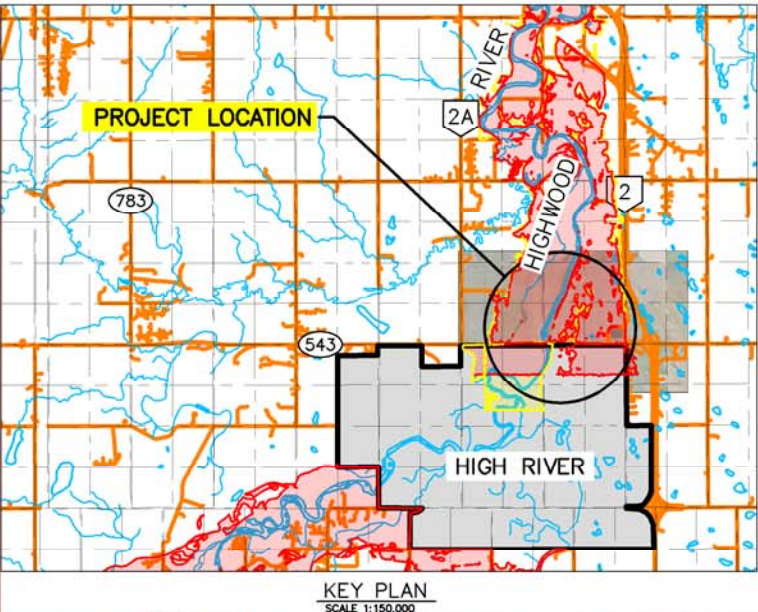
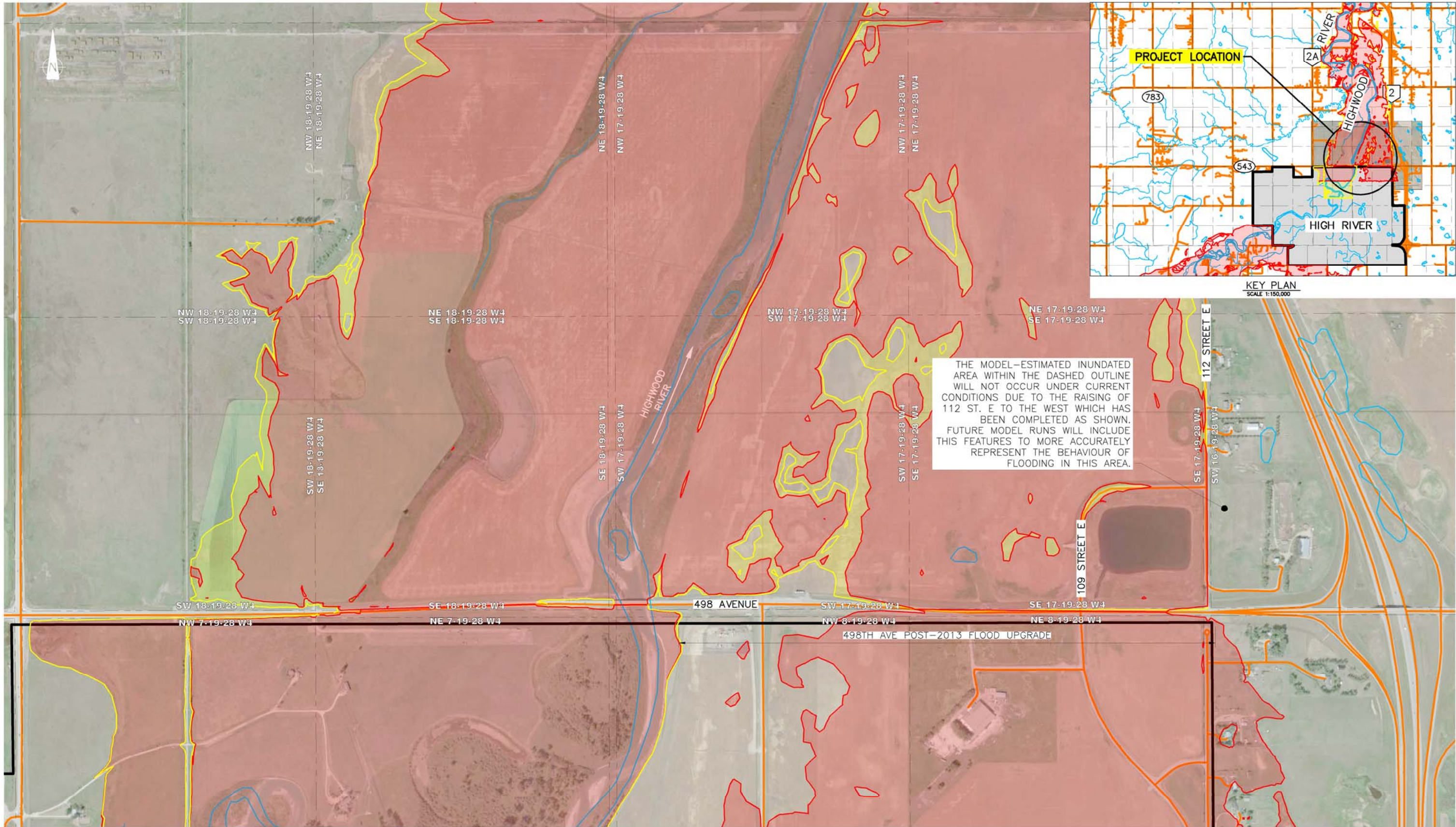
Figure 2.1 is a location plan that shows 2013 flood inundation extents including the increased flooding that occurs due to the flood mitigation works constructed by the Town of High River. The flood inundation extents are based on 2D modeling undertaken by Advisian.

During the 2013 flood, the Highwood River spilled its banks downstream of 498 Ave and back flooded across 498 Ave, crossing the road north to south, into the Hamptons neighborhood in the Town of High River. The raising of 498 Avenue E was undertaken after the flood to protect the east side of the Town. Due to flood mitigation works undertaken by the Town of High River (i.e., flood control dyke construction upstream of the 498 Ave bridge crossing), there has been an increase in flow through the 498 Ave Bridge during high flow events. An investigation of modeling results was recommended for this bridge crossing in Amec/Advisian (March 2017) to assess the suitability of flow conveyance through this crossing in future flood events. Specifically, the review should determine if the bridge can withstand a future event similar to the 2013 flood, considering the additional discharge expected due to the Town of High River mitigation works.

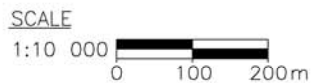
The terminology used herein for the flood scenarios evaluated is the same as in Amec/Advisian (March 2017) and is summarized below. The previous study should be referred to for a detailed discussion.

- ▶ 2013 Flood Landscape Scenario based on the 2013 flood magnitude and the landscape that existed at that time. This can be considered the baseline scenario used to determine subsequent changes or effects.
- ▶ Complete Town Mitigation Scenario (Scenario 28A), which includes all as-built dike information and the proposed 12 Avenue-Centre St. Dike required to protect the southern boundary of the Town. This scenario has been used as a conservatively based design scenario.

Scenario 28A peak flow magnitude at the 498 Ave bridge is estimated to be approximately 180 m³/s greater than the 2013 Flood Landscape Scenario (which is synonymous with the existing condition at the time of the 2013 flood or the condition pre 2013/2014 flood mitigation works), increasing from 1,225 m³/s to 1,405 m³/s for a 2013 magnitude flood equivalent.



- LEGEND:
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
 - 2013 FLOOD EXTENT
 - ROADS
 - WATERBODIES



CLIENT: **M.D.OF FOOTHILLS NO. 31**

PROJECT:	498 AVE BRIDGE HYDRAULICS INVESTIGATION			
TITLE:	LOCATION PLAN AND 2D MODEL INUNDATION EXTENT CHANGES			
DATE:	OCTOBER 2017	JOB No.:	CW216706	REV. A
CAD FILE:	216706-N01.dwg	FIGURE No.:	FIGURE 2.1	

3.0 1D HYDRAULIC MODELING

1D hydraulic modeling, to supplement the Advisian 2D modeling, was required to more accurately review the flood impacts on the bridge due to the additional flow and also to review mitigation options. While 2D modeling has advantages and is preferable to 1D modeling in many instances, it does have some limitations. For example, the 2D model does not incorporate the hydraulic impact of bridge features such as bridge piers and bridge low chord and deck. In contrast, the 1D HEC-RAS hydraulic model has very robust bridge algorithms and the hydraulic impacts of all these features can be accounted for. Additionally, once the 1D hydraulic model for existing conditions is completed, it can be readily modified to review mitigation options.

Previous 1D hydraulic modeling was undertaken for this area by Northwest Hydraulic Consultants (NHC, 1992). This previous model forms the basis for the current flood hazard mapping for the Highwood River. The previous 1D model was not used for this study since the topography and infrastructure has changed considerably (for example the 498 Ave Bridge was not constructed at the time of the previous study). Additionally, the previous model was implemented in HEC-2, which is a predecessor to the current HEC-RAS model and is not easily transferable. However, some parameters from the previous 1D model were used to inform our 1D model including channel and floodplain roughness coefficients and cross section locations.

The extent of the 1D modeling is shown on **Figure 3.1**. Additional modeling details are listed below:

- ▶ The length of channel modeled was 1,673 m. The channel lengths were 912 m and 761 m, upstream and downstream of the bridge, respectively.
- ▶ The channel and floodplain cross sections were extended to high ground on either side in order to encompass the full extent of flooding.
- ▶ The channel and floodplain geometry was based on Light Detection and Ranging (LiDAR) data from the MD. The LiDAR data was obtained during a time of low flow in the Highwood River. Although LiDAR does not penetrate water, since it was obtained at a time of low flow in the river, the water surface is assumed to be approximately equal to the riverbed and representative for the purpose of this assessment of extreme discharge events. This approach was corroborated by a review of the ISL bridge design drawings which contains a channel cross section at the bridge.
- ▶ The selected channel and floodplain roughness coefficients of 0.026 and 0.06, respectively, were the same as those contained in NHC (1992).
- ▶ One of the 1D model input parameters is the downstream starting water level. This is referred to as the downstream boundary condition since backwater has significant influence on the water levels at the bridge. In particular, the usefulness of mitigation options such as lowering the roadway elevation west of the bridge or large size culverts under the roadway can be limited by these backwater conditions. An accurate downstream boundary condition for the 1D model was obtained from the Advisian 2D model.

Channel bridge parameters obtained from the ISL bridge design drawings include configuration, elevations and size of abutments, riprap, bridge piers and bridge low chord and deck.



Figure 3.1: HECRAS Cross Sections Alignment US and DS of the 498 Ave Bridge

In addition to the two scenarios that were modeled in the 2D modeling (2013 Flood Landscape Scenario and Scenario 28A), there were two more scenarios that were modeled in the 1D modeling. These two additional scenarios include a debris blockage and mitigation scenario. The four 1D scenarios modeled are detailed in the following sections and results are shown in the following figures and tables.

- ▶ **Table 3.1** contains the discharge, water level and velocity at the bridge opening and the roadway west and east of the bridge.
- ▶ **Figure 3.2** shows the water surface profiles for the study reach. The west and east low chord elevations of the bridge are also shown.
- ▶ **Figure 3.3** is a cross section immediately upstream of the bridge that shows the water surface, ground and bridge elevations.
- ▶ **Figure 3.4** is a plan view that shows the increase in inundation extents for the debris blockage scenario.
- ▶ **Appendix A** contains 2013 flood photographs at the 498 Ave Bridge and Alberta Environment and Parks (AEP) High Water Mark (HWM) information.
- ▶ **Appendix B** contains a summary table of water levels and a plot of the cross sections upstream of the bridge.

3.1 2013 Flood Landscape Scenario – Discharge = 1,225 m³/s

Appendix A contains valuable information that was used for modeling and verifying the results for the 2013 Flood Landscape Scenario. This information includes the following:

- ▶ Photo A1 shows that the road was overtopped west of the bridge. The 2D model also shows this overtopping.
- ▶ Photo A1 also shows flow from the west towards the bridge opening. This indicates that the water levels were higher to the west (where the road was overtopped) than they were at the bridge.
- ▶ Photo A2 shows the extent of inundation to the east of the bridge.
- ▶ The bridge deck is on a slope and the east side is 1 m higher than the west side. The elevation of the AEP HWM upstream of the bridge is 1034.77 m. In comparison the west and east low chord elevations are 1034.5 m and 1035.5 m, respectively. This means the bridge superstructure was partly submerged during the 2013 flood (the water level was 0.27 m higher than the bottom of the bridge girder on the west side). However, the bridge deck was not overtopped.

Table 3.1 indicates the 1D model does an excellent job of replicating the information collected during the 2013 flood and contained in **Appendix A**. The modeled water level of 1034.77 m at the bridge crossing is the same as the AEP HWM. The modeled water level west of the bridge which overtops the roadway of 1035.46 m is 0.69 m higher than at the bridge. The bridge opening and roadway overtopping discharges are 1169 m³/s and 56 m³/s, respectively.

Table 3.1: 1D Model Results at 498 Ave Bridge

Scenario	Roadway West of Bridge			Directly Upstream of Bridge		
	Flow (m ³ /s)	Water Level (m)	Velocity (m/s)	Flow (m ³ /s)	Water Level (m)	Velocity (m/s)
2013 Landscape Scenario (Flow = 1225 m ³ /s)	56	1035.46	0.05	1169	1034.77	2.64
Scenario 28 A (Flow = 1405 m ³ /s)	238	1035.83	0.16	1167	1035.68	1.14
Debris Blockage (Flow = 1405 m ³ /s)	478.5	1036.11	0.22	926.5	1036.03	0.84
Mitigation – Roadway Lowering (Flow = 1405 m ³ /s)	461	1035.61	0.38	944	1035.52	0.96

The mean channel velocity through the bridge opening is 3 m/s and the erosion Class 2 riprap is able to withstand this velocity.

3.2 Scenarios 28 A (Town's Complete Mitigation Scenario) – Discharge = 1,405 m³/s

Although the additional 180 m³/s results in a 0.91 m increase in water level at the bridge, the increase in discharge through the bridge (2 m³/s) is negligible. Almost all the additional flow is conveyed over the roadway to the west. The reason for this is that the bridge waterway opening was near capacity for the previous scenario. The increase in water level at the bridge does result in the east low chord also being inundated, as well as the west low chord.

Since these hydraulic parameters are estimated immediately upstream of the bridge, the velocity (which is the product of discharge divided by wetted area) decreases since the discharge remains near constant and the wetted area increases. The 1D model estimates the velocity through the bridge is similar to the previous conditions. The increased headwater upstream of the bridge does not increase velocities through the bridge opening due to the relatively high water levels at the downstream end of the bridge. However, the flow condition under the bridge is hydraulically complex due to turbulence and flow separation under the bridge when the low chord becomes submerged. It would be prudent to review hydraulics in a subsequent phase of the study just to confirm there are no adverse impacts on the bridge erosion protection.

FIGURE 3.2
Highwood River Flow Profiles at 498 Avenue Bridge

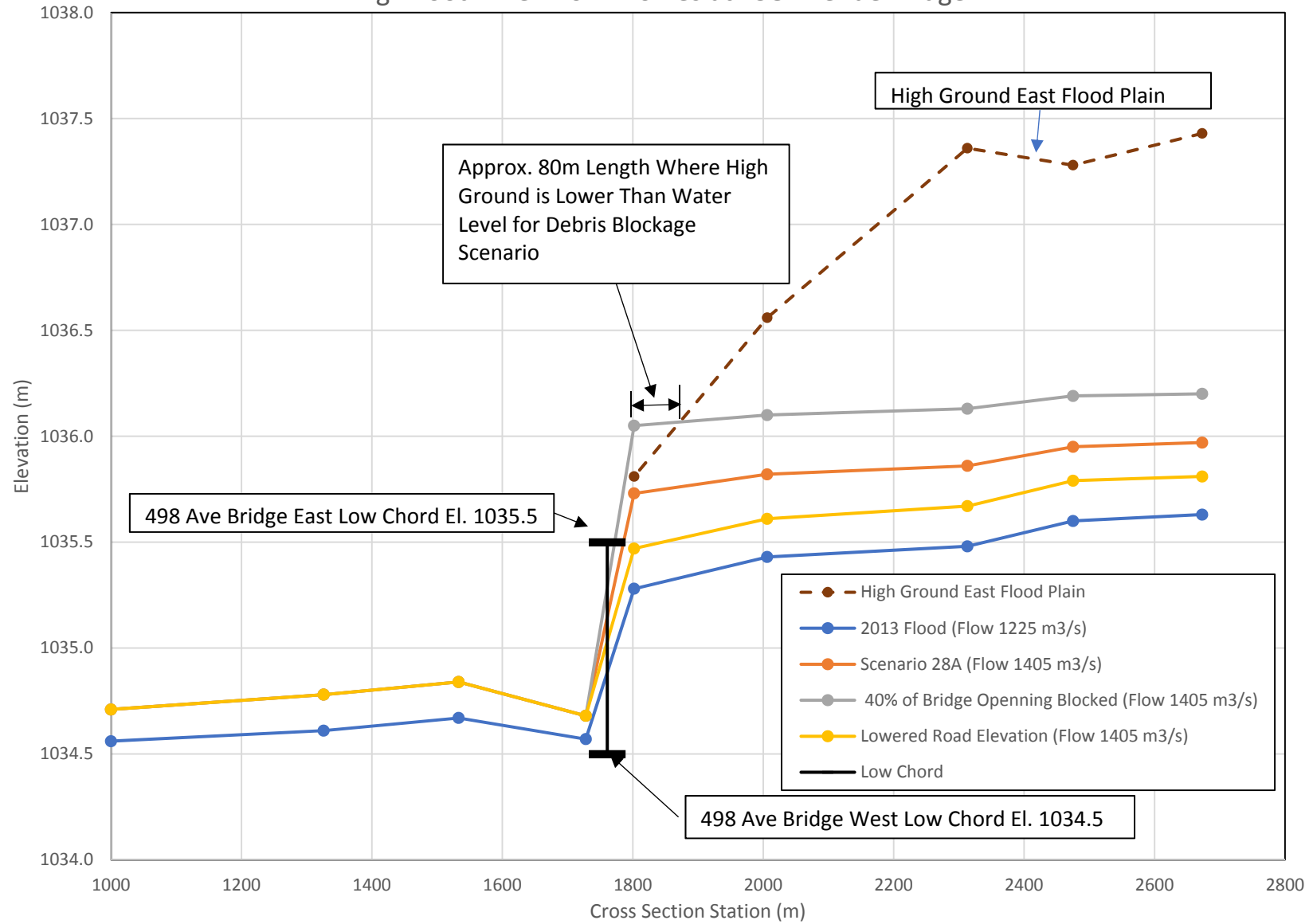
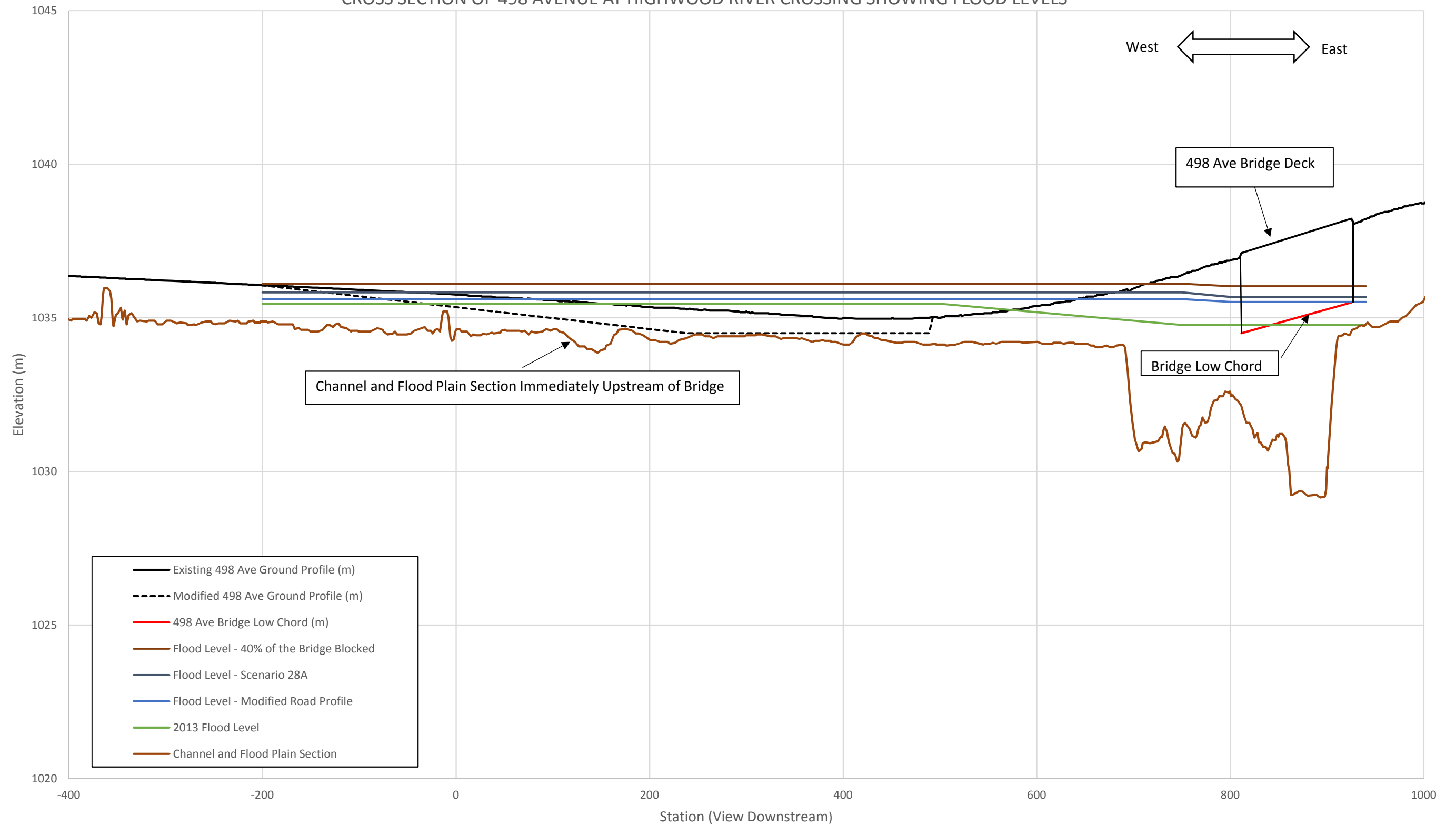


FIGURE 3.3
CROSS SECTION OF 498 AVENUE AT HIGHWOOD RIVER CROSSING SHOWING FLOOD LEVELS



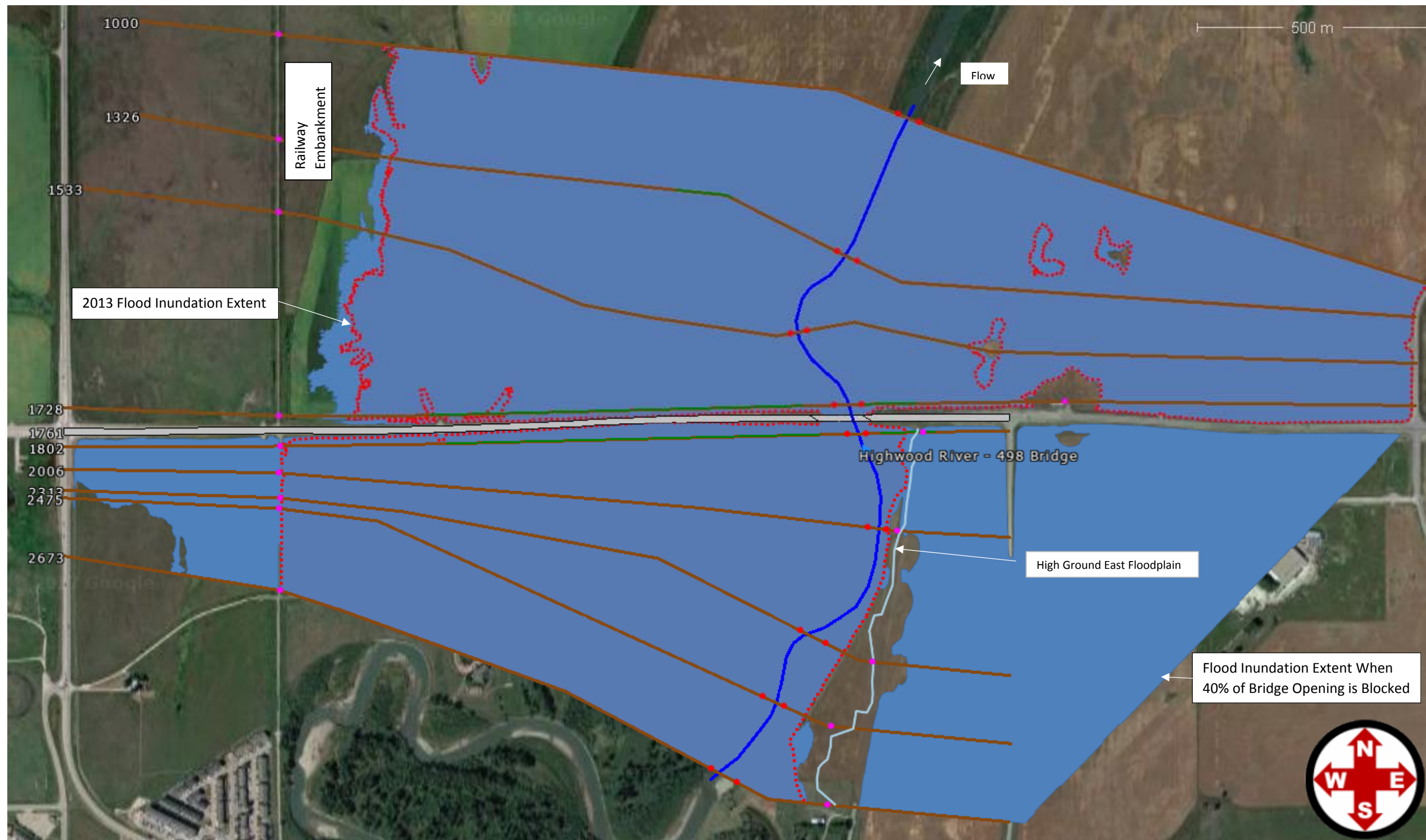


Figure 3.44: Flood Inundation Extents for the 40% of Bridge Opening Blocked Scenario and 2013 Flood

3.3 Debris Blockage Scenario – Discharge = 1,405 m³/s

The Town's flood mitigation works have disconnected not only the interchange of flow between the channel and floodplain but also the interchange of debris and sediment. Debris conveyed from the upper and middle portion of the watershed that would previously have deposited in the Town, is now conveyed downstream. The Highway 2A Bridge in Town is relatively low and is currently an impediment to debris passage. However, at some point, this bridge will be replaced with a higher structure and the 498 Ave Bridge could potentially be a barrier to debris passage. The debris blockage scenario is similar to Scenario 28 A (Discharge = 1,405 m³/s) but assumes that 40% of the bridge waterway opening is blocked by debris.

The debris blockage results in a 0.35 m increase in water levels at the bridge and a 240 m³/s decrease in flow. This additional flow is conveyed over the roadway to the west.

As shown in **Figure 3.2**, there is an approximately 80 m section of the high ground east of the channel and upstream of the bridge that is overtopped due to the debris blockage. **Figure 3.4** shows a plan view that delineates the high ground on the east floodplain. This 80 m section is only overtopped in the debris blockage scenario and results in additional flood inundation of the east floodplain upstream of the bridge as shown in **Figure 3.4**. Flooding of the east floodplain south of 498th Avenue would be a highly negative outcome since 498 Ave was raised to prevent this. For this scenario, no additional inundation occurs on the west floodplain.

As compared to the base-case, the mean channel velocity increases 0.5 m/s to 3.5 m/s. The Class 2 riprap erosion protection can withstand this velocity.

3.4 Mitigation Scenario – Discharge = 1,405 m³/s

Mitigation options were reviewed to reduce the discharge and water levels associated with Scenario 28A at the bridge opening. Potential options include lowering the roadway west of the bridge or a large culvert under the roadway. As previously noted, usefulness of this option can be limited by backwater conditions. In particular a culvert is not an efficient option as the high tailwater downstream (north) of the road drowns out the culvert outlet and limits its effectiveness. Overtopping of the roadway to the west is similar to a weir and has better hydraulic characteristics than a culvert. Hence, lowering the roadway west of the bridge opening was evaluated as a mitigative measure to reduce discharge and water levels at the bridge opening.

As shown by the dashed line on **Figure 3.3**, the mitigation option evaluated consists of lowering a 250 m length of the road west of the bridge to an elevation of 1034.5 m.

As shown in **Table 3.1**, as compared to Scenario 28A, the roadway lowering results in a 223 m³/s reduction in the discharge through the bridge opening as this discharge is now conveyed over the road. Although there is a 0.16 m reduction in the water level to 1035.52 m, the entirety of the bridge low chord is still submerged.

4.0 EVALUATION OF IMPACTS AND RECOMMENDATIONS

The discharges, water levels and velocities associated with the four scenarios were evaluated by Amec Foster Wheeler bridge engineers to determine the impacts on the bridge from a structure and stability perspective. The evaluation was based on the ISL bridge design drawings as well as the hydraulic parameters. The bridge engineering evaluation determined that none of the four scenarios had any structural or stability issues associated with the bridge.

The following conclusions are based on this study:

- ▶ The bridge is structurally stable for Scenario 28A. However, there is an increased risk of debris blockage due to increased water levels at the bridge and also due to the loss of floodplain and river channel interaction due to the Town's flood mitigation works.
- ▶ The main Scenario 28A impacts are flooding of adjacent areas. Specifically there is an increased flood hazard for the land on the west floodplain, north of 498th Avenue, due to a 183 m³/s increase in discharge.
- ▶ Given that Scenario 28A does not significantly impact bridge stability, there is no significant benefit from the lowering roadway mitigation scenario. This mitigation marginally reduces water levels at the bridge by 0.16 m, which does not significantly reduce the debris blockage risk. Additionally, this roadway lowering increases the road topping overflow by 223 m³/s, further increasing flood hazards at the location discussed above.
- ▶ The higher upstream water levels due to a debris blockage at the bridge would increase the flooding potential on the east floodplain south of 498th Avenue. There is an 80 m section of ground upstream of the bridge that would get overtopped. This would be a highly negative outcome given that 498 Ave east of the bridge was raised to prevent flooding of the east floodplain.

The following recommendations are based on this study:

- ▶ Future land-use and development of the west floodplain, north of 498th Avenue, should review the increased flood hazard noted herein.
- ▶ Further study is required evaluate the feasibility of an 80 m long berm south of 498th Avenue on the east floodplain to reduce the flood hazard risk in the event of debris blockages at the bridge during floods. Additionally, the study should confirm whether there is an adverse impact on the abutment erosion protection due to complex hydraulics through the bridge waterway opening.

5.0 CLOSURE

This report has been prepared for the exclusive use of the MD of Foothills. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, expressed or implied, is made.

Yours truly,

**Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited**

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Permit to Practice No. P-4546

6.0 REFERENCES

Amec Foster Wheeler, Advisian, March 2017, Scoping Study of Flood Related Areas of Concern on the Highwood River Within the MD of Foothills and the Little Bow River Upstream of the Twin Valley Reservoir. Prepared for the MD of Foothills.

Northwest Hydraulic Consultants Ltd, August 1992. High River Flood Risk Mapping Study, Prepared for Alberta Environment.



Appendix A

2013 Flood Photo and High Water Mark



Photo 1 View west from upstream side of bridge. Oval shape delineates roadway overtopping area. Note the higher water levels at the roadway overtopping result in flow parallel to the road and towards the bridge.



Photo 2 View southeast from upstream side of bridge.

Highwood River

SITE #: 2013-HW-19.2
LOCATION: Hwy 543 Bridge over Highwood River
LAT/LONG: 50.6013769 -113.859298°

Benchmark TBM
Elevation (m): 1037.286
Description: Most SW bolt supporting guard rail post on SW corner of the George Groenveld Bridge.

DATE OF SURVEY: July 9, 2013

PHOTO #1: Looking NE at the first handrail support bolted to the concrete abutment of the George Groenveld Bridge (Hwy 543). Prism is resting on TBM. Photo taken on July 9, 2013.



HWM: 2013-HW-19.2-a
HWM Elevation (m): 1034.766
Description: Left bank, approximately 5m upstream of bridge.
50.601334 / -113.859227

WL: 2013-HW-19.2-a-wl
Elevation (m) @ hour: 1029.720 @ 5:15 pm
Description: 50.601279 / -113.858490



Appendix B

HEC-RAS Summary Table and Cross Section Plot

Table B1
HEC-RAS Summary Table
Water Surface Levels

River Station	Water Surface Elevation (m)			
	2013 Flood (Flow 1225 m ³ /s)	Scenario 28A (Flow 1405 m ³ /s)	40% of Bridge Opening Blocked (Flow 1405 m ³ /s)	Lowered Road Elevation (Flow 1405 m ³ /s)
2673	1035.63	1035.97	1036.2	1035.81
2475	1035.6	1035.95	1036.19	1035.79
2313	1035.48	1035.86	1036.13	1035.67
2006	1035.43	1035.82	1036.1	1035.61
1802	1035.28	1035.73	1036.05	1035.47
1761	498 Ave Bridge			
1728	1034.57	1034.68	1034.68	1034.68
1533	1034.67	1034.84	1034.84	1034.84
1326	1034.61	1034.78	1034.78	1034.78
1000	1034.56	1034.71	1034.71	1034.71

Notes:

1. For this option a 250m length of road west of the bridge was lowered to an elevation of 1034.5 m to increase the flow overtopping the road

Water Levels at Cross Sections Upstream of 498 Avenue at Highwood River Crossing.

