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MUNICIPAL DISTRICT OF FOOTHILLS NO. 31

Little Bow River Modelling Flood Mitigation Effects Assessment

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MUNICIPAL DISTRICT OF FOOTHILLS NO. 31
LITTLE BOW RIVER MODELLING
FLOOD MITIGATION EFFECTS ASSESSMENT

PROJECT 307076-07348 - LITTLE BOW RIVER MODELLING

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1. INTRODUCTION

WorleyParsons Canada Services Ltd., operating as Advisian, was retained by the Municipal District of Foothills No. 31 (MD) to undertake Phase 1 Little Bow River Modelling: Flood Mitigation Effects Assessment (LBR-FEA). The Study Area for the LBR-FEA includes lands of the MD, Vulcan County (Vulcan) and Municipal District of Willow Creek No. 26 (Willow Creek) potentially affected by Little Bow River flooding along the river segment starting at Highway 2 and continuing downstream to the Twin Valley Reservoir (TVR) northern end (Legal section NW-34-15-26-W4) as shown in the map views of Figures 1-1 to 1-6 and in the profiles of Figures 1-7 to 1-12.

Flood mitigation works, which have been constructed (or proposed) within the MD and the Town of High River (the Town) upstream from the Study Area, have resulted in a change to flood hazard level over this segment of the river (Figure 1-14). The MD has identified the need to assess downstream effects of these works on residential and agricultural lands adjacent to the Little Bow River. The Study Area is downstream of existing coverage of previous modelling extents (i.e. the High River Flood Model as shown in Figure 1-13 also known as the Town Model), which covers the Highwood River segment from the Woman's Coulee Canal inlet downstream to the Highway 2 crossing and the Little Bow River from its origin with the Little Bow Canal downstream to the Highway 2 crossing. As part of the LBR-FEA, a model with similar application and function to the High River Flood Model has been developed for the Study Area. The purpose, scope and document outline of the LBR-FEA are provided below similarly to the relevant document produced for the Highwood River Modelling: Flood Mitigation Effects Assessment (HR-FEA), which is a companion study that assesses flooding effects on the Highwood River downstream from Highway 2 to its confluence with the Bow River (within the MD; see Advisian 2016). The methodology and results of Phase 1 of the LBR-FEA are presented herein.

Phase 2 of the HR-FEA and LBR-FEA, if required, includes supplemental model updating and refinement with bathymetric survey cross-section data. The need for Phase 2 will be determined following collection of the bathymetric survey information and/or review of the Phase 1 report.

1.1 Purpose and Scope of Work

The overall purpose of LBR-FEA is to characterize the change in flood hazard and effects associated with MD, Vulcan and Willow Creek residential lands and infrastructures in context of the 2013 flood for both pre and post-flood conditions. The post-2013 flood conditions will be integrated into the LBR-FEA model which includes all flood mitigation measures that have been constructed or are planned for construction in and around the Town (Figure 1-14). The high-level scope of work to achieve this purpose is as follows:

- review available reports and data;
- collect high water mark (HWM) data and anecdotal evidence for the 2013 flood throughout the Study Area;
- develop and calibrate a two-dimensional (2D) hydrodynamic river model (2D model) representing 2013 flood conditions for the Study Area;
- undertake sensitivity runs to better understand the sensitivity of the model results to changes in input parameters and accuracy of the model;



-
- develop a post-Flood Model that includes the influence of all flood mitigation measures and simulate the potential effects of these measures under a flood equivalent to the 2013 event; and
 - report on the methodology and results of the aforementioned tasks.

1.2 Document Outline

Considering the purpose and scope of work, this report presents the results of the LBR-FEA through the following sections:

- Section 2: Background and Study Area description including watershed information, hydrology, morphology and key existing reports;
- Section 3: Approach overview (including data collection and review as well as computational modelling development and simulations);
- Section 4 and 5: Results and discussion (including presentation of the developed model, calibration, sensitivity analysis, effects assessment and limitations/accuracy); and
- Section 6: Summary and recommendations.

2. BACKGROUND AND STUDY AREA DESCRIPTION

The following section summarizes background information pertaining to the LBR-FEA and Study Area in general. The discussion begins with an overview of the Little Bow River watershed and then moves to discussion of the Study Area in terms of general land characteristics and uses. Following this, Study Area river morphology and the historic and flood-related Little Bow River hydrology (including a description of the Highwood-Little Bow flow split during extreme floods in the Highwood River) are discussed. The Highwood-Little Bow overflow area, which becomes active during extreme flooding on the Highwood, is a unique morphologic characteristic that underlies the changes to extreme flooding within the Study Area. The morphology of this overflow area causing the flow split was changed due to post-flood mitigation measures downstream of the Woman's Coulee canal inlet. Lastly, key existing reports are summarized to provide additional context for the LBR-FEA.

2.1 Little Bow River Watershed

The Study Area is located in the Little Bow River watershed, approximately 5 km downstream of the river's source.

The Little Bow River watershed originates east of the Highwood River-Little Bow River drainage divide within the Town (Figure 2-1). The drainage divide is discussed further in Section 2.3.1.

The Little Bow River is a tributary of the Oldman River in southern Alberta. It is about 190 km long. From its headwaters in the Town it flows south into the TVR, then turns east and flows into Travers Reservoir. After leaving Travers Reservoir, it flows southeast into the Oldman River ultimately feeding the South Saskatchewan River. The total drainage area is of 3,276 km² as indicated for the Water Survey of Canada (WSC) hydrometric station of Little Bow River near the Mouth (05AC023).

In addition to overflow during extreme flooding and local groundwater contributions, water is diverted from the Highwood River and Bow River into the upper Little Bow (from headwaters to the TVR) to support water licensed use for irrigation, livestock and municipal supply in the surrounding plain. The Little Bow Diversion on the Highwood River in High River provides the main upstream source to the Little Bow River via the Little Bow Canal. The Highwood River's waters are also diverted into the Woman's Coulee, upstream of the Town, to flow into the Mosquito Creek to support similar licensed uses along that drainage which ends in the TVR. The TVR regulates discharges into the mid Little Bow River (between TVR and Travers Reservoir). The TVR was completed in 2004, with a storage capacity of 61.7 million m³. It was designed to reduce water diversions to the Little Bow River from the Highwood River during summer low flow periods, thus ensuring irrigation and municipal water supplies.

A major water body in the catchment of the Little Bow River between Highway 2 and the TVR (the Study Area) is Frank Lake, a restored lake and wetland area divided into three main basins. The basins are separated by control structures operated by Ducks Unlimited Canada (DUC) to stabilize water level for water fowl/shore bird habitats. These operations may contribute to spills to the Little Bow: when lake level rises start to compromise shore bird habitat DUC releases water to the Little Bow. Other times Highwood River water is diverted to the Lake to compensate for evaporation. Frank Lake also receives treated effluent from the Town's Wastewater Treatment Plant and a local food processing plant. The Lake is substantially an evaporative waterbody and the potential discharges from its southernmost



basin to the Little Bow River are generally insignificant in relation to the major flood events (Sosiak 1994 and 2011). These flows may become more significant under lesser flood condition and may need to be considered in updating and using the model for more frequent events.

Bow River's waters, diverted into the Bow River Irrigation District (BRID) Main Canal, flow into the McGregor Lake which in turns feeds the Travers Reservoir. The Reservoir's regulates discharges into the lower reach of the Little Bow River (from Travers Reservoir to the mouth). The Travers Reservoir, built in 1954, is an on-stream storage for the Little Bow River valley. However the vast majority of the stored volume is diverted from the Bow River. It has a capacity of 104.6 million m³ mainly stored for BRID use and to attenuate potential flooding of the Little Bow River. During the June 2013 flood event the dam was opened by Alberta Environment, thus increasing downstream flow from a normal of 3 m³/s to circa 60 m³/s (Alberta Emergency Alert 2013).

Downstream of the Travers Reservoir's Dam the Little Bow receives the regulated contribution from the Lethbridge Northern Irrigation District Canal, fed by the Keho Lake outflow. Flows in the lower Little Bow River are therefore controlled by irrigation reservoirs (Travers and Keho) and agricultural water use. Runoff to the river often occurs from fall irrigation.

Due to the intensive agricultural and ranching in its catchment, nutrients (from manure and fertilizers), and bacteria (from manure), are believed to be impacting the Little Bow River's water quality (Agriculture and Agri-Food Canada 2013).

Surficial geology within the river valley consists mainly of glacial till. The upland terrain is undulating with slopes between 2 and 5%.

Average annual precipitation is about 386 mm, of which approximately one-third falls as snow (Agriculture and Agri-Food Canada 2013).

Land use in the Little Bow River watershed includes a wide range of agricultural activities and intensities that can be grouped in few main categories:

- a) cow-calf operations on native range;
- b) dryland farming;
- c) intensive irrigated forage and row crop farming; and
- d) intensive livestock operations.

2.1.1 Study Area Overview

The Study Area is located just south of the Little Bow River's origin, beginning at the Highway 2 crossing 5 km Southeast of the Town, and continuing past the southeastern limit of the MD (after circa 40 km) until reaching the northern end of the TVR circa 60 km downstream of the crossing. The effective drainage surface of the Study Area is approximately 800 km², whereas the area draining to the Little Bow between from the drainage divide to the Highway 2 crossing, the upstream starting point of the new two-dimensional analysis performed, is approximately 117 km² (Figure 1-1).

The river segment in the Study Area, with its potential flood-affected lands and relative land uses are discussed below.

As discussed, the Study Area begins at the Highway 2 crossing of the Little Bow River. This location coincides with the existing High River Flood Model downstream modelling boundary (Figure 1-13) (WorleyParsons 2014). The river flows south and east from Highway 2 through the Study Area within a well-defined valley, to the TVR's northern end.

Figures 1-2, 1-3, 1-4, 1-5 and 1-6 show the Study Area subdivided in five major sections to allow for a more detailed aerial photo view:

- from Highway 2 to the crossing on 168 Street E (km 0 to 14 circa),;
- from the crossing on 168 Street E to the crossing on 232 Street E (km 14 to 26 circa),;
- from the crossing on 232 Street E to the MD southern limits (km 26 to 40 circa);
- from the MD southern limits to the crossing on Highway 533 (km 40 to 50 circa); and
- from the crossing on Highway 533 to the TVR northern end (km 50 to 60 circa).

All main crossing structures are located on the above maps, with other potentially relevant minor crossings and the frequent locations of fording utilized during agricultural practices as evident from the aerial photos, taken soon after June 2013 events.

Figures 1-7, 1-8, 1-9, 1-10, 1-11 and 1-12 show the longitudinal profile of the Little Bow River in the same five sections, also displaying the HWMs along the River's channel, its average slope variation and the location along the profiles of the major bridge crossings. HWM data collection will be expanded upon in Section 3.1.2.

The land uses around the upper 60 km of Little Bow River do not differ from the one described for the overall watershed in the previous section. More specific land uses observed during site visits include:

- farmsteads;
- bee farms;
- Hutterite colonies;
- abandoned farmsteads;
- ancillary farm residences; and
- commercial / recreational enterprises.

The latter included operations such as dog training facilities and pheasant breeding and release areas.

Vegetation coverage is principally driven by the agricultural and farming activities in the majority of the areas outside of the riparian zone, which cover the large valley of the Little Bow. Here the impacts of livestock grazing and cropland management practices are predominant.

Non-native vegetation includes crested wheat grass and Canadian thistle (Bernat and Cleland 2007).

Riparian trees and shrubs are present in the form of scattered woodlands consisting of few wolf-willows, balsam poplar and occasionally, trembling aspen.



Specifically, five dominant plant communities (outside cultivated areas) have been recognized along the upper Little Bow River and therefore the Study Area, designated by dominant species as follows (Bigelow 2003):

- riparian tree group, dominated by balsam poplar but also including trembling aspen,
- a riparian shrub group, dominated by willow species;
- a riparian shrub group primarily made of wolf-willow but also including wild rose, Saskatoon berry, choke cherry, western snowberry and sage;
- a wetland community consisting of common cattail, and emergent plants; and
- the graminoids and represented grass-like species, particularly grasses and sedges.

The composition of the five plant communities can differ abruptly between different fenced parcels of land, strongly dependent on the different management practices.

2.2 Study Area – River and Valley Morphology

This section discusses the planform and channel characteristics of the Little Bow River.

The upper Little Bow River is much smaller than the wide valley it resides in (Bigelow 2003). There are thought to be two sources to the formation of this river valley:

- the Highwood River and Little Bow River were naturally connected in the geologic past, and
- the large valley is a runoff channel from the last glaciation period: The meltwater channels from the receding glaciers are thought to have eroded and shaped the valley (Bernat and Cleland 2007).

The existing Little Bow River channel morphology was likely initially developed due to flow frequently emanating from the Highwood River watershed over various periods. The headwater channels appear to be similar to high-water channels of the Highwood River, however the Little Bow River headwater channels do not return flow back to the Highwood but instead divert water south to the Oldman River.

It is speculated that during the last ice age the continental ice sheet took up a position immediately northeast of Town (NHC 1992). Meltwater from retreating alpine glaciers to the west followed the present Highwood River valley to the Town and then flowed southeast across a broad gravelly outwash fan formed south of the Town site, into the present day Little Bow River valley. The planform of the Little Bow River channel immediately southeast of the Town closely resembles the modern day planform of the Highwood River upstream of the Town. When the retreat of the continental ice sheet from the area was complete, the Highwood River eventually returned to its pre-glacial path along its present course north and east of the Town, towards the Bow River. Although there are numerous swales visible across the fan surface south and southeast of the Town, there is no evidence of recent down-cutting or channelization. The scarcity of substantive silt deposition and the lack of longitudinal braided scars on the outwash fan surface suggests that Highwood River overflows into the Little Bow River basin south of the Town have been relatively infrequent (in terms of annual flooding and with the exception of the last hundred years) and of short duration since the end of last glaciation (NHC 1992).

The main channel of the Little Bow River begins in the Town. The channel meanders south in an irregular pattern while converging with other contributing overflow channels from the Highwood River from the west. These channels are only active during large, infrequent flood events (i.e. six occurrences from 1900 to the present). Just upstream of Highway 2, the main channel of the Little Bow River enters the Little Bow River Valley, which is approximately 500 to 1,000 m wide and approximately 25 to 35 m deep. This characteristic indicates an origin as a glacial meltwater channel. The river valley bottom is very flat in cross section with only minor topographic diversity and terracing. Downstream of Highway 2, the river channel continues its irregular meandering planform within the valley for approximately 60 km, the downstream end of the present study. The average channel bank-full width is approximately 15 m with a very low degree of confinement (MSA 2002). The average thalweg water depth tends to be below 1 m at flows up to 8 m³/s. The average longitudinal slope is approximately 0.12%. Because flood hydrology is characterized mainly by local early season runoff from snow melt as well as rainfall for the majority of years, the river does not appear to be laterally active.

The river is also fed by the Little Bow Canal which diverts water from the Highwood River to the Little Bow River. The confluence of the river and canal occurs near the southern extent of the Town. Late fall and over winter diversions are typically maintained around 0.5 m³/s and start to be increased in April based on Highwood flows where diversions are constrained by instream flow objective monitored near Aldersyde (Alberta Environment, 2008b). Typically diversions are increased and reach peak flow during the Highwood spring, early summer melt to maintain TVR full supply level (FSL, i.e. 964.80 m) and upper Little Bow licensed water use while maintaining an upper Little Bow summer base flow of 0.85 m³/s. Maintenance of Highwood fish habitat summer water temperature and dissolved oxygen levels further constrain diversion flow operations to the Little Bow. When either of these operations criteria is triggered diversion flows are reduced to try to restore these habitat conditions (Alberta Environment, 2008a). Potential flooding and erosion impacts leading to Little Bow channel changes under a maximum of 8.5 m³/s diversion flow tests were run in 2004 and 2005. Observations showed the highest affected area was in the upper reach upstream of 658 Avenue to High River where the river channel is generally narrower. During these tests some valley homes experienced basement flooding requiring additional sump-pump capacity and there was reactivation of some abandon channels/oxbow connections in this upper reach. Some valley water wells were also monitored for changes in water level and pump inflow performance and some showed direct influence by the increased diversion.

The diverted flows never reached the established maximum of 8.5 m³/s either due to low irrigation demand in the wetter years or constraining low Highwood River freshet flows during drier periods since 2005. Such flows are, for the most part insignificant in relation to the large infrequent flood events that may be produced by overflow from the Highwood River (e.g. an estimated 560 m³/s diverted peak in 2013). The operational procedures result in closing of the Little Bow canal intake during flooding of the Highwood River. However, these smaller persistent flows from the canal, around 4.0-5.0 m³/s, likely influence local channel morphology and capacity. Following the 2013 flood Alberta Environment reported alteration impact areas associated with bridge crossings and on primary meander cut bank bends, particularly where meander migration was constrained by the valley wall (Pickering 2017, pers. comm.). The channel appeared to have a maximum capacity of approximately 3.0 m³/s in most locations (although this varied) before the morphological changes caused by the 2013 flood and diversion rate increases (from about 3 to a limit of 8.5 m³/s) initiated in 2004 (MSA 2002). Even with



significant increases in bank-full channel capacity that may have resulted from the flows during the June 2013 flood, the floodplain would likely still be at least partially inundated for flows above the 20 m³/s. Aside from bank flooding such flows would likely saturate the riparian zone and the underlying alluvial aquifer system in both flooded and unflooded areas in the adjacent flood plain where active hydraulic connection to broader floodplain is evident from abandon channel reactivation and water well performance during tests (Pickering 2017, pers. comm.).

A more detailed understanding of channel morphology and floodplain saturation effects may be developed in future phases of the project.

The longitudinal profile of Figures 1-7, 1-8, 1-9, 1-10, 1-11 and 1-12 show how the River slope varies from 0.16 to 0.10% in the first 14 km between Highway 2 and 168 Street E crossings, from 0.13 to 0.08% between 168 Street E and 232 Street E, from 0.10 to 0.07% between 232 Street E and the MD limits, then from 0.04 to 0.12% between the MD limits and Highway 533, and finally from 0.15 to 0.08% between Highway 533 and the TVR inlet.

Sinuosity represents a measure of the curviness of a stream and is generally calculated by dividing the river channel length (thalweg) by river valley length. In the Study Area the Little Bow River has a complex meandering pattern that includes a combination of large meanders and smaller inset meanders. Figures 1-3 shows two examples of such hydro-morphologic combinations. Sinuosity provides a measure of river curvature. The most commonly used measure is sinuosity index (SI) which is calculated as the ratio of river channel distance to river valley distance. Due to the complexity of the channel planform, sinuosity varies along the Study reach from straight (SI about 1.2) sections to very sinuous (SI >2.0) (Bigelow 2003).

2.3 General Flood Hydrology

The hydrology of the Little Bow River is characterized by low fall and winter base flows transitioning to an increased flow period driven by local freshet effects (i.e. snow melt) and rainfall-driven flow increases in the spring and diversion contributions in the summer. The river's hydrology is greatly influenced through man-made diversions from the Highwood River (via Woman's Coulee Canal and Little Bow Canal) and regulation (mainly by Twin Valley Dam, the Travers Reservoir Dam and more downstream the Lethbridge Northern Irrigation District Canal. To a minimal degree the river hydrology is affected by flows from the Frank Lake control structure in the Study Area.

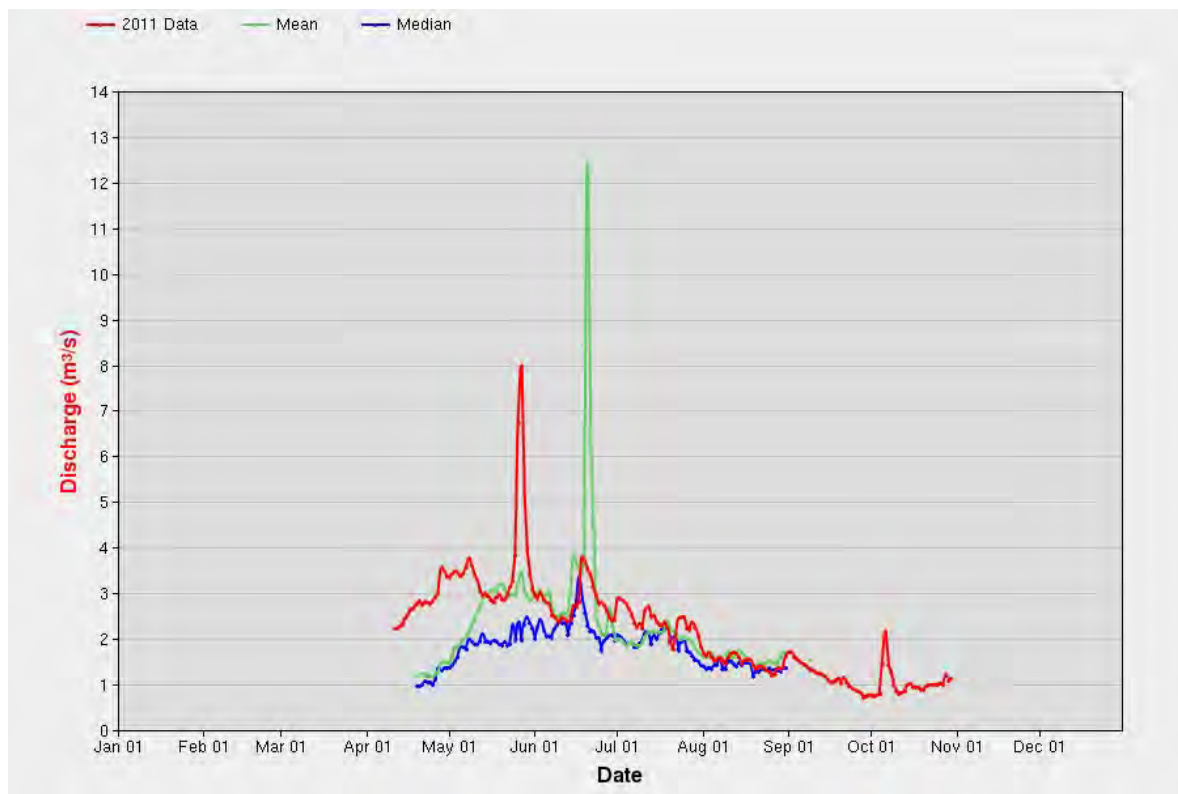
Overall the flows on the Little Bow River are very consistent due to the numerous diversions and controlled releases, the 2013 event being the highest registered exception.

The diversions system didn't start until about 10 years ago. Before that, during the increasing flow periods, significant peak flows (one or more per year) could be experienced. Freshet, rain-on-snow and rainfall driven floods events could be 20 to over 100 times greater than fall and winter base flows. Under the current diversion regime summer peak flows, when not associated with spillover from the Highwood River, are 2 to 8 times the base flow, and winter peaks about 1.5 to 4 times the base flow.

Following the spring freshet, flows tend to stay elevated above base levels through spring and early summer before receding back to base levels in late summer and fall. This behaviour is shown in Figure A below, which shows the daily average flow hydrograph for 2011 at the station Little Bow River

at Highway No. 533 (05AC930), located about 57 km downstream of the headwaters in the Town and 10 km upstream from the downstream boundary of the Study Area (see Figure 1-1).

Figure A Little Bow River at Highway No. 533: 2011 Daily Average Flow Hydrograph, Mean and Median Flows Hydrographs over the period 1999-2013

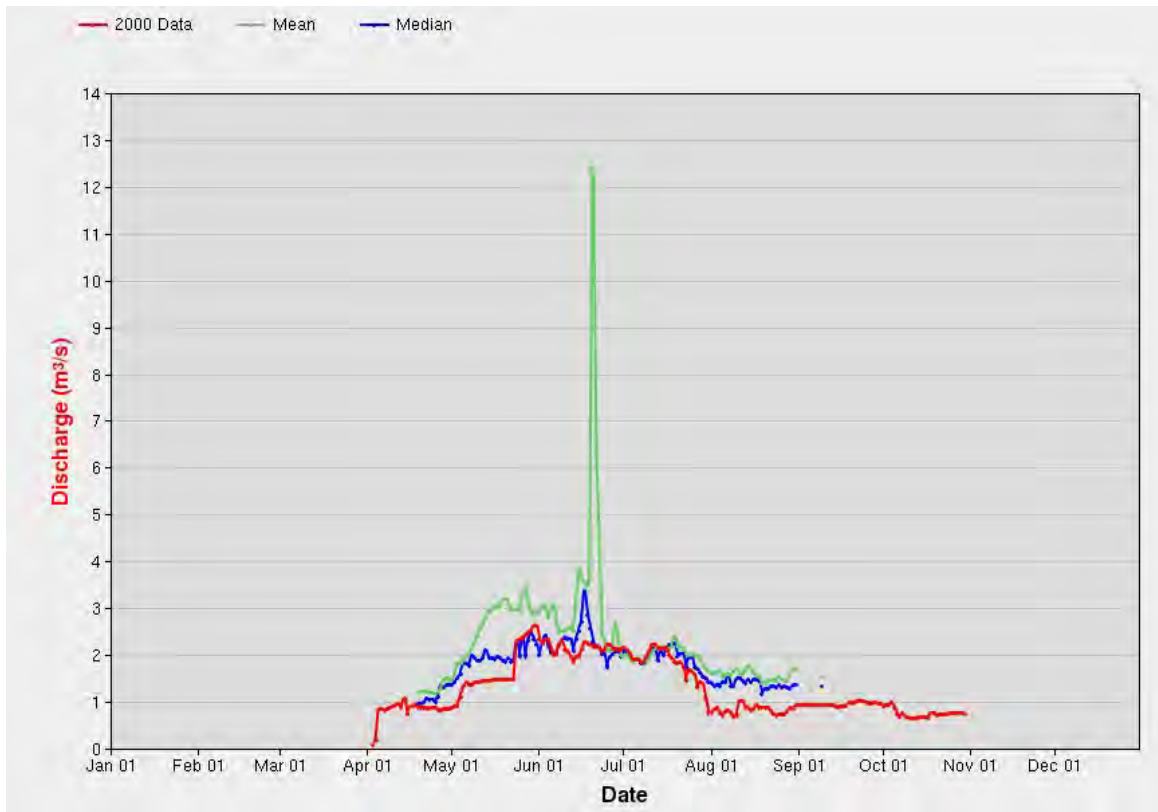


The 2011 hydrograph presents a peak of about 8 m³/s in late May and then remains above 2 m³/s almost until August, above its mean and median values for the same period, June to August.

In dry years, however, in which little rainfall occurs, flows used to be very low throughout summer. This is the case illustrated in Figure B for the same station, when the spring and summer flow barely exceeds 2 m³/s in year 2000. Nowadays this phenomenon is not present anymore due to the diversions into the Little Bow which started, as said, about 10 years ago.



Figure B Little Bow River at Highway No. 533: 2000 Daily Average Flow Hydrograph, Mean and Median Flows Hydrographs over the period 1999-2013



The hydrometric station of Little Bow River at Highway No. 533 is the first station, downstream of Highway 2, with natural regime and a meaningful number of years of flow data, as it has been active since 1999. The mean daily flows of Figures A and B shows a peak in late June influenced by the 2006 peak (Table 2-1). However the analysis does not include the 2013 flood event as a flow rate for this station was not developed at the time the WSC website was consulted (June 2016).

Table 2-1 shows all annual maximum daily flows and instantaneous peaks historically registered at the station.

Table 2-1 Annual Maximum Daily Discharge and Instantaneous Peak Flow for the Little Bow River at Highway No. 533 (05AC930)

Year	Maximum Daily Discharge		Maximum Instantaneous Discharge	
	Date	Value (m³/s)	Date/Time	Value (m³/s)
1999	20/07/1999	3.46	18/07/1999 7:00	3.68
2000	31/05/2000	2.64	31/05/2000 12:00	2.73

**MUNICIPAL DISTRICT OF FOOTHILLS NO. 31
LITTLE BOW RIVER MODELLING
FLOOD MITIGATION EFFECTS ASSESSMENT**

Year	Maximum Daily Discharge		Maximum Instantaneous Discharge	
	Date	Value (m ³ /s)	Date/Time	Value (m ³ /s)
2004	21/05/2004	8.26	2004	---
2005	07/06/2005	9.60	01/06/2005 10:00	10.90
2006	16/06/2006	15.80	16/06/2006 10:15	17.30
2007	23/07/2007	3.67	04/05/2007 7:15	3.99
2008	21/05/2008	3.97	21/05/2008 5:15	4.19
2009	20/06/2009	6.47 ^E	2009	---
2010	28/05/2010	4.14	28/07/2010 20:45	5.67
2011	28/05/2011	7.99	28/05/2011 12:00	8.92
2013	21/06/2013	212 ^A (105)	21/06/2013 3:30	487 ^A (175)

Notes:

A – Modelled result, in brackets the WSC value

Other data from Water Survey of Canada

E – Estimated

“---” Data not available

Peak flow hydrology can vary significantly, depending on the source of flood water (local or overflow from the Highwood River).

The low-probability, high-magnitude flood hydrology of the Little Bow River is mainly governed by spill-over from the Highwood River during large flood events in the Highwood River greater than approximately 650-700 m³/s above Woman's Coulee Canal Inlet. Additional information pertaining to this mechanism is provided in Section 2.3.1.

Table 2-1 can therefore help in giving an indication of the amount of water that originates only in the Little Bow watershed. In fact, apart from year 2013 the Highwood River above Woman's Coulee Canal Inlet was below 700 m³/s at its peak in the period from 2000 to 2013. During this period the maximum instantaneous flow in the Little Bow varies approximately between 3 and 11 m³/s, with the relevant exception of year 2006 in which the maximum instantaneous flow reached a value of 17.3 m³/s.

A number of stations were investigated to obtain instantaneous flow peaks on the Little Bow River between High River and the TVR northern end or even further downstream:

- 05BL015 Little Bow Canal at High River;
- 05AC928 Little Bow River at Highway No. 2;
- 05AC911 Little Bow River below Frank Lake;
- 05AC930 Little Bow River at Highway No. 533;
- 05AC941 Little Bow River below Twin Valley Reservoir. and



- 05AC003 Little Bow River at Carmangay.

The Little Bow Canal at High River (05BL015) has a regulated flow and was closed during the two latest high flood events in the area (2005 and 2013 respectively) according to the WSC daily discharge historical database.

Some stations (i.e. 05AC928: Little Bow River at Highway No. 2, from 1999 to 2000, and 05AC911: Little Bow River below Frank Lake, only year 2000) have a too limited period of record to be of relevance.

Some peak flows of the Little Bow River at Highway No. 533 (05AC930: Table 2-1) are inconsistent with the historical succession of peak values. The 2013 peak of $175 \text{ m}^3/\text{s}$ is well below the $560 \text{ m}^3/\text{s}$ model estimated flow into the Little Bow River at Highway 2 via the Highwood-Little Bow flow-split in High River. However there would not be a stage-discharge relationship for very high flows at this gauge as the 2013 flood flow is a significant outlier to the previously recorded peak discharges. Backwater effect of the TVR located downstream and completed in 2004 has also been investigated after the Little Bow River model for this Report was extended from the MD southern limits to the TVR northern (see Section 5.2.3).

The Little Bow station downstream of the Twin Valley Reservoir (05AC941) is characterized by a regulated rather than a natural regime.

The station Little Bow River at Carmangay (05AC003) has a period of record that starts in 1918 and the station is still active. However instantaneous peak flows have not been considered after the Twin Valley Dam, located upstream of Carmangay, became operational in 2004. Among the larger events only the 1995 value was available and has been reported as observed.

Table 2-2 summarizes Little Bow River (excluding dam regulation) values for the eight years with greatest instantaneous peak flows.

Table 2-2 Low-Probability Instantaneous Peak Flows related to the Study Area

Year	Little Bow River Flood Peak Estimate Peak Flow (m ³ /s)
2013 ¹	560 ^A (175 ^C)
1923 ¹	38.5 ^B
2006	17.3 ^C
1995 ¹	15.5 ^B
2005	10.9 ^C
1932 ¹	---
1942 ¹	---
1929 ¹	---

Notes:

1 – Grey cells indicate years with overflow to the Little Bow Basin from the Highwood River. However a magnitude of this overflow is not available

A – Little Bow River at Highway 2, estimate using High River Flood Model

B – Little Bow River at Carmangay (05AC003), before Twin Valley Reservoir inauguration in 2004

C – Little Bow River at Highway No. 533 (05AC930)

“---“ Data not available

Overflow to the Little Bow Basin from the Highwood River, over the systematic record, was observed for the years 1923, 1929, 1932, 1942, 1995 and 2013 (see Section 2.3.1 for discussion).

In relation to the 2013 event, the WSC estimated the upstream flow boundary condition for the High River Flood Model (WorleyParsons 2014 and Figure 2-3) using slope-area methodology, was 1,820 m³/s (this figure has since been revised to 1,770 m³/s). The model then estimated flow losses due to flood plain storage (~equivalent to 100 m³/s over the high flow period of the 2013 flood), overflow to the Little Bow (560 m³/s) and overflow to storage within the east side of the Town (200 m³/s).

2.3.1 Highwood-Little Bow Flow-Split

Extreme flood hydrology of the Study Area is influenced by the amount of water that overflows from the Highwood River to the Little Bow River during floods greater than approximately 650-700 m³/s (i.e. the Highwood-Little Bow flow split). Therefore, topographic changes (e.g. construction of dikes) in this area can change the Highwood-Little Bow flow split, resulting in changes to downstream flood hydrology in both rivers

As briefly described above, historic observations and computational model analyses indicate that under the conditions that existed before the construction of 2013 flood mitigation infrastructure, flood peaks



above approximately 650-700 m³/s in the Highwood River at Woman's Coulee result in water overflowing (or "flow-splitting") to the Little Bow River watershed from the south Highwood River floodplain. This mechanism occurs over an extended length of the watershed divide of the Highwood River south floodplain, as shown in Figure 2-2. Peak overflow to the Little Bow occurred below the Highwood River flow spill range of 650-700 m³/s in the early to mid-1900s. Upgrades to the diking systems (e.g. Town and Hoeh dikes) over the last half of century have decreased overflow to the Little Bow River and increased flow magnitudes contained in the Highwood River system in, and downstream, of the Town. These dikes create a hydraulic condition where an increase in the peak flow magnitude in the Highwood is required upstream for overflow to the Little Bow to occur. Note that the flow estimate of 650-700 m³/s needed to initiate overflow to the Little Bow watershed is gauged above the Woman's Coulee Canal inlet before flow-splitting occurs.

Overflow from the Highwood River occurs when significant flood waters enter its southern floodplain downstream of Woman's Coulee Canal inlet (Figure 2-2). Flood discharge from the Highwood River overflows to the Little Bow River watershed via the southern floodplain over an area that begins just downstream of the inlet continuing downstream until reaching the area just downstream of the Little Bow Canal inlet located within the Town (see Figure 2-2). During these overflow flood events (as mentioned, six have been documented since 1900), overflow has been observed to flow east and south flooding the Town (and areas south of Town) before entering the Little Bow River. It is worth noting that the headwaters of the Little Bow River are located within the Town and hence when flooding occurs within the centre of Town, the floodwater feeds these headwater channels.

Baker Creek is an intermittent high-water side channel of the Highwood River that originates just downstream of Woman's Coulee headworks and discharges to the river at George Lane Park in the Town (Figure 2-2). Anecdotal evidence suggests that in addition to providing floodwater conveyance, the channel also received significant quantities of groundwater in the early and mid-1900s. However construction of the Hoeh Dike (starting in the early decades of the 20th century) appears to have significantly alter both floodwater and groundwater contributions to the channel. Baker Creek is the southern boundary of the Highwood River flood plain (watershed) over this segment of river. The right downstream bank (RDB) of Baker Creek, in general, can be considered the watershed divide between the Little Bow River and the Highwood River for areas west of its confluence with the main channel of the Highwood River, which is located within the Town.

In addition to overflow from the RDB of Baker Creek, flood waters during extreme flood events can also escape south to the Little Bow River from the main channel and floodplain of the Highwood River in the river reach downstream of the mouth of Baker Creek to the Little Bow Canal Dike (Figure 2-2). New dike infrastructure (West Town Dike [WTD], Town Dike [TD] and Little Bow Canal Dike) are designed to prevent overflow from the main channel for flood magnitudes below 1,820 m³/s (measured upstream of Woman's Coulee Canal Inlet).

West of Town, water that overflows the RDB of Baker Creek is routed naturally to the Little Bow River along various high-water channels, the adjacent floodplain or through developed portions of Town (Figure 2-2). Natural high-water channels within the developed portion of Town have been largely infilled to accommodate development and hence are not apparent when observing existing conditions or reviewing recent aerial photographs. High-water paths south of the developed portion of Town can be described as floodway "fingers" based on GoA's (Government of Alberta's) High River Flood Risk

Mapping Study (NHC 1992). In the early and mid-1900s, understanding that these southern floodway “finger” routes were a significant flood concern to the Town and residents adjacent to the Little Bow River, efforts were made: 1) to minimize the amount of flood flow entering Baker Creek (which feeds these ‘overflow’ fingers) through diking (e.g. Hoeh Dike construction was initiated in 1907, with upgrades occurring over the next century and repairs still being undertaken today); and 2) to minimize the amount of water leaving Baker Creek via its RDB (e.g. construction of the Baker Creek Dike just south of 12th Ave. and west of 72nd St), and increasing bank heights in some areas north of 12 Ave. During the 2013 flood, significant flow: 1) escaped Baker Creek’s RDB southwest of Town, before flooding the Town from the south; and 2) flowed north over 12th Avenue within Baker Creek and the adjacent floodplain, before overflowing the creek’s RDB and entering the southwest portion of Town. Both of these mechanisms resulted in significant Town flooding. During the 2013 flood the majority of these overflows eventually drained into the Little Bow River.

Limiting the amount of water entering the upstream portion of Baker Creek and discharging from Baker Creek’s RDB during extreme flood events protects the south side of Town and residents adjacent to the Little Bow River. These modifications, however, increase flow in the Highwood flow through the center of the Town and to the channel between the Town and the Bow River during flood events greater than 650-700 m³/s.

The WTD has been designed and constructed to protect the south portion of Town (north of 12th Ave) from Baker Creek RDB overflow (Figure 1-9). The TD and Little Bow Canal Dike have been constructed to protect the Town from flooding originating from the main channel of the Highwood River (Figure 1-9). These structures, however, result in significant increases to extreme flood flow magnitudes in the Highwood River at, and downstream of the Town as summarized in Figure 2-3. These flow increases can be summarized as follows:

- A portion of flood flow within the southern floodplain of the Highwood River/Baker Creek high-water channel that flooded the Town from the west and south, and that was eventually routed down the Little Bow River, is now directed by the WTD down the main channel of the Highwood River resulting in greater peak flows downstream of the Town during extreme flood events greater than 650-700 m³/s in the Highwood River. Figure 2-3 provides preliminary estimates of increases in flow downstream on the Highwood River for a range of flood peak magnitudes.
- Water from the main channel of the Highwood River that flooded the Town’s centre from the north, and that was eventually routed down the Little Bow River, now remains in the main channel of the Highwood River (being diverted by both the Town Dike and the Little Bow Canal Dike) resulting in significantly greater peak downstream flows during extreme flood events in the Highwood River.

Preliminary estimates of the effect of the two flow additions described above indicate an increase of approximately 180 m³/s (from 1,225 during the 2013 flood to 1,405 m³/s with flood mitigation infrastructure in place), in the Highwood River just downstream of the Town, (Figure 2-3). Conversely, the Little Bow River is expected to experience a decrease in peak flow from about 560 m³/s to 410 m³/s with the flood mitigation infrastructure in place under flow conditions similar to the 2013 flood (Figure 2-3).



Immediately following the 2013 flood, the Town and the MD, supported by Advisian (WorleyParsons), realized that the diking projects within the Town would have this effect on the flow-division between the Highwood River and Little Bow River during extreme flood events (WorleyParsons 2014).

Understanding the flood diversion caused by diking, the Town and the MD committed to a design criterion to guide flood mitigation projects with a focus on: 1) minimizing downstream impacts on the Highwood River by attempting to restore the 2013 Flood Landscape Scenario flow conditions in the Highwood River-Little Bow River system during extreme floods (i.e. restoring pre-mitigation flow conditions); 2) providing consistent downstream design conditions to ensure that new dike, bridge and erosion protection infrastructure was/is not under designed due to these potential flood flow changes in the Highwood River; and 3) provide an equitable solution to downstream stakeholders. However, the criterion and proposed flow restoration measures (i.e. the Little Bow-Enhanced Natural Floodway) were not supported by the GoA.

2.4 Existing Reports (FMMP, AECOM, MD Scoping, Deltares)

A considerable number of studies were undertaken after the 2013 flood. A select listing of important information sources that were reviewed to support HR-FEA and LBR-FEA includes:

- AECOM's (2014) Southern Alberta Flood Mitigation Feasibility Study for Sheep, Highwood River basins and South Saskatchewan River Sub-Basin; Highwood River Water Management Plan, Prepared for Alberta Flood Recovery Task Force. July 2014. This study investigates various regional diversions plans within the Highwood and Little Bow watersheds.
- Advisian's (WorleyParsons 2014) 2013 Flood Management Master Plan (FMMP) and supporting preliminary High River Flood Modelling results prepared for the Town. March 2014. The FMMP provides the philosophical framework for flood mitigation planning, an overview of modeling efforts, as well as the summary of flood mitigation works undertaken by the Town. It provides information pertaining to the flow-split situation and also discusses possible solutions such as the Little Bow-Enhanced Natural Floodway.
- Deltares' (2014) Preliminary Review of Flood Mitigation Proposals for High River (prepared for Southern Alberta Flood Recovery Task Force). The Deltares report contains review of 1) AECOM (2014) study that investigated regional diversion options; and 2) the WorleyParsons (now Advisian) modelling results and planning document (WorleyParsons 2014) which included information pertaining to the proposed Little Bow-Enhanced Natural Floodway prepared for the Town.

3. APPROACH OVERVIEW

LBR-FEA analysis focused on two main tasks: 1) Data Collection and Review; and 2) Computational Modelling and Interrogation of Output. An overview of the approach taken for these two tasks is provided in the following sub-sections.

3.1 Data Collection and Review

Data collection and review included gathering existing data as well as collecting essential high water mark (HWM) data and anecdotal flood information to support model development and calibration.

3.1.1 Existing Data

Existing data collection and review included reported information as well as collection of various existing data sources to support model development. The key reports reviewed are discussed in Section 2.4.

Key data collected, reviewed and compiled for use in the computational modelling component includes:

- Terrain Data: LiDAR (Light Detecting and Ranging) bare earth data, acquired post June 2013 flood and made available by the GoA provided the basis for digital elevation model (DEM) and subsequent model surface network development;
- Bathymetry Data: collected in 2001 by Alberta Transpiration. They cover the portion of the Little Bow River going from the mouth of the Little Bow Canal in the Town of High River to about 50 km downstream of the Highway 2 crossing;
- Bridge Data: gleaned from the Alberta Transportation hydrotechnical database;
- Remote Imagery: Ortho-rectified air photographs of the Study Area were provided by the MD. This information was used to provide background imagery for model development including assessment of land use/cover. In addition, Google Earth imagery was used to refine and characterize the Study Area (and model); and
- Flow data: flow data estimated from High River Flood Model (WorleyParsons 2014, Advisian 2016) to provide boundary conditions for model simulations.

Additional information pertaining to key data will be discussed in the Section 4 Model Development and in Section 5 Model Execution Results and Discussion.

3.1.2 High Water Mark (HWM) and Flood Information Collection

Over the periods January 20 to February 6, 2015 and October 18 to 20, 2016, WorleyParsons completed a survey to gather HWMs data and correlated information from land owners affected by the June 2013 flood event, for Flood Model calibration purposes.

HWMs coordinates and elevations were collected along with related flood observations, historical photos, and anecdotal evidences of flood mechanisms, erosion or deposition areas, morphological and fluvial changes. The Highwood River data collection area in the 2015 survey was from the crossing at



Highway 2 downstream to its confluence with the Bow River, whereas the Little Bow River area covered from the river crossing at Highway 2 downstream to the MD's boundary crossing (Legal section SE-13-17-27-W4). The Little Bow River area from the MD's southern boundary downstream to the TVR was covered in the 2016 survey.

2013 floodwaters left marks on trees, ground and buildings from the silt, debris, and the effects of water itself on the structures. Many of these marks were still present at the time of the surveys and were marked by visual inspection supported by the recollection of the residents who witnessed the extraordinary event.

118 HWMs were registered for the Highwood River and 78 for the Little Bow River, plus a number of other points of interest reported, together with relevant pictures and notes, in Field Reports completed for each visited landowner. The HWMs were surveyed with Real Time Kinematic (RTK) Global Position System (GPS) equipment with an instrumental accuracy of ± 1 cm (horizontal) and ± 2 cm (vertical). However during the survey some HWMs appeared to be distinct while others were more ambiguous and often the location determined the accuracy. Based on the quality and evidence provided, the confidence in the HWM's has been rated from Excellent, Good, Average or Poor with an estimated elevation uncertainty of ± 10 cm, ± 20 cm, ± 40 cm or over ± 40 cm respectively.

A letter-report describing each landowner's HWMs survey was produced and is included in Appendix 1. Section 3 of the Appendix describes the content of the "digital attachments" folder which is also provided at the end of the report. The attachments include all survey photos and landowner 2013 flood photos or videos, and other historical information where available.

3.2 Model Development and Execution

The main task of the LBR-FEA was development of a hydrodynamic model of the Little Bow River and its floodplain within the Study Area. This model is referred to herein as the Little Bow Flood Model. The Little Bow Flood Model was developed using the RMA-2 modelling platform. RMA-2 was also used for development of the existing upstream hydrodynamic model whose domain extends from approximately 1 km upstream of the Woman's Coulee Canal inlet downstream to where both the Highwood River and Little Bow River cross Highway 2 (i.e. the Highwood River Flood Model). The overall approach for development and execution of the Little Bow Flood Model development can be summarized as follows:

- Develop the topographic mesh network including cell elevations and cell properties (e.g. land and channel roughness) using available data;
- Input appropriate boundary conditions: inflow at the upstream end and water levels at the downstream end;
- Calibrate the model to observed HWM information through iterative refinement of the in-channel network mesh and roughness of the channel and floodplain applied to the network mesh;
- Undertake a sensitivity analysis to better understand the effects of uncertainty associated with various components of the model including channel topography, roughness and boundary conditions; and

- Undertake an assessment of the effects of post-2013 flood mitigation measures which were implemented upstream of the Study Area. This is accomplished by changing the boundary conditions (input flow) and simulating the effects. The results of the post-2013 mitigated scenario (Scenario 28A) are then compared to results of the 2013 Flood Landscape Scenario to determine effects. Note that additional information pertaining to model scenarios is provided in Section 3.2.3.

Additional details pertaining to the selected modelling platform; modelling scenarios that will reflect the 2013 landscape and the scenario associated with installation of all flood mitigation measures; and the overall modelling approach is provided in the following sub-sections. Additional detail pertaining to the methodology can also be found in Section 4.0 Model Development.

3.2.1 RMA-2 Modeling Software

The RMA-2 modelling platform is a fully two-dimensional (2D) depth-averaged hydrodynamic numerical model developed by Resource Management Associates and Professor Ian King from the University of New South Wales, Australia. RMA-2 enables the computation of water surface elevations and horizontal velocities for sub-critical, free surface flow in 2D fields. RMA-2 has been applied since the mid-1970s and as such is one of the initial widely used 2D modelling tools applied to riverine applications.

RMA-2 has been shown to be particularly adaptable to the simulation of wetting and drying of swamps, and across floodplains where floodwaters escape from the main river channel to the surrounding floodplain. This capacity ensures that the interaction between mainstream and overbank flows is reliably modelled and that changes in flow paths arising from modifications to floodplain features can be identified.

The finite element method is adopted in RMA-2 in which a variable grid or mesh is used to create a network that represents the model topography. The variable mesh is constructed of irregular triangles and/or quadrilaterals which are made up of either three or four corner nodes. The two-dimensional network mesh is therefore used to define features such as river and/or creek channels, banks, floodplains and breakout areas.

A major advantage of using RMA-2 over traditional finite difference models is that the model resolution (i.e. the size of each cell within the network) can be varied to provide less or greater detail of areas of particular interest. It is also relatively simple to adjust the model network to incorporate structural flood mitigation works such as channel modifications or dikes, as may be required to assess effectiveness and/or upstream and downstream effects.

3.2.2 Model Development

Creation of the Little Bow Flood Model RMA-2 model network mesh was based on the input/assessment of a number of data sources that were introduced in Section 3.1.1. Briefly, these sources included: topographic data derived from bare-earth LiDAR; aerial photography of the floodplain and channel; and bridge data. Each step of the model development is discussed in terms of these sources.



Digital Elevation Model and Network Development

A hydrodynamic model is developed from data that defines the bathymetry of the channel and the topography of the floodplain. This information is combined to develop digital elevation model (DEM) of the entire river system including channel and floodplain areas. The DEM essentially forms a complete three-dimensional (3D) representation of the geometry of the entire river channel and floodplain of the Study Area.

LiDAR, aerial photograph and bridge data were used to guide the creation of the Little Bow Flood Model DEM. Standard hydrodynamic modelling approaches most often require channel bathymetry. A set of channel bathymetric data, collected for Alberta Transpiration in 2001 (MSA 2002) and used to create a one-dimensional HEC-RAS model of the Little Bow River, was made available to complete the Little Bow Flood Model bathymetry development.

A preliminary DEM was created using only post June 2013 flood LiDAR and aerial imagery data, estimating the bathymetry below the water surface based on aerial photograph information and visual observations performed during the HWM survey. This first estimate was checked against the bathymetry offered in the corresponding cross sections of the 2001 HEC-RAS model. It is worth noting, however that significant changes may have occurred in the active channel of the Little Bow River since 2001. These changes could have been caused by increases to diversion rates from the Highwood River and extreme flows associated with the 2013 flood event.

In general, as the LiDAR information was collected during the low water period, it provided significant information for in-channel areas outside the wetted width of the low-flow channel. The lowest point of the corresponding 2001 cross section was added to create a triangular or trapezoidal bathymetry of equivalent channel area. It is in any case estimated that this channel, often less than 1 m of depth, only makes up a small portion of the overall model network with a conveyance of approximately 1% of the 2013 flood magnitude, estimated at 560 m³/s at the Highway 2 crossing.

A linear interpolation of the low points completed the channel thalweg for the segment of river between HEC-RAS cross section locations.

It has to be noted that the one-dimensional HEC-RAS model terminates about 10 km upstream of the TVR northern end, which represents the downstream limit of the 2D model object of the present study. Therefore the channel thalweg from about km 50 to km 60 of the Model was estimated with various relationships/equations providing curves which interpolate between the HEC-RAS model cross section inverts and the TVR lowest contour line near the dam (at 950.00 m), obtained from the General Arrangement Plans or Site Layout and Site Plans for Twin Valley Dam site, provided by the Data Management Group of the Bow Operations Infrastructure Branch of Environment and Parks. Selecting an interpolated curve then became a calibration variable for the downstream segment of the Model as further discussed in Sections 4 and 5.

In consideration of the increased diversion flows from the Highwood River and other potential morphological modifications since 2001, aerial photograph imagery was used to identify and compare major morphologic features over time that could indicate a different surface into the low-flow cross section of the stream.

The next step of the modelling process is creating a finite element model (network) from the DEM using the RMA-2 modeling platform. The finite element model represents the DEM via a network of geometric shapes (or elements) such as triangles, squares and rectangles. The elements are joined together to form a network or 'mesh' to cover the entire Study Area. Basically, each element represents a piece of the earth's surface (defined by elevations at each corner), with the sum of the elements representing the Study Area.

The network development process for the Little Bow Flood Model involved an incremental review of the floodplain and channel to identify locations where greater network detail (i.e. smaller elements) was necessary based on topographic features, locations of hydraulic controls and if any significant changes in floodplain/channel characteristics occurred that needed to be defined. This process is particularly important in order to take advantage of a finite element model's flexibility whereby there is often no benefit to the model output to incorporate a small element/grid size where there is little change in topography or land characteristics. For example, there is likely to be little to no improvement in the model output whether a flat floodplain area is defined by a singular rectangle with four corner nodes or a collection of 5, 10 or even 20 elements. The unnecessary use of the latter leads to excessive simulation times, unnecessary resource use and data limitations. The Little Bow Flood Model was therefore constructed to realize the benefits of the flexible finite element model platform.

Beyond the elevation, each element also must be characterized in terms of influence on hydraulic behavior as water passes over its surface. The most important characteristic, which is often varied for calibration purposes, is hydraulic roughness. Each element has a defined roughness value that influences flow. Equivalent roughness values are applied over areas with similar characteristics. Areas of thick vegetation and large cobble-boulder material have higher roughness than bare earth, void of vegetation or finer-grained material such as small gravel. Channel and floodplain roughness for the Little Bow Flood Model were estimated from aerial photograph and field observations, as well as through comparison of vegetation and bed material roughness applied in the existing Highwood River Flood Model. Additional information pertaining to DEM and network development of the Little Bow Flood Model is provided in Section 4.1.

Boundary Conditions

Once the model network or "surface" has been developed, water needs to be added to the model. This is accomplished through use of boundary conditions. Flood models most often have the upstream boundary (or upstream ends of the model) defined by a known discharge. For every upstream channel end, a flow discharge boundary needs to be entered into the model. The Little Bow Flood Model required one unique upstream boundary condition: discharges were provided for the Little Bow River at the Highway 2 crossing.

The downstream boundary (or downstream end of the model) condition is most often characterized by water level. This boundary condition may be a calculated water level based on known parameters (e.g. normal flow for a particular slope and roughness), may be a constant defined water level (e.g. a reservoir with constant level) or a defined time-varying water level (e.g. ocean affected by tides). The boundary condition applied for the Little Bow Flood Model is based on the time-varying water level registered at the WSC water level station 05AC940 (Twin Valley Reservoir at Highway No. 529) with



hourly interval between June 21, 2013 at 1 am and June 22, 2013 at 11 pm. Additional information pertaining to boundary condition used is provided in Section 4.2.

3.2.3 Model Scenarios

Different modelling scenarios are often used to investigate effects or effectiveness of various management or mitigation options. Outflow from two High River Flood Model scenarios have been used to define the scenarios (via inflow) for the two Little Bow River Flood Model used in the LBR-FEA:

- a) outflow from the High River Flood Model - 2013 Flood Landscape Scenario (previously referred to as the Existing Condition Scenario) is used as the inflow boundary condition for the Little Bow Flood Model – 2013 Flood Landscape Scenario developed as part of the LBR-FEA.. The High River Flood Model is based on the landscape data (i.e. channel and enhanced LiDAR topographic data) collected immediately after the 2013 flood, as well as data available before the flood; and
- b) outflow from High River Flood Model Scenario 28A (Complete Mitigation Scenario) which includes all as-built or to-be-built dike configurations and the proposed 12 Ave-Centre St. Dike required to protect southern boundary of the Town (see Figure 1-14) is used as the inflow for the Little Bow Flood Model 28A Scenario. Scenario 28A has been used as a conservatively-based design (i.e. based on the Town's complete mitigation scenario) and effects assessment scenario. That is, the design of the southern protection option (e.g. the Southwest Dike [SWD] or the 12th Avenue –Centre Street Dike) will not direct additional water north to the Highwood River, when compared to Scenario 28A.

Outflow from the High River Flood Model scenarios 2013 Flood Landscape and 28A are used as input (upstream) boundary conditions for the Little Bow Flood Model scenarios 2013 Flood Landscape and 28A, respectively. The basis for the 2013 Flood Landscape and 28A modelling scenarios are further discussed below.

A version of the RMA-2 High River Flood Model began development before the 2013 flood. This model was further refined, enhanced and validated against data (channel cross-section over some reaches of the river and new LiDAR data) collected immediately after the flood. This model scenario is referred to as the 2013 Flood Landscape Scenario. Following development of the 2013 Flood Landscape Scenario, the model was validated using a synthetic hydrograph shape (based on historic information) with a peak equivalent to WSC's estimated 1,820 m³/s, 2013 flood magnitude upstream of Woman's Coulee Canal Inlet. The preliminary 2013 Flood Landscape Scenario model achieved satisfactory results during the validation exercise when compared to 2013 flood collected high water marks. The preliminary 2013 Flood Landscape Scenario model continues to be updated and refined based on available data to improve accuracy and performance (Advisian 2016).

The baseline complete mitigation scenario is Scenario 28A (Complete Mitigation Scenario). The mitigation features associated with Scenario 28A are shown in Figure 1-14. Scenario 28A incorporates all proposed and constructed mitigations measures throughout and outside the Town. The south portion of Town is protected by the 12 Ave-Centre Street Dike alignment. This scenario is considered the baseline mitigation and design scenario as it was used as the conservative (i.e. no more water can

be directed north and thus reduce flood flows in the Little Bow River) design scenario for the majority of the dike structures through and downstream of Town.

3.2.4 Calibration

Calibration and verification of the hydrodynamic model is likely the most important step in the model development process. However, verification data for the Little Bow River Flood Model is not available and hence this step focused on calibration to 2013 HWM levels only. If acceptable calibration of the model to recorded events can be achieved, it provides a reasonable level of certainty and reliability in terms of future assessment results.

Calibration focused on developing a model that provided simulated water levels that were similar to those observed for the 2013 flood (documented through HWM data as discussed in Section 3.1.2). The calibrated modelling scenario can be described as the 2013 Flood Landscape Scenario as discussed in Section 3.2.3. Calibration most often focuses on adjustment of roughness values. Initial roughness values were mainly adopted from equivalent land covers in the High River Flood Model (WorleyParsons 2014) and hence adjusted in a trial and error process. Hydraulic control sections adjustments were also relevant to progressively improve model water levels in comparison to the surveyed HWMs. Such control sections were found within the low-flow portion of the channel in correspondence to key features such as collapsed bridges on 168 St E (02009), on 232 St E (00957) or on 296 St E (00918) (as shown on Figures 1-2 to 1-6). Additional information pertaining to the methods and results of the calibration exercise is provided in Section 5.1.

3.2.5 Sensitivity Analysis

Sensitivity analysis is often included in hydrodynamic modeling, following calibration and validation, to assess the sensitivity of the results generated by the model to variations in various modelling parameters. Sensitivity analysis also helps assess and characterize model uncertainty and accuracy. The most common parameters used for hydrodynamic model sensitivity analysis include variations pertaining to inflow/downstream boundary conditions and roughness.

Sensitivity analysis for the Little Bow River Flood Model was completed following calibration. Sensitivity analysis incorporated changes to the inflow boundary conditions (shape of the inflow hydrograph), downstream boundary conditions and roughness (channel, floodplain and combined). However, because bathymetric data were based on a 2001 survey of the channel, sensitivity analysis was expanded to include raising and lowering of the low-flow channel profile. Additional information and results of the sensitivity analysis are provided in Section 5.2.

3.2.6 Effects Assessment

Effects assessment is the final modelling task for the LBR-FEA. Effects assessment focused on characterizing the effects of flooding in the Study Area at a flow reduced in magnitude in comparison to the 2013 flood event (i.e. from a peak value of 560 m³/s to 410 m³/s) as a results of the flood mitigation measures modelled in Scenario 28A, as described in Section 3.2.3. Development of Scenario 28A for the Study Area consisted of changing the inflow/upstream boundary conditions of the calibrated Little Bow River Model (i.e. the 2013 Flood Landscape Scenario) to the output from the High River Flood



Model Scenario 28A. That is, the inflow/upstream boundary condition of the Little Bow River Model was changed to the flow condition defined by the outflow of the existing High River Flood Model 28A Scenario. The corresponding downstream boundary condition was changed to the time-varying water level for the reduced peak flow.

Following simulation of the Little Bow River Model Scenario 28A as described above, the results of the model were interrogated to determine various hydraulic variables including water level, depth, flow velocity and inundation extents. These results were then compared to the results of the 2013 Flood Landscape Scenario to arrive at differences maps which show the estimated impact between the two scenarios. These results give the estimated effects on the Little Bow valley due to flood mitigation works taken within the Town.

4. THE LITTLE BOW RIVER FLOOD MODEL

The Little Bow River Flood Model network was developed in the following three stages:

- a) Creation of the network mesh based on a DEM,
- b) Refinement of the network to incorporate bed elevations and river morphology, and
- c) Input of floodplain and channel roughness' as element types based on aerial imagery.

Once the network was completed, conditions needed to be assigned to define flow behaviour at the upstream and downstream model boundaries. The upstream boundaries are typically defined by an inflow hydrograph and the downstream boundaries by a stage-discharge curve or by a known or time-varying water level.

Each of the above stages is discussed in the following sections.

4.1 Model Development

4.1.1 Set-Up of the Model Mesh and River Bathymetry

As discussed in Section 3.2.2, the DEM has been developed from LiDAR survey and channel bathymetry. LiDAR data were collected in 2015 by Airborne Imaging. The LiDAR has a 15 cm vertical accuracy 95% of the time (95th percentile).

The adopted DEM is particularly important for developing the network mesh as the placement of all nodes (*that combine to create elements of varying shapes and sizes*) are largely guided by the variations in topographic elevations.

In general, areas of steep topography or areas of interest such as hydraulic controls (*dikes, bridges, road embankments, weirs etc.*) are defined or '*picked-up*' by closely spaced nodes and elements. On the other hand, flatter topography with little hydraulic importance is generally represented with wide spacing of nodes and larger elements. These general principles govern the shape and density of the model mesh and ensures that the model has sufficient detail where required yet is not overly cumbersome in size which can lead to long run times and significant data requirements.

The base network is shown in Figure 4-1 with the DEM superimposed. Two localised sections of the model are highlighted to more closely show the network detail with respect to the DEM.

As mentioned above, the base network obtained from the LiDAR information has little detail incorporated to define the Little Bow River channel, due to the limitations of LiDAR to penetrate the water surface and '*pick-up*' channel bathymetry. Figure 4-2 shows how the HEC-RAS model's cross sections, based on a 2001 Alberta Transportation survey (MSA 2002), were used to derived a simplified channel cross sectional area with a triangular or trapezoidal shape of flow surface equivalent to the HEC-RAS cross section.

The 2001 survey covered the Little Bow River area from its headwaters to about km 50 downstream of the Highway 2 crossing (i.e. the starting point of the Model). The thalweg from the end of the 2001 survey to the downstream end of the model, which is about 10 km further downstream, were estimated.



Different relationships (see Figure C) were assessed to interpolate the bottom points of the channel between the last points from the 2001 survey and the TVR known bottom elevation at its southern end at the Dam: 950.00 m.

Figure C Example of Relationships Used to Interpolate Last 10 km of the Modelled Channel's Bottom

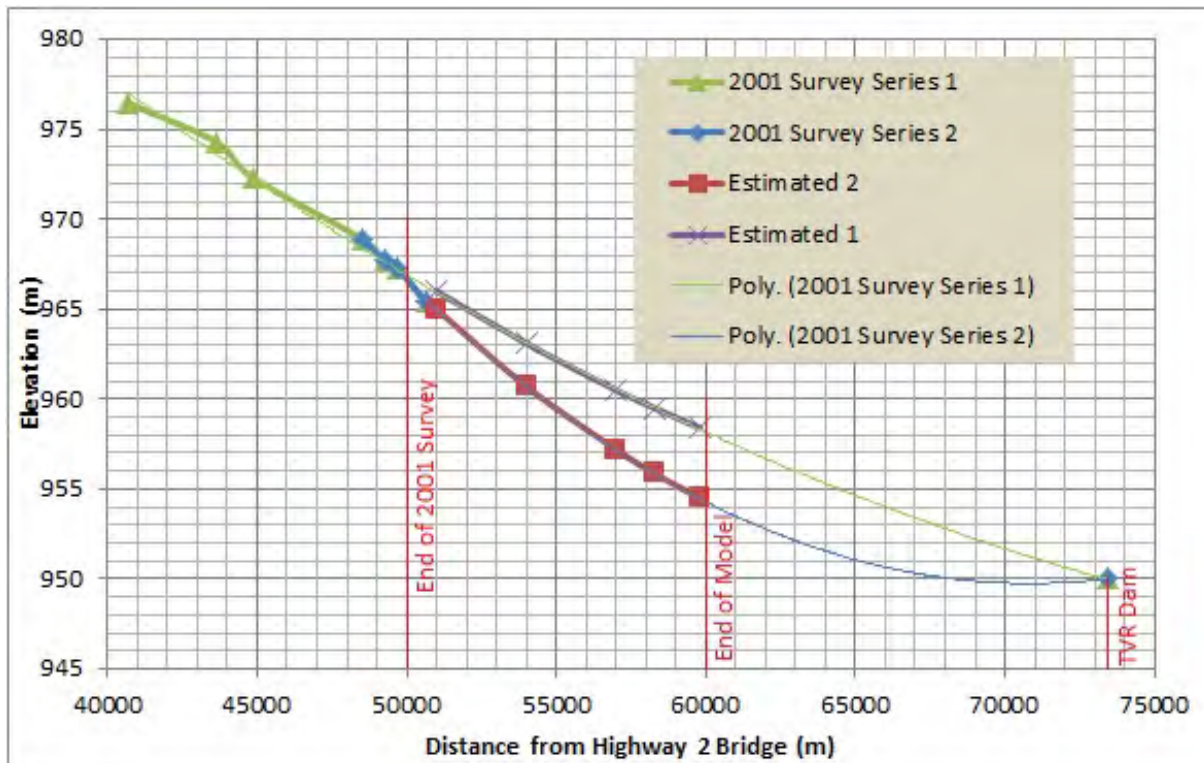


Figure C shows the latest two relationships tested to represent the thalweg. As discussed, the relationships between the end of the 2001 Survey and the end of the Model became a calibration variable as described in Section 5.2. Estimated points of the series 1 relationship were eventually selected as the thalweg bottom.

In consideration of the morphologic modifications potentially caused by increased diversions rates and the 2013 flood event, the bathymetry based on the 2001 survey and the interpolation of the downstream last 10 km described above was the subject of a model sensitivity scenario which is discussed further in Section 5.2.

4.1.2 Model Mesh Refinement

The network mesh discussed in Section 4.1.1 and shown in Figure 4-1 was refined over the calibration process in order to incorporate additional detail along the Little Bow River channel. In particular, additional nodes and elements were added to define bed elevations and terrain elevation of control sections and relative embankments.











This additional detail was incorporated into the model based on a detailed review of available aerial photography combined with on-site observations. The final mesh was made up of 35,492 nodes and 39,403 elements.

4.1.3 Floodplain & Channel Roughness

Main channel and overbank roughness' were estimated for the Study Area from aerial photograph analysis and field observations of the channel bed and floodplain vegetation density. The adopted roughness values were based on those adopted for the High River Flood Model upstream of Highway 2, reflecting the similar vegetation types and densities that are observed across both Study Areas.

The adopted material roughness types and roughness values are shown below in Table 4-1. The final distribution of ground cover types across the RMA-2 Flood Model are shown in Figure 4-3, Figure 4-4 and Figure 4-5.

Table 4-1 Adopted RMA-2 Element Roughness Values

RMA-2 Model Element Type^	Description	Manning's Roughness Value	Material Colour (Refer to Figure 4-3 to Figure 4-5)
2	Vegetated bars and banks (light)	0.050	
3	Pasture / Grassland (light)	0.035	
4	Pasture / Grassland (medium)	0.040	
5	Pasture / Grassland (dense)	0.045	
7	Brush / Forest (dense)	0.140	
8	Brush / Forest (light)	0.080	
10	Pavement / Cut grass	0.030	
11	Cut grass / Some trees	0.040	
14	Clear overbank areas	0.030	
35	River channel	0.023	

Note:

^ Element numbering is based on the broader element type selection adopted for the Town RMA-2 model



4.1.4 Crossing Representation

The main road crossings (bridge or culverts) in the model were represented with focus on properly replicating the conveyance of the control section. This was achieved via the calibration process selecting in the process the most suitable combination of elements number, size and roughness for the section of the crossing.

In the instance of failed crossing structures (as reported in Figure 1-2 to 1-6), the crossings were modelled without the bridge (or culverts) to reflect average conditions pre and post-structure failure. Manning's roughness around the control section has also been aptly increased to compensate for the potential flow-constraint effect caused by the failing structure and its potential debris accumulation.

4.2 Model Boundary Conditions

4.2.1 Upstream Boundary Conditions

The Little Bow River RMA-2 Flood Model has a single upstream boundary located along the Little Bow River at the Highway 2 crossing, about 5 km downstream of the Little Bow Canal headworks in High River Town. The location is shown in Figure 4-6.

The discharge hydrographs for both the June 2013 Flood Landscape and the Mitigated 28A scenarios were generated directly from the flow output of the High River Flood Models whose network extension is shown in Figure 1-13 and were adopted as inflow hydrographs for the Little Bow River. The Little Bow River upstream hydrographs are shown in Figure 4-6.

4.2.2 Downstream Boundary Conditions

The RMA-2 Flood Model has one downstream boundary that is located along the Little Bow River at the northern end of the TVR approximately 60 km south of the Highway 2 crossing and 13.5 km north of the TVR Dam at Highway No. 529. The location of this boundary is shown on Figure 4-6 (Legal section NW-34-15-26-W4).

The downstream boundary adopts a time-varying water level condition located where the HWM 74 elevation was taken at 965.97 m during the survey described in section 3.1.2. HWM 74 is considered particularly reliable because the June 2013 water peak elevation was marked with a post in the ground by the local landowner, and is shown in Photos A and B.

As HWM 74 was located at the upstream end of the TVR, it was deemed to represent the best available data on the maximum water level during the 2013 flood for the Model pending full bathymetric information of the TVR itself during the flood event.

Photo A Survey of HWM 74 in Legal Section NW-34-15-26-W4



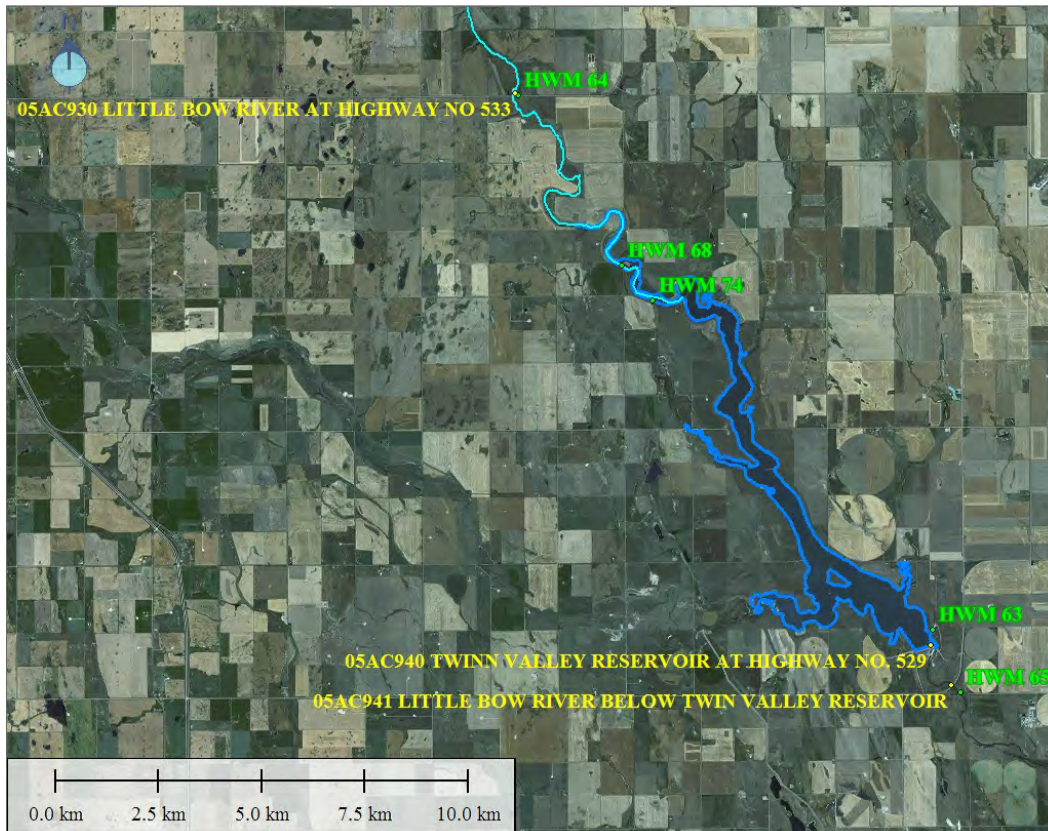
Photo B Close-Up of the Survey of HWM 74





Figure D shows HWM 74 and others and the WSC station for flow and level around the TVR.

Figure D HWMs and WSC Stations around the Twin Valley Reservoir



WSC registered the time-varying water level of the TVR at the Dam, station 05AC940 (Twin Valley Reservoir at Highway No. 529) with hourly interval between June 21, 2013 at 1 am and June 22, 2013 at 11 pm. The registered peak was at 965.87 m at 10 pm of June 21.

The time-varying water level was then transferred from station 05AC940 to HWM 74 by adjusting the elevations by the difference between the HWM and the station's registered peak elevation.

After calibration for the June 2013 Flood Landscape scenario, a discharge-stage rating curve was determined at the Little Bow cross section at HWM 74.

The rating curve allowed the determination of the elevation corresponding to the Mitigated Scenario 28A's peak flow. For the mitigated scenario downstream boundary condition the time varying water level curve was therefore scaled in elevation to have its peak matching the one suggested by the rating curve. The time varying curves are shown in Figure 4-6.

The almost complete concurrence of the two elevation curves for the 2013 Flood Landscape and the 28A Mitigated scenarios reflects the attenuation effect of a large storage body such as the TVR. Tail-water control range of the TVR is further discussed in section 5.2.3.

The sensitivity of the model results to the adopted downstream boundary condition is discussed in Section 5.2.

5. MODELING EXECUTION RESULTS AND DISCUSSION

5.1 Model Calibration

As discussed in Section 3.2.4, calibration and/or verification of a hydrodynamic model are likely the most important steps in the model development process. They ensure that the model is able to accurately predict flood conditions, in particular flood levels and extents, which are in good agreement to those observed during a specific event. In that regard, model calibration is often completed to recorded HWMs, recorded gauge readings or post-flood aerial photography, or a combination of each.

For the Little Bow River Flood model calibration has been undertaken to the June 2013 flood to the HWM information that was surveyed in January and February 2015 and October 2016. In total, of the 78 HWMs collected for the Little Bow River, 74 were inside the Study Area. Further information on the HWMs and the collection process is provided in Section 3.1.2.

The Little Bow River model was predominantly calibrated by fine-tuning the models representation of the Little Bow River channel. This included estimate of the bed elevation in the last downstream segment towards the TVR and features such as embankments and control sections of bridges collapsed or damaged by the flood. A calibration was performed also in terms of fine tuning the material roughness values in different sections of the network using different Manning's values used in the High River Flood Model which was validated against the June 2013 flood to over 350 HWMs, and also calibrated/validated to other flood events such as the 1995, 2005 and 2008 floods. In that regard, the material roughness' have already been proven to be appropriate for the Highwood River channel and overbank areas and the Little Bow River down to the Highway 2 crossing.

The results of the model calibration to the June 2013 flood are shown from Figure 5-1 to Figure 5-5. The calibration figures show a comparison of the flood levels predicted by the RMA-2 model to the flood levels recorded at each of the HWMs.

The Figures also report both the confidence assigned to each HWM during the survey (Excellent, Good, Average or Poor) and how closely the modelled value is to the surveyed one: green is assigned for a difference between 0 and 0.2 m, orange between 0.2 and 0.4 m, red above 0.4 m.

HWMs in obvious disagreement with the neighbouring ones have been marked as erroneous (orange shaded boxes) and excluded from the statistical analysis for the calibration process: this reduced the analyzed HWMs from 74 to 62.

The RMA-2 model predicts peak flood levels for the June 2013 that are generally in fair agreement with the recorded HWMs, although there are locations where the modelled and recorded levels are in poor agreement (*i.e. modelled versus surveyed difference is greater than 0.4 metres*). These discrepancies can be attributed to uncertainty in the collected HWM elevation (e.g. HWM, if anecdotal may have been observed prior to or after the peak flood level was reached); limited ability of the regional model network to represent local hydraulic features such as narrow driveways, berms surrounding residences and buildings; overall accuracy of the network (which is limited by accurate data availability, especially in the channel); and uncertainty in boundary conditions.



Specifically, local disagreements in some cases are also likely the results of lack of detailed or updated bathymetry on the River's channel as well as its local crossing structures. An example Figure 5-2 shows HWM 52 to be underestimated by the model while the neighboring HWM 53 and 54 are much closer. As seen from Photo C below, the indicated mark was visible as debris coloration left in the internal walls of a closed agricultural shelter. Due to the confined space, the localized effect could not be replicated by the LiDAR information normalized to bare earth elevations and the model could not represent the hydraulic influences associated with the enclosure.

Photo C Survey of HWM 52 in Legal Section NE-36-17-28-W4



In other locations, such as the upstream area of crossing on 232 Street E in Figure 5-3, the surveyed HWMs (HWM 11 and 12 versus HWM 13) simply differ significantly thus creating uncertainty in relation to the true high water level.

A basic statistical analysis of the calibration results over the 62 confirmed HWMs from the June 2013 flood is shown in Table 5-1.

The calibration results summarised in Table 5-1 indicate that, notwithstanding the described shortcomings in a few areas, the model was successfully calibrated to an absolute mean difference of ± 0.34 m. This statistic, in conjunction with a median difference of 0.11 m, indicates that the model provides acceptable results in most areas when compared to the HWM data.

Table 5-1 Overview of the June 2013 Model Calibration Results

Statistic	Calibration result [^]
<u>Minimum</u> Difference	-0.74 m
<u>Maximum</u> Difference	+1.16 m
<u>Median</u> Difference	+0.11 m
<u>Mean</u> Difference	+0.22 m
<u>Mean</u> Difference (absolute value)	0.34 m
Percentage of Differences between <u>+/-0.10 m</u>	21%
Percentage of Differences between <u>+/-0.20 m</u>	53%
Percentage of Differences between <u>+/-0.30 m</u>	61%
Percentage of Differences between <u>+/-0.40 m</u>	69%
Percentage of Differences between <u>+/-0.50 m</u>	73%
Percentage of Differences between <u>+/-0.60 m</u>	81%

Notes:

[^] Excludes results for HWM that were determined to be erroneous following a detailed review and comparison with other nearby HWMs and review of field information.

Based on the analysis of the calibration the model is considered suitable to progress to Sensitivity Analysis and for use to test the impacts of the Town Mitigation Scheme.

5.2 Sensitivity Analysis

Sensitivity analysis was undertaken for the Little Bow River Flood Model to establish the potential for changes in flood level predictions due to changes in a number of model parameters and inputs. This stage is often completed to determine which inputs or adopted parameters which the model is most sensitive to, from which the relative model uncertainty or accuracy can be assessed.

The adopted sensitivity scenarios are shown below in Table 5-2.



Table 5-2 Adopted Sensitivity Scenarios

Sensitivity test	Sensitivity scenarios	ID
River Bed (Active Channel) Elevations	0.25m increase in channel elevations	Scenario 1
	0.25m decrease in channel bottom elevations	Scenario 2
Inflow Boundary Conditions	20% increase in inflow hydrograph length	Scenario 3
	20% decrease in inflow hydrograph length	Scenario 4
	15% increase in inflow magnitude	Scenario 5
	15% decrease in inflow magnitude	Scenario 6
Roughness Parameters	15% increase in floodplain roughness	Scenario 7
	15% decrease in floodplain roughness	Scenario 8
	15% increase in channel roughness	Scenario 9
	15% decrease in channel roughness	Scenario 10
	15% increase in channel and floodplain roughness	Scenario 11
	15% decrease in channel and floodplain roughness	Scenario 12
Downstream Boundary Condition	0.5m increase in downstream boundary water levels	Scenario 13
	0.5m decrease in downstream boundary water levels	Scenario 14

Each of the 14 Sensitivity Scenarios was set-up in the model by modifying channel bottom elevations, boundary conditions, roughness parameters or downstream boundary condition. The Model was then run for each Scenario for the June 2013 flood hydrograph.

The results for the Sensitivity Scenarios are discussed in the following sections.

5.2.1 Model Sensitivity Results

The results for the Sensitivity Scenarios are shown as flood level difference mapping in Figure 5-6 to Figure 5-23.

Results of Sensitivity Scenarios 9 and 10 (15% increase or decrease in channel roughness), were not mapped as in the vast majority of the modelled Little Bow River's segment the difference in peak water elevations against the calibrated scenario was null to +/-0.01 m, with the maximum change being +/- 0.05 m in localized areas. In other words, the sensitivity of the model to modified roughness only in the channel is very limited and variations in results are less than the model's uncertainty/expected accuracy.

The results for each of the other Sensitivity Scenarios are also shown as Water Surface Profile (WSP) plots in Figure 5-24 to Figure 5-41.

The HWMs have also been included on the plots to show the model accuracy relative to recorded data. The HWM represented in the profiles figures are only those close to the River's channel, to avoid the comparison of simulated water levels in the middle of the stream with HWM in other areas of the floodplain where local ground elevation will dictate a different HWM elevation.

5.2.2 Model Sensitivity Statistics

Due to the large number of sensitivity scenarios and associated figures a statistical analysis was performed to summarise overall findings. The analysis has been completed for the entire reach of the Little Bow River in the Study Area, and also for the usual five sub-sections used to discuss morphology of the River. The analysis compares the results in profiles showing differences in flood level:

- Section 1 spanning from HWY-2 to Bridge 02009 on 168 St E;
- Section 2 from Bridge 02009 on 168 St E to Bridge 00957 on 232 St E;
- Section 3 from Bridge 00957 on 232 St E to the MD southern limits;
- Section 4 from the MD southern limits to Bridge 00962 on Highway 533; and
- Section 5 from Bridge 00962 on Highway 533 to the TVR northern end;

The peak water levels differences between each sensitivity scenario and the calibrated 2013 Flood Landscape model (Base Case) are measured along the River's centerline.

The predicted mean differences in water levels are shown in Figure E below for the entire Study Area. The results of the overall analysis are shown in Table 5-3 which includes the entire stretch between Highway 2 crossing and the TVR northern end but also the breakdown of the statistical parameters for the above sub-sections.

Figure E Sensitivity Scenarios 1 to 14 - Mean Differences with the calibrated 2013 Flood Landscape Scenario's Peak Water Levels

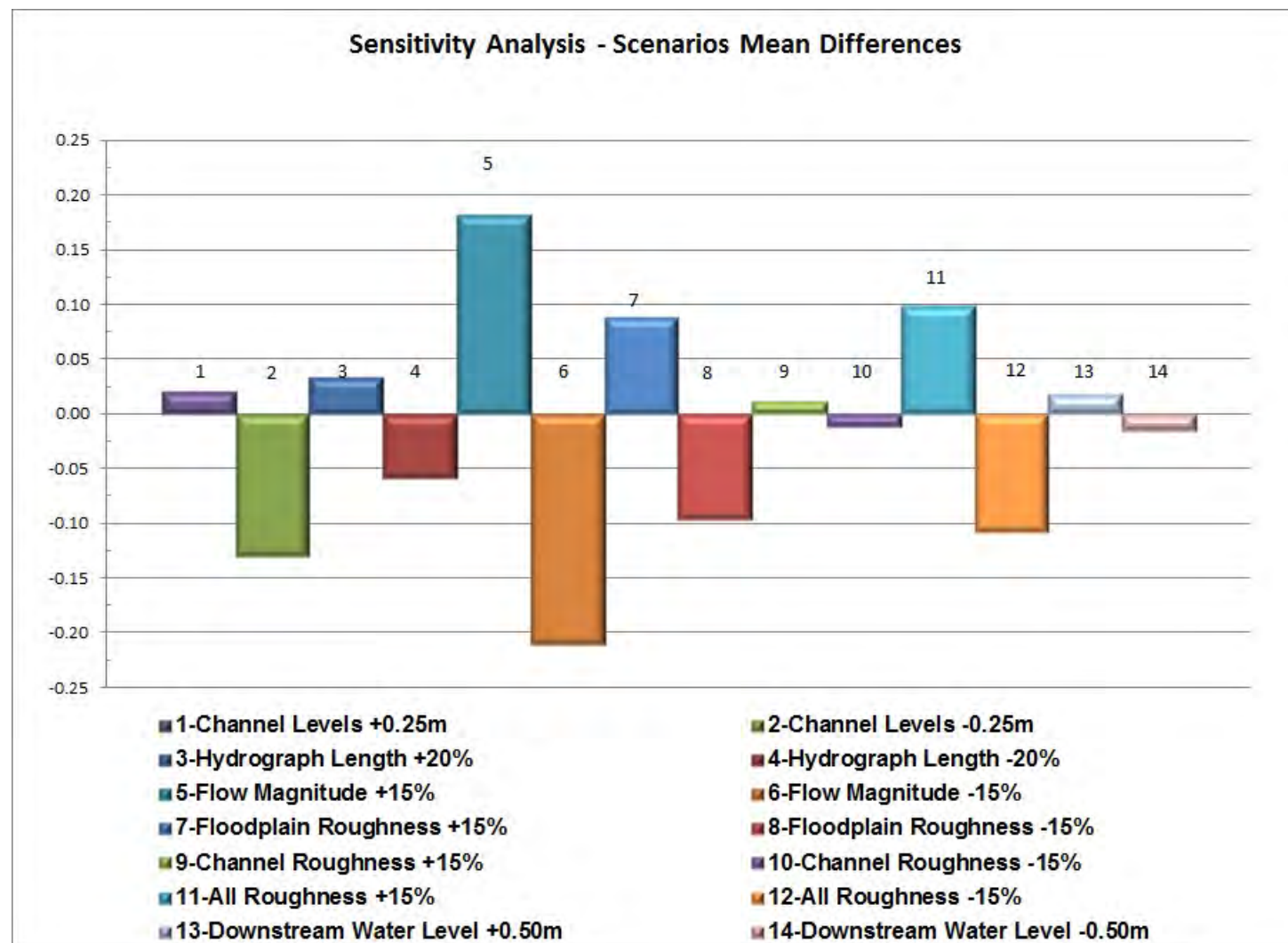


Table 5-3 Statistical Analysis of Sensitivity Results

Section of Little Bow River	Statistic	Difference in Peak Water Surface Level compared to Base Case (m)													
	Sensitivity Test	Channel Elevations		Hydrograph Length / Flow Magnitude				Roughness						Downstream Water Level	
								Floodplain		Channel		Channel & Floodplain			
		Scen. 1 +0.25m	Scen. 2 -0.25m	Scen. 3 +20% length	Scen. 4 -20% length	Scen. 5 +15% magn.	Scen. 6 -15% magn.	Scen. 7 +15%	Scen. 8 -15%	Scen. 9 +15%	Scen. 10 -15%	Scen. 11 +15%	Scen. 12 -15%	Scen. 13 +0.50m	Scen. 14 -0.50m
All Data: Highway 2 to TVR	Mean	0.02	-0.13	0.03	-0.06	0.18	-0.21	0.09	-0.10	0.01	-0.01	0.10	-0.11	0.02	-0.02
	Median	0.01	-0.12	0.03	-0.05	0.23	-0.20	0.09	-0.09	0.01	-0.01	0.10	-0.10	0.00	0.00
	Min	-0.05	-0.40	-0.01	-0.18	0.23	-0.39	-0.13	-0.33	-0.02	-0.07	-0.14	-0.39	-0.01	-0.52
	Max	0.21	0.11	0.12	0.01	0.22	0.00	0.35	0.17	0.07	0.02	0.40	0.19	0.51	0.01
Highway 2 to Bridge on 168 St E	Mean	0.01	-0.10	0.00	0.00	0.13	-0.14	0.08	-0.08	0.00	0.00	0.09	-0.08	0.00	0.00
	Median	0.01	-0.09	0.00	0.00	0.11	-0.13	0.08	-0.08	0.00	0.00	0.08	-0.08	0.00	0.00
	Min	-0.02	-0.36	0.00	-0.02	0.05	-0.28	-0.13	-0.33	-0.02	-0.06	-0.14	-0.39	-0.01	-0.01
	Max	0.14	0.10	0.01	0.01	0.31	0.00	0.35	0.17	0.06	0.02	0.40	0.19	0.01	0.01
Bridge on 168 St E to Bridge on 232 St E	Mean	0.02	-0.10	0.01	-0.03	0.16	-0.20	0.07	-0.08	0.00	0.00	0.07	-0.08	0.00	0.00
	Median	0.01	-0.10	0.01	-0.01	0.16	-0.19	0.08	-0.08	0.00	0.00	0.08	-0.08	0.00	0.00
	Min	-0.05	-0.19	0.00	-0.08	0.09	-0.30	-0.05	-0.17	-0.02	-0.06	-0.05	-0.19	-0.01	-0.01
	Max	0.21	-0.05	0.04	0.00	0.28	-0.09	0.16	0.04	0.06	0.01	0.18	0.17	0.01	0.01
Bridge on 232 St E to MD southern limits	Mean	0.01	-0.16	0.04	-0.08	0.21	-0.24	0.12	-0.12	0.01	-0.01	0.13	-0.13	0.00	0.00
	Median	0.01	-0.15	0.04	-0.07	0.20	-0.22	0.12	-0.12	0.01	-0.01	0.13	-0.13	0.00	0.00
	Min	-0.03	-0.26	0.02	-0.15	0.14	-0.35	-0.05	-0.26	-0.01	-0.04	-0.05	-0.32	-0.01	-0.01
	Max	0.18	-0.07	0.08	-0.04	0.30	-0.10	0.23	0.00	0.04	0.01	0.25	0.00	0.01	0.01



Section of Little Bow River	Statistic	Difference in Peak Water Surface Level compared to Base Case (m)													
	Sensitivity Test	Channel Elevations		Hydrograph Length / Flow Magnitude				Roughness						Downstream Water Level	
								Floodplain		Channel		Channel & Floodplain			
		Scen. 1 +0.25m	Scen. 2 -0.25m	Scen. 3 +20% length	Scen. 4 -20% length	Scen. 5 +15% magn.	Scen. 6 -15% magn.	Scen. 7 +15%	Scen. 8 -15%	Scen. 9 +15%	Scen. 10 -15%	Scen. 11 +15%	Scen. 12 -15%	Scen. 13 +0.50m	Scen. 14 -0.50m
MD southern limits to Bridge on Hwy 533	Mean	0.03	-0.17	0.07	-0.12	0.24	-0.28	0.10	-0.11	0.02	-0.02	0.11	-0.13	0.00	0.00
	Median	0.03	-0.16	0.08	-0.13	0.25	-0.29	0.09	-0.11	0.02	-0.02	0.11	-0.13	0.00	0.00
	Min	-0.05	-0.29	0.03	-0.18	0.11	-0.39	0.01	-0.22	0.00	-0.06	0.01	-0.25	-0.01	-0.01
	Max	0.10	-0.04	0.12	-0.05	0.34	-0.12	0.16	-0.01	0.06	0.00	0.19	-0.01	0.01	0.01
Bridge on Hwy 533 to TVR northern end	Mean	0.04	-0.17	0.08	-0.13	0.23	-0.27	0.08	-0.10	0.03	-0.03	0.11	-0.14	0.13	-0.11
	Median	0.04	-0.20	0.09	-0.16	0.26	-0.32	0.10	-0.13	0.03	-0.03	0.13	-0.16	0.03	-0.02
	Min	0.00	-0.26	-0.01	-0.18	-0.01	-0.37	-0.01	-0.23	0.00	-0.07	-0.01	-0.27	0.00	-0.52
	Max	0.08	0.01	0.12	0.00	0.31	0.00	0.20	0.01	0.07	0.00	0.23	0.00	0.51	0.00



Highlights section of Little Bow River that is most sensitive to the relevant (-) test; i.e. where the Mean or Minimum decrease equals or exceeds that for the entire section



Highlights section of Little Bow River that is most sensitive to the relevant (+) test; i.e. where the Mean or Maximum increase equals or exceeds that for the entire section

The yellow cells in Table 5-3 give the general statistics for the entire Study Area for each sensitivity scenario: The Mean Differences in the first row are graphically represented in Figure E above.

Higher Mean and Median values in Table 5-3 indicate a higher sensitivity to the particular factor (channel elevation, flow, roughness, downstream water level) altered in the sensitivity scenario. We can conclude that flow magnitude is the factor which the model is most sensitive to (scenarios 5 and 6) and also that, in respect to the roughness, the results are far more sensitive to a variation in the floodplain roughness (scenario 7 and 8) than in the active channel (scenario 9 and 10) as expected for the very rare event when overbank flow occurs. This type of event is the focus of the model and its calibration.

The purpose of the lower part of Table 5-3 is to show which segment of the River in the Study Area can be associated with the higher sensitivity to each particular parameter.

For the sensitivity runs which increase the parameter in question (odd numbers) red colour has been used to mark the Section where the Mean water level increment is equal or superior to the value of the entire River and also where the maximum increase in water level is located. Thus it can be noted that, for example, for a 15% increase in flow magnitude (Scenario 5) the downstream Section 4 between the MD limits and Bridge on Highway 533 has a Mean water increment greater than the entire River, flagging it as the most sensitive Section to flow magnitude increase. Section 4 also displays the maximum level increment (+0.34 m).

For the sensitivity runs which decrease the parameter in question (even numbers) light blue colour has been used to mark the Section where the Mean water level decrement is equal or less than the entire River's value and also where the highest decrease in water level is located. Similarly it can be noted that for a 15% decrease in flow magnitude (Scenario 6) both Sections 4 and 5 have a Mean decrease higher than the overall river's Mean value, but Section 4 is also the one with the highest decrease (-0.39 m).

In summary, review of the difference mapping, WSP plots and statistical analysis indicates also the following key findings:

- The sensitivity scenarios 9 and 10 (+/-15% changes to roughness values for the channel) and scenarios 13 and 14 (+/-0.50 m change to the downstream boundary water level) have shown the least change in peaks for June 2013 flood levels. As shown in Figure E and Table 5-3, these scenarios have a maximum mean difference equal or less than 0.02 m.
- The model was most sensitive to the increase/decrease in flow magnitude of 15%. As shown in Table 5-3, this scenario resulted in a maximum mean difference in water surface elevation of -0.21 m.
- The variation of active channel roughness and hydrograph length are confirmed to have minimal to no impact on predicted peak flood levels along the Little Bow River for a huge flow as the one of the event of June 2013. The Flood Model has therefore no significant sensitivity to these three parameters;



- The model seems to present increased sensitivity for all factors on the three most downstream Sections. It can be speculated that this is linked to the lower quality of the calibration against the HWMs downstream of the MD southern limits (Section 4 and 5). In fact these HWM's were collected almost 2 years later than the remaining HWMs and over 3 year after the flood event who produced them in June 2013; and
- In general mean differences are lower than those found for similar sensitivity test in the Lower Highwood River model (Advisian 2016), indicating a model less responsive to parameters variation and therefore less flexible to calibration.

Profile Figures 5-26 to 5-32 show how the model becomes more sensitive with flow magnitude variations (Scenarios 5 and 6) as the valley narrows. This effect is magnified at the bridges. The particular sensitivity to flow variation led to the hypothesis that the peak flow in the inflow hydrograph could be slightly over-estimated.

This hypothesis seems to be supported by the statistical values for water levels differences from the surveyed HWMs, within sensitivity scenario 6, where the upstream flow values have been reduced by 15%. The upstream inflow hydrograph was an input to the Little Bow River Flood Model (a function of the High River Flood Model or the WSC 2013) and not a calibration variable. However in Table 5-4 the reduced flow scenario demonstrates a better fit to the 62 HWM values than the calibrated 2013 Flood Landscape scenario.

Statistical parameters for the calibrated 2013 Flood Landscape Scenario of Table 5-1 are repeated in Table 5-4 below against the values relative to sensitivity scenario 6.

Maximum difference, median difference, mean difference and mean absolute value difference are all lower than the calibrated correspondents; with the minimum difference being the only higher overall statistical parameter.

Table 5-4 Statistic Results against the Surveyed HWMs. Calibrated vs. Sensitivity Scenario 6

Statistic	Calibration Result ^	Sensitivity Scenario 6 Result ^
<u>Minimum</u> Difference	-0.74 m	-0.95 m
<u>Maximum</u> Difference	+1.16 m	+0.99 m
<u>Median</u> Difference	+0.11 m	-0.08 m
<u>Mean</u> Difference	+0.22 m	+0.03 m
<u>Mean</u> Difference (absolute value)	0.34 m	0.30 m
Percentage of Differences between <u>+/-0.10 m</u>	21%	23%

Statistic	Calibration Result [^]	Sensitivity Scenario 6 Result [^]
Percentage of Differences between <u>+/-0.20 m</u>	53%	44%
Percentage of Differences between <u>+/-0.30 m</u>	61%	61%
Percentage of Differences between <u>+/-0.40 m</u>	69%	74%
Percentage of Differences between <u>+/-0.50 m</u>	73%	82%
Percentage of Differences between <u>+/-0.60 m</u>	81%	87%

Notes:

[^] Excludes results for HWM that were determined to be erroneous followed a detailed review and comparison with other nearby HWMs and review of field information.

In particular the mean difference in absolute value goes from 0.34 m to 0.30 m. For this parameter a threshold value of 0.35 m was set to consider the model as calibrated.

The maximum range of flood level differences predicted through the sensitivity analysis can also be used to derive an estimate of the model accuracy, provided that the different parameters variation adopted in the scenarios reflect reasonable expected uncertainty on those specific parameters. As this condition had been followed in setting those parameter variations (flow magnitude or roughness +/-15% uncertainty is typical etc.) sensitivity will be utilized again in the Limitations and Accuracy Section 5.4.

5.2.3 Local Sensitivity Assessments

Further and more localized sensitivity assessments were completed on the Little Bow River model results to verify:

- Influence of tail-water from the TVR on the peak level at the crossing of Highway No. 533 (location of the WSC station 05AC930); and
- Sensitivity of the Flood Model results for flows significantly lower than those of the extreme events.

In sensitivity scenarios 13 and 14 the time-varying TVR water level set as downstream boundary condition of the Model has been incremented and lowered by 0.50 m respectively. This has allowed estimating how far upstream the backwater from the Reservoir would influence water levels along the Little Bow River for its highest historical flow, which occurred in June 2013. Figure 5-41 captures such an effect comparing the “predicted June 2013 flood level” against sensitivity scenarios 13 and 14. The scenarios with 50 cm of water level differential set upstream limit of the segment influenced by TVR backwater at about km 50 (distance measured from Highway 2 crossing [upstream boundary of the



model], which is 10 km upstream from the model's downstream boundary). The elevation differentials between the reservoir and upstream limit are:

- are decreased to about 40 cm at about km 57 where all the water profiles present a break in the slope, going from approximately 0.001% (downstream) to approximately 0.008% (upstream), which is also the bed profile slope in the area. This indicates that upstream of that water profile break point the river is in a normal flow state;
- are reduced to about 10 cm at km 55;
- are further reduced to about 2-3 cm at km 53; and
- are practically disappeared around km 50 or 51.

The Highway No. 533 crossing is positioned at about km 49.50. Therefore, according to the sensitivity tests, at such distance the effects of the TVR water levels along the subcritical flow are not present anymore. The river presents, in fact, normal flow conditions (water profile slope equal to bed profile slope) as far down as km 57.

For the purpose of evaluating the sensitivity of the 2D Model at lower flow discharges, the rating curve of the Little Bow River at the cross section located 29 km downstream of Highway 2, about midway through the Study Area, has been analyzed. See also Figure 5-29 for its location on the profile view.

Figure F Cross section and 2013 Flood Landscape peak water level at km 29 of the Model

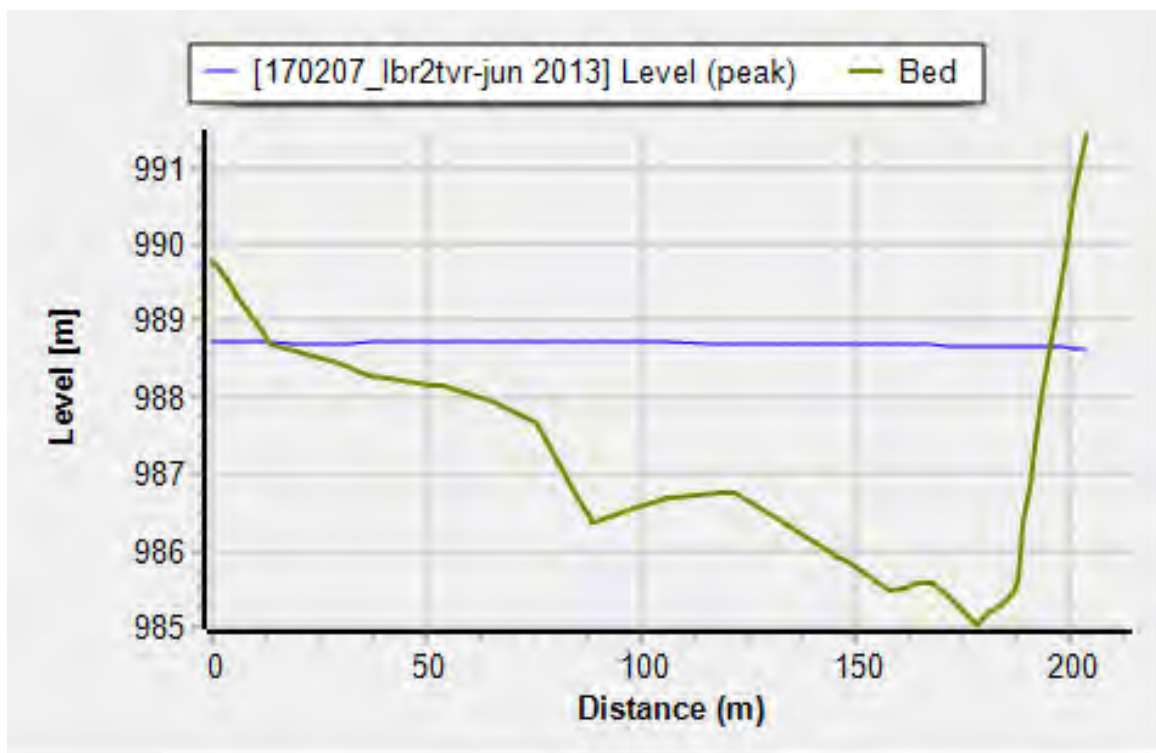
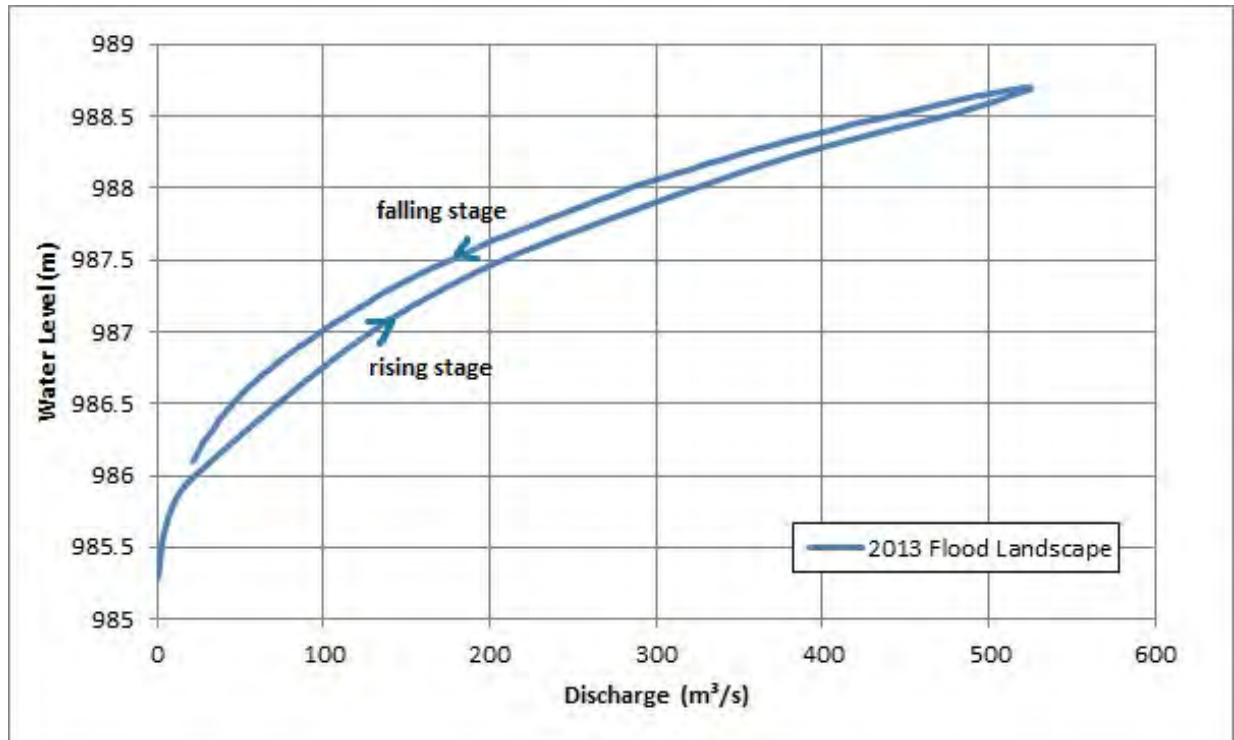


Figure F above shows the geometry of the cross section as represented in the RMA-2 network, with bottom at 985.00 m elevation, and the peak water level for the 2013 Flood Landscape scenario.

Figure G Loop-Rating Curve at km 29 for the 2013 Flood Landscape scenario

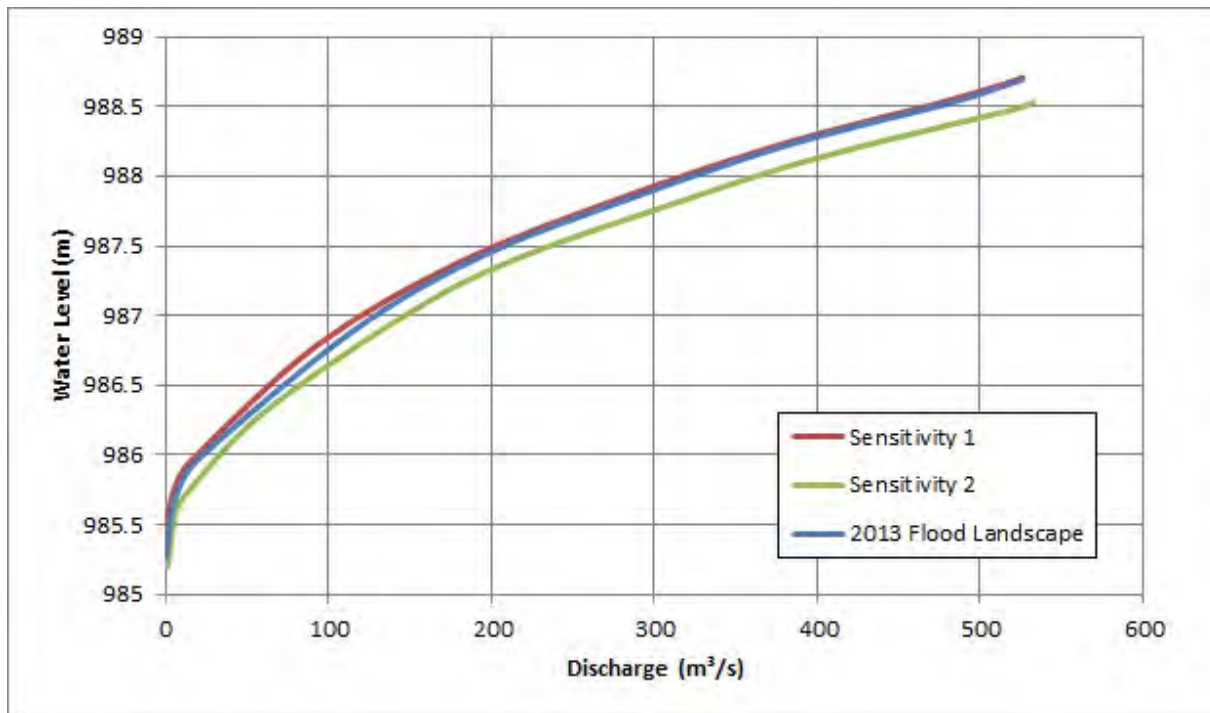


In Figure G the loop rating curve is obtained from the Model's results relative to the June 2013 Flood Landscape scenario, with a greater discharge during the rising stage of the flood than on the falling stage for a given depth, as is characteristic during the progress of a flood along a river.

In Figure H the 2013 Flood Landscape scenario rating curve has been compared to the same rating curve produced by a 0.25 m variation in the channel elevation (sensitivity scenarios 1 and 2).



Figure H Rising Stage of the Loop-Rating Curve at km 29 for the 2013 Flood Landscape Scenario and Sensitivity Scenarios 1 and 2



As described, scenarios 1 and 2 tested the sensitivity of the model to a limited variation of 0.25 m in the lower channel bathymetry.

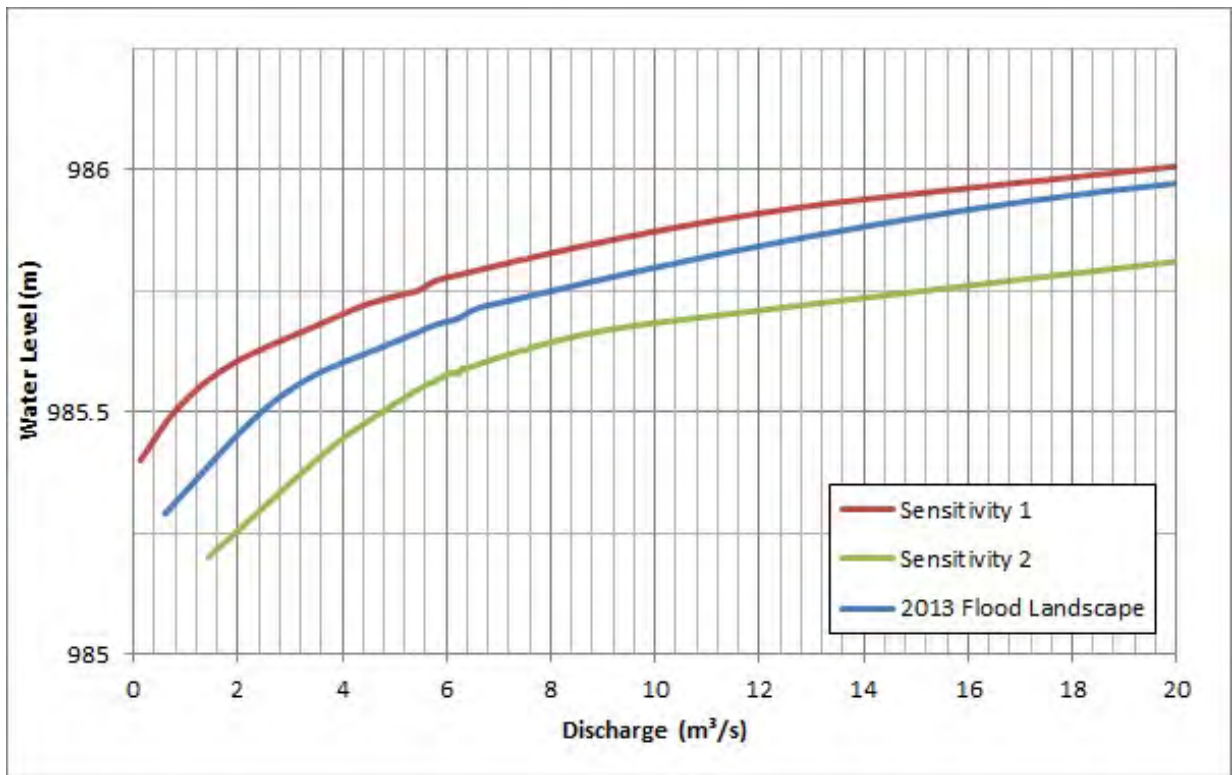
In the range of the extreme discharges the channel, typically 0.5 to 1 m deep, makes up a negligible portion of the conveyance provided by the total cross section which, during the extreme flow, includes an about 200 m wide valley above the channel itself.

However in the lower peak (i.e. those not associated with overflow from the Highwood River) and normal flow condition, channel geometry is bound to be more influential and the limitation of using a bathymetric survey antecedent to the 2013 event, as described in section 4.1, may significantly lower model confidence and applicability.

The magnitude of the 2013 event has in fact produced mutations on the river morphology in various locations, with areas of degradation and other areas of aggradation, as well as relocation of significant quantities of river bed gravel.

Rating curves of Figure H are shown in Figure I below for discharges up to 20 m³/s only.

Figure I Low Flow Rating Curves at km 29 for the 2013 Flood Landscape Scenario and Sensitivity Scenarios 1 and 2



At a given water depth, for example 0.5 m corresponding to elevation 985.5 m, the discharge indicated in the 2013 Flood Landscape curve is about 2.4 m³/s, and goes to 0.8 and 4.8 m³/s in scenario 1 (decrease of 1.6 m³/s) and 2 (increase of 2.4 m³/s) respectively, for relevant variations of -67% and +100%.

Such relative level variation is significantly decreased for the water depths associated with flood events of extreme magnitude similar to what was experienced in 2013. For example when measured in Figure H along the rising stage of the loop rating curves of the three scenarios for an elevation 988.00 m (3.0 m of depth) discharge variation was:

- -2% between 2013 Flood Landscape and sensitivity scenario 1; and
- +12% between 2013 Flood Landscape and sensitivity scenario 2.

The different sensitivity of the model at different range of water depths reflects the applicability of the Model itself and the quality of the data used to build it. Currently, the Flood Model is oriented to an analysis of extreme events (e.g. greater than 100 m³/s) rather than locally derived peaks and normal daily hydrology.



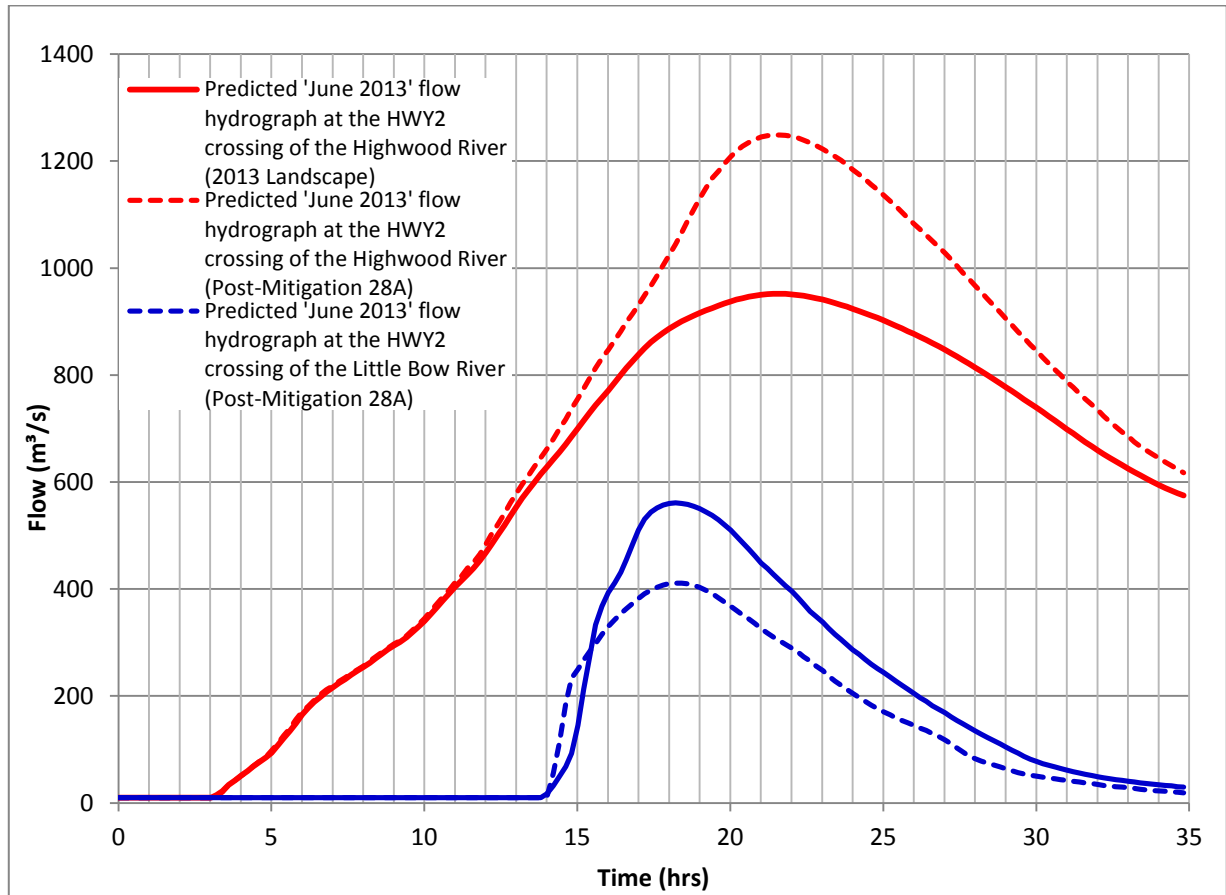
5.3 Effects Assessment

The effects assessment is focused on characterising the flood across the Study Area due to the mitigation works that have been completed to protect the Town. The assessment included a comparison of the flood behaviour for pre versus post-mitigation conditions in order to estimate where, and to what magnitude the mitigation works have altered flow behaviour; i.e. peak flood levels and velocities. For the purposes of this assessment, post-development conditions are defined by Post-Mitigation Scenario 28A which is described in detail in Section 3.2.3. The adopted upstream inflow hydrograph for the Little Bow River model in Scenario 28A is derived from the High River Flood Model under Scenario 28A mitigated conditions (see Figure 2-3 location 6, and Figure 4-6) with an incoming Highwood River flow magnitude above Woman's Coulee Canal Inlet of $1,820 \text{ m}^3/\text{s}$.

Detailed Flood Modelling completed by Advisian for the Town has shown that Post-Mitigation Scenario 28A results in changes to the discharge of floodwaters through the Town when compared to the 2013 Landscape Scenario. That is, during a flood equivalent to the June 2013 event the mitigation infrastructures will cause a greater magnitude of flow to be directed north along the Highwood River, rather than East and South to the Little Bow River as would have occurred for pre-mitigation conditions. Under mitigated condition, under preliminary assessment conditions, approximately $410 \text{ m}^3/\text{s}$ at the peak are diverted to the Little Bow versus $560 \text{ m}^3/\text{s}$ for the 2013 landscape.

The mitigation works are predicted to result in about an additional $300 \text{ m}^3/\text{s}$ (approximately 30% increase from 950 to $1250 \text{ m}^3/\text{s}$ approximately) flowing north in the Highwood River immediately upstream, through and downstream of the Town and a decrease of $150 \text{ m}^3/\text{s}$ (approximately 27% decrease) flowing south along the Little Bow River. Pre and post-mitigation flow hydrographs for the Highwood River and Little Bow River are plotted on Figure J.

Figure J Pre and Post-Mitigation Hydrographs for the Highwood River and Little Bow River



The increase in flows in the Highwood River, and commensurate decrease for the Little Bow River, will have the potential to impact flood levels, flood extents and flow velocities downstream of the mitigation works in both rivers. The following sections present the predicted flood characteristics under post-development conditions along the Little Bow River downstream of HWY-2. The approximate magnitude of any changes to peak flood levels and peak flow velocities and any changes to predicted pre and post-mitigation flood extents will also be reported.

5.3.1 Predicted Flood Characteristics of Scenario 28A

Predicted flood levels at the peak of a June 2013 magnitude flood are shown in Figure 5-42 to Figure 5-46 for Post-Mitigation Scenario 28A.

Estimated flood depths at the peak of a June 2013 magnitude flood are shown in Figure 5-47 to Figure 5-51 for Post-Mitigation Scenario 28A. Velocity vectors are superimposed on the figures to indicate the direction of flow and, by the arrow length, the estimated relative magnitude of the peak flow velocities.

Both sets of figures also provide a representation of estimated flood extents.



5.3.2 Predicted Changes to Flood Characteristics Due To Scenario 28A

Peak flood level, peak flow velocity and peak flood extents difference maps were generated to assess the changes due to Post-Mitigation Scenario 28A. These flood level, extent and flow velocity difference maps are provided as Figure 5-52 to Figure 5-56, Figure 5-57 to Figure 5-61 and Figure 5-62 to Figure 5-66 respectively.

A difference map provides a graphical representation of the magnitude and location of estimated changes in flood levels, extents of flooding or velocities by comparing the results generated at each node in the hydrodynamic model from simulations of pre and post-mitigation scenarios. This effectively creates a contour map of post-development “affluxes” and allows easy determination of the impact of the proposed mitigation measures.

The estimated changes in peak flood levels and peak flow velocities are discussed in the following sections.

Flood Level Changes

As shown in Figure 5-52 to Figure 5-56, the decrease in peak flows along the Little Bow River associated with Post-Mitigation Scenario 28A has resulted in a decrease in peak flood levels downstream of HWY-2. This is reflected by the blue colour gradations which indicate flood level decreases of varying magnitudes.

A statistical analysis of flood level differences between the June 2013 Landscape and Post-Mitigation Scenario 28A for a ‘June 2013’ size flood is included below in Table 5-5. The mean, median, minimum and maximum changes in levels are provided for the Little Bow River over the five river reaches used to display the simulation information in the report.

Once again the statistical population used is represented by peak water level differences at various intervals along River’s centerline. The intervals vary between 5 and 50 m to represent segments of the River with different sinuosity.

As shown in Table 5-5, flood levels are estimated to decrease by an average of 0.37 metres as a result of the flood mitigation measures in High River over the entire length of the Little Bow River downstream of HWY-2.

Table 5-5 Statistical Analysis of Differences between Mitigated and June 2013 Results

Section of Little Bow River	Statistic	Difference in Peak Water Surface Level Due to Decreased Flows Associated with Mitigation Scenario 28A (m)
All Data: Highway 2 to MD limits	Mean	-0.37
	Median	-0.36
	Min	-0.69
	Max	0.00
Highway 2 to Bridge on 168 St E	Mean	-0.27
	Median	-0.24
	Min	-0.62
	Max	0.00
Bridge on 168 St E to Bridge on 232 St E	Mean	-0.35
	Median	-0.34
	Min	-0.51
	Max	-0.20
Bridge on 232 St E to MD southern limits	Mean	-0.43
	Median	-0.38
	Min	-0.68
	Max	-0.18
MD southern limits to Bridge on Hwy 533	Mean	-0.47
	Median	-0.48
	Min	-0.69
	Max	-0.23
Bridge on Hwy 533 to TVR northern end	Mean	-0.45
	Median	-0.54
	Min	-0.61
	Max	-0.01



Flow Velocity Changes

Changes to peak flow velocities during a June 2013 size flood as a result of Post-Mitigation Scenario 28A are shown in Figure 5-57 to Figure 5-61. Decreases in velocities are shown to occur both in-channel and within overbank areas.

Velocity decreases typically ranging between -0.1 to -0.3 m/s are estimated quite consistently between HWY-2 and the TVR, locally reaching -1 m/s (refer to Figure 5-58) or presenting small increases, around +0.1 m/s, in very few locations (Figure 5-60). These are due to localized hydraulic mechanisms. The maximum decrease or the few increases are found in proximity of the hydraulic control sections such as occurs between bridges abutments.

As expected, Figure 5-57 to Figure 5-61 shows that in about 90% of the Little Bow River modelled segment there is a reduction of the peak velocity, - an intuitive consequence of the reduced flow from the Highwood River resulting from the mitigation measures in scenario 28A in the Town.

Comparison of Flood Extents

The predicted areal extents of flooding along the Little Bow for a June 2013 size flow in the Highwood upstream of the Town have been superimposed in Figure 5-62 to Figure 5-66 for the June 2013 Landscape Scenario and Post-Mitigation Scenario 28A. Due to the confined valley of the Little Bow (see Section 2.2 for discussion) there is little reduction in flood extents throughout of the Study Area because of the easily accessible (flat) floodplain at flows greater than bankfull and the confining valley walls.

However the largest decreases in flooded land is predicted to occur, mainly due to local topography:

- in the first 2 to 3 km downstream of HWY-2 (see Figure 5-62);
- in the first 2 to 3 km downstream of the crossing at 168 St E (Bridge 02009 in Figure 5-63);
- in the meandering portion of the Little Bow in the 4 km upstream of the crossing with 685 Avenue (Bridge 00957 in Figure 5-64); and
- in the first 2 km upstream of the crossing at Hwy 533 (Bridge 00962 in Figure 5-65).

Elsewhere flood extents are predicted to be close between the two scenarios.

5.4 Limitations and Accuracy

The estimated average accuracy to which RMA-2 model is able to predict flood levels is inferred based on the outcomes of the model calibration, sensitivity analysis, the quality of input data, the convergence parameter adopted for the simulations and professional judgement. Consideration for each of these items is typically required to reliably assess the confidence level assigned to the flood model predictions.

Although quantitative consideration of each of the above is ideal, it tends to result in an overly complicated approach to determining accuracy. In an alternative, simplified approach the model accuracy can be defined based on consideration of the above mentioned variables from a high-level

quantitative review along with the maximum range of flood level differences predicted through the sensitivity analysis. This is considered appropriate as long as variation of inflows, channel elevations and roughness parameters used in the model are within reasonable and expected margin of uncertainty for those parameters.

Based on this approach the Little Bow River RMA-2 model has been estimated to have a confidence level for peak flood elevation prediction of +/-0.40 m for 80% of the area.

Other limitations relative to the modelling exercise were discussed herein and can be summarized as follows:

- Limited existing information on the bathymetry of actual Little Bow River channel. Sensitivity analysis indicates that the active channel has a minor effect on water levels associated with a 2013 flood magnitude. Locally and cumulatively, however, having this information would improve model accuracy and overall calibration results. In addition,, at lower flows (e.g. spill-over to the Little Bow River at 750 m³/s) the channel bathymetry will likely play a more important role in determining water levels;
- Lack of data on the TVR bathymetry, especially at the 10 km upstream end of the Reservoir's on the northern. In addition to the above considerations relative to the River channel, an updated bathymetry of the Reservoir would help to re-create effects on water levels in this area. Moreover, an extension of the Study Area to include the entire TVR would allow to set up downstream boundary condition directly at the active WSC level station 05AC940, potentially improving accuracy;
- Limited existing information on the minor agricultural crossing (e.g. fording) and culverted crossing along the Little Bow River channel. Again their limited capacity has little effect on water levels associated with a 2013 flood magnitude. However, at lower flows they will increasingly play a more important role as intermediate control sections;
- Lack of flood high water mark information to perform a model validation step. Additional peak flow information from another significant flood event is not available for model validation. This would help improve our understanding of model uncertainty and robustness;
- Lack of a measured 2013 inflow flow hydrograph (including peak magnitude, duration and overall volume) on the Little Bow River. The hydrograph used for modelling purposes is based on an estimated hydrograph from an upstream modelling exercise which adds another level of uncertainty with the model. In addition, the upstream model (i.e. the High River Flood Model) also has significant uncertainty in terms of its upstream boundary condition (input flow hydrograph) as the magnitude was determined post-flood by the slope-area and backwater calculation methods; and the hydrograph shape was estimated based on past flood hydrograph information as all monitoring stations were destroyed during the 2013 flood;
- Limited detail of the model domain and the large extent of the model. The Little Bow River Flood Model has been developed as a regional model and may lack detail required to accurately simulate local hydraulic effects caused by small changes in topography, land use or



infrastructure. This would create local errors in the model that would be reflected in the calibration results;

- Limited accuracy of the LiDAR surface and its control on floodplain levels and flow patterns. Although LiDAR accuracy is considered very good, even an error in the 10 cm range can cause significant error in flood plain flow and routing because of its sensitivity to elevation over a broad cross-sectional area. This is a major limitation when simulating relatively shallow flooding throughout a complex flood plain;
- The accuracy in which the DEM can be represented by the model surface network. Significant detail can be lost through this process which must consider the model run times, project resources and the overall goal of the project;
- Limitations with the accuracy of HWMs that were collected in two separate sessions, about 19 or 40 months following the flood event. The HWMs had to be estimated in many cases and very few were considered good to excellent in quality;
- Potential of hydraulic effects of buildings not included in the model. This is an important factor if the HWM is near a building that is not in the model;
- Inability of the model to represent scour as the flood wave passes; at least part of the error between estimated water levels and HWMs, for example in Figure 5-26 or 5-30, is likely due to this mechanism. Scour was likely significant at the bridges and most of the water went probably through bridge opening versus around abutments;
- Inability of the model to reflect the failure of bridges and the pre and post-water levels associated with this mechanism at crossing with 168 St E, 232 St E and 296 St E. During flooding, water levels likely experienced back water effects upstream due to pressurized or confined flow associated with the bridges and potentially surges downstream which would have influenced HWMs and limited the ability of the model to replicate the marks; and
- RMA-2 only provides results in the subcritical domain. At some crossings, flows within the channel at the crossing may have been super critical. At these locations the model would not be able to accurately predict the water levels. For example near the bridge water levels would be significantly overestimated as shown at crossing with 168 St E.

6. SUMMARY AND RECOMMENDATIONS

A two-dimensional model of the Little Bow River between Highway 2 and the TVR northern end (Little Bow River Flood Model) has been set up to evaluate the effects of the flood mitigation measures completed or under consideration in the Town after the June 2013 flood event.

The model geometry has been derived mainly from LiDAR terrain data and supplemented by active channel bathymetric data associated with 2001/2002 modelling exercise (MSA 2002). The 2013 input flow hydrograph for the model, used as the upstream boundary condition, was adopted from an upstream model (i.e. the High River Flood Model) under two scenarios (1) the 2013 Landscape Scenario; and 2) Post-mitigation Scenario 28A). The 2013 Landscape Scenario input flow hydrograph represented flood conditions at the time of the 2013 flood before any mitigation measures were constructed or planned. The 2013 Landscape Scenario has been used for the calibration against HWMs left by the 2013 event that were determined during two high water mark survey campaigns.

The model was predominantly calibrated by fine-tuning the models representation of the Little Bow River active channel and control sections at the major crossing, accompanied by fine-tuning of floodplain roughness. After calibration the model predicted peak flood levels for the June 2013 generally in fair agreement with the recorded HWMs, although few local areas still showed discrepancies due to a number of factors. The factors included, among other variables, uncertainty/accuracy of the collected HWMs, limited ability of the regional scale network to represent local hydraulic features and uncertainties in boundary conditions.

The model has been extensively tested in a series of sensitivity analyses aimed at obtaining statistical parameters on flood level variations derived from changes in flow magnitude and length, channel and floodplain roughness, channel elevations and downstream boundary conditions. The analysis indicated that flow magnitude is the most sensitive input variable influencing the produced results, followed by roughness of the floodplain areas. The results were instead much less influenced by variables such as active channel roughness, hydrograph duration or downstream boundary conditions and channel bathymetry.

In addition to the 2013 Landscape Scenario, Scenario 28A was developed to determine the effects of mitigation measures constructed or planned for construction in and around the Town. The system of dikes and other flood mitigation infrastructures completed or proposed on the Highwood River for protection of the Town (i.e. Scenario 28A) results in a reduced flood volume and peak routed towards the Little Bow River. For a flow equivalent to the 2013 flood magnitude, with an estimated peak of $1,820 \text{ m}^3/\text{s}$ (above Woman's Coulee Canal Inlet), the flow magnitude routed to the Little Bow is estimated to be reduced from 560 to $410 \text{ m}^3/\text{s}$ at its peak.

The effects assessment portion of the study consisted of comparing the 2013 Landscape Scenario results to the Scenario 28A results. A summary of the effects can be described as follows:

- The post-mitigation flood levels associated with Scenario 28A decrease substantially over the Study Area for an upstream flood magnitude on the Highwood River of $1,820 \text{ m}^3/\text{s}$. The water level decreases range from about 0.20 to 0.50 m over the study area. Maximum and minimum decreases have been estimated at 0.69 m and 0.00 m;



- Velocity decreases typically ranging between -0.1 to -0.6 m/s with very occasional increases contained within 0.1 m/s or less and due to local hydraulic effects; and
- Extents of the flooded areas, in consideration of the over-sized valley and active channel morphology of the Little Bow River downstream of HWY2, are reduced in limited locations.

Recommendations to improve the model's shortcomings and limitations in the version used for the present Report includes:

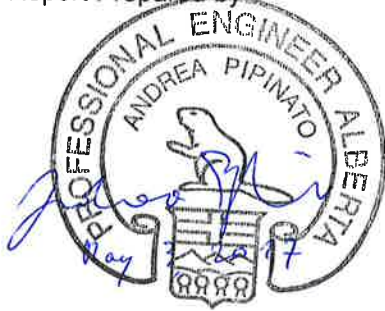
- Re-establish HWMs in those areas where the model appears to have significant errors;
- A bathymetry survey of the Little Bow River channel post 2013 flood
- A bathymetry survey of TVR's northern end associated with the domain;
- Additional survey to confirm additional topography and double check LiDAR information in areas characterized by relatively shallow flooding through a complex flood plain where significant error appears to exist;
- Run further sensitivity tests which includes the effects of the bridges eventually destroyed during the June 2013 flood as produced before total collapse;
- Verify/adjust the model performance for major event less extreme than the June 2013 flood;
- Update the upstream boundary condition as the High River Flood Model is advanced and refined; and
- Extend the model to cover stations where WSC can provide historical variations of a reservoir water level as downstream boundary condition and a stage-discharge curve for a stable cross section (for example Twin Valley Reservoir at Highway No. 529, 05AC940).

The regional Flooding Model produced for the Little Bow River can be a tool for design purposes which can be made more robust by enhancing the details in the model DEM in the area of interest and implementing any or all of the suggested recommendations locally. The regional model will always provide a base for the detailed DEM and boundary conditions as a minimum. It also provides an assessment tool for planning considering extreme flooding with water levels with an accuracy of approximately +/-0.4 m.

7. CLOSURE

We trust that this report satisfies your current requirements and provides suitable documentation for your records. If you have any questions or require further details, please contact the undersigned at any time.

Report Prepared by



Andrea Pipinato, M.Sc., M.Eng., P.Eng.
Senior Water Resource Engineer

Senior Review by

A blue ink handwritten signature, likely belonging to Joal Borggard, written in a cursive style.

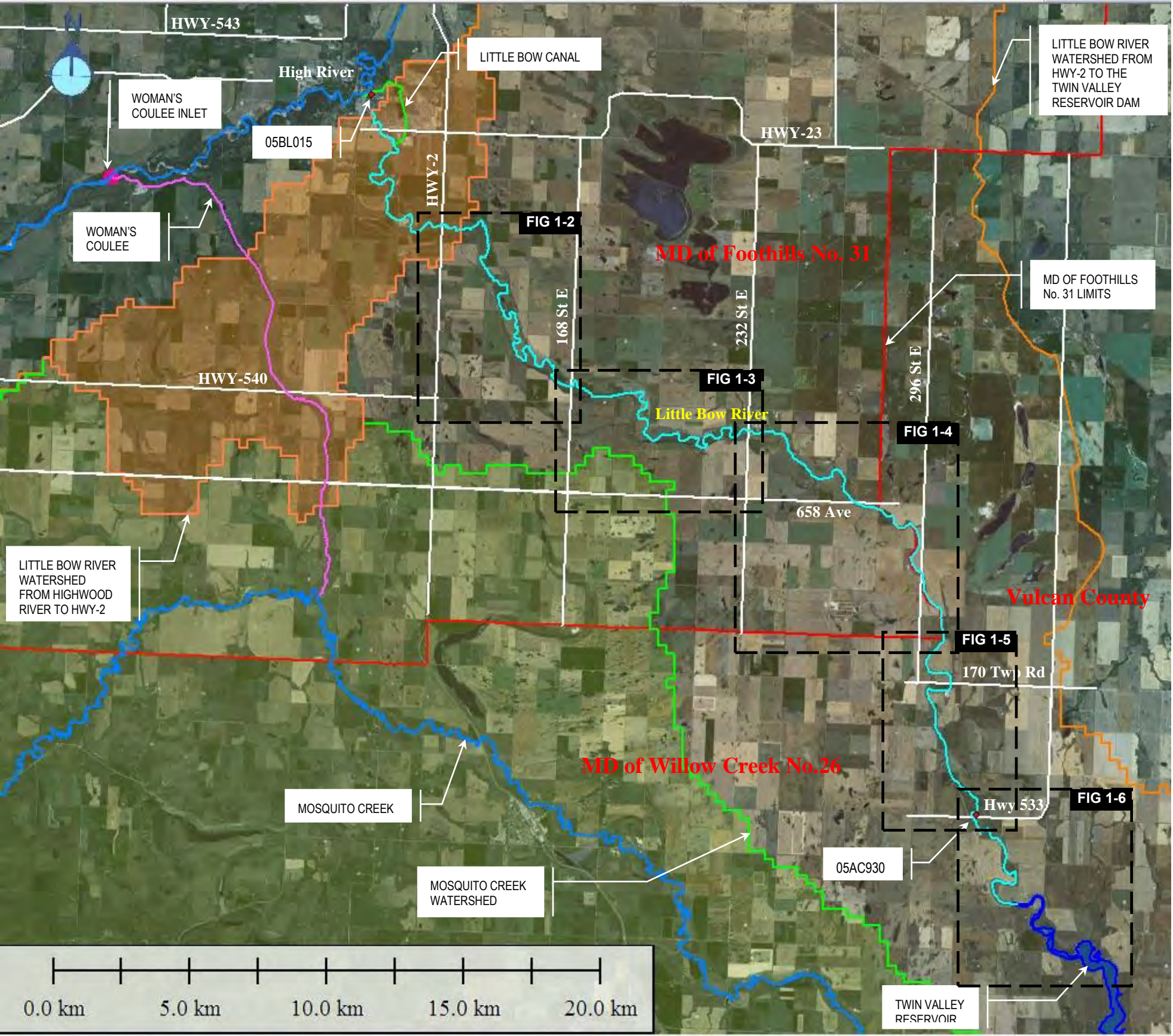
Joal Borggard, M.Eng., M.E.Des., CPESC, LEED AP
Technical Director, Water Resource Engineering


APEGA Permit to Practice No. P00725

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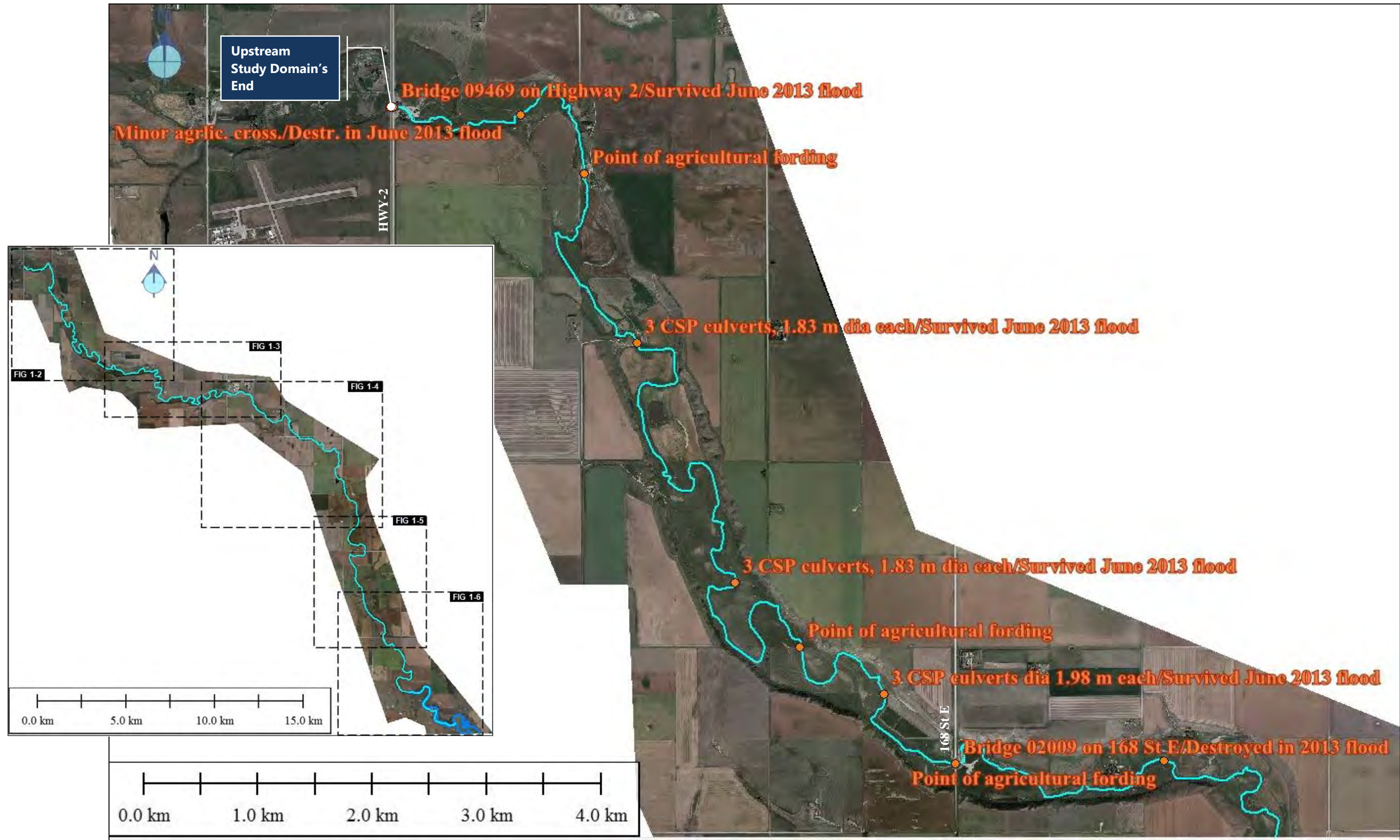
Figures



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Study Area Overview				
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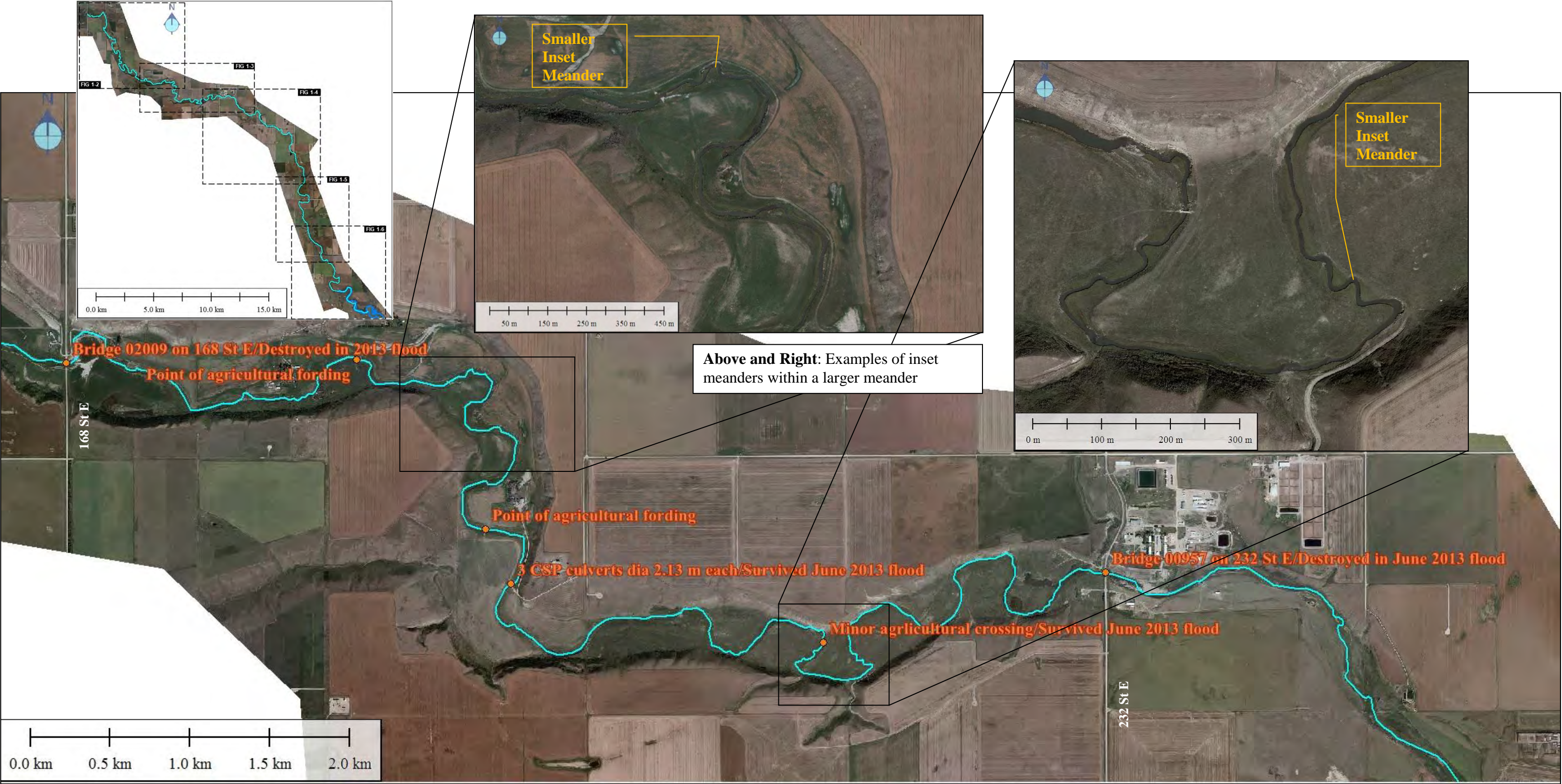
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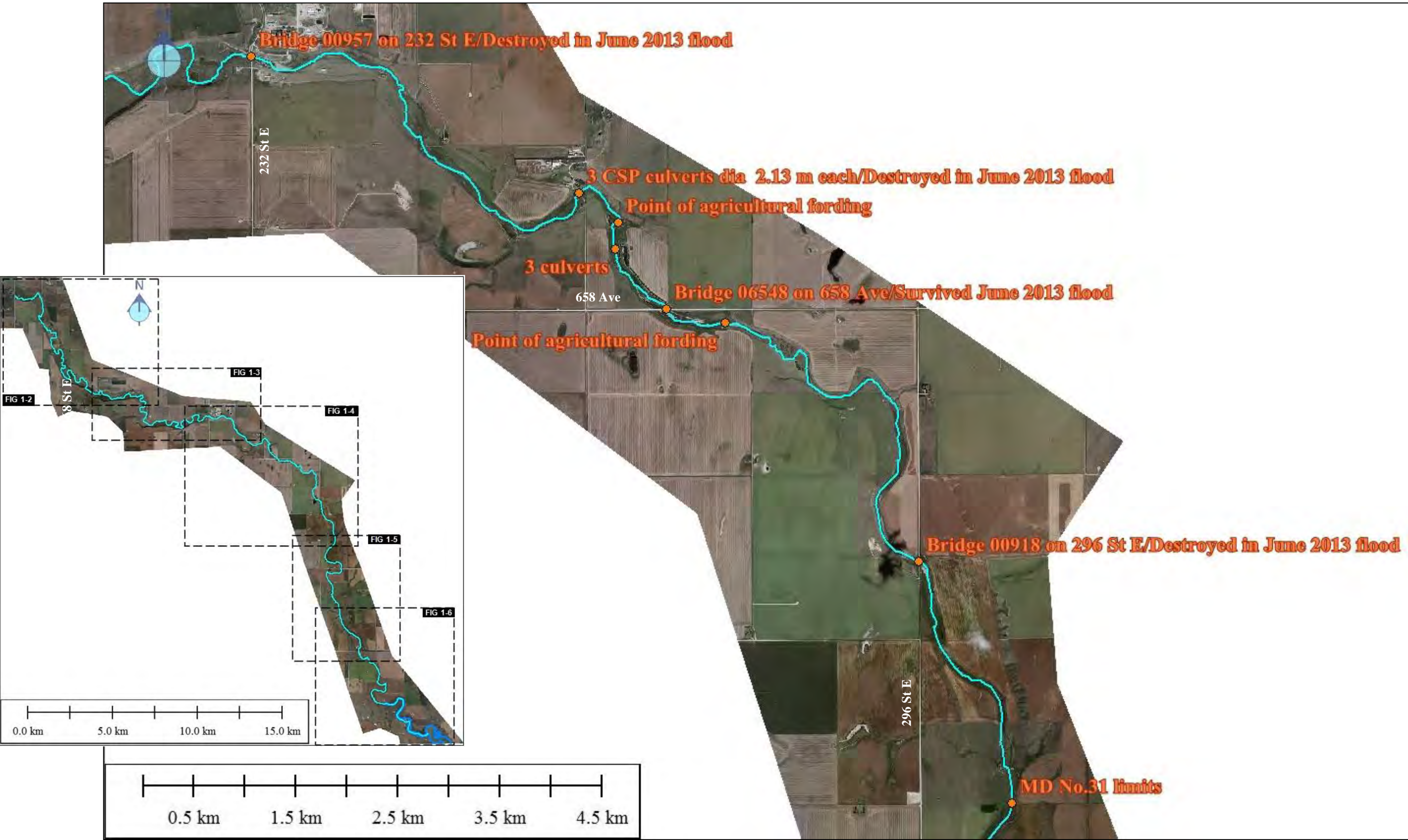
Municipal District of Foothills No. 31- Little Bow River Modelling

River Model Extents Map (1 of 5)

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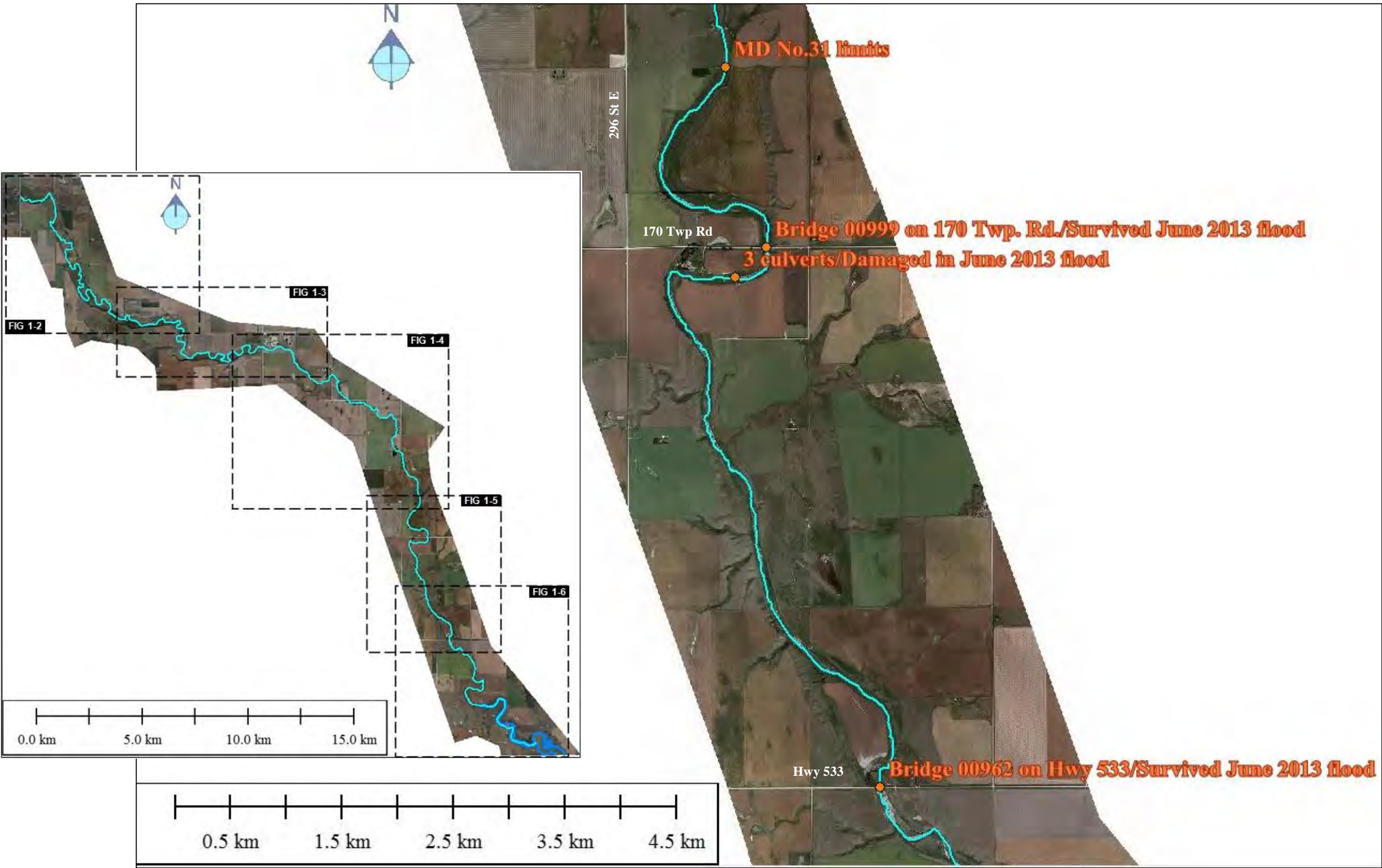
Municipal District of Foothills No. 31- Little Bow River Modelling			
River Model Extents Map (2 of 5)			
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River Model Extents Map (3 of 5)

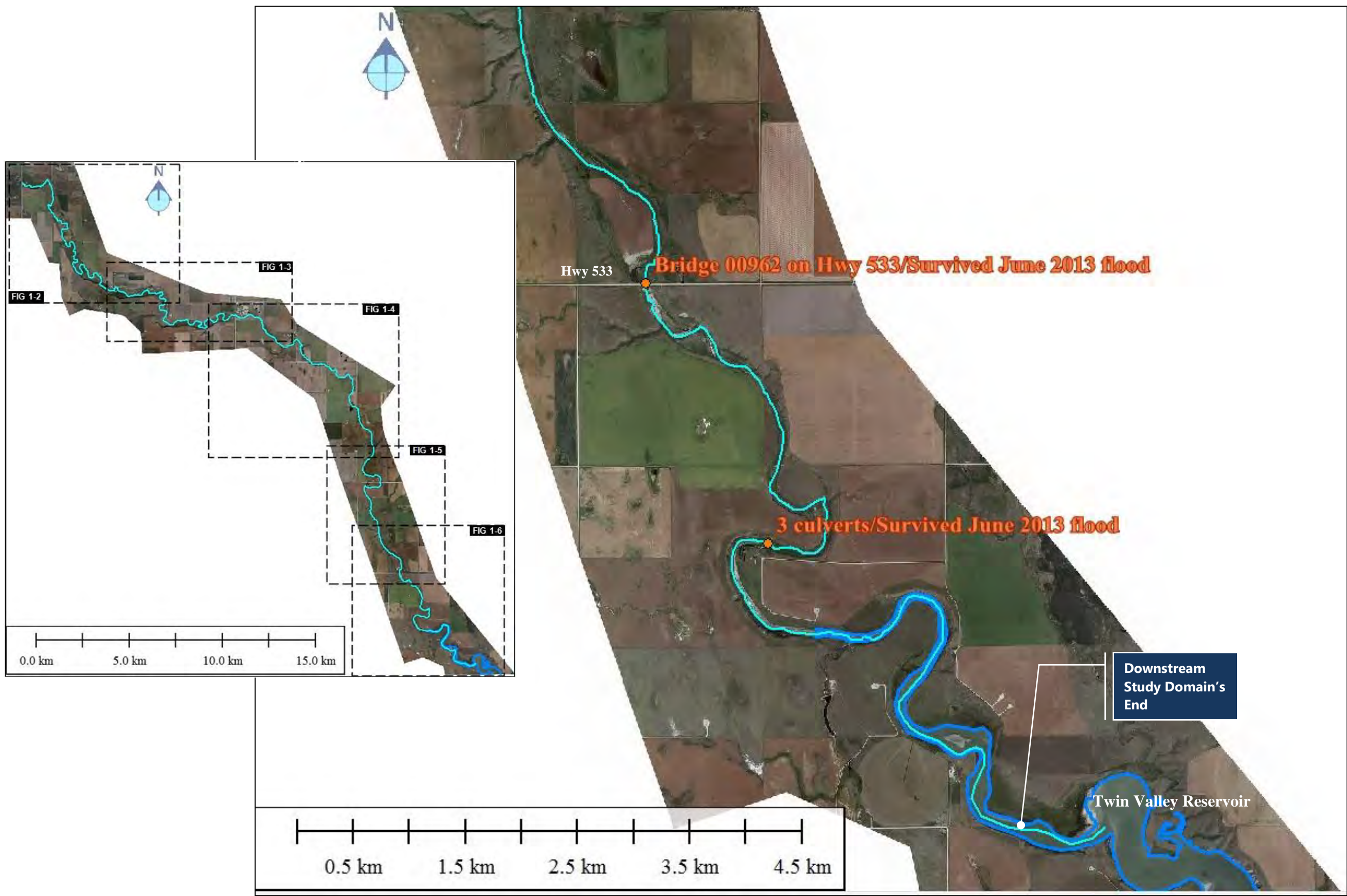
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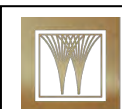
River Model Extents Map (4 of 5)

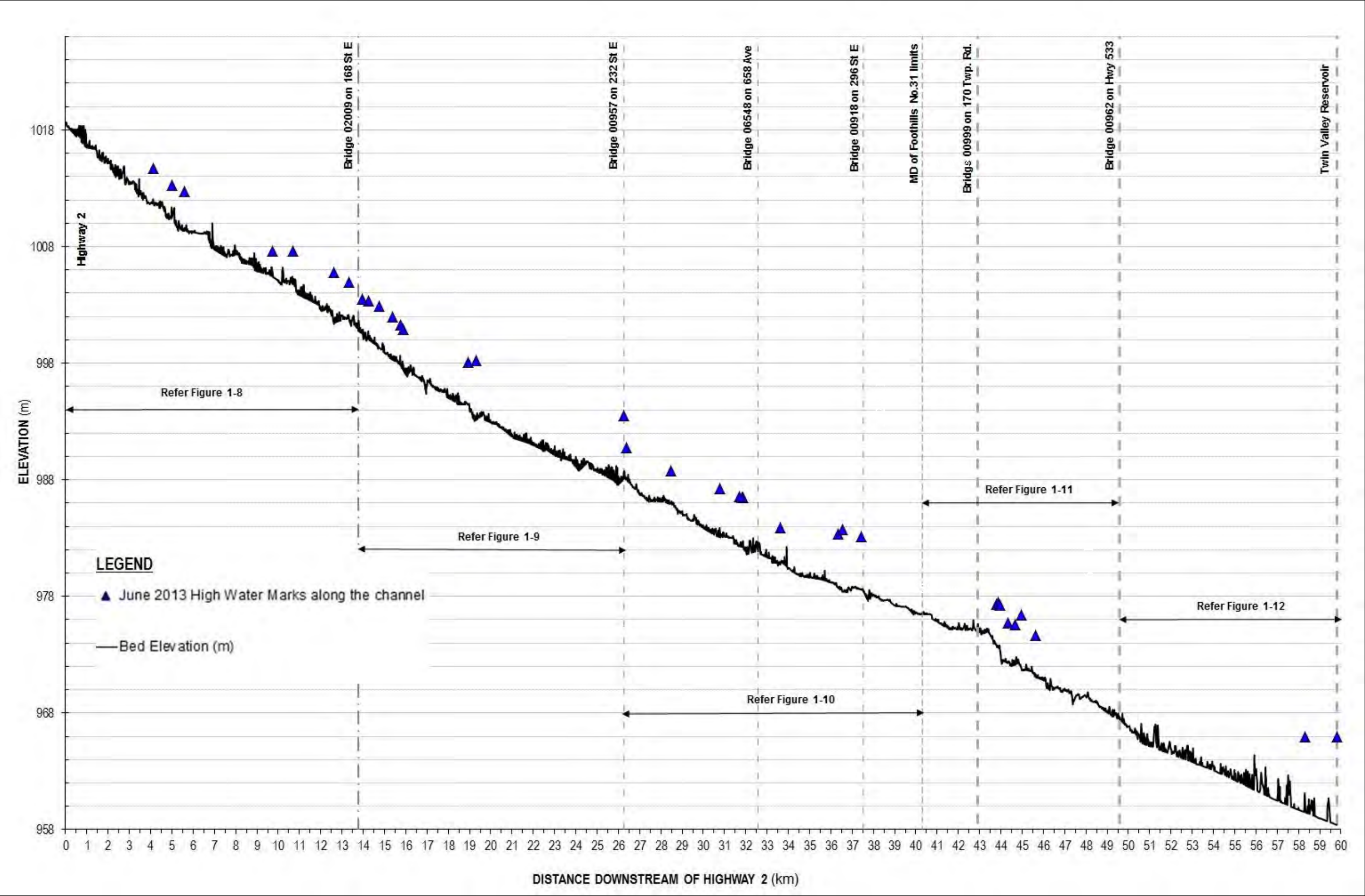
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River Model Extents Map (5 of 5)

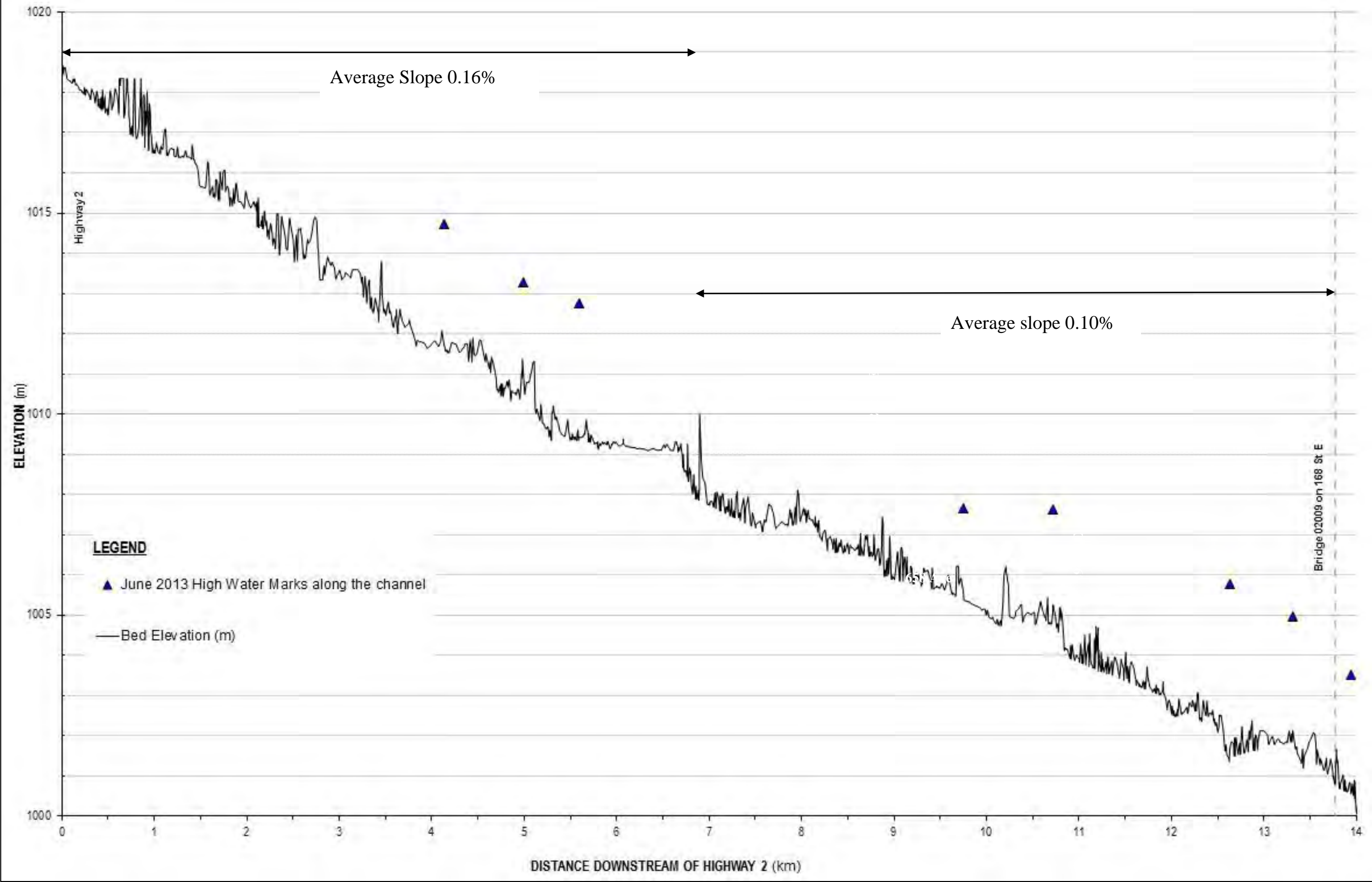
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Municipal District of Foothills No. 31- Little Bow River Modelling

River Model Extents Profile - Overview

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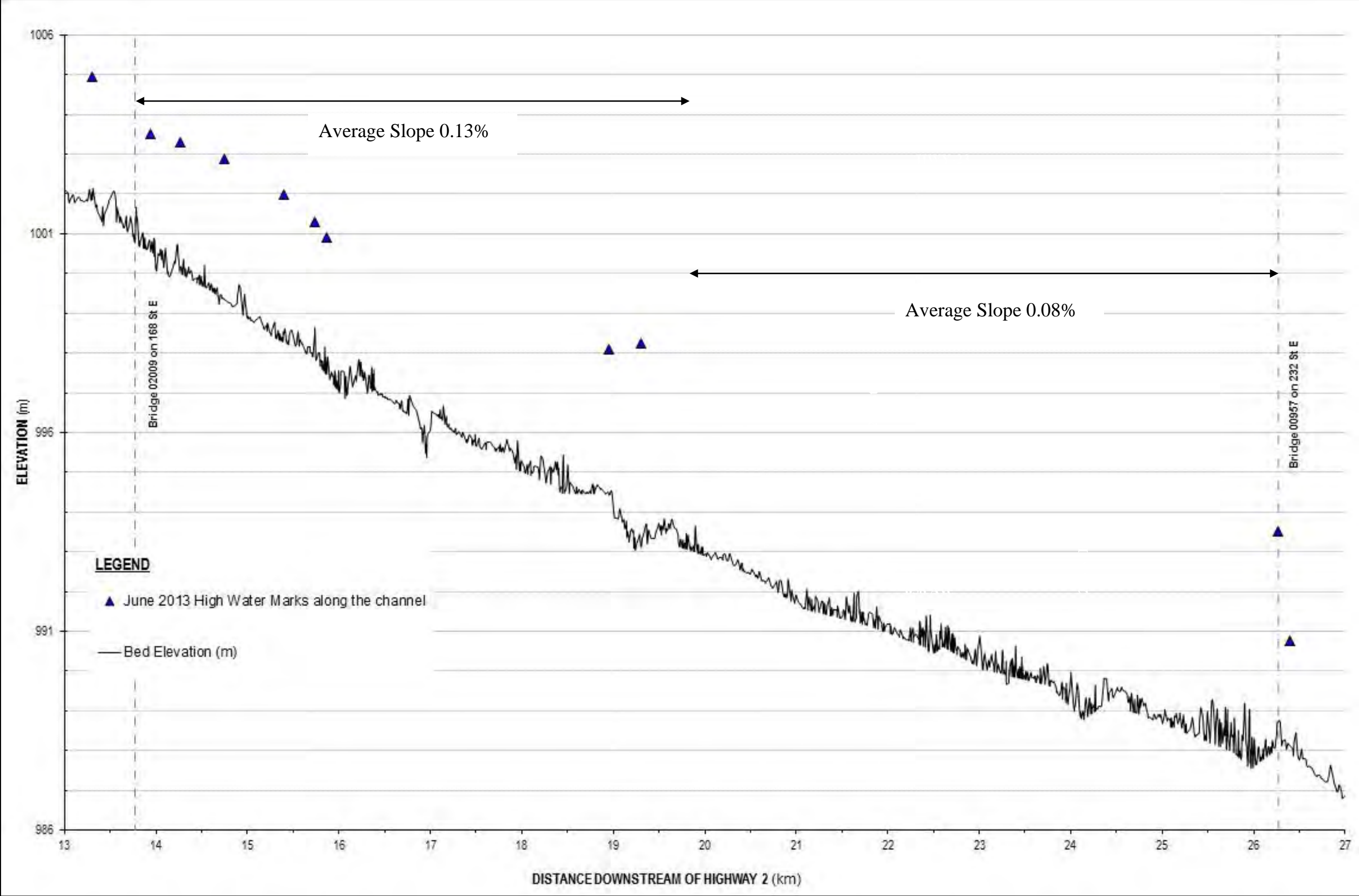


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River Model Extents Profile (1 of 5)			
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River Model Extents Profile (2 of 5)

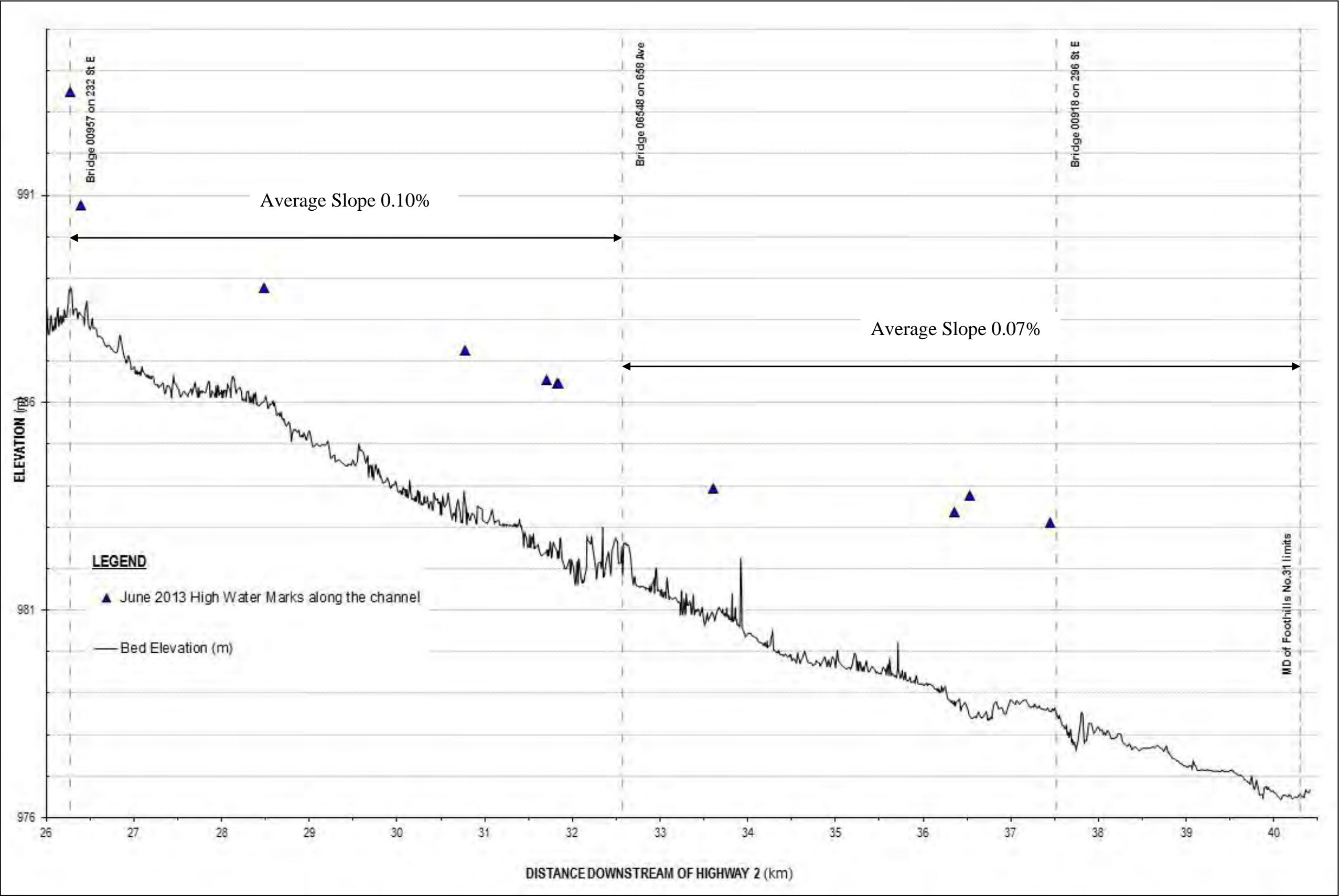
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River Model Extents Profile (3 of 5)

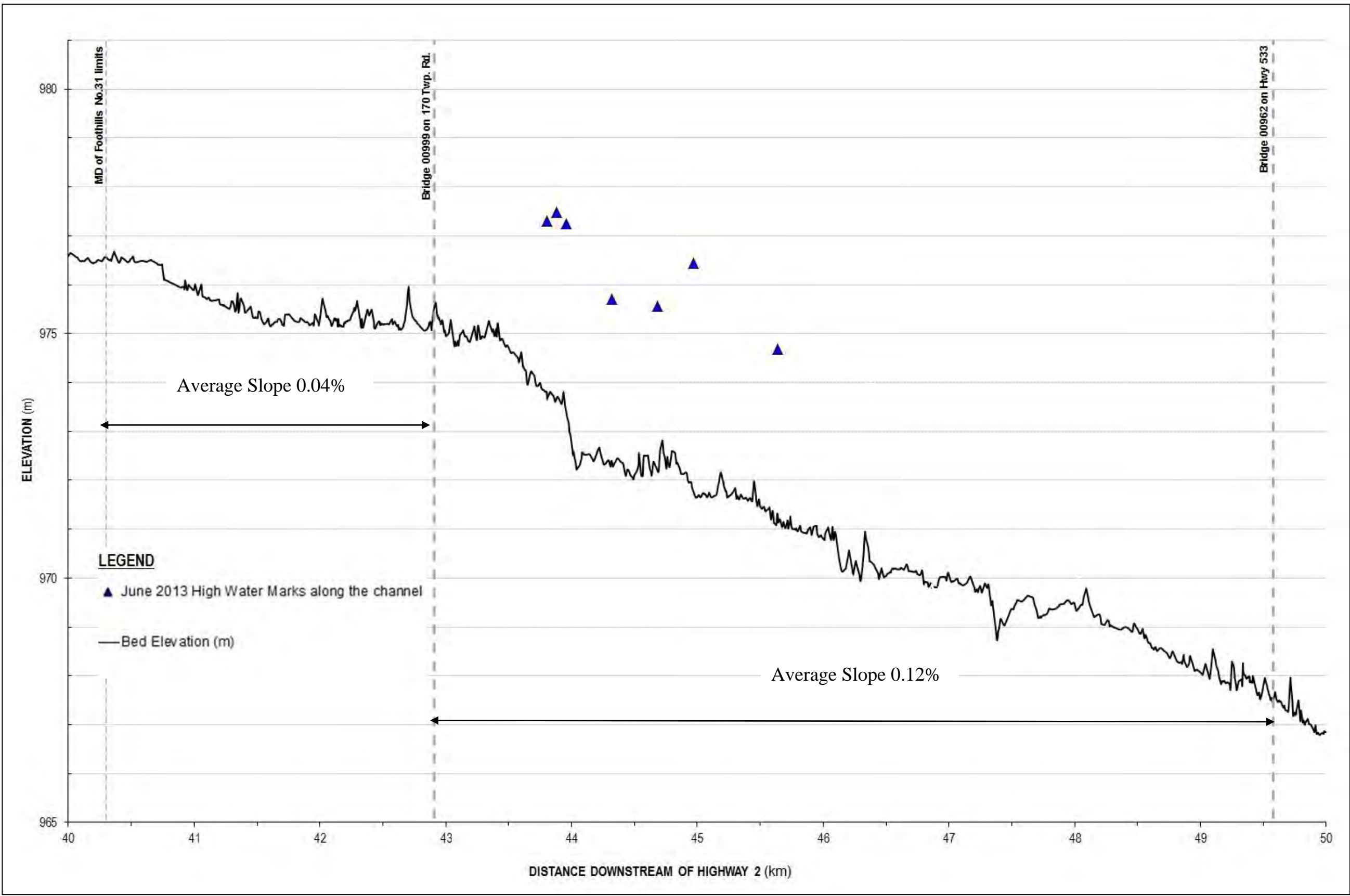
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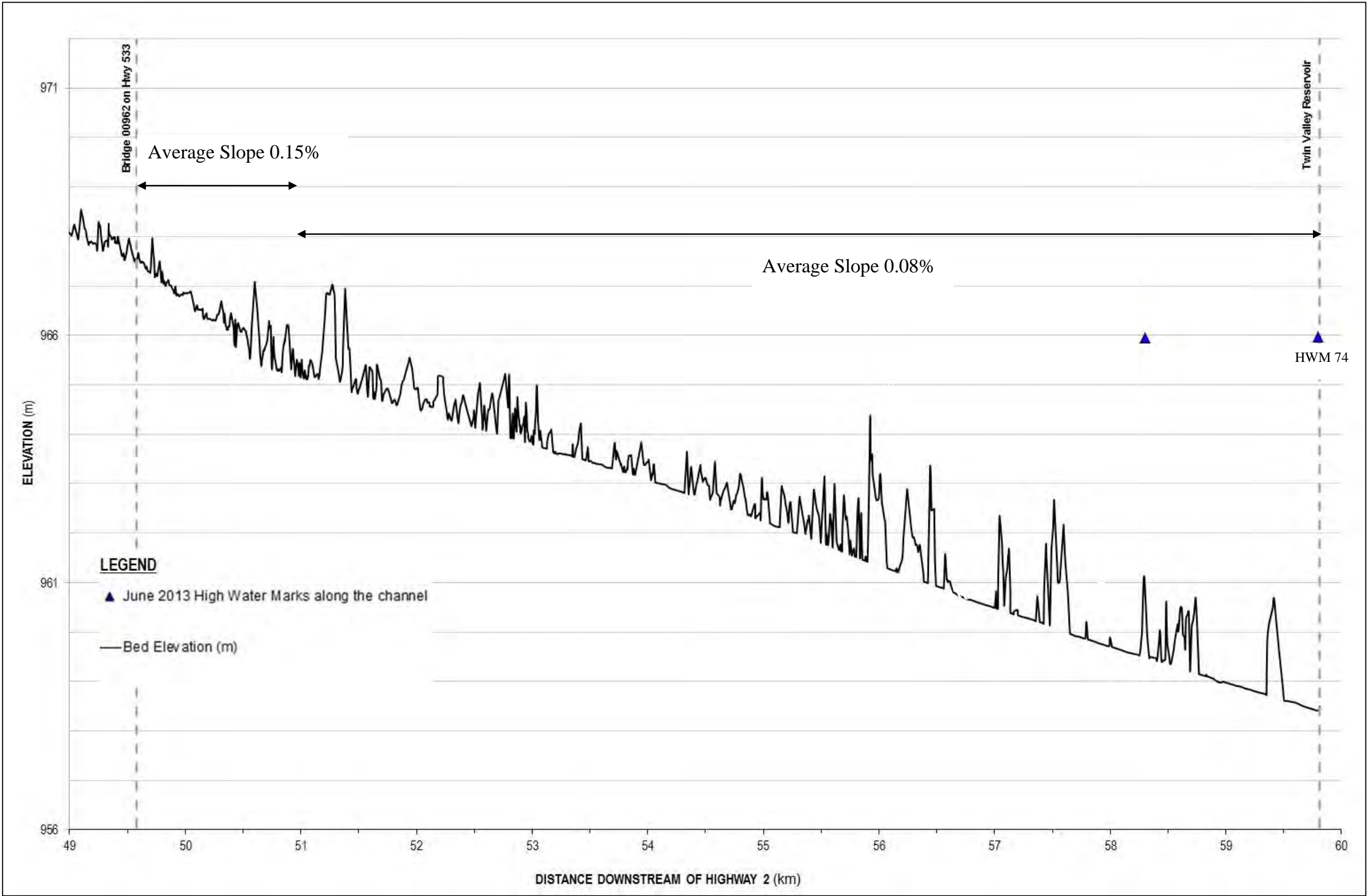


Municipal District of Foothills No. 31- Little Bow River Modelling				
River Model Extents Profile (4 of 5)				
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Created By:	AP	Reviewed By:	JB	Rev: 1
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River Model Extents Profile (5 of 5)

Date: May 1, 2017


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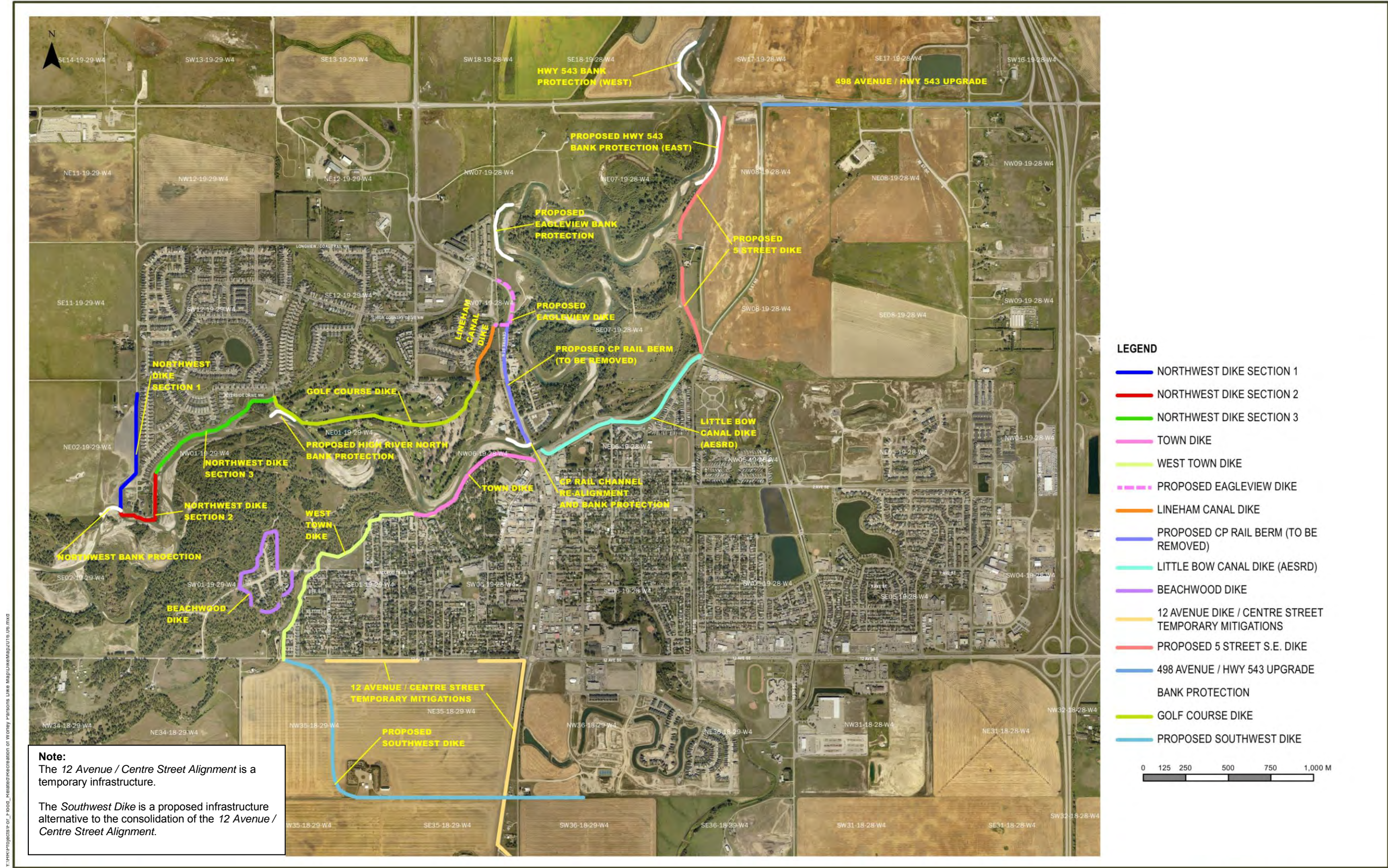
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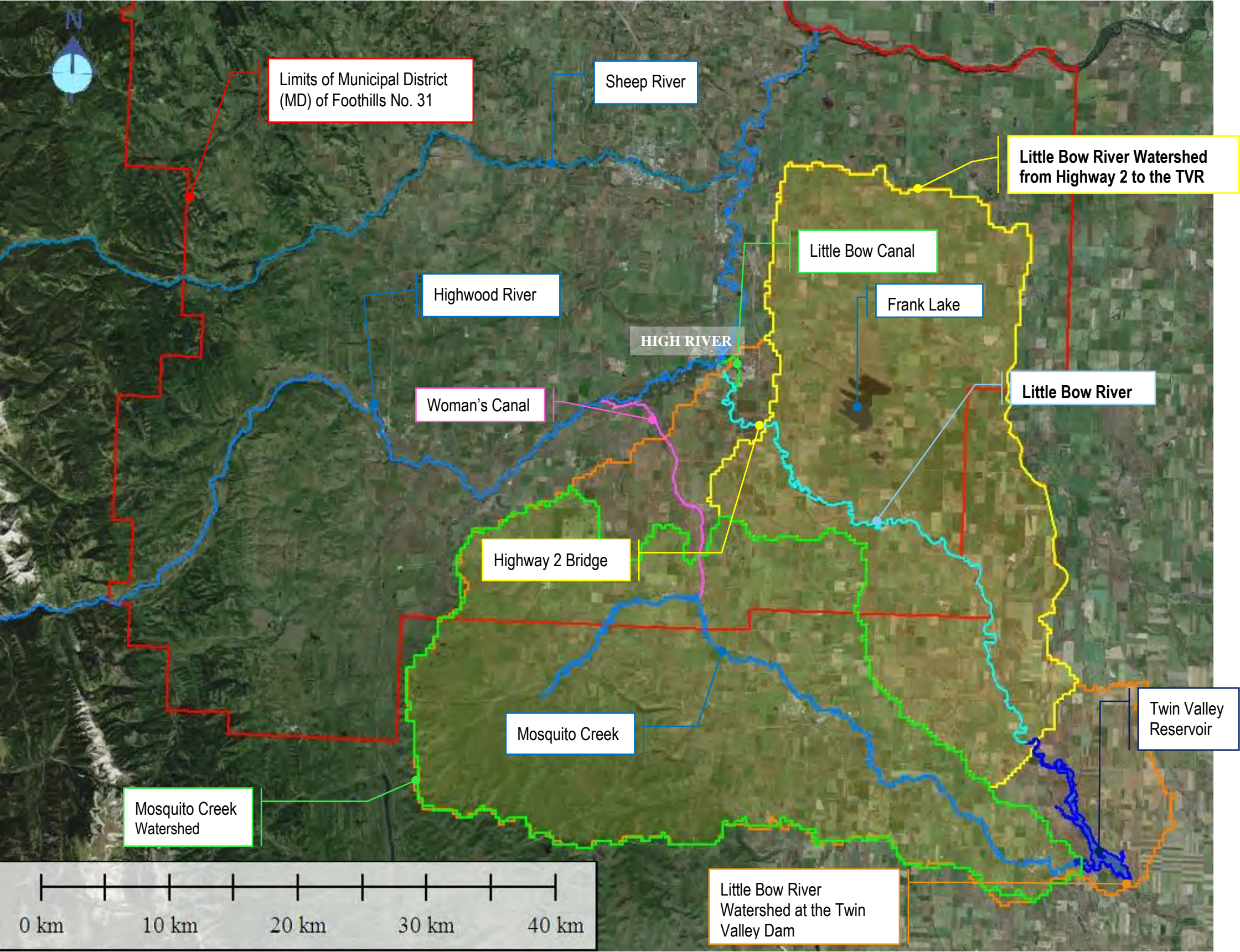
Municipal District of Foothills No. 31- Little Bow River Modelling				
Model Extents for High River Town Flood Model				
<div><div><div>Advisian</div><div>WorleyParsons Group</div></div></div>	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 1-13
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Town of High River Flood Mitigation Infrastructures (Existing and Proposed)

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Municipal District of Foothills No. 31 – Little Bow River Modelling

Little Bow River Watershed



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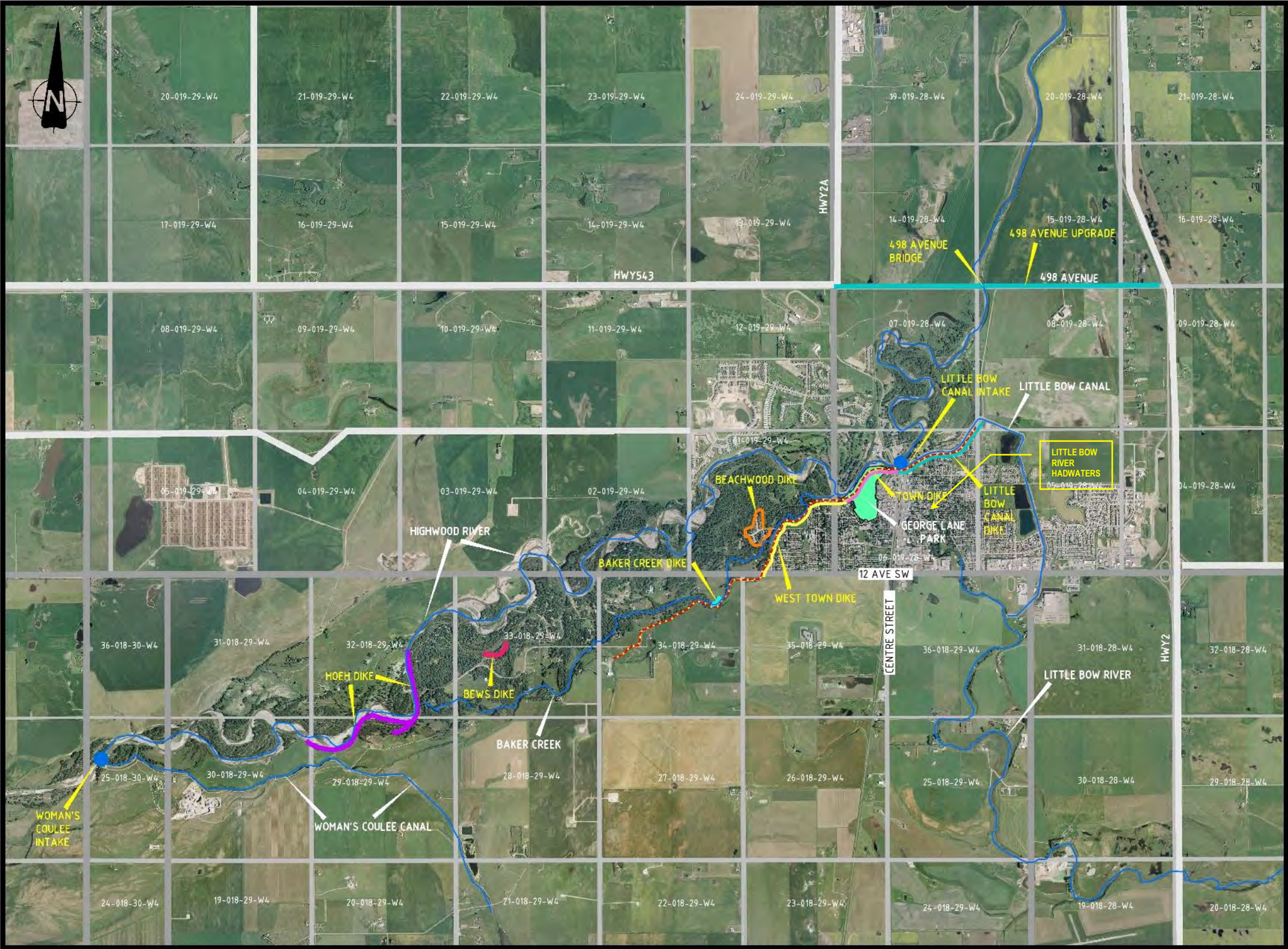
Date: Jan 30, 2017

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Figure No: 2-1

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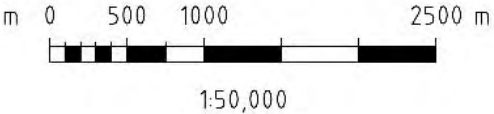


DATA SOURCE:

- 1. M.D. BOUNDARY REFERENCE FROM M.D. OF FOOTHILLS NO. 31, LAND USE MAP
- 2. IMAGE SOURCE: TOWN OF HIGH RIVER 2005

LEGEND:

- WATERCOURSE/CANAL
- LITTLE BOW-HIGHWOOD WATER SHED DIVIDE
- WEST TOWN DIKE
- TOWN DIKE
- BAKER CREEK DIKE
- HOEH DIKE
- BEACHWOOD DIKE
- BEWS DIKE
- INTAKE



Municipal District of Foothills No. 31 – Little Bow River Modelling

Key Features between Woman’s Coulee Canal Inlet and the Town of High River


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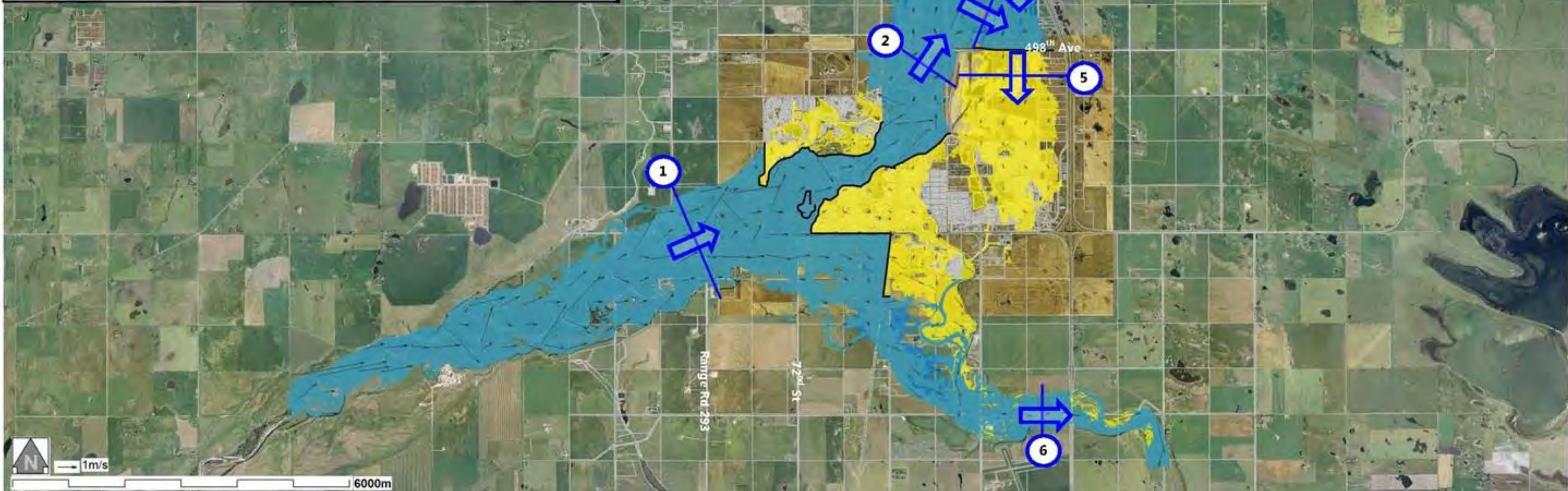
TABLE 1 Summary of Peak Flow Differences for Existing and Post Mitigation Scenario 28A

Location	Predicted Peak Flow (m³/s)	
	2013 Landscape Scenario	28A
1. Upstream of Town	1820	1820 0
2. Upstream of 498 Ave (Highwood River)	1225	1405 180
3. Upstream of HWY2 (Highwood River)	955	1245 290
4. To 498 Ave (North of 498 Ave)	200	155 -45
5. To Hampton Hills (South of 489AVE)	200	0 -200
6. Upstream HWY2 (Little Bow River)	560	410 -150

Note: Post-Mitigation Scenario 28A includes all proposed berms/dikes

LEGEND

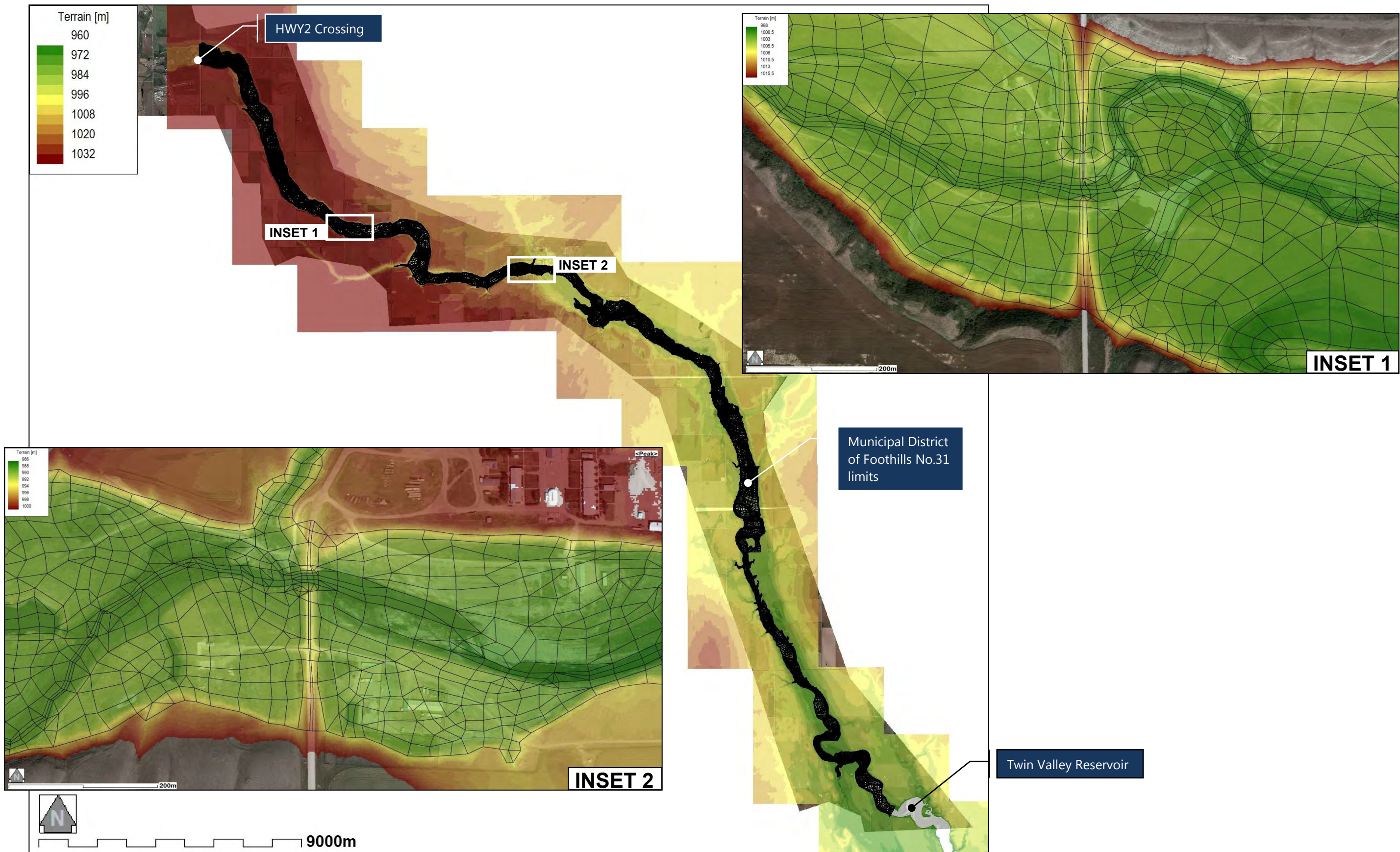
- Predicted June 2013 Flood Extents for Existing Conditions (2013 Landscape Scenario)
- Predicted June 2013 Flood Extents for Post-Mitigation Condition 28A (Post-Mitigation)



Municipal District of Foothills No. 31 – Little Bow River Modelling


Flow Split Summary for 2013 Flood Equivalent

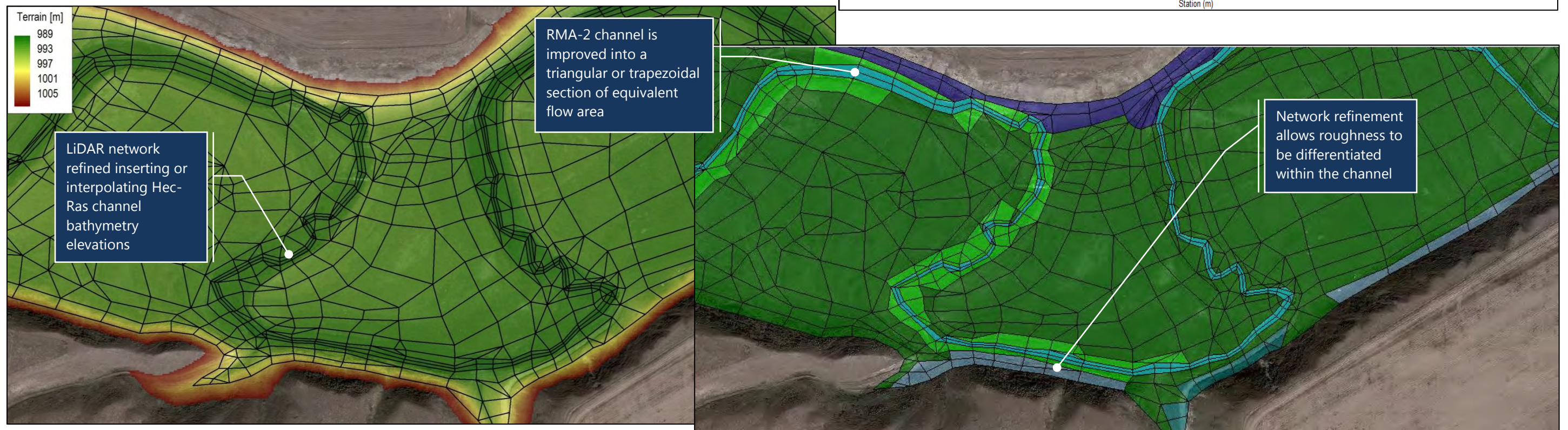
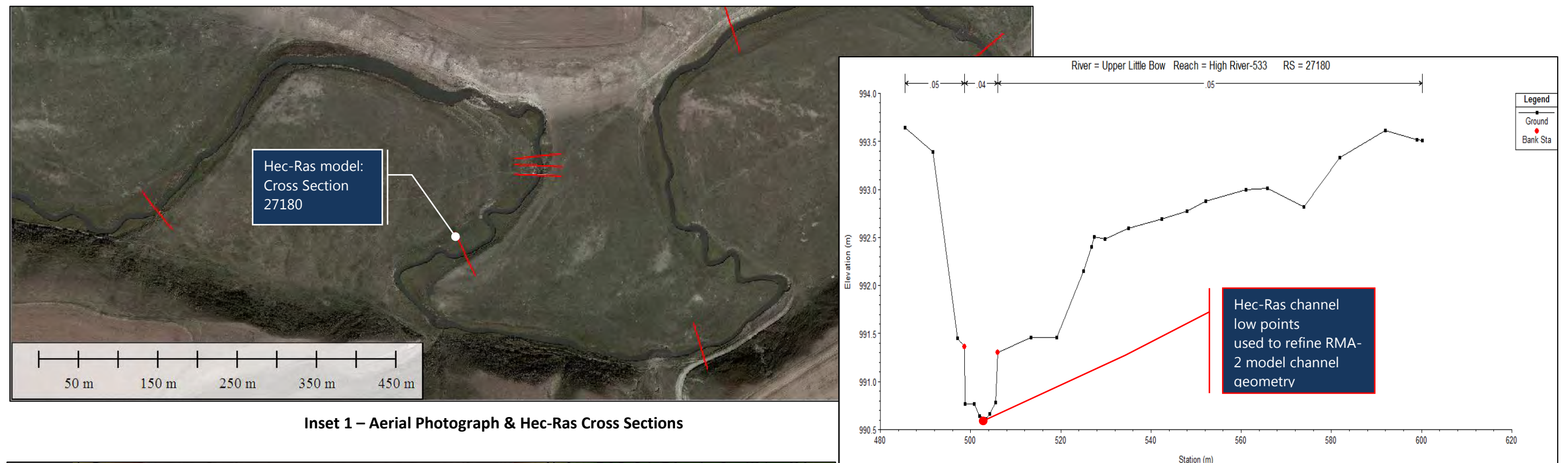
<div><div></div><div><div>Advisian</div><div>WorleyParsons Group</div></div></div>	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\IGBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 2-3	Rev: 0
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.			



Municipal District of Foothills No. 31 – Little Bow River Modelling

Overview of the Little Bow River RMA-2 Model Network

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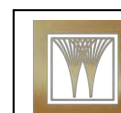


Inset 3 – RMA-2 Network & Model Roughness'

Note: Hec Ras model was part of the study:

Mack, Slack and Associates Inc. (MSA), 2002. Upper Little Bow River Mitigation. Hydrotechnical Analysis and Conceptual Design Study.

Prepared for: Alberta Transportation. January 2002. Edmonton, AB.



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Municipal District of Foothills No. 31 – Little Bow River Modelling

Channel Details Incorporated into Little Bow River RMA-2 Model

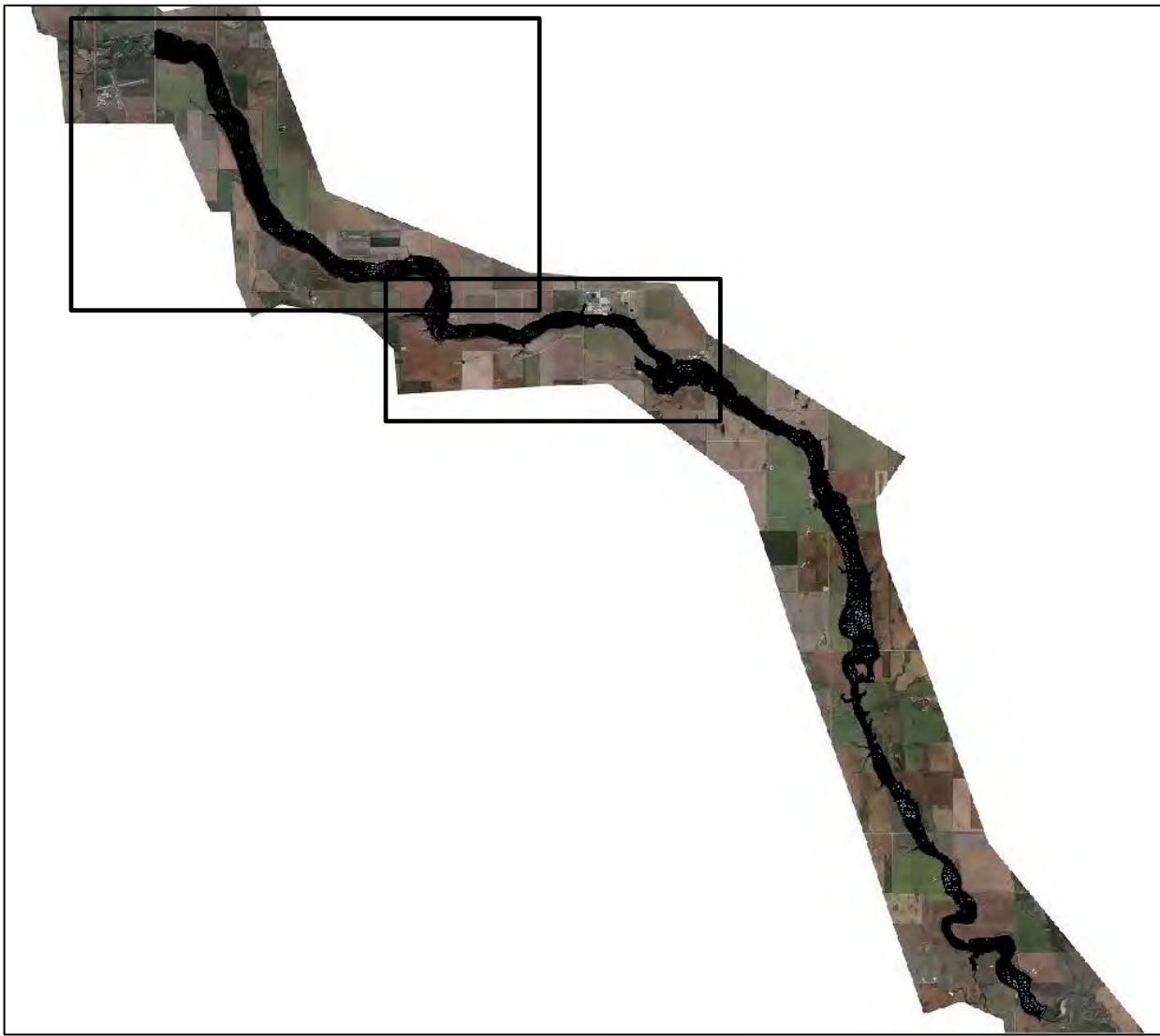
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Figure No: 4-2

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LEGEND

RMA-2 MODEL ELEMENT TYPE^	DESCRIPTION	MANNING'S ROUGHNESS VALUE	MATERIAL COLOUR
2	Vegetated bars and banks (light)	0.050	
3	Pasture / Grassland (light)	0.035	
4	Pasture / Grassland (medium)	0.040	
5	Pasture / Grassland (dense)	0.045	
7	Brush / Forest (dense)	0.140	
8	Brush / Forest (light)	0.080	
10	Pavement / Cut grass	0.030	
11	Cut grass / Some trees	0.040	
14	Clear overbank areas	0.030	
35	River channel	0.023	

Municipal District of Foothills No. 31 – Little Bow River Modelling

Adopted Roughness Distributions for the Little Bow River RMA-2 Model (1 of 3)

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Reviewed By: JB

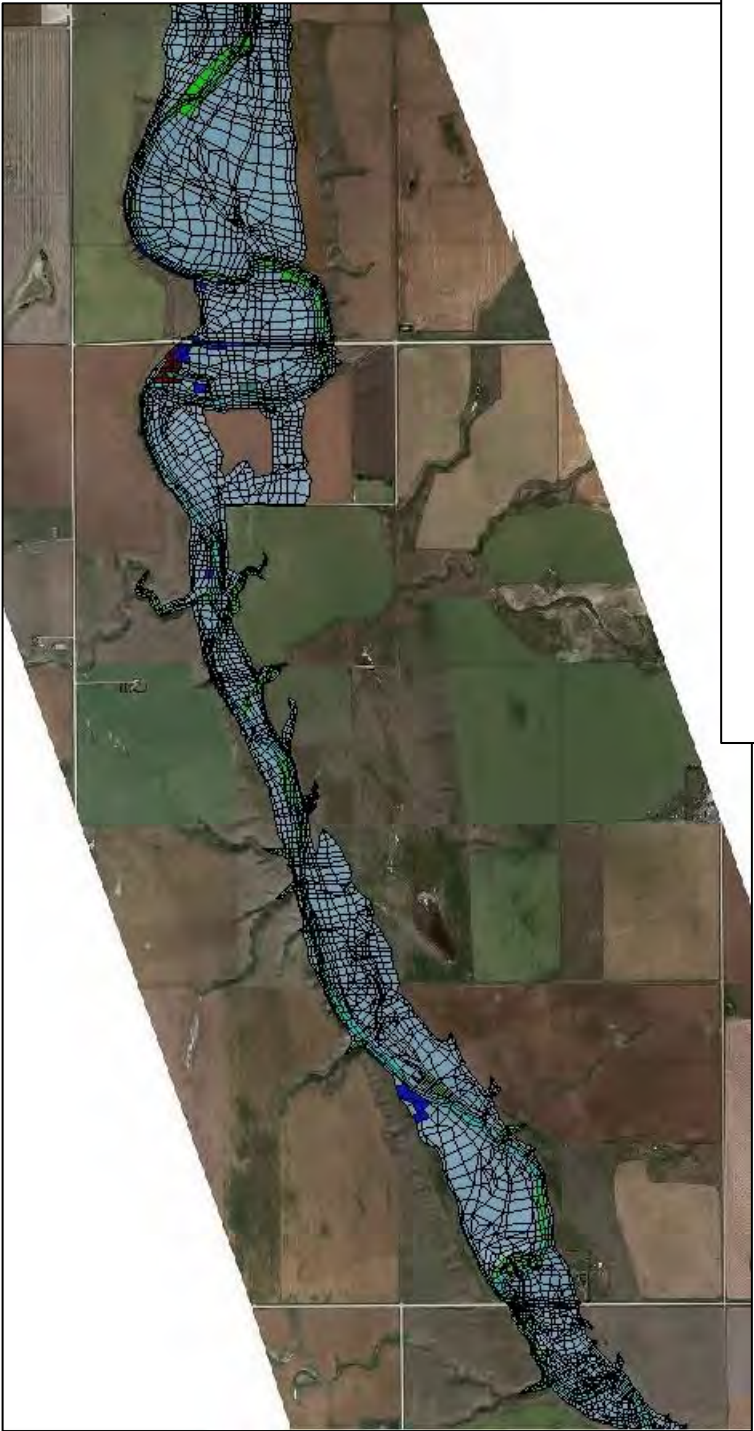
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

Figure No: 4-3

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8	Brush / Forest (light)	0.080	
10	Pavement / Cut grass	0.030	
11	Cut grass / Some trees	0.040	
14	Clear overbank areas	0.030	
35	River channel	0.023	

Municipal District of Foothills No. 31 – Little Bow River Modelling

Adopted Roughness Distributions for the Little Bow River RMA-2 Model (2 of 3)



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Reviewed By: JB

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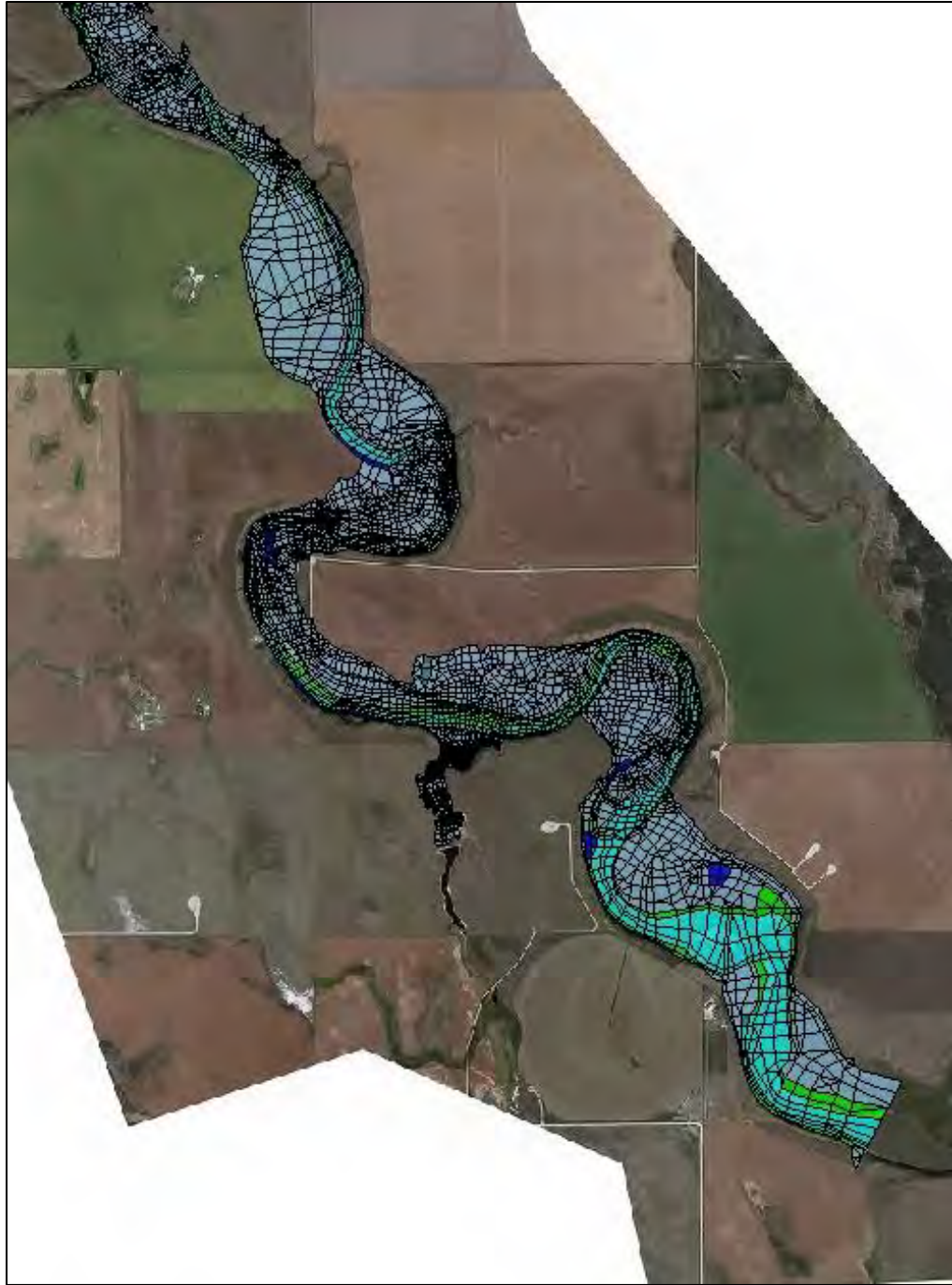
Figure No: 4-4

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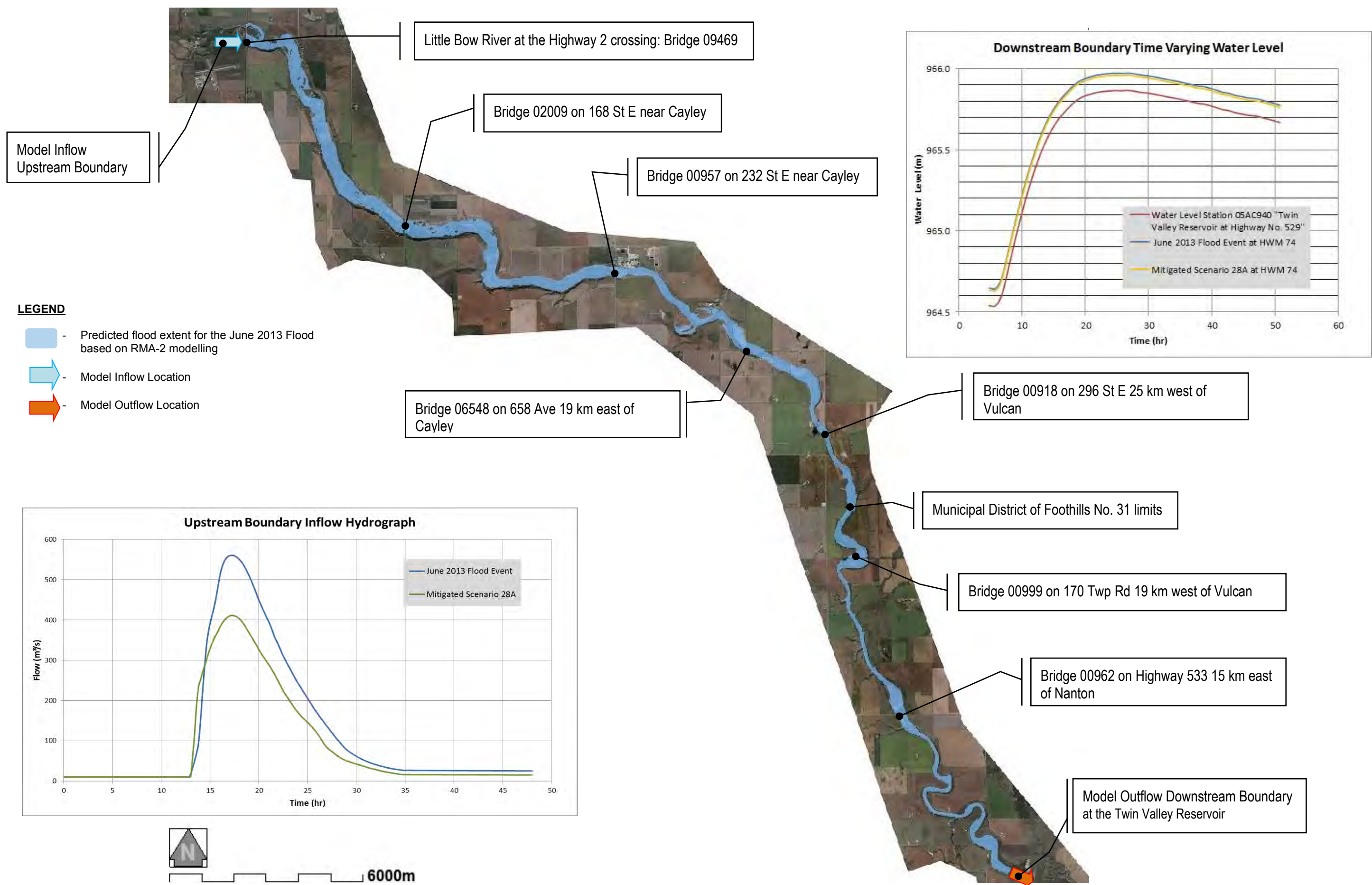
LEGEND

RMA-2 MODEL ELEMENT TYPE^	DESCRIPTION	MANNING'S ROUGHNESS VALUE	MATERIAL COLOUR
2	Vegetated bars and banks (light)	0.050	
3	Pasture / Grassland (light)	0.035	
4	Pasture / Grassland (medium)	0.040	
5	Pasture / Grassland (dense)	0.045	
7	Brush / Forest (dense)	0.140	
8	Brush / Forest (light)	0.080	
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14	Clear overbank areas	0.030	
35	River channel	0.023	

Municipal District of Foothills No. 31 – Little Bow River Modelling

Adopted Roughness Distributions for the Little Bow River RMA-2 Model (3 of 3)

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Municipal District of Foothills No. 31 – Little Bow River Modelling

Location of Little Bow River RMA-2 Model Boundaries



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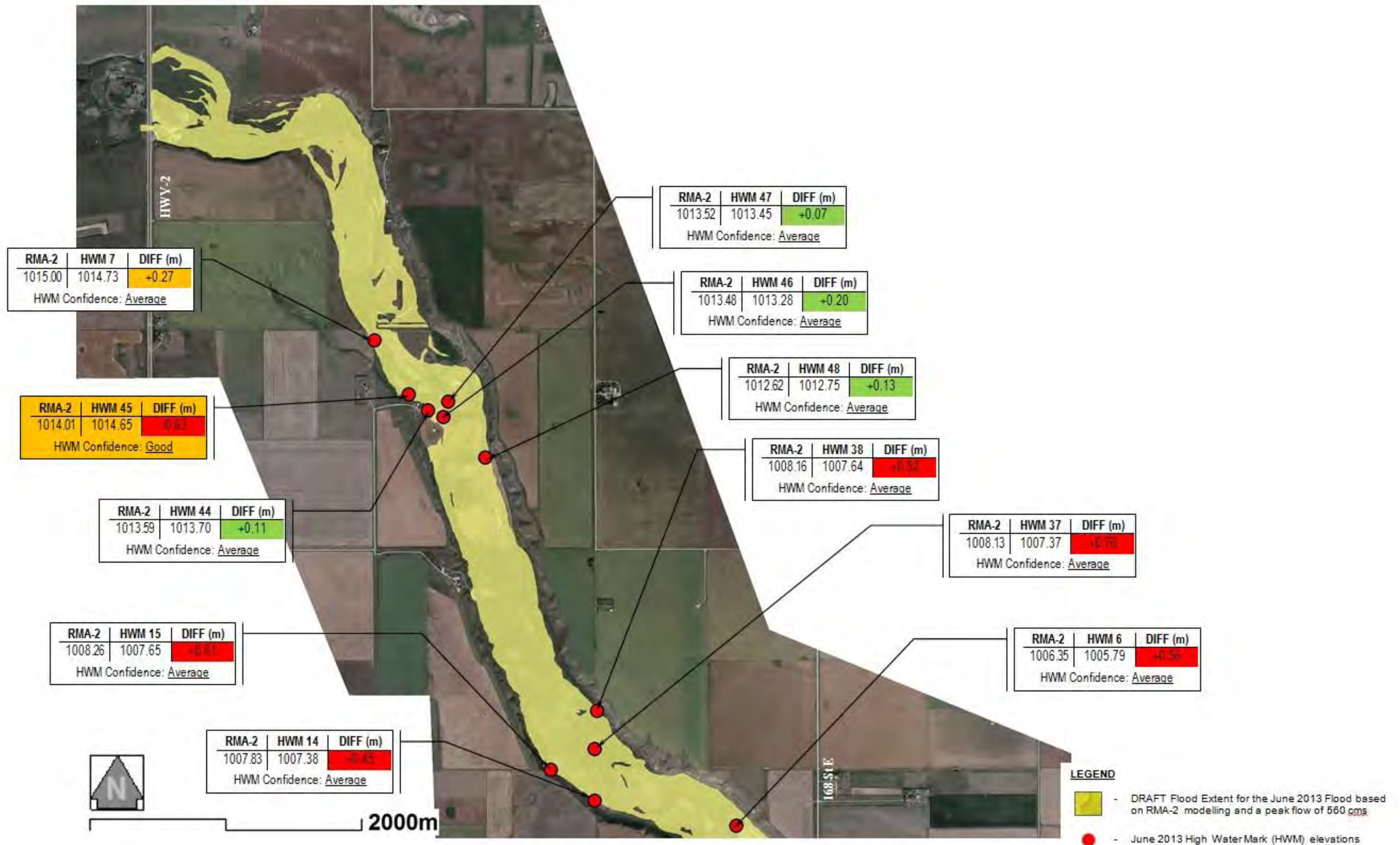
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Figure No: 4-6

Rev: 0

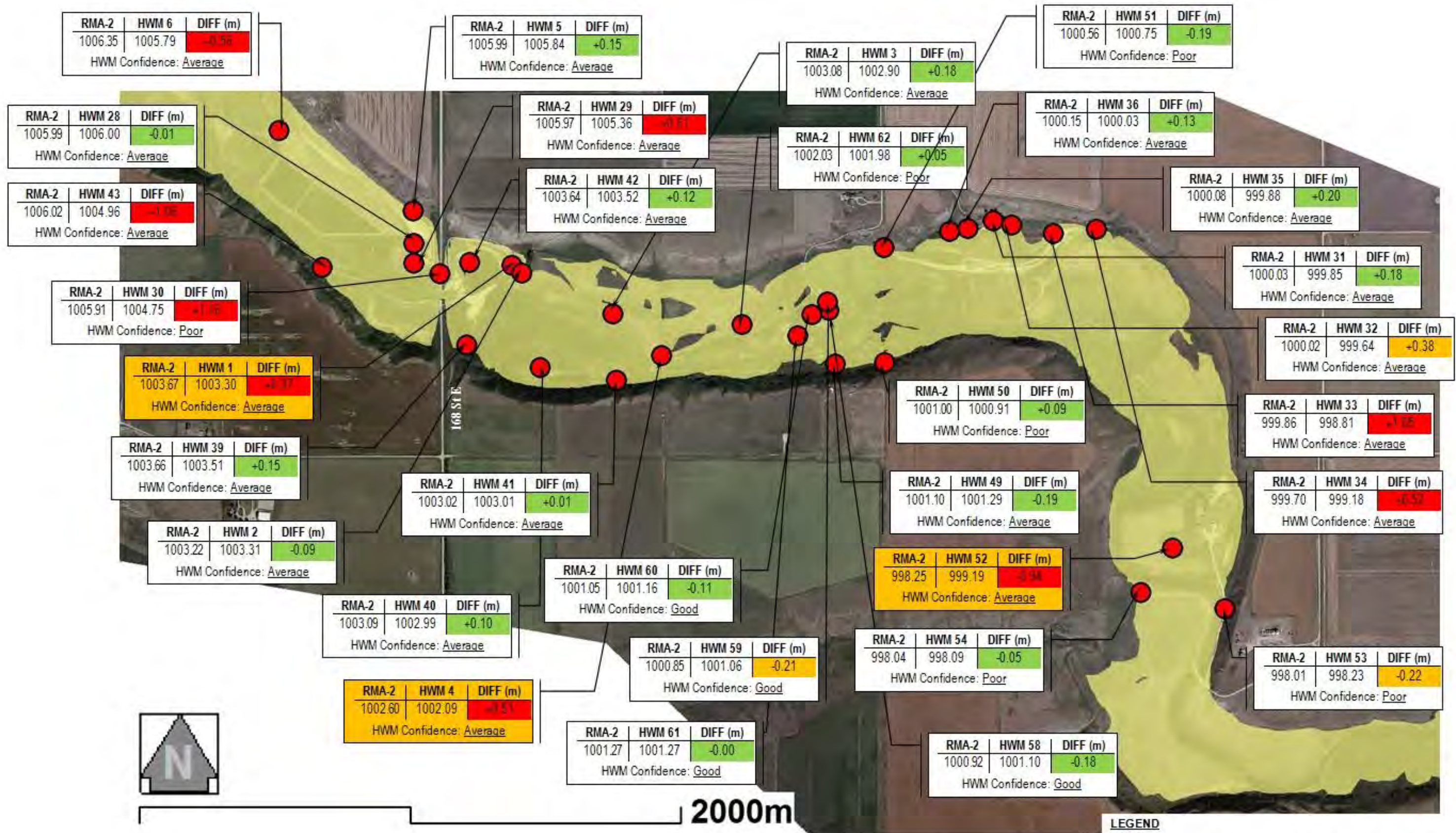
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Note: Shading representative of magnitude of WL difference between observed and modelled flood levels. Green = 0 – 200 mm difference, Orange = 200 – 400 mm difference, Red = 400+ mm

Text boxes shaded entirely in orange represent those that we believe to be erroneous. Erroneous HWMs have been identified based on a comparison with surrounding HWMs.

Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of RMA-2 Modelled Levels for the ‘June 2013 – 560 m³/s’ Flood to Surveyed HWMs (1 of 5)				
	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-1
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of RMA-2 Modelled Levels for the 'June 2013 – 560 m³/s' Flood to Surveyed HWMs (2 of 5)

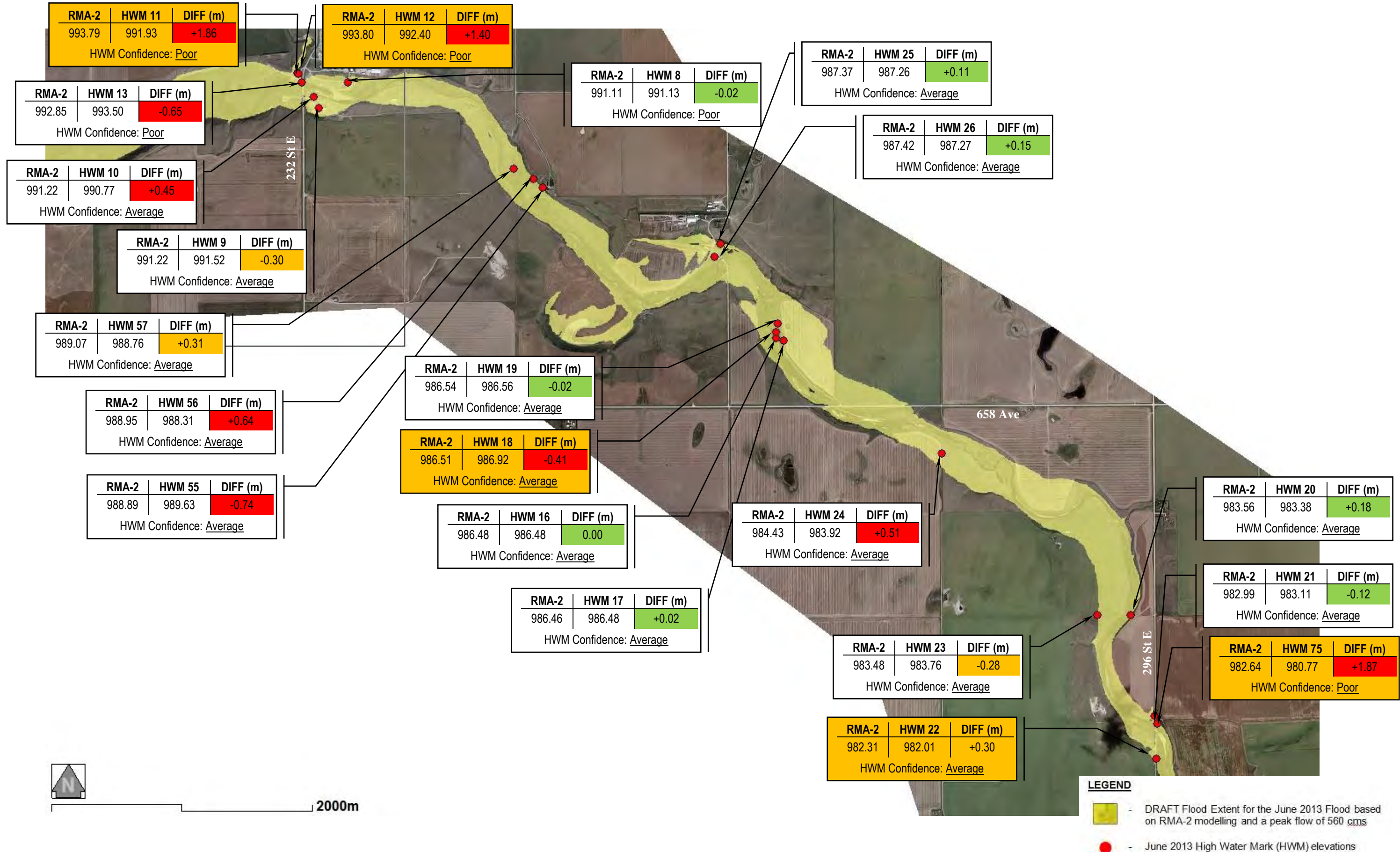
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Figure No: 5-2


Rev: 0

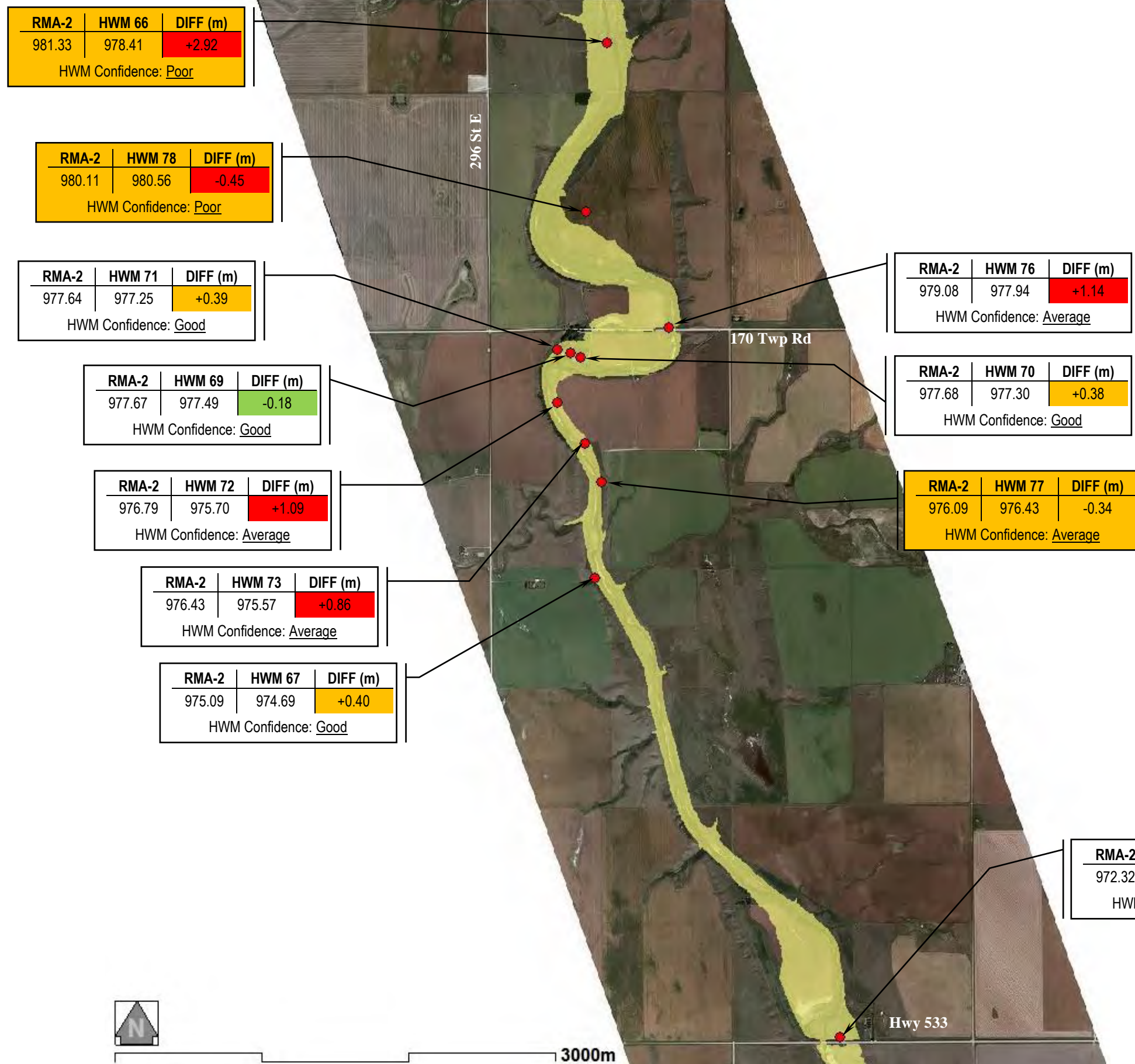
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of RMA-2 Modelled Levels for the ‘June 2013 – 560 m³/s’ Flood to Surveyed HWMs (3 of 5)				
 <div>Advisian WorleyParsons Group</div>	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-3
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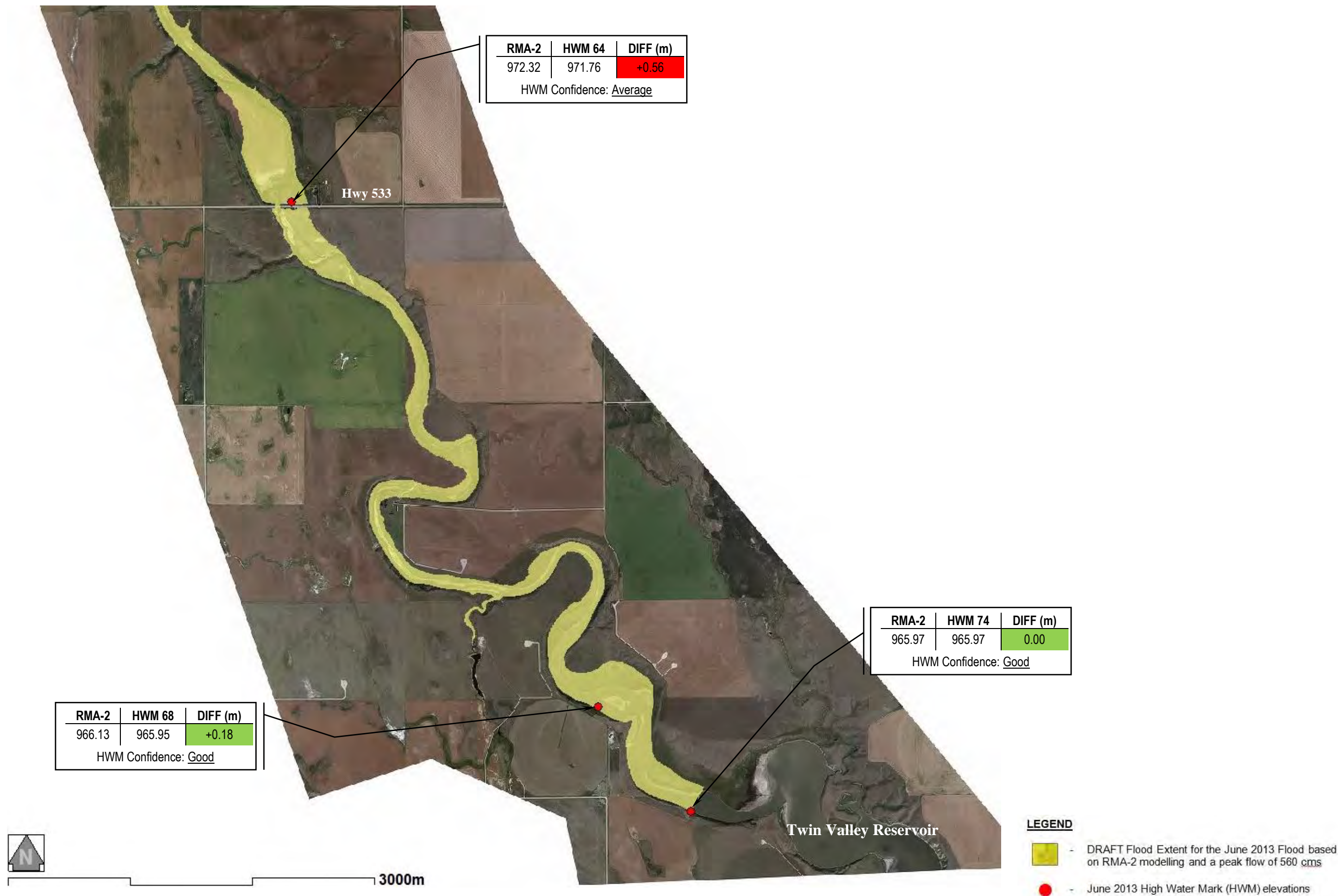


- LEGEND**
- DRAFT Flood Extent for the June 2013 Flood based on RMA-2 modelling and a peak flow of 560 cms
 - June 2013 High Water Mark (HWM) elevations

Note: Shading representative of magnitude of WL difference between observed and modelled flood levels.
Green = 0 – 200 mm difference, Orange = 200 – 400 mm difference, Red = 400+ mm


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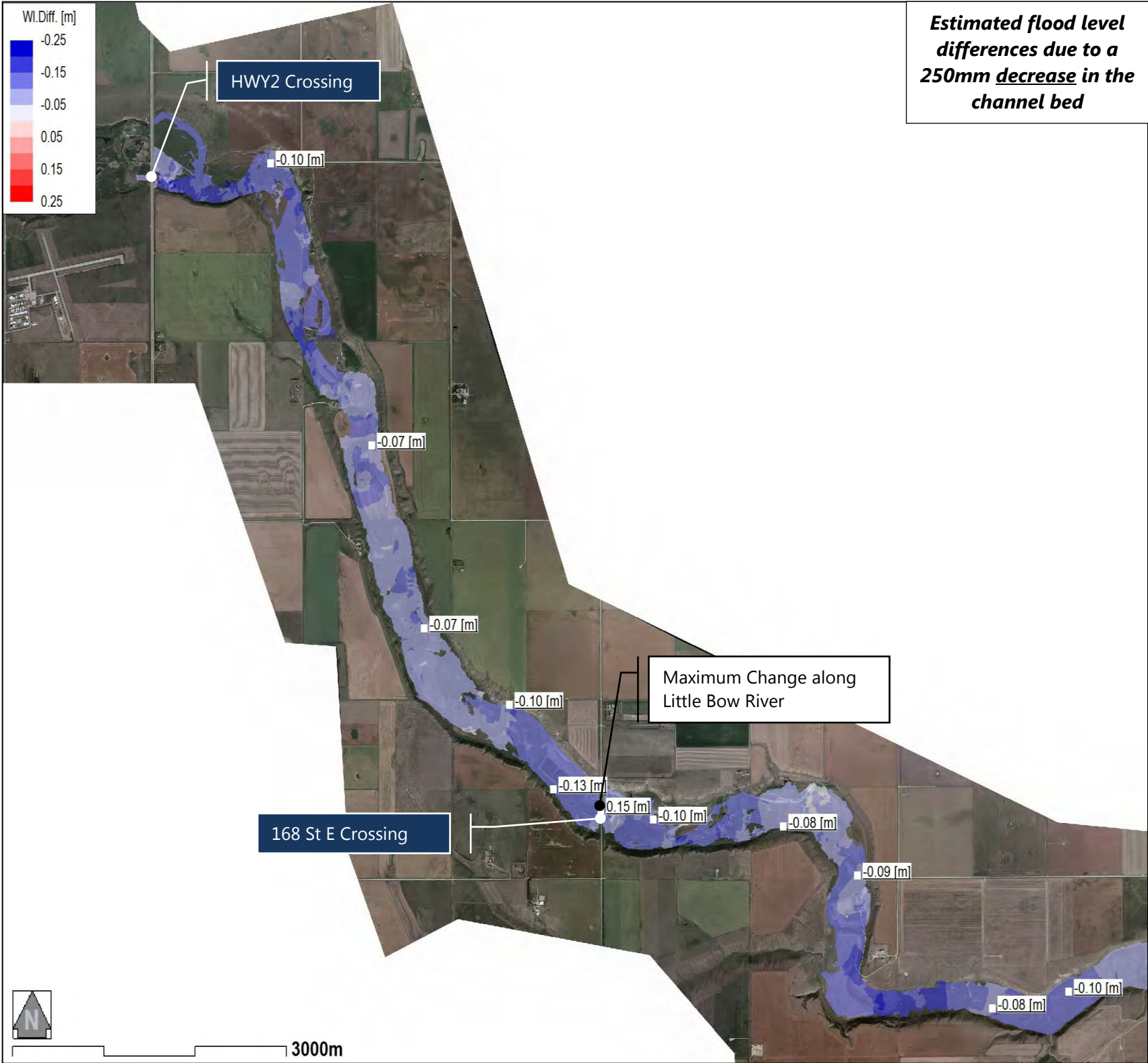
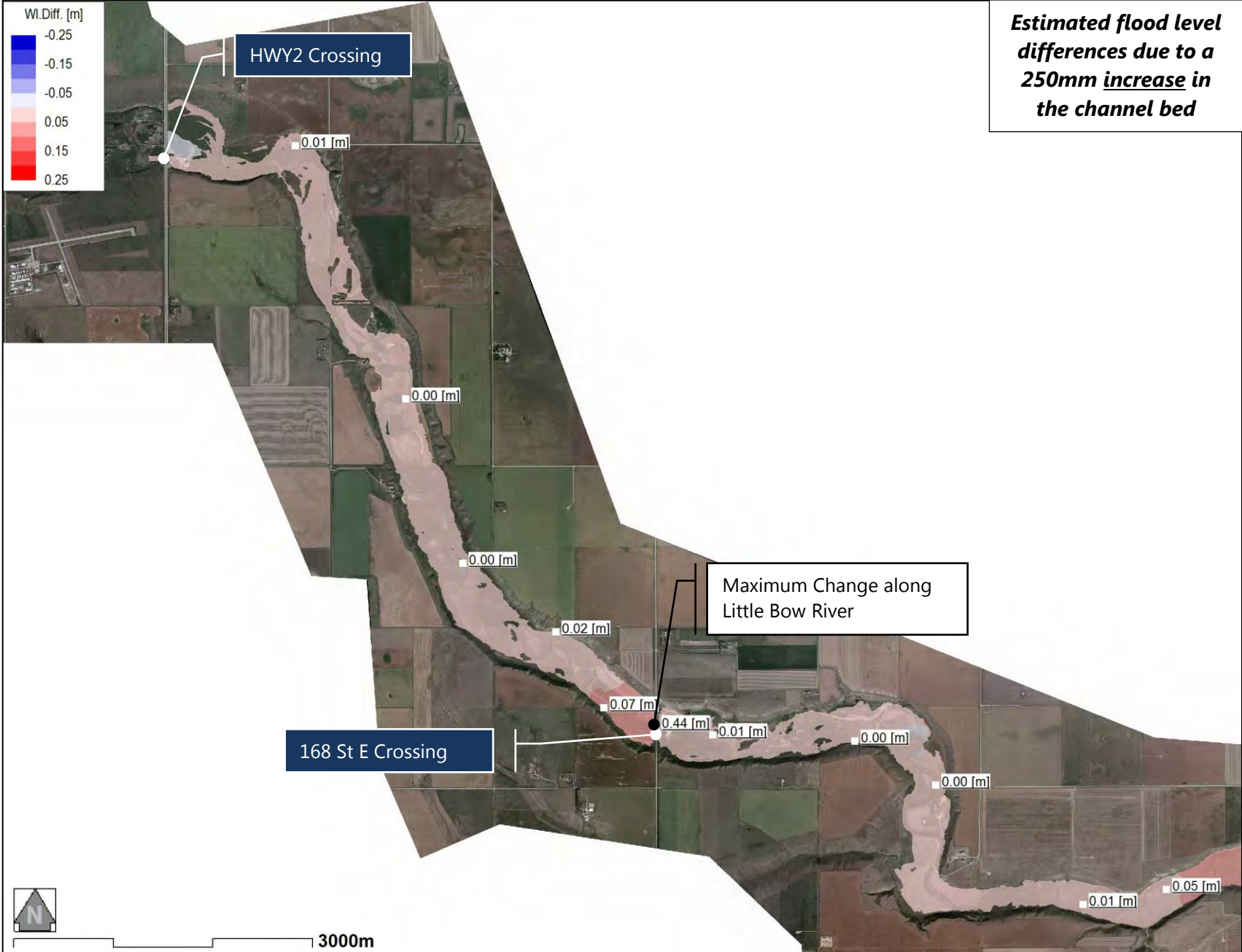
Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of RMA-2 Modelled Levels for the ‘June 2013 – 560 m³/s’ Flood to Surveyed HWMs (4 of 5)				
 Advisian WorleyParsons Group	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-4
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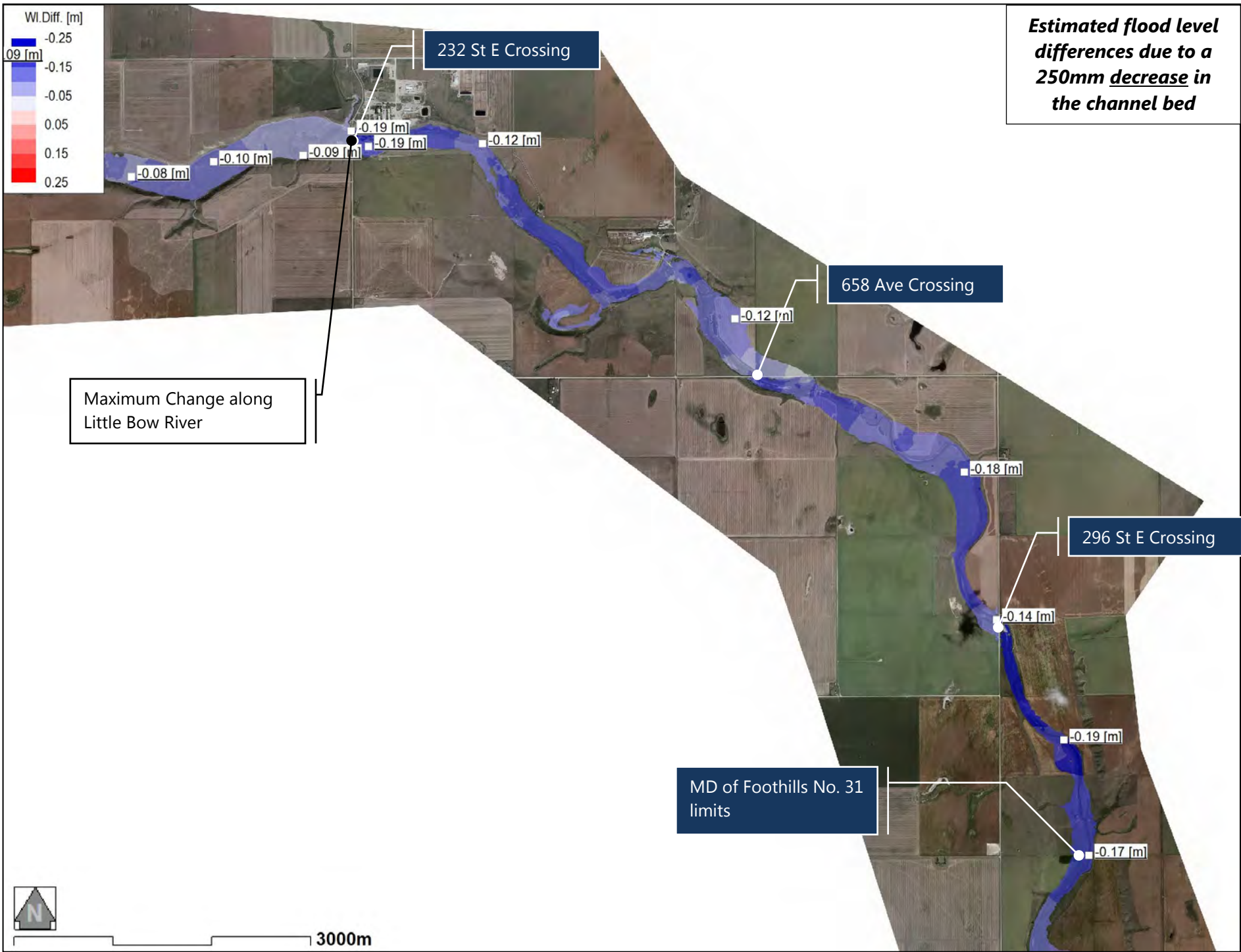
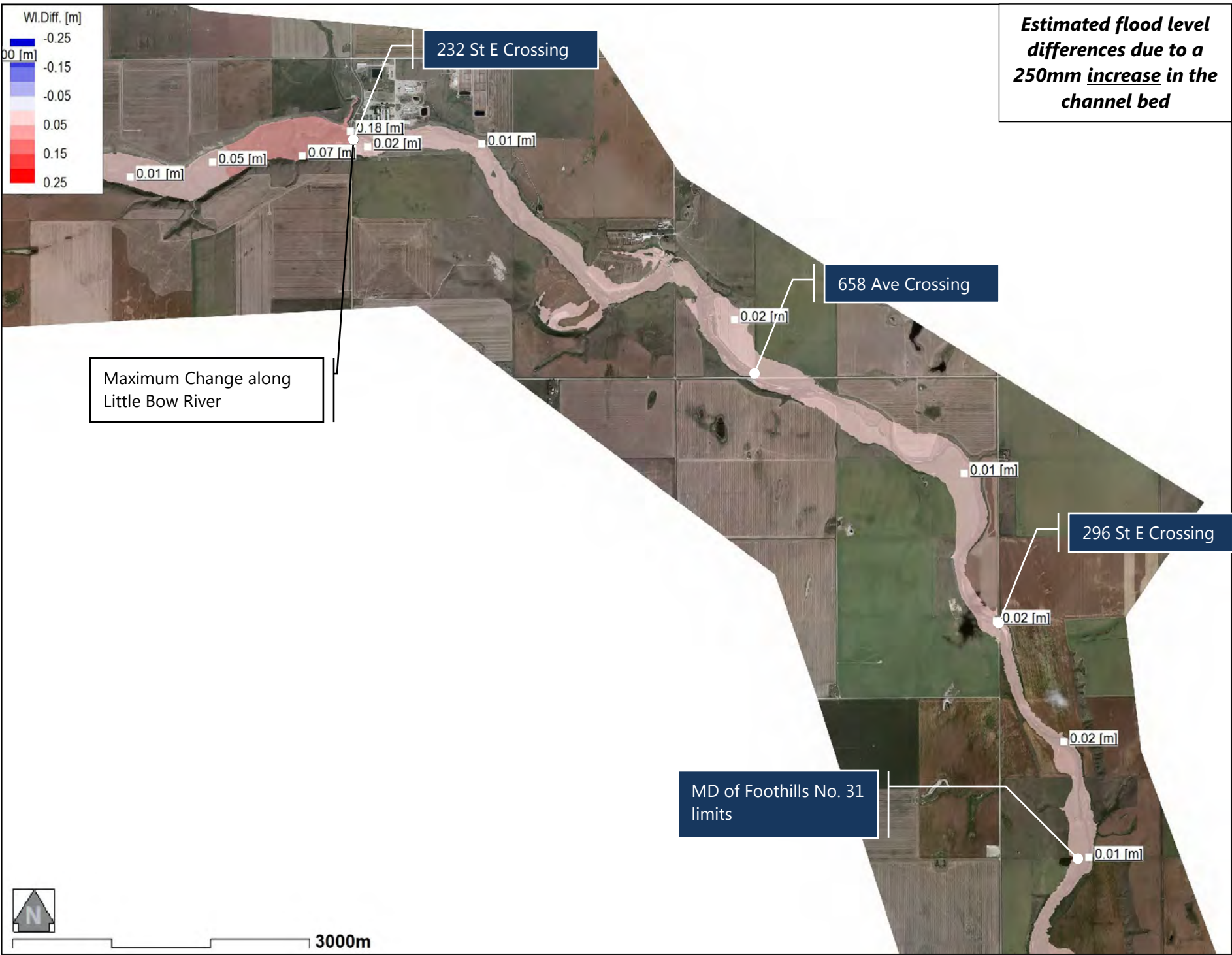


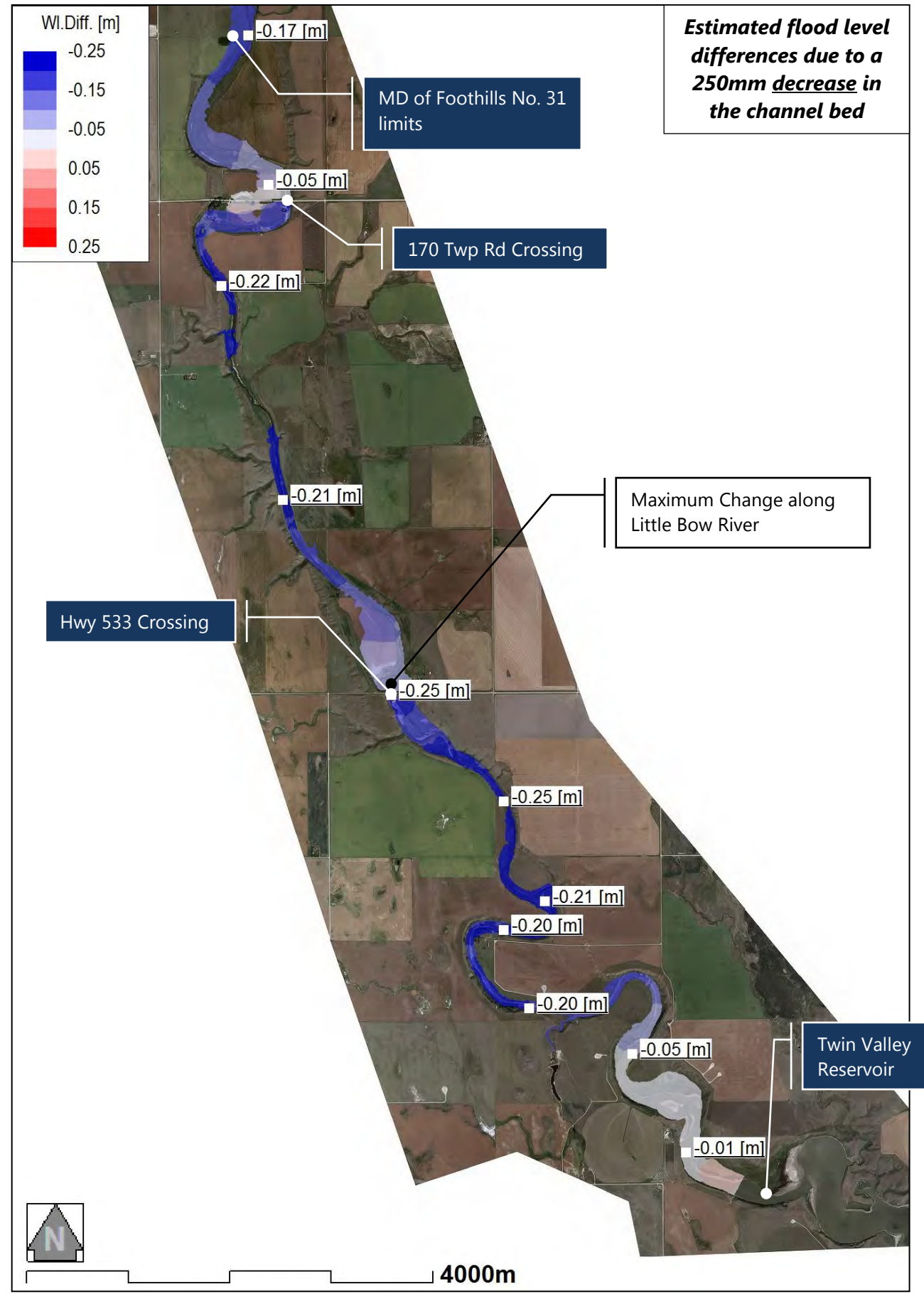
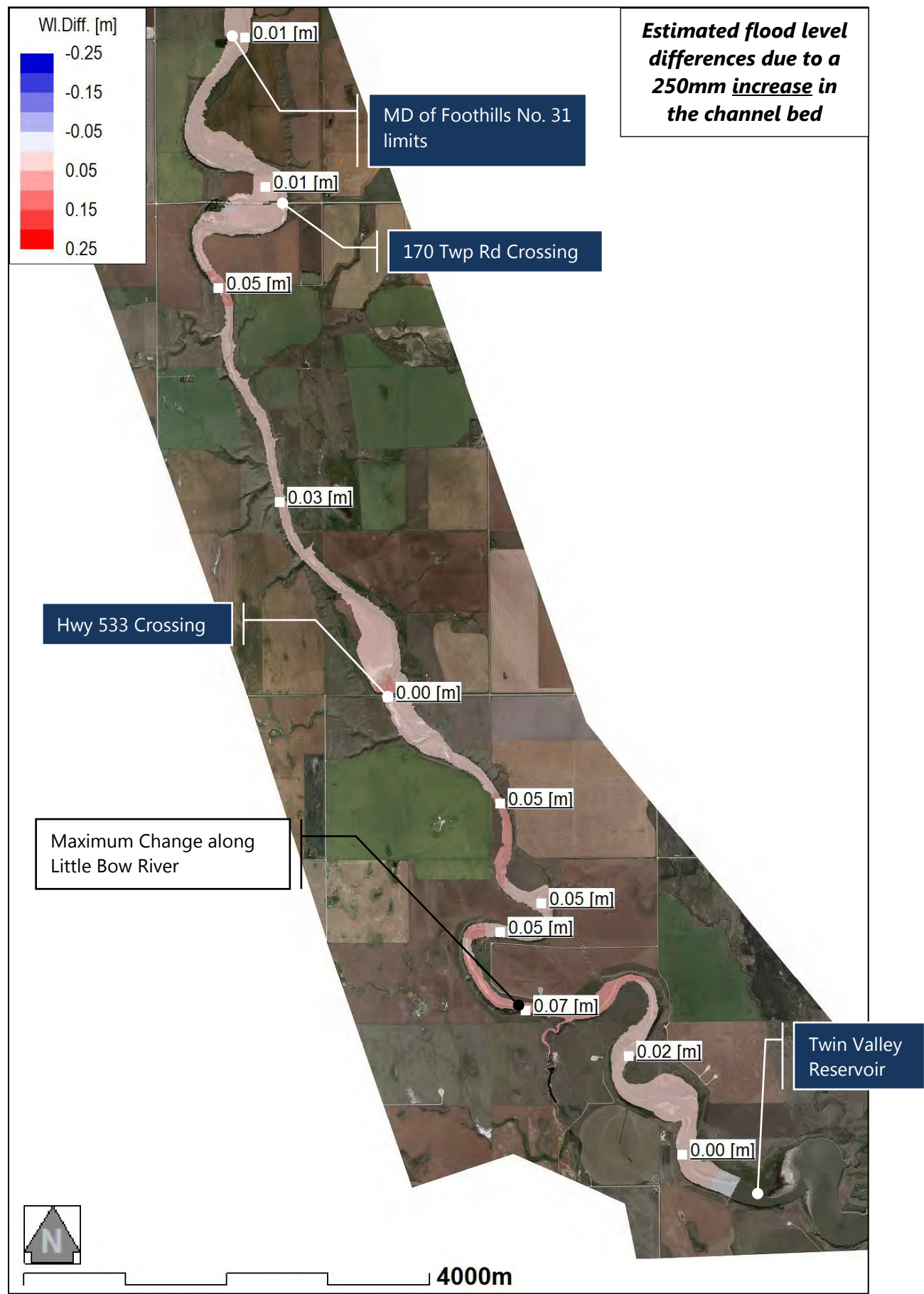
Note: Shading representative of magnitude of WL difference between observed and modelled flood levels.
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of RMA-2 Modelled Levels for the ‘June 2013 – 560 m³/s’ Flood to Surveyed HWMs (5 of 5)				
 Advisian WorleyParsons Group	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-5
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 560 m³/s' Flood Levels as a Result of A 250mm Decrease or Increase In Channel Bathymetric Levels (3 of 3)

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Date: May 1, 2017

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Figure No: 5-8

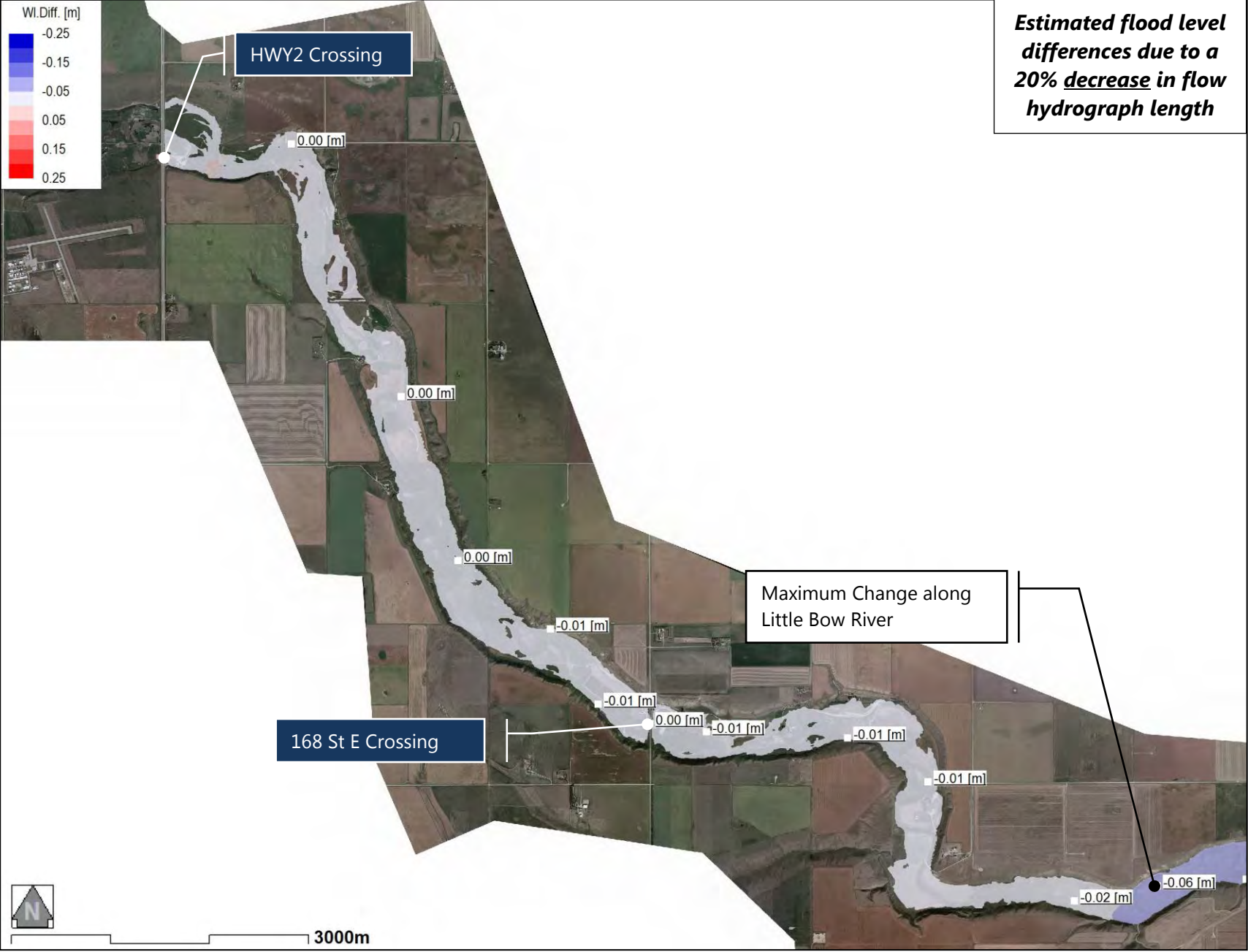
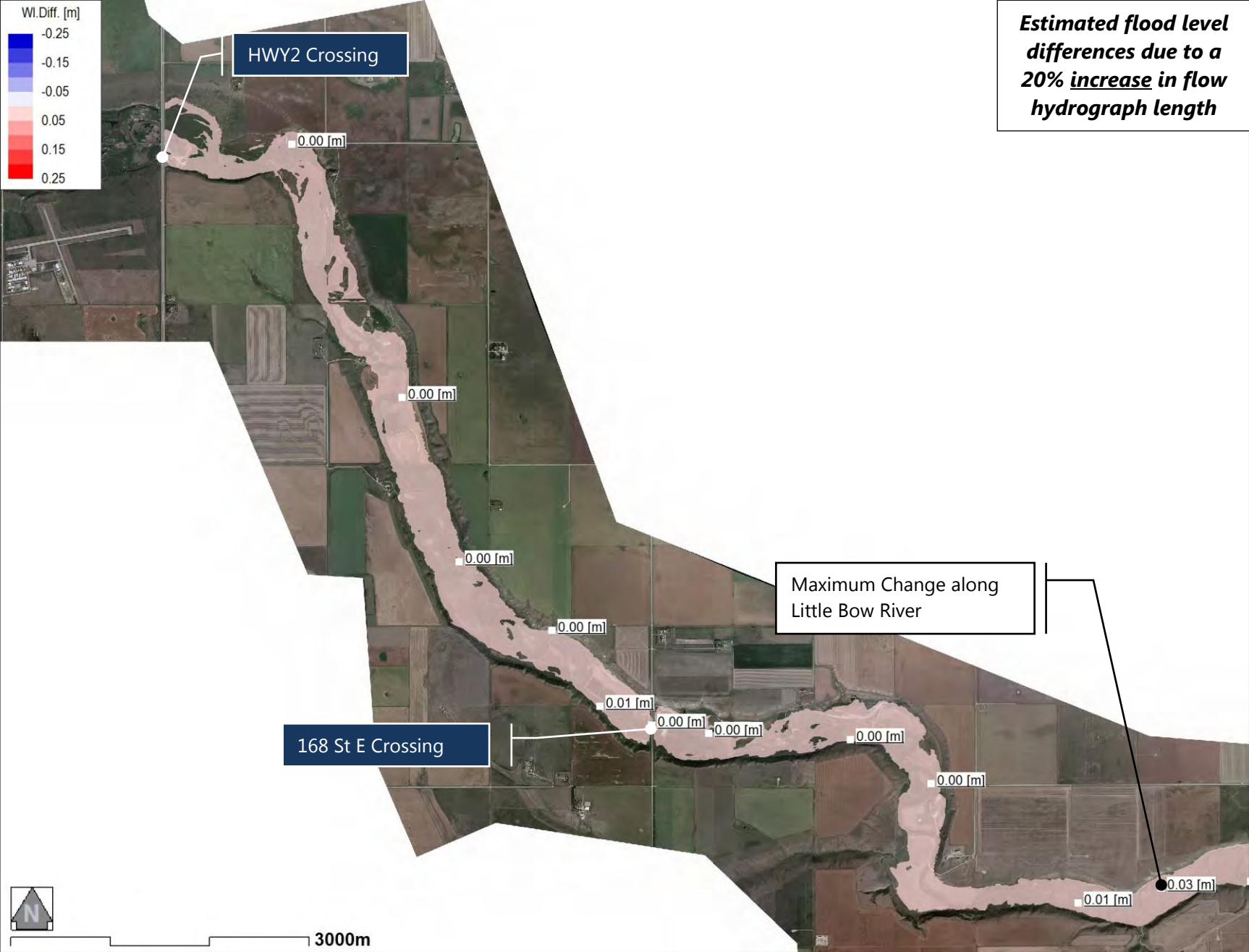
Rev: 1

Reviewed By: JB

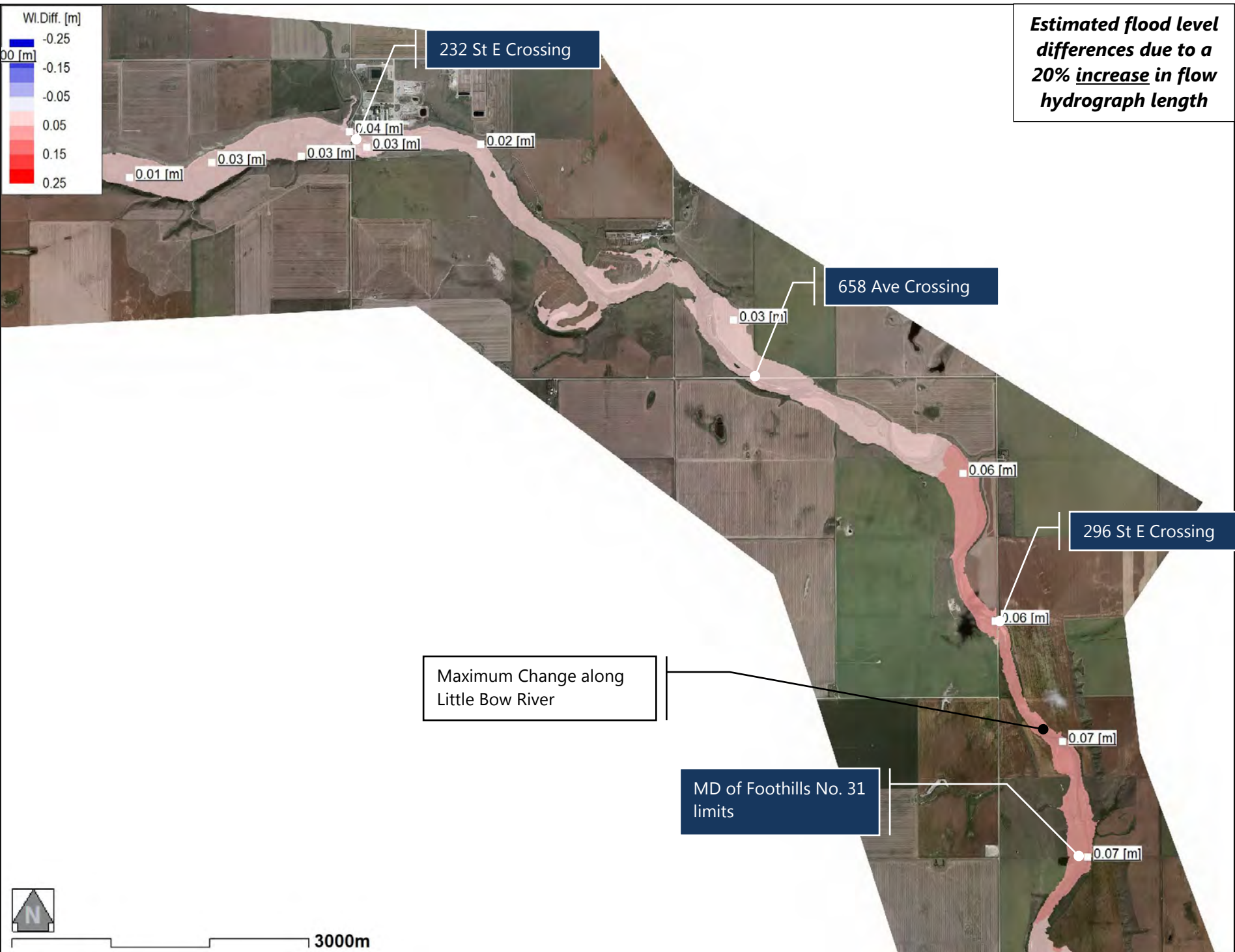
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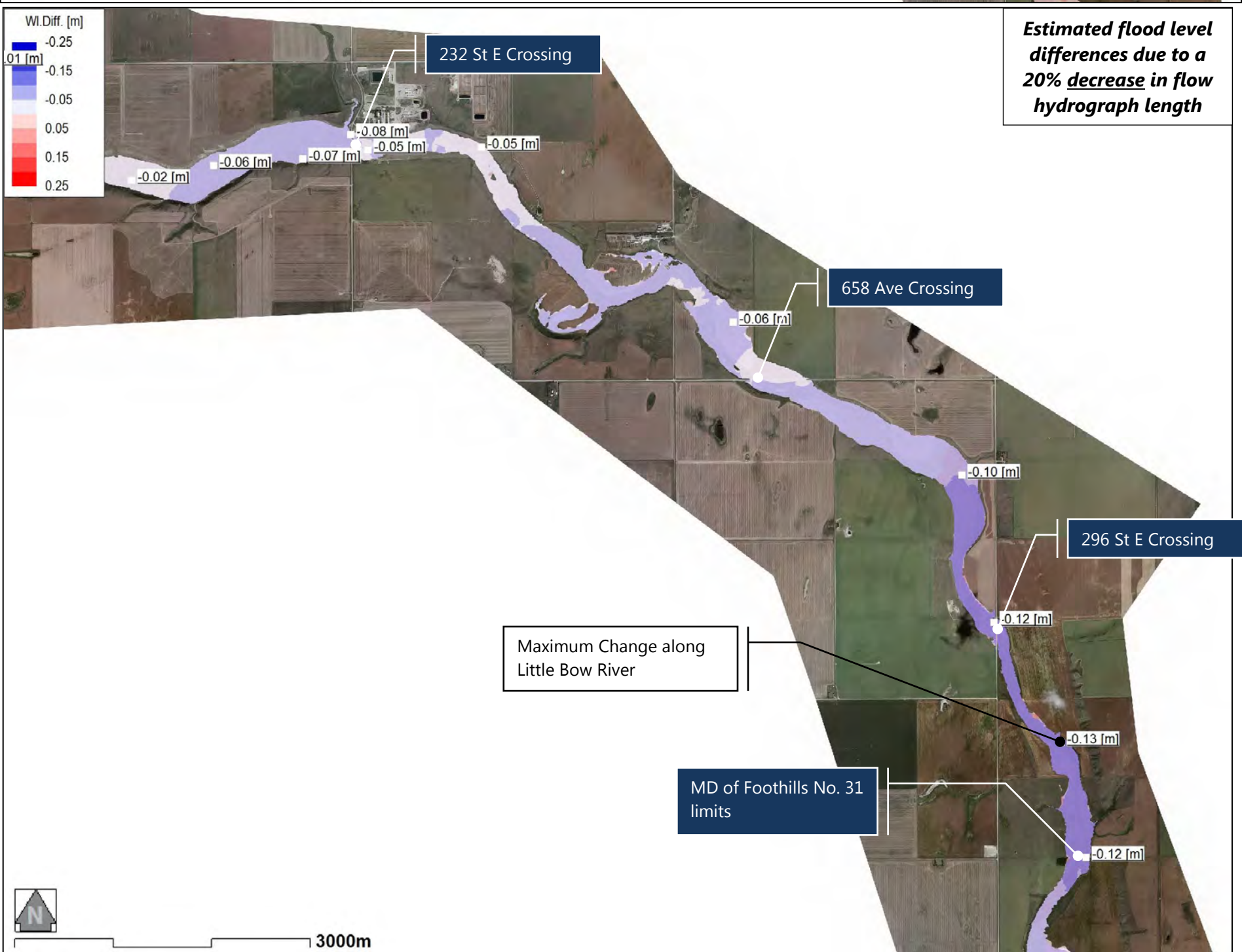
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 15% Increase or Decrease In Flow Hydrograph Length (1 of 3)				
Date:	Jan 30, 2017	File Path:	U:\CAL\GBS\307076-07348\12_0_Reports\12_3_Backend\Little Bow River Modelling\Figures	Figure No: 5-9
Created By:	AP	Reviewed By:	JB	Rev: 0
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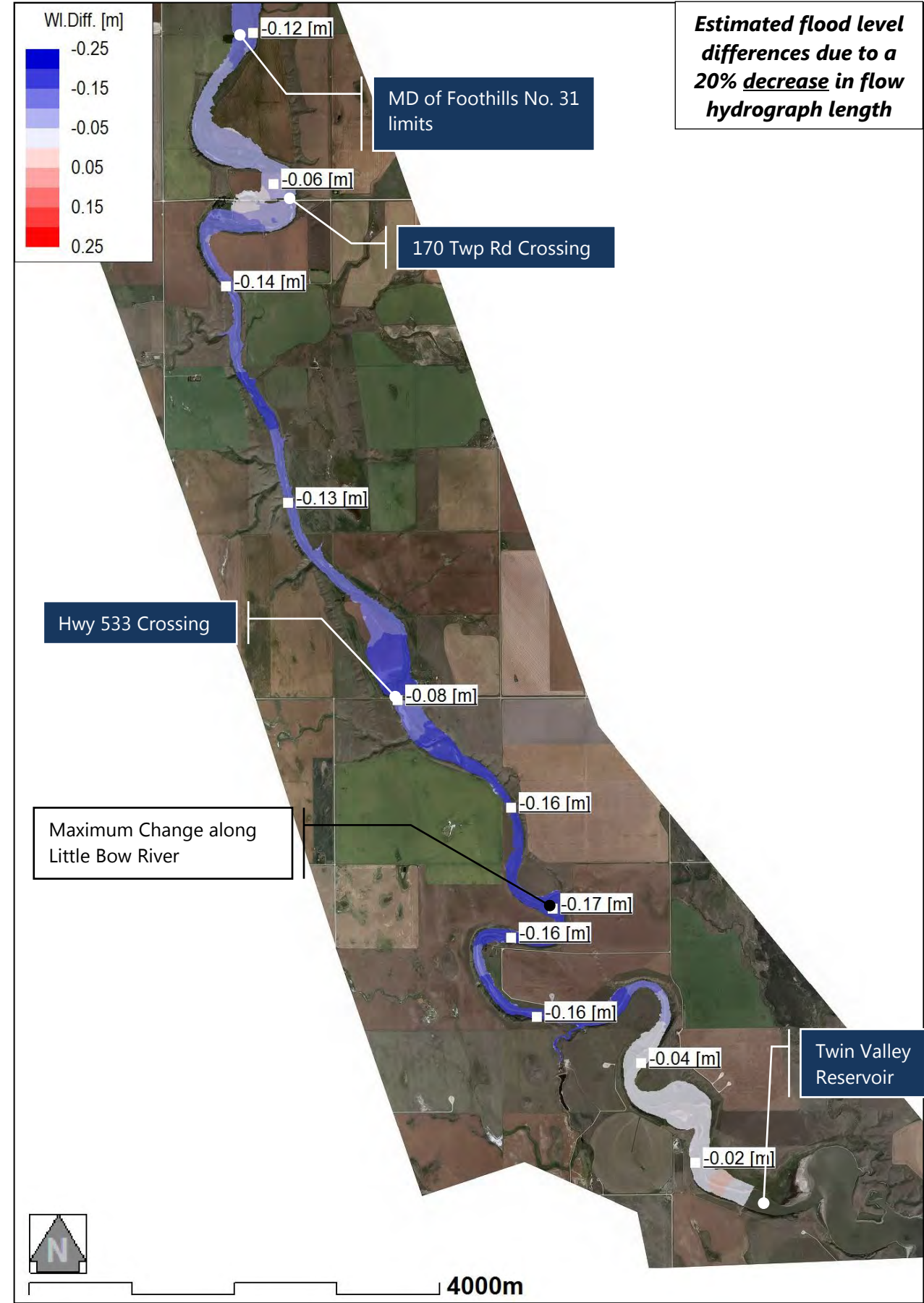
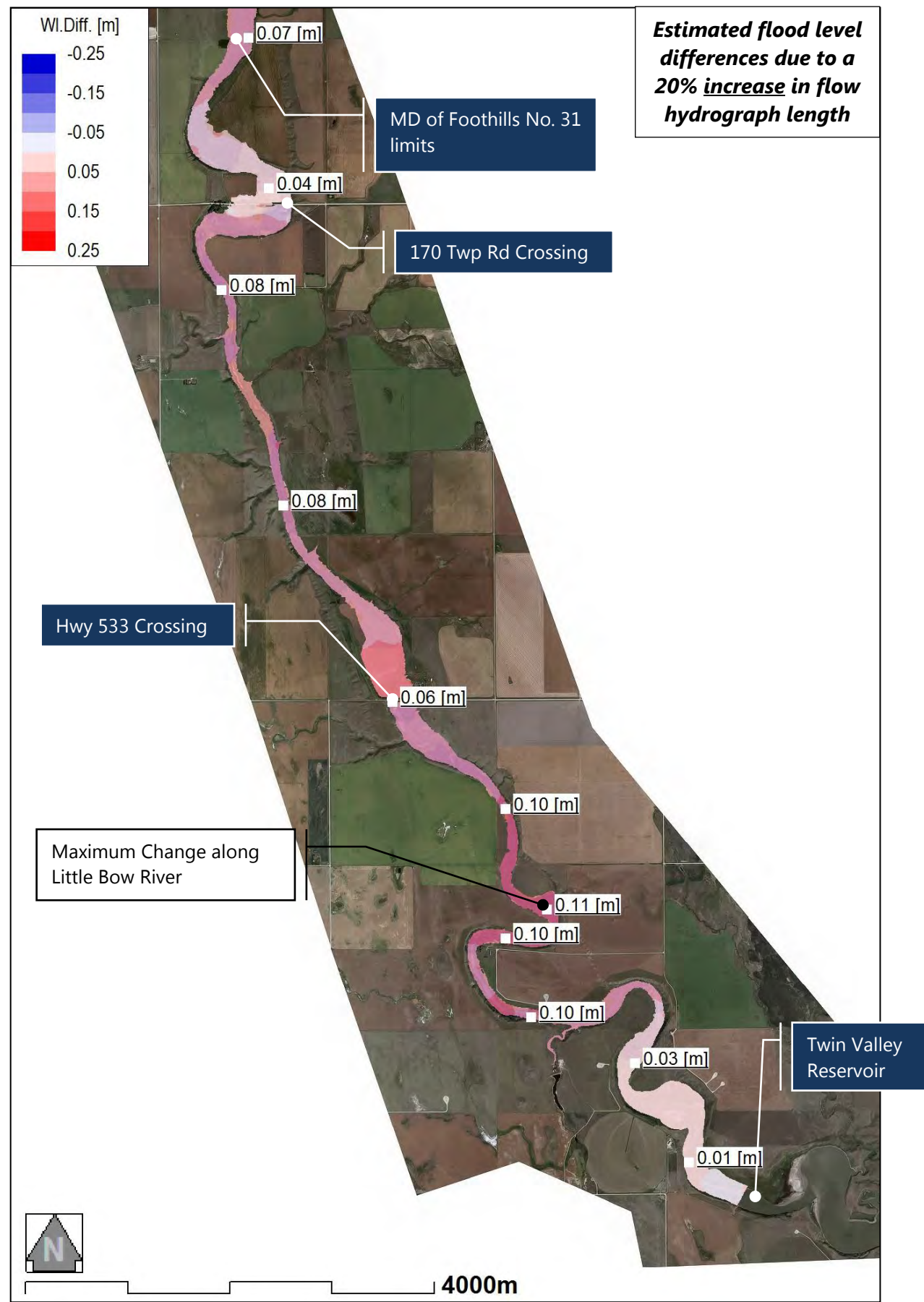
Estimated flood level differences due to a 20% increase in flow hydrograph length



Estimated flood level differences due to a 20% decrease in flow hydrograph length

Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 560 m³/s' Flood Levels as a Result of a 15% Increase or Decrease in Flow Hydrograph Length (2 of 3)



Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 560 m³/s' Flood Levels as a Result of a 15% Increase or Decrease in Flow Hydrograph Length (3 of 3)

Created By: AP

Date: May 1, 2017

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Figure No: 5-11

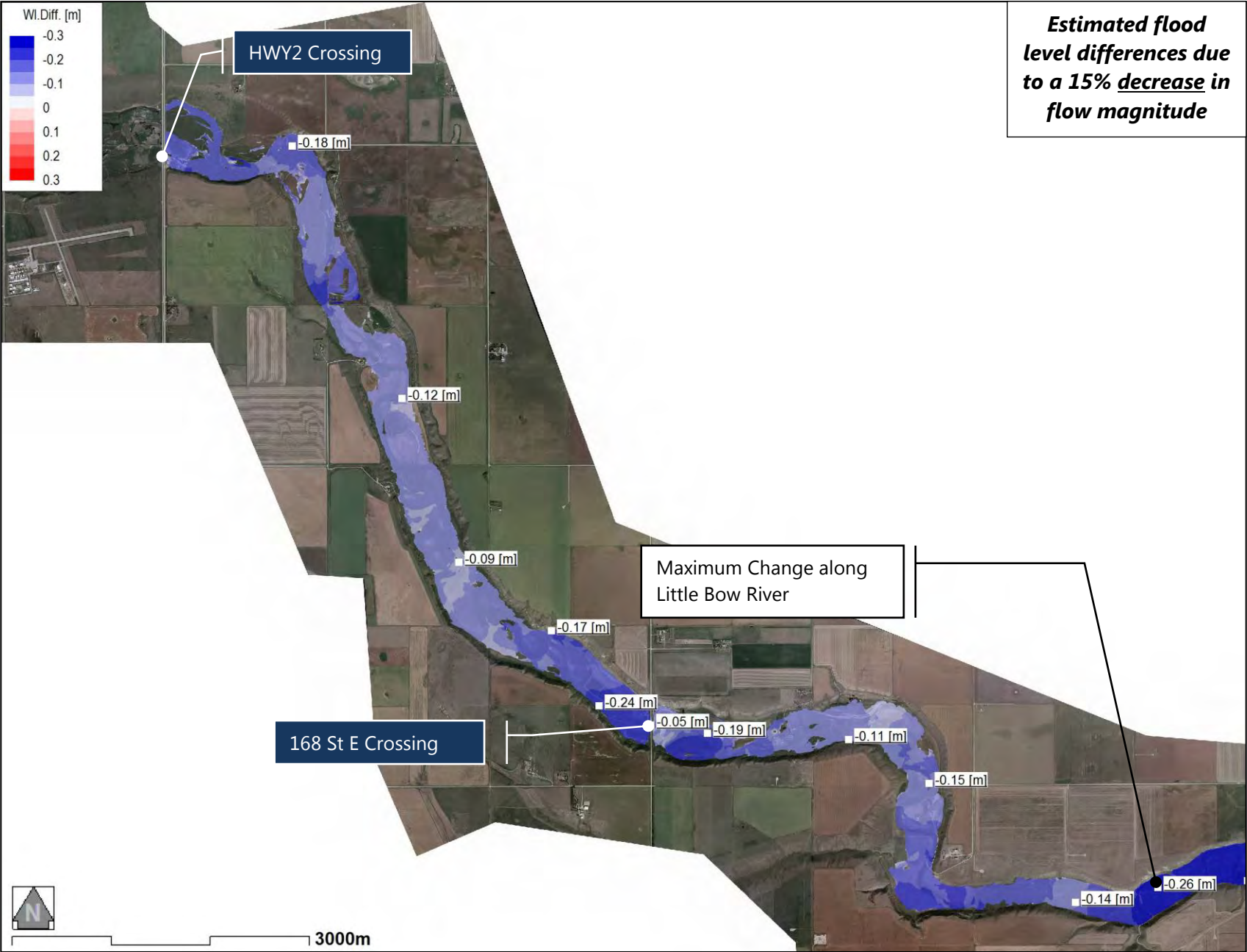
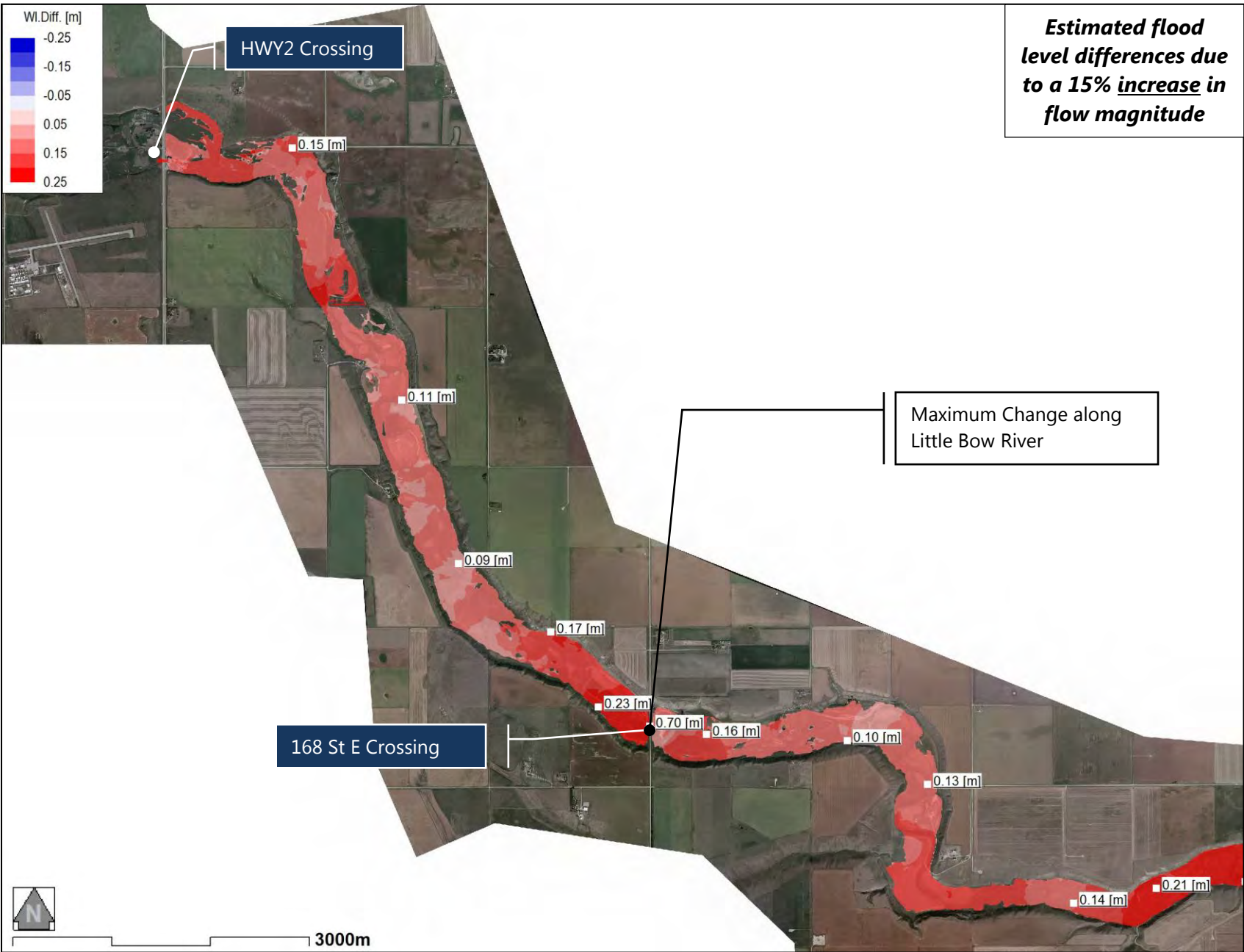
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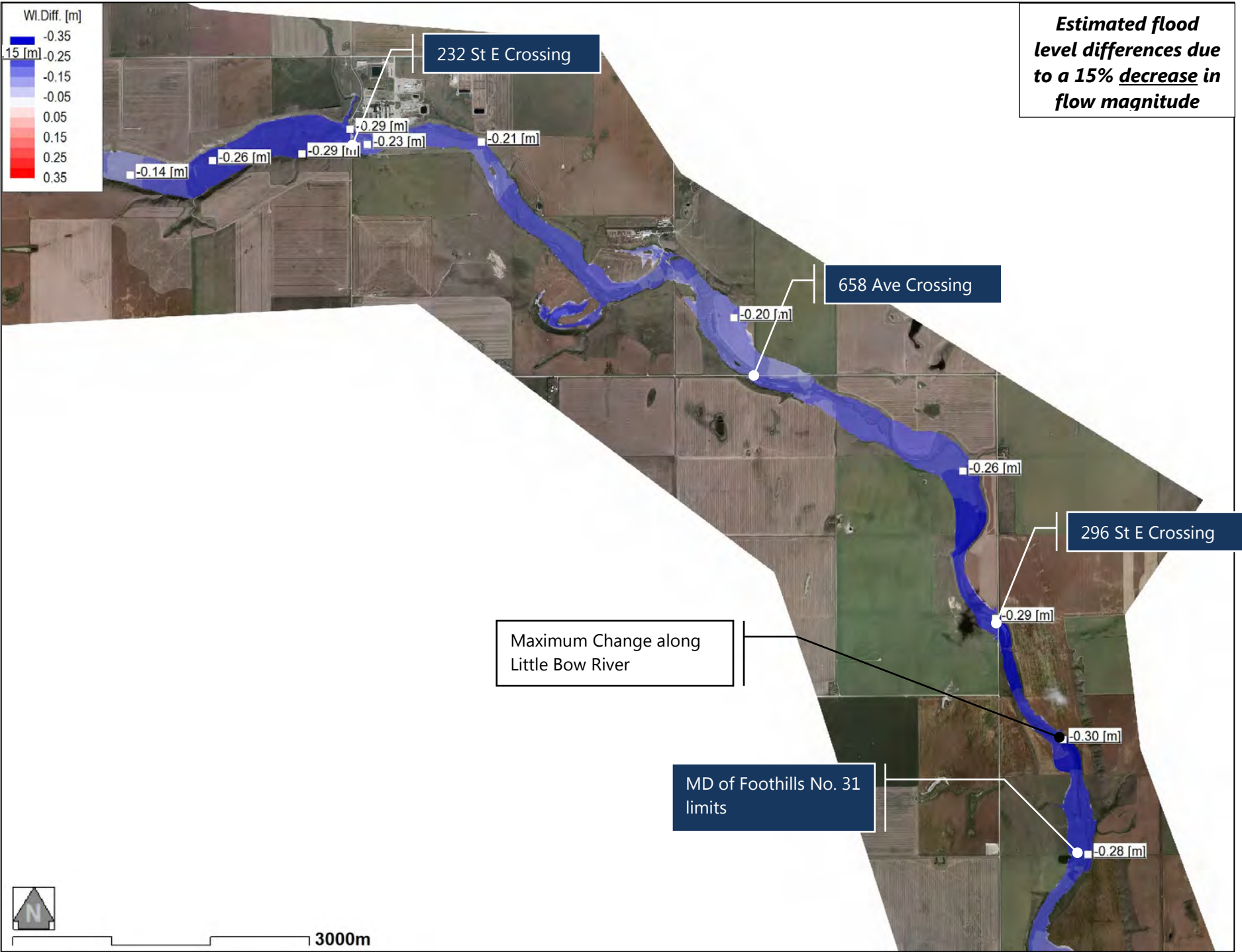
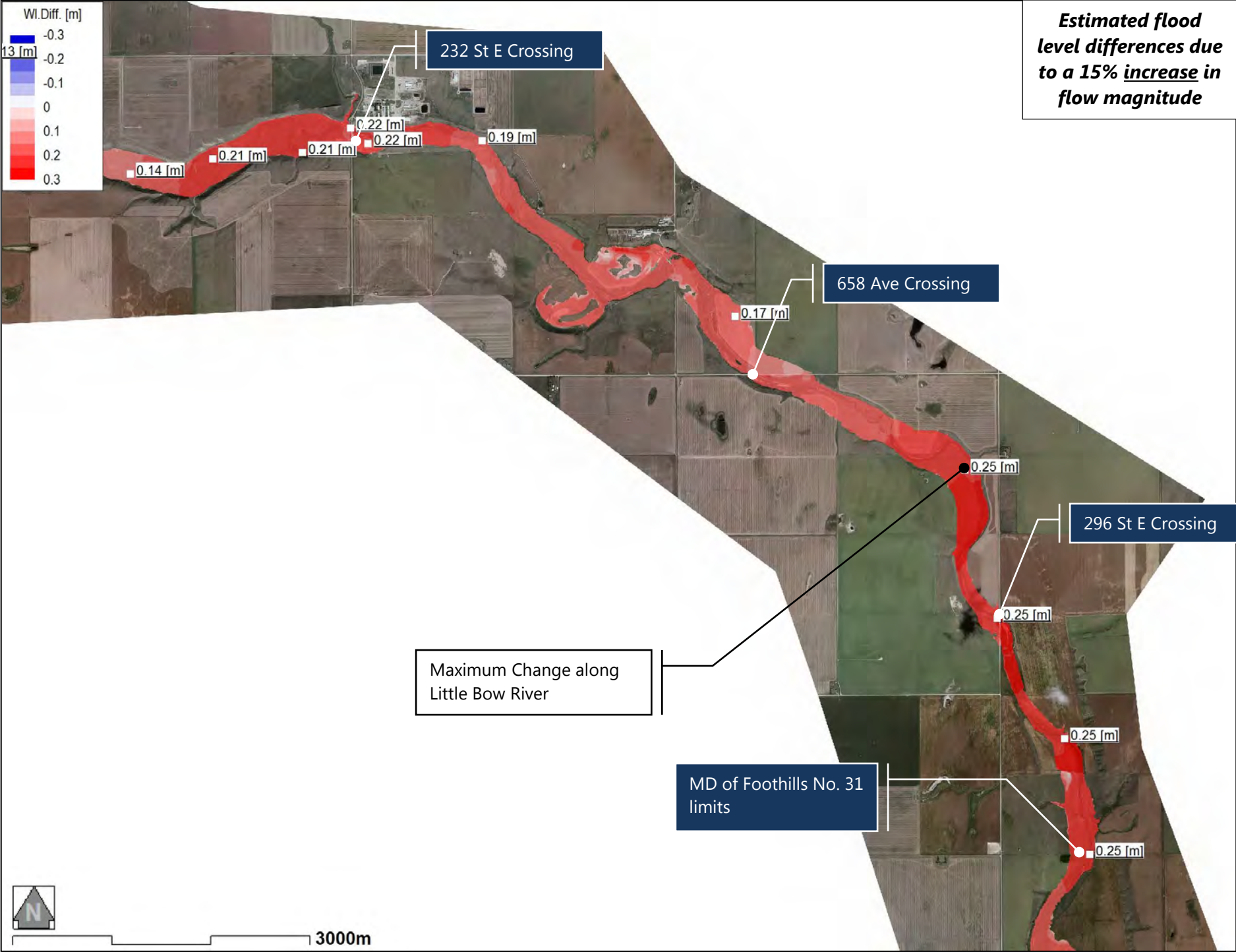
Reviewed By: JB

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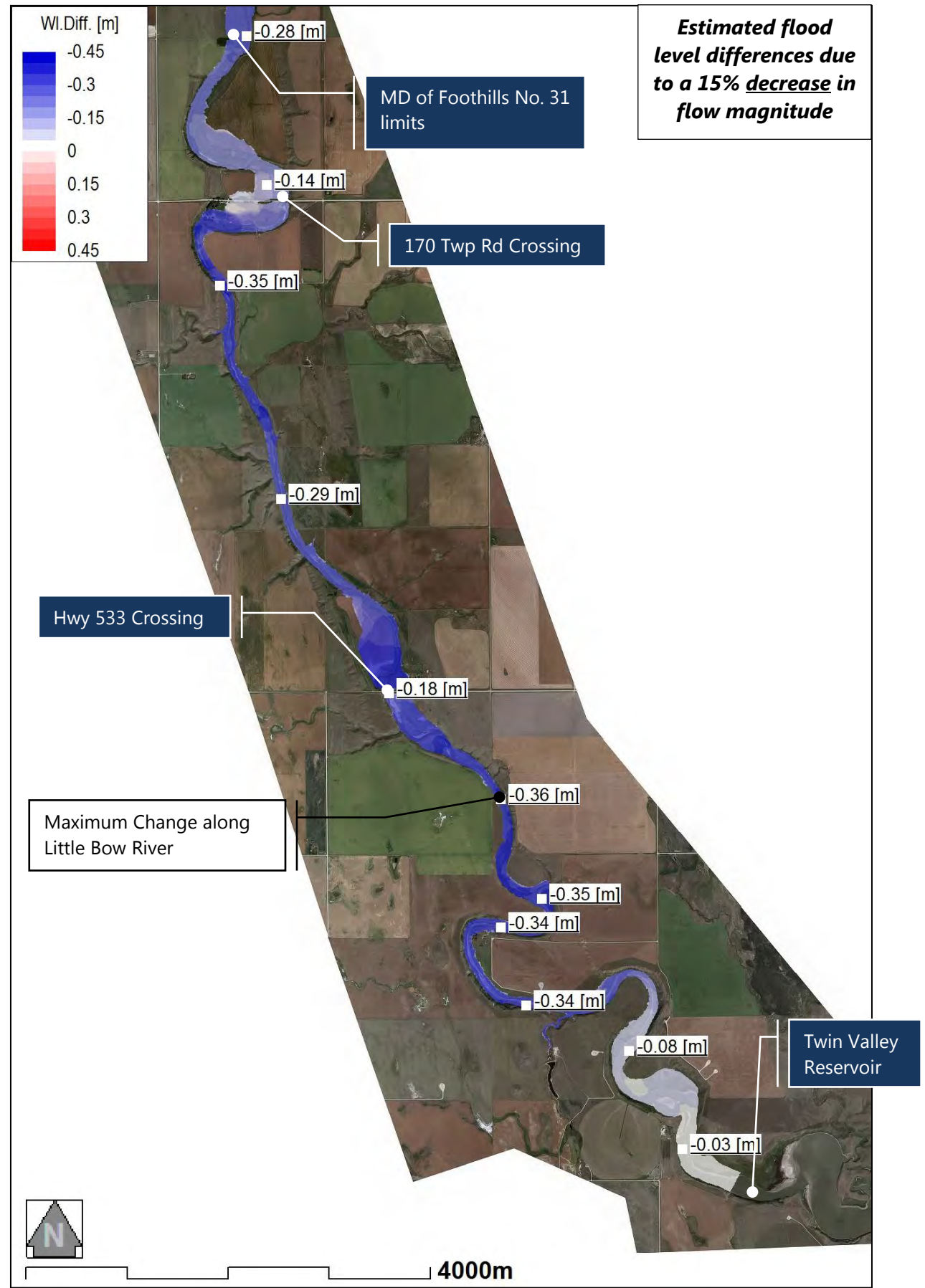
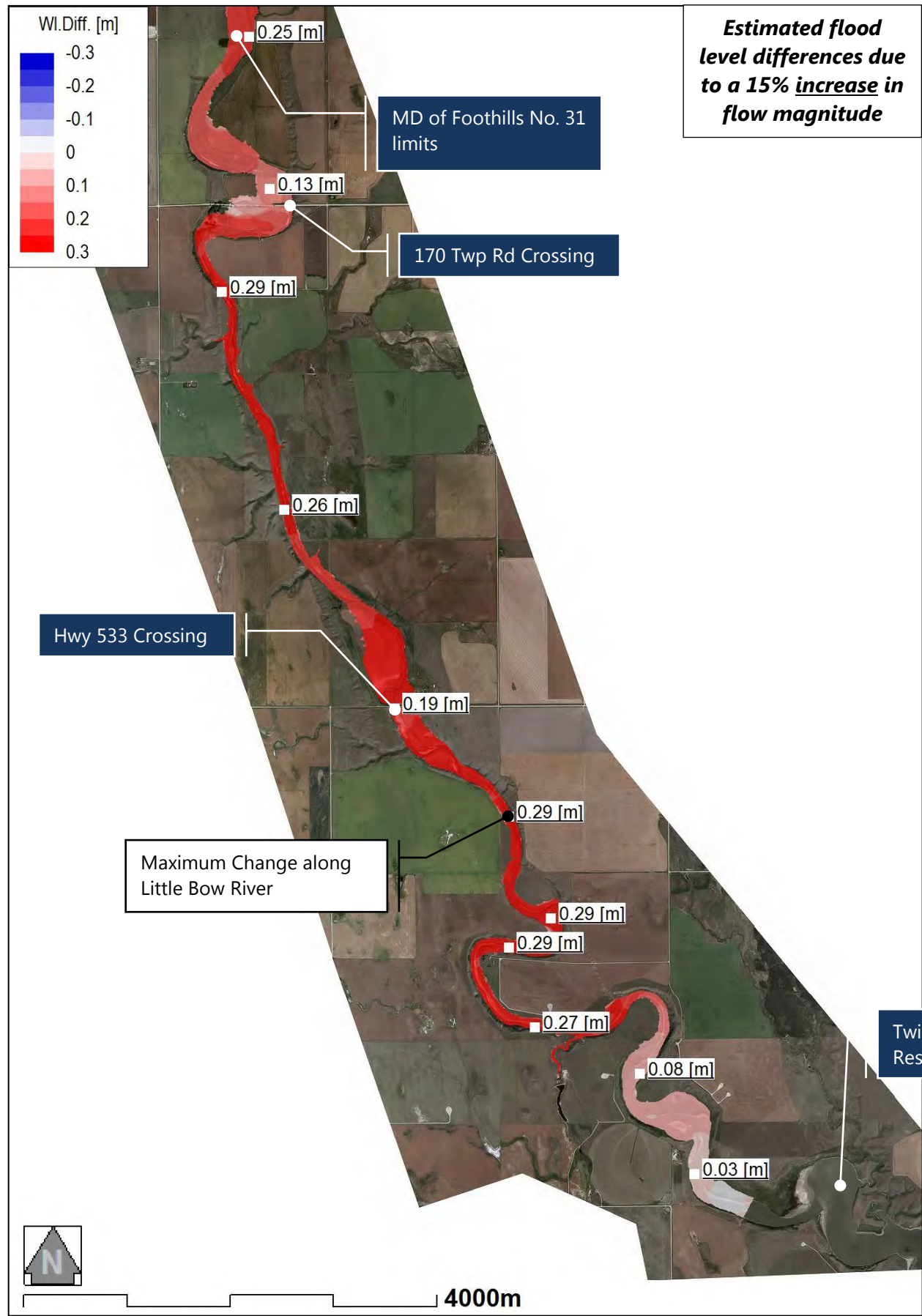
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Figure No: 5-13


Rev: 0

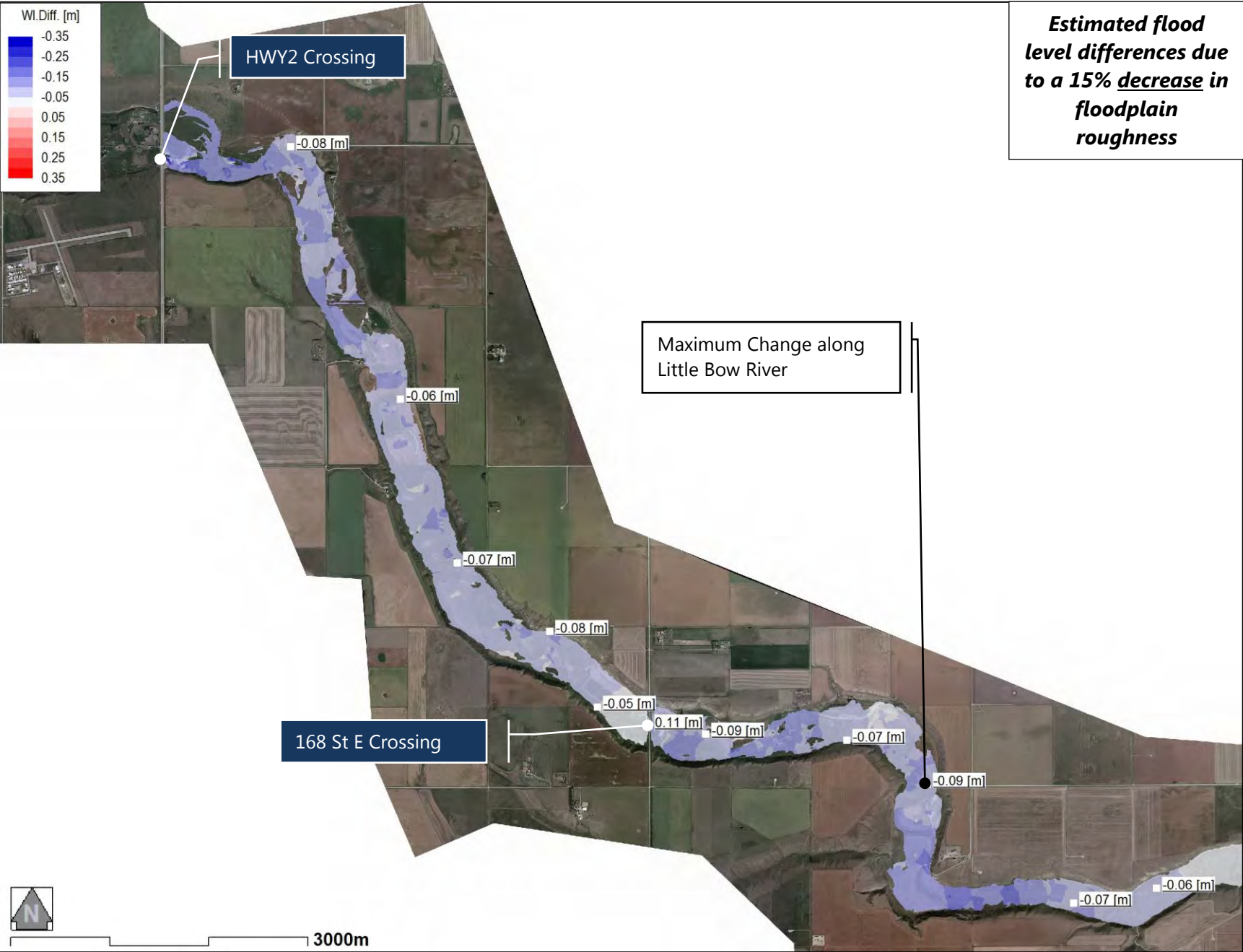
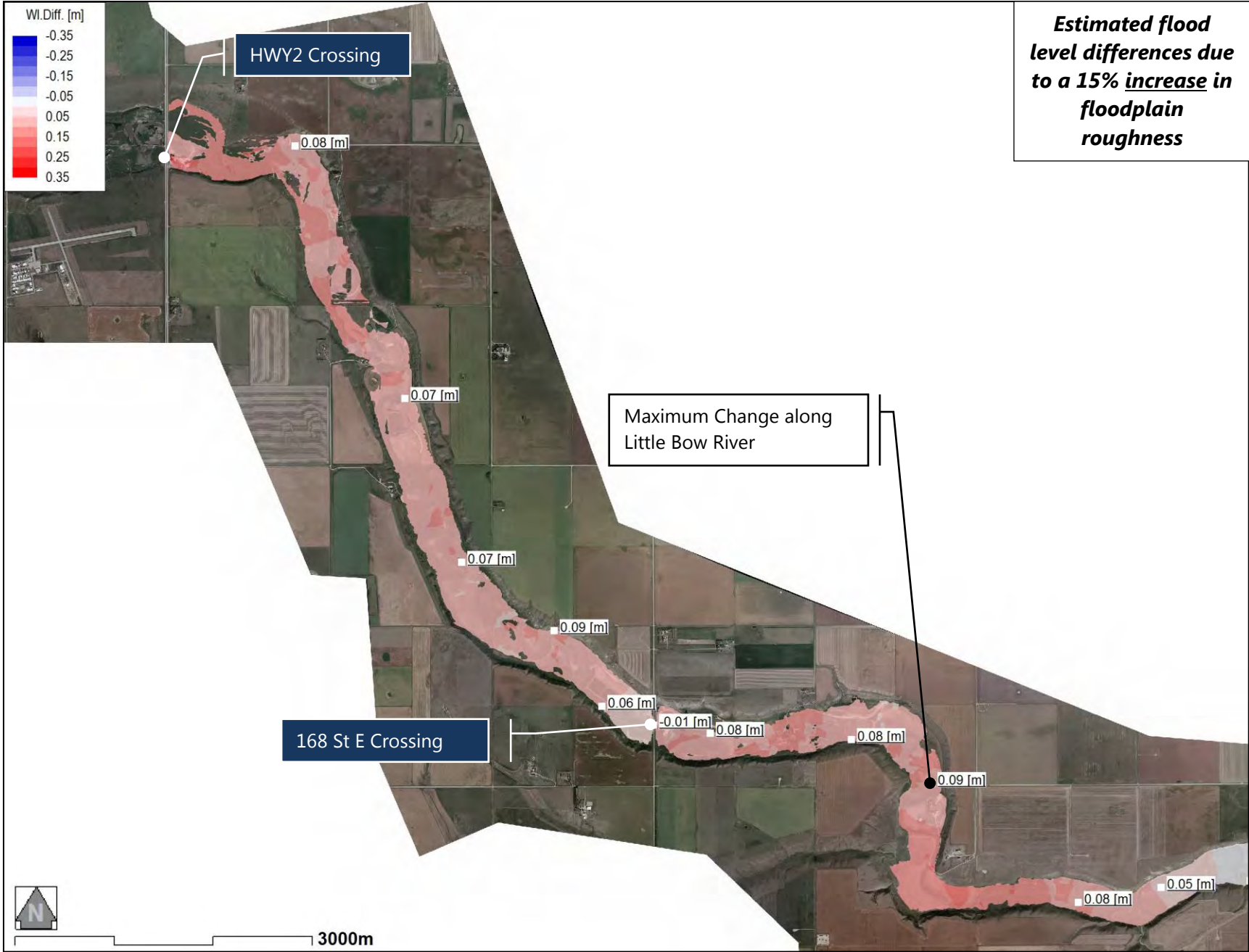
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 560 m³/s' Flood Levels as a Result of a 15% Increase or Decrease in Flow Magnitude (3 of 3)

 <p>Advisian WorleyParsons Group</p>	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-14	Rev: 1
	Reviewed By: JB	<p><i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.</i></p>			



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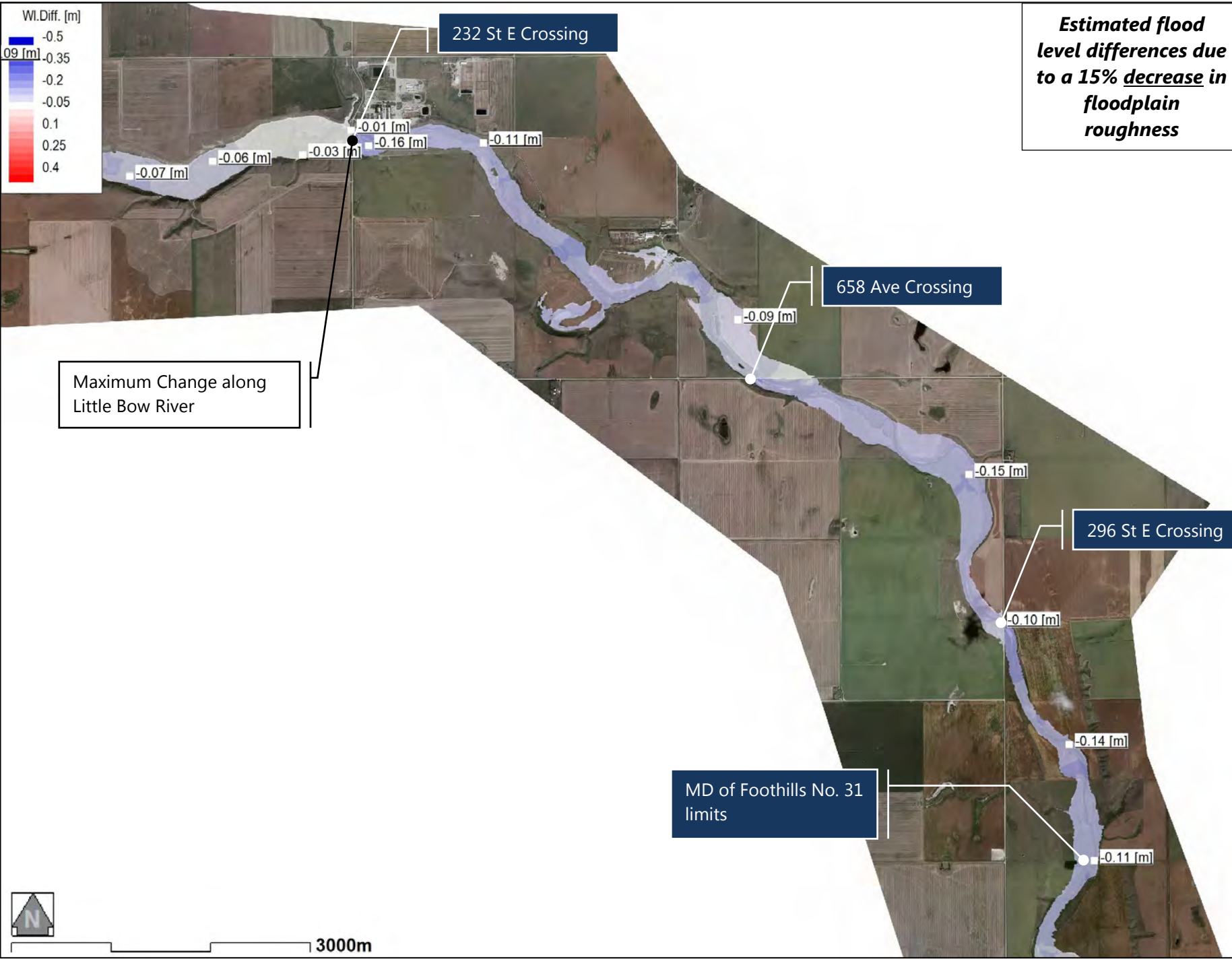
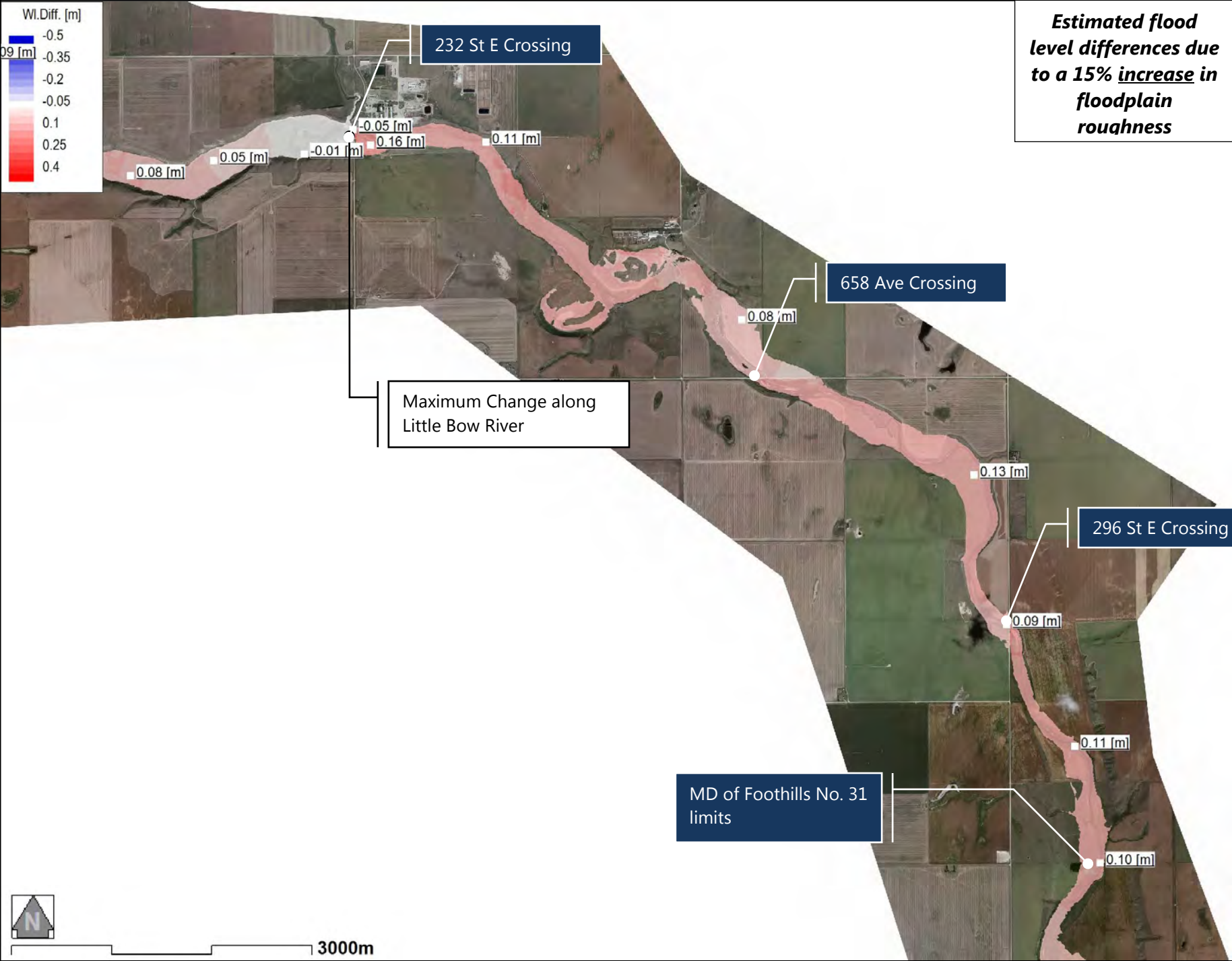
Figure No: 5-15

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Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 15% Increase or Decrease in Floodplain Roughness (1 of 3)



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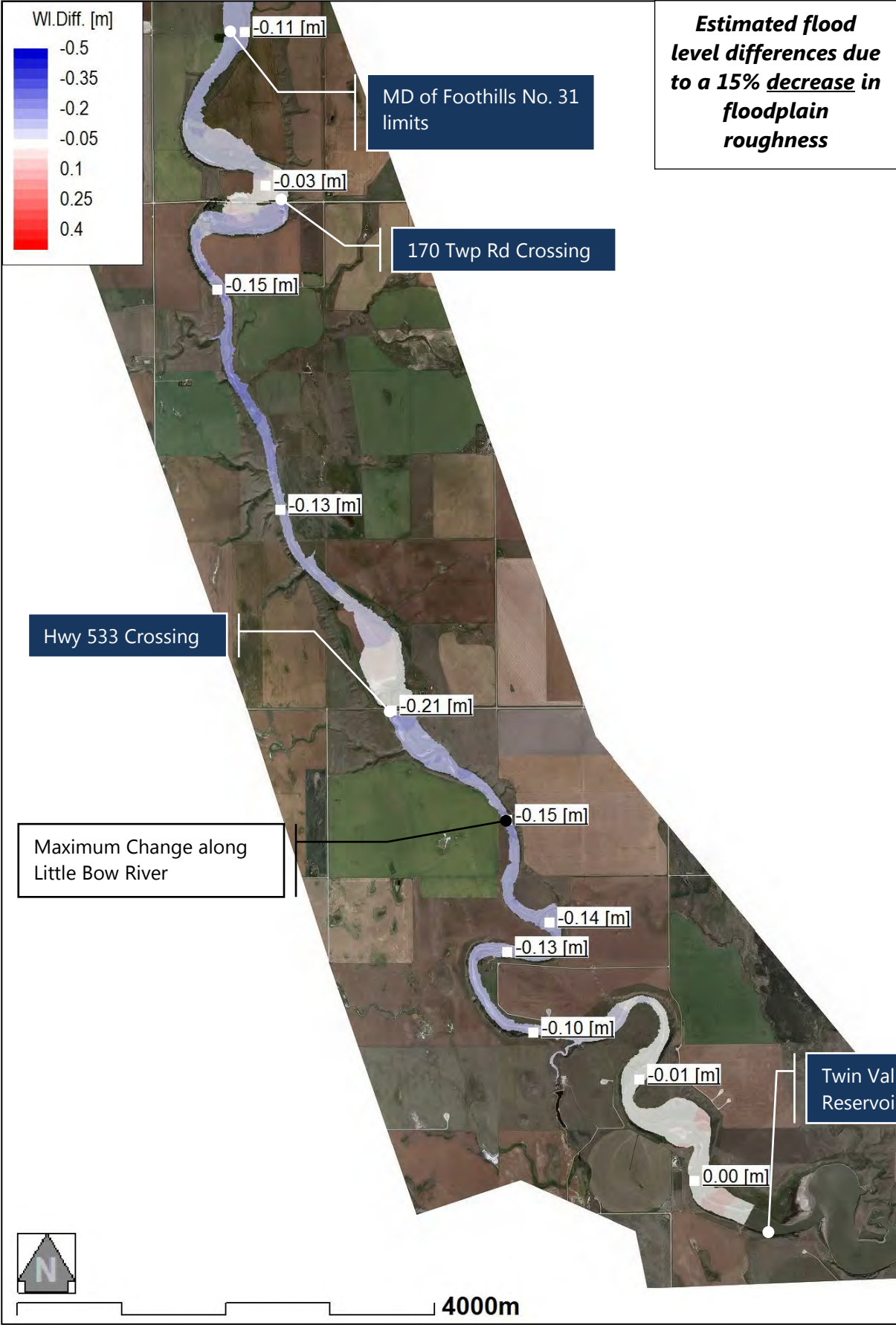
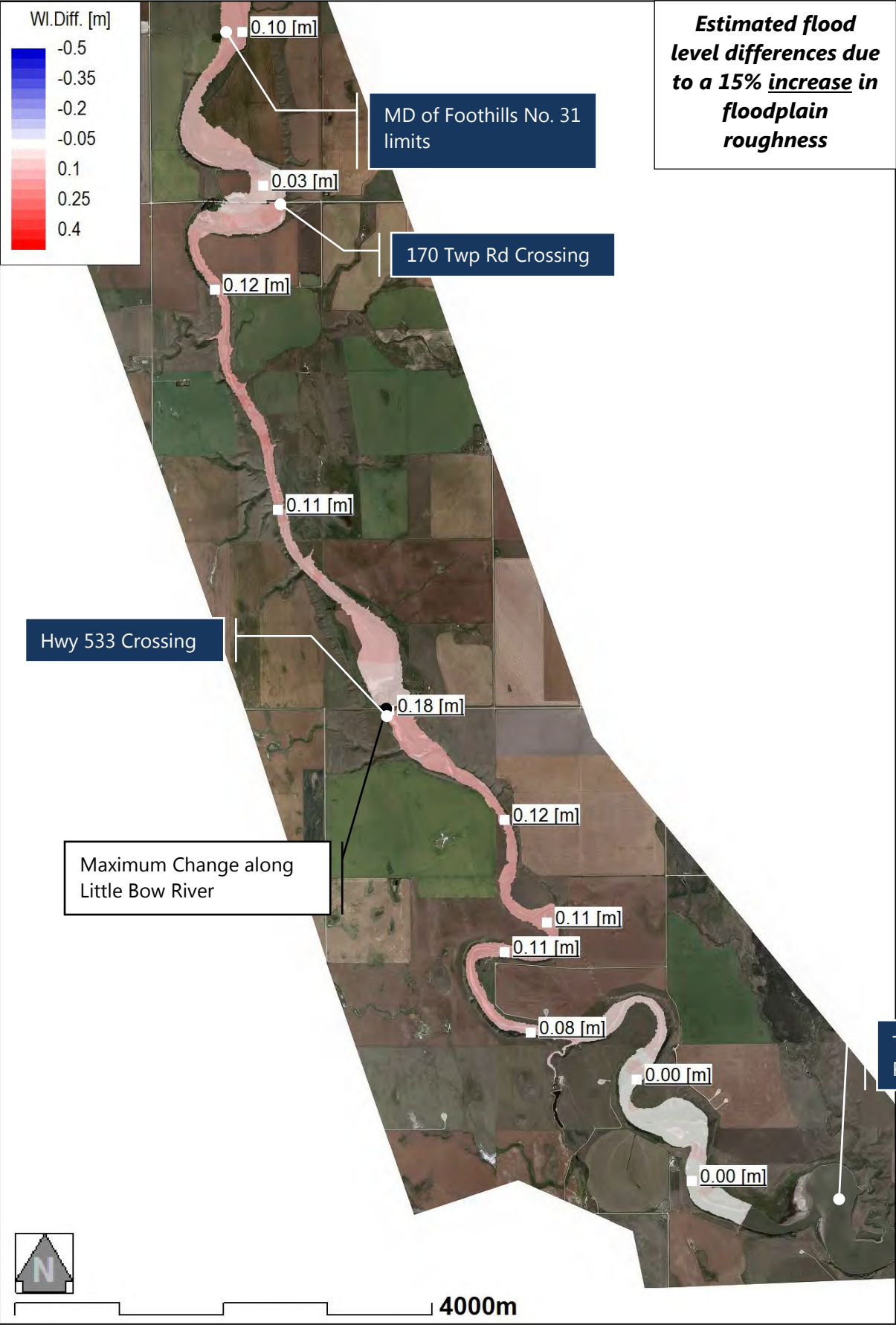
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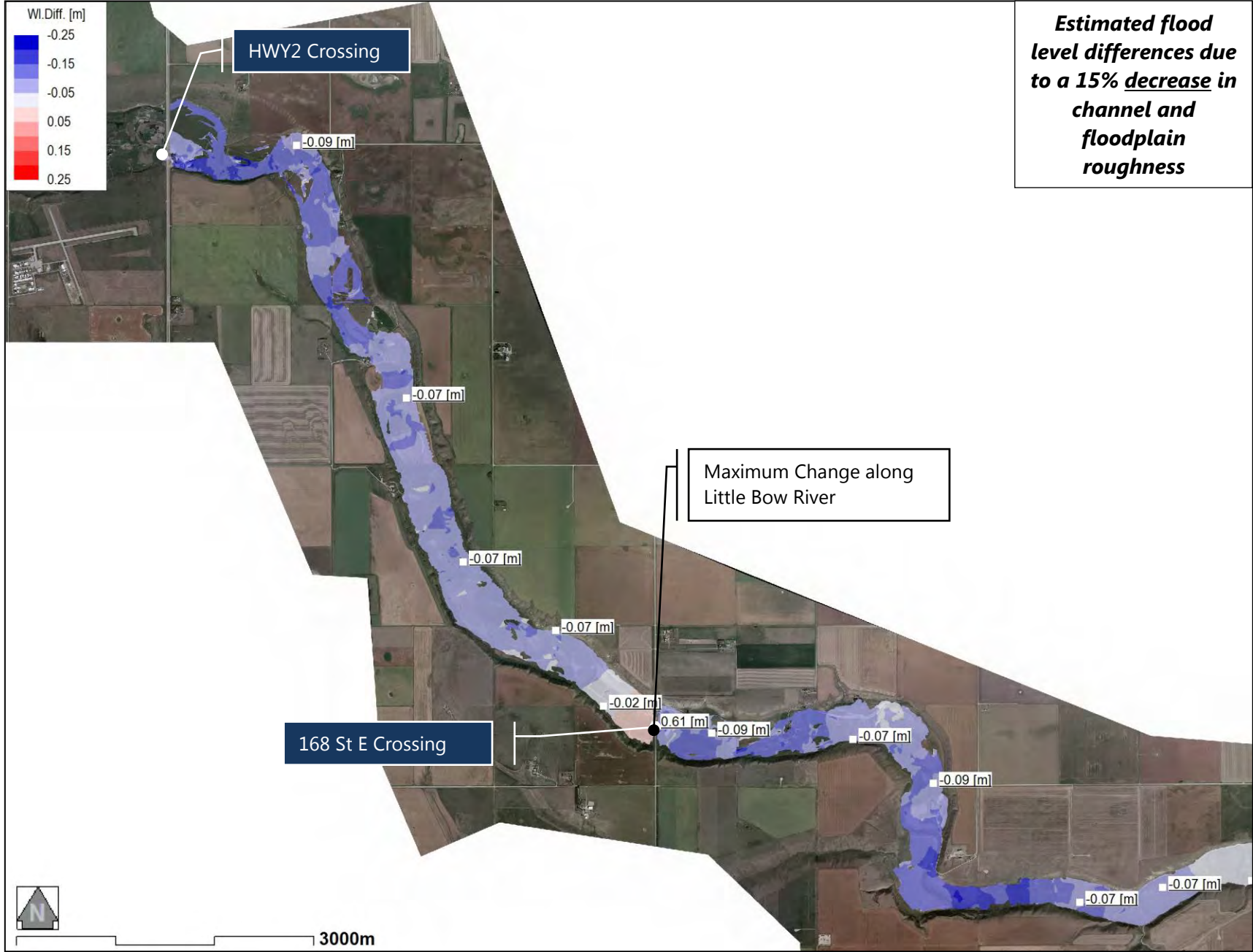
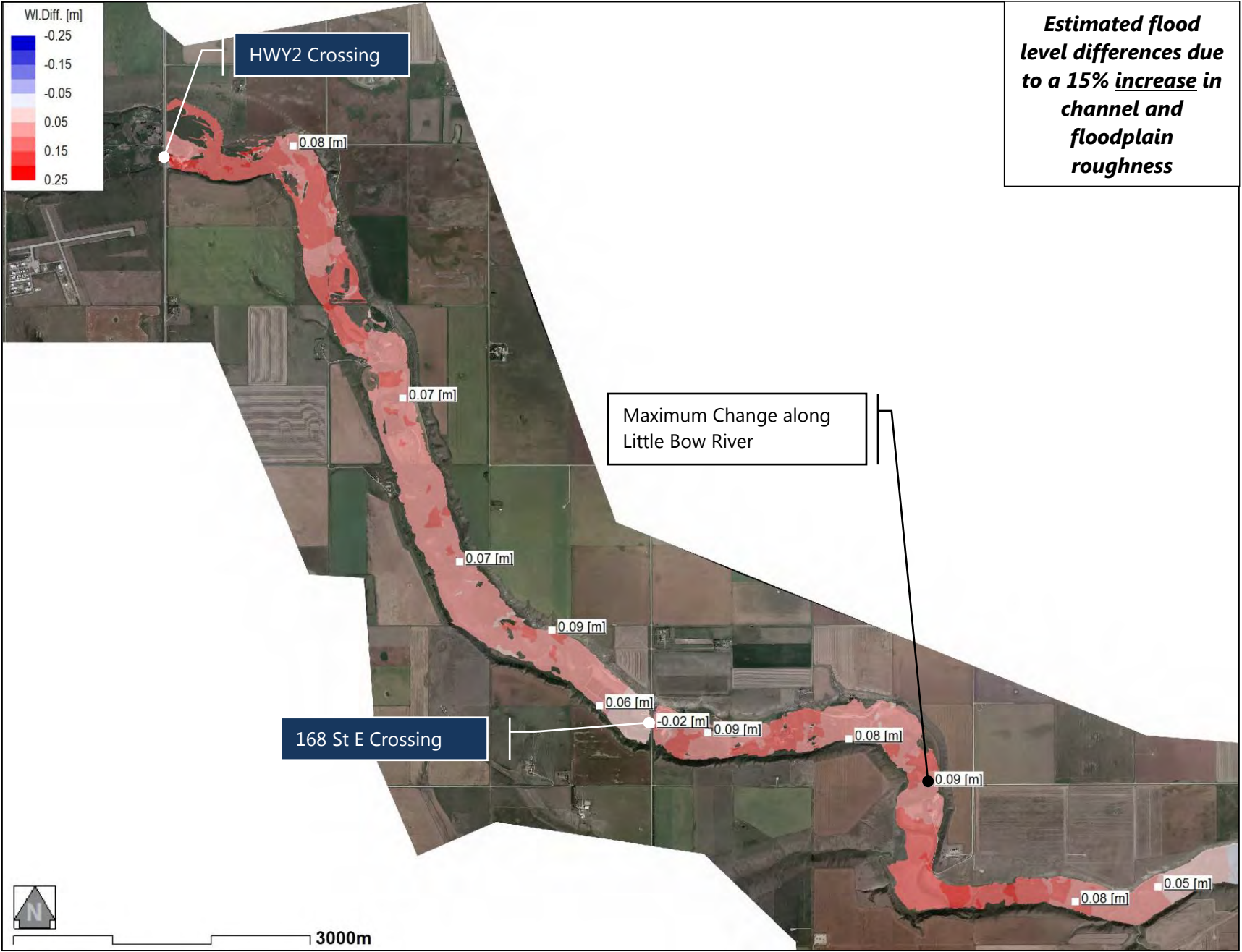
Figure No: 5-16

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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 15% Increase or Decrease in Floodplain Roughness (3 of 3)				
Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-17	Rev: 1	
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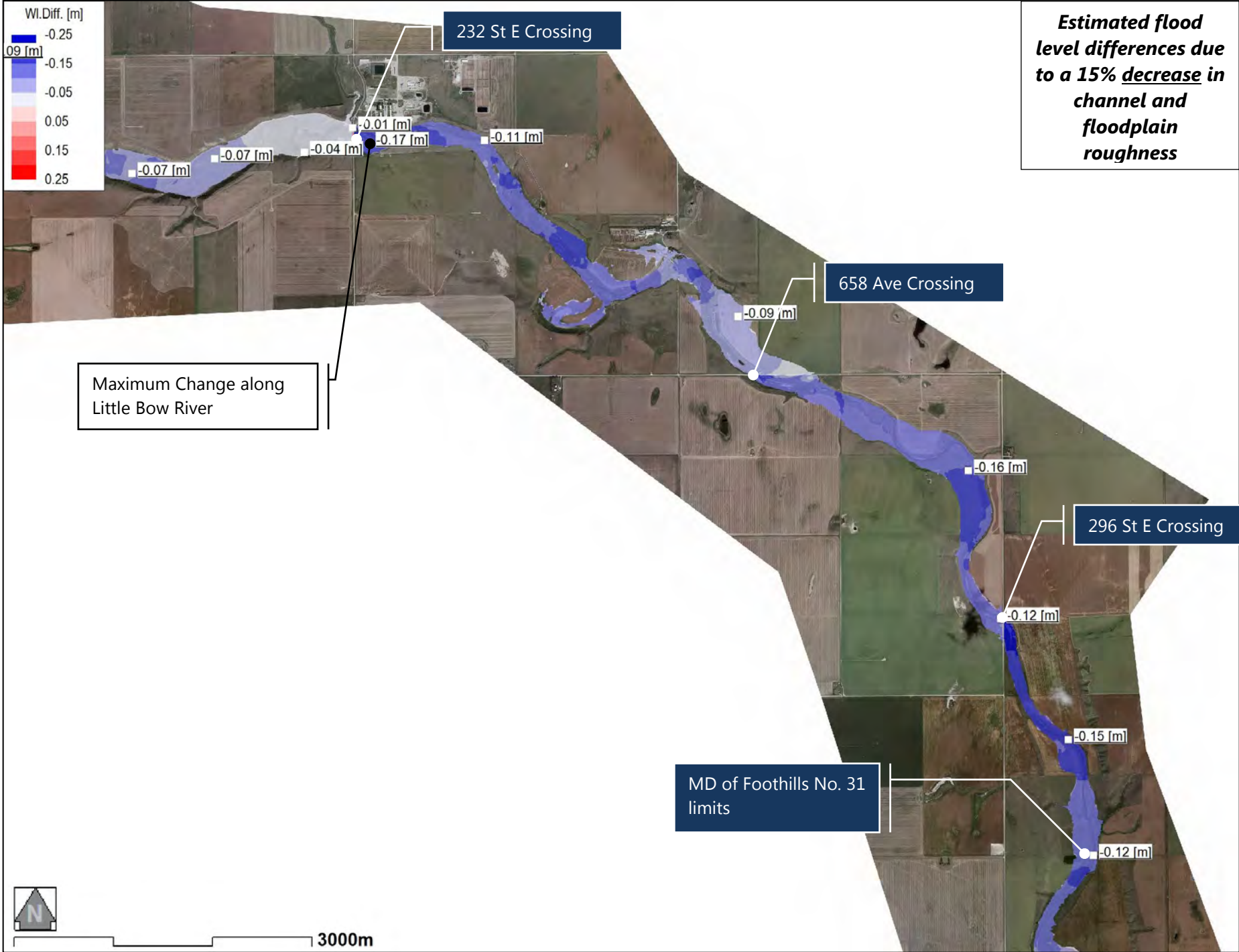
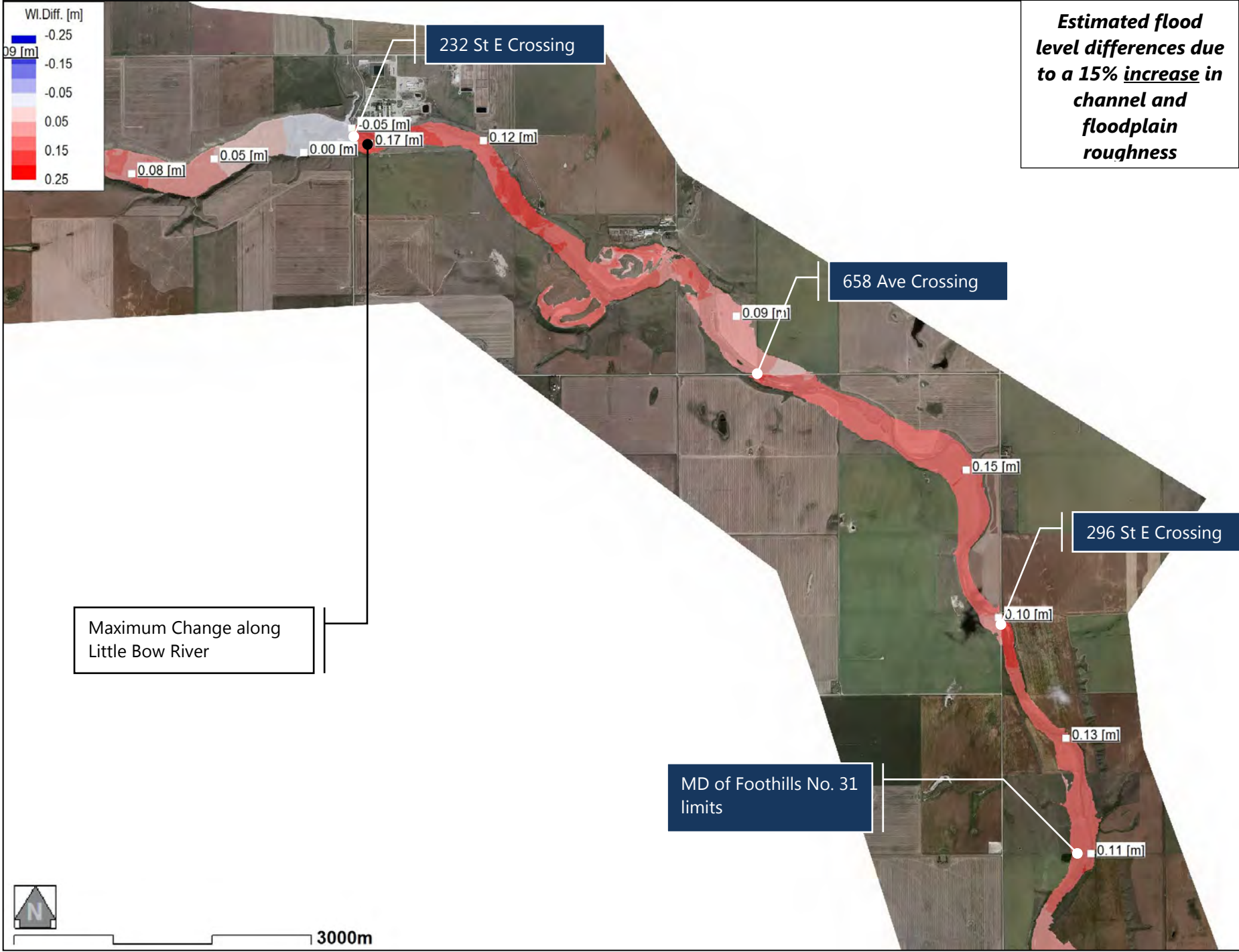
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Figure No: 5-18

Rev: 0

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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 15% Increase or Decrease in Channel and Floodplain Roughness (1 of 3)				
Date:	Jan 30, 2017	File Path:	U:\CAL\GBS\307076-07348\12_0_Reports\12_3_Backend\Little Bow River Modelling\Figures	Figure No: 5-18
Created By:	AP	Reviewed By:	JB	Rev: 0
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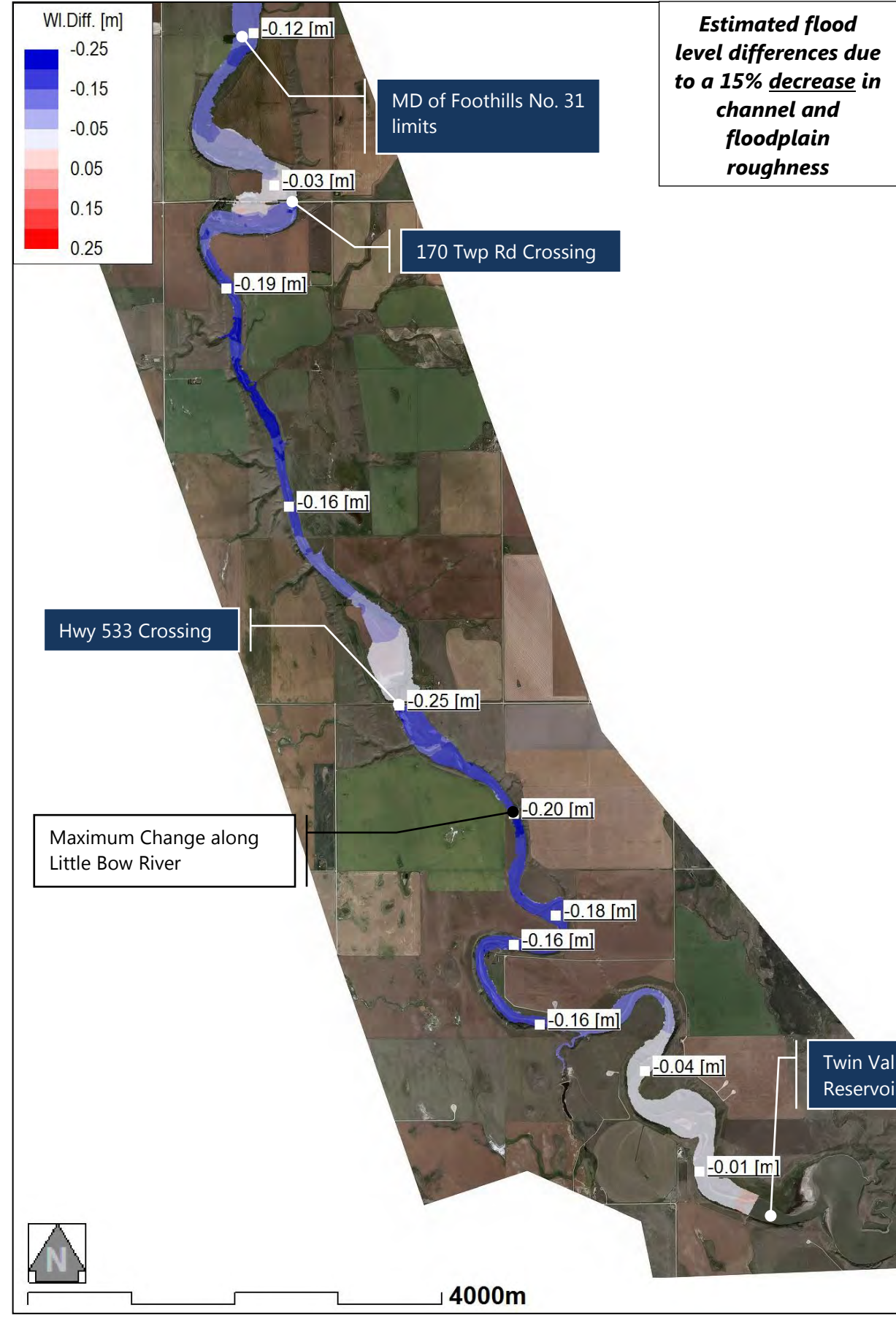
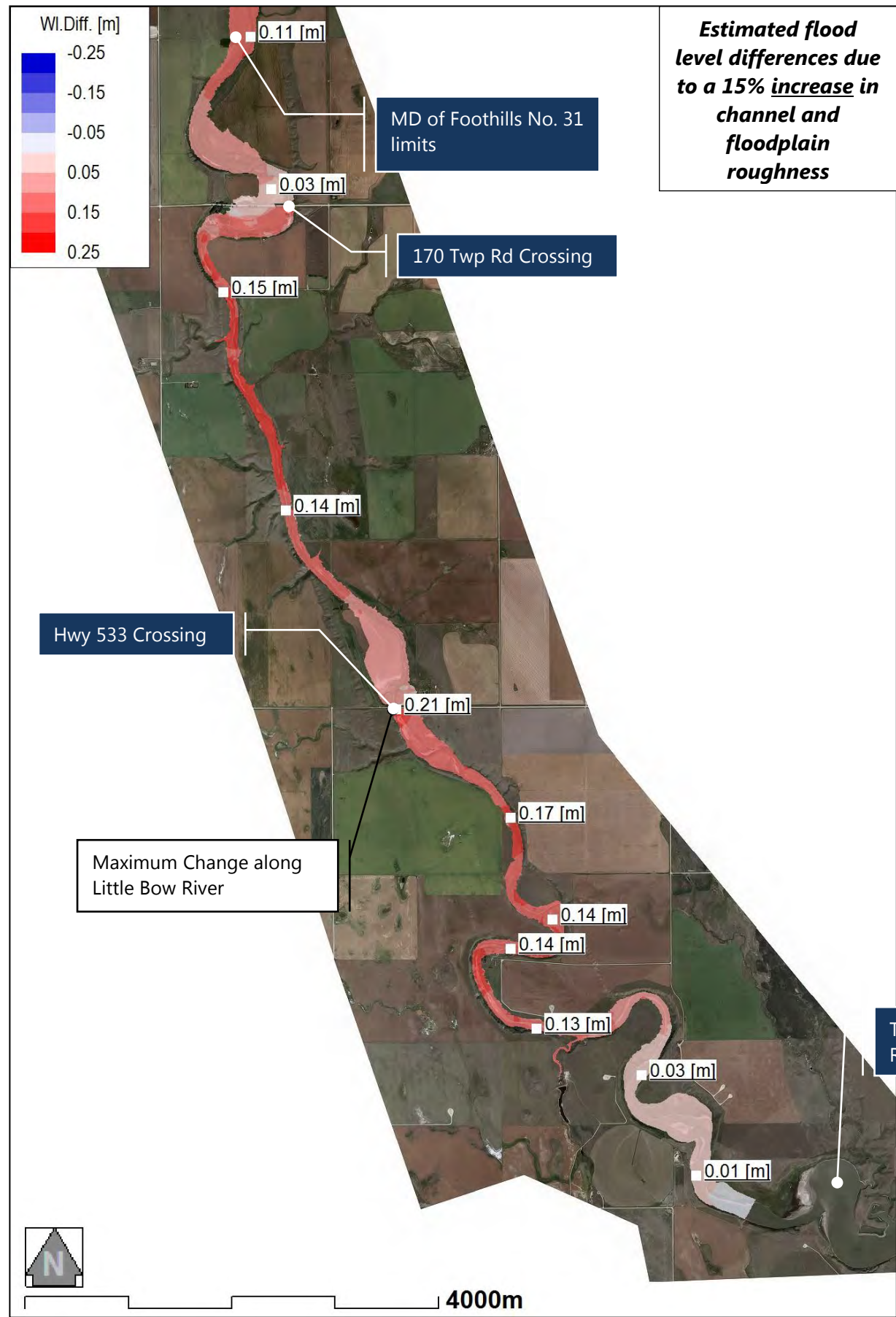
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Figure No: 5-19
Rev: 0

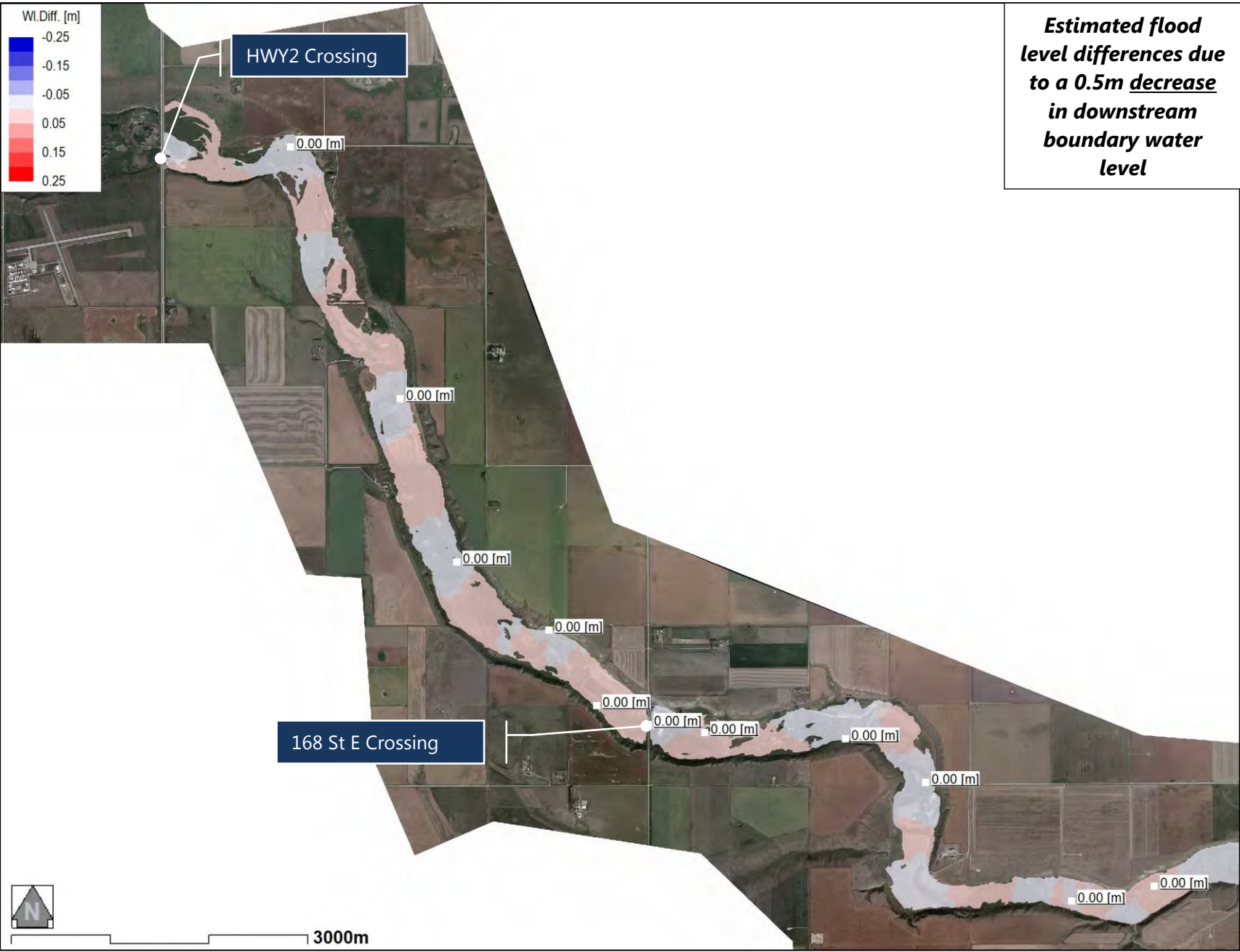
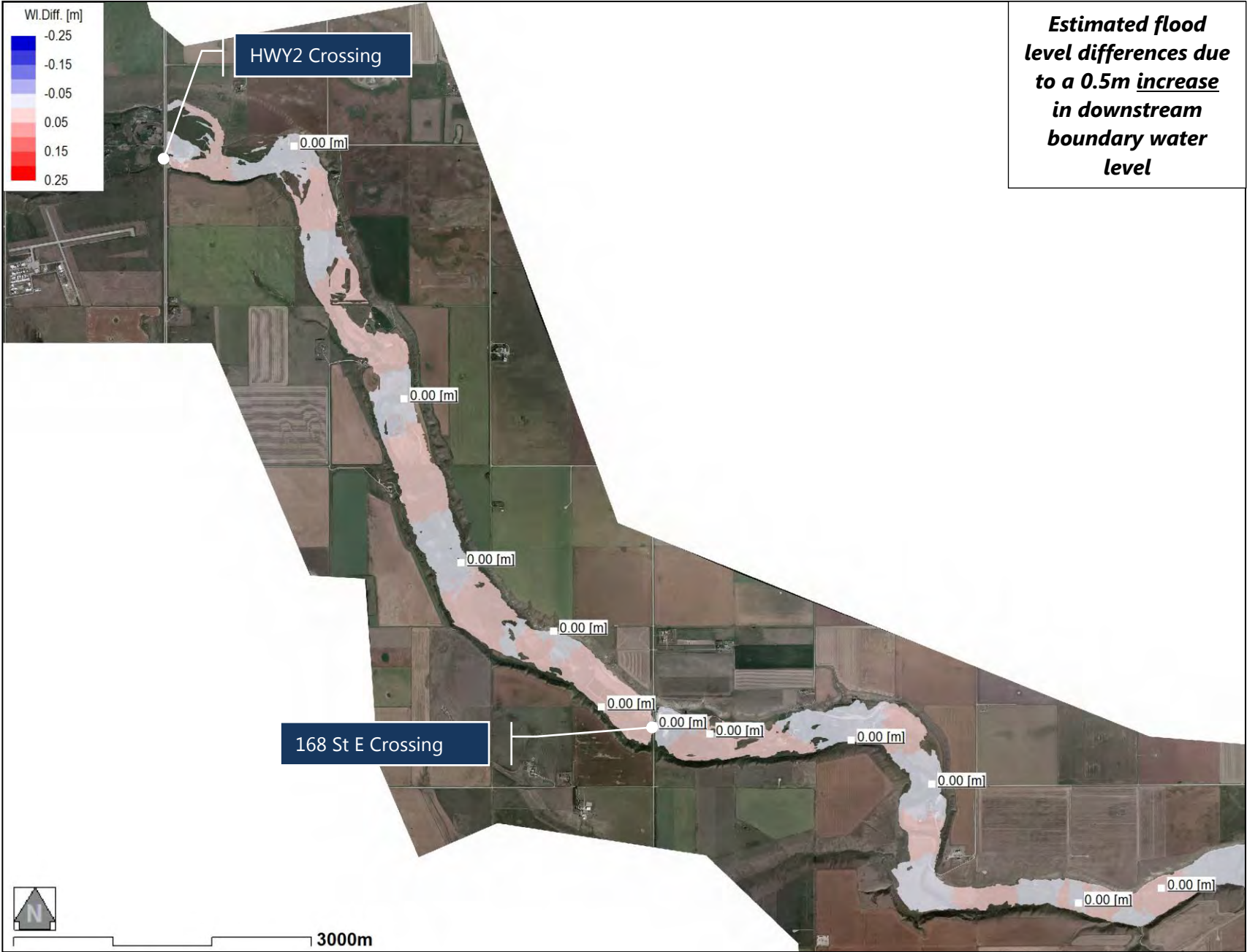
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 15% Increase or Decrease in Channel and Floodplain Roughness (2 of 3)



Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 15% Increase or Decrease in Channel and Floodplain Roughness (3 of 3)				
Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-20	Rev: 1
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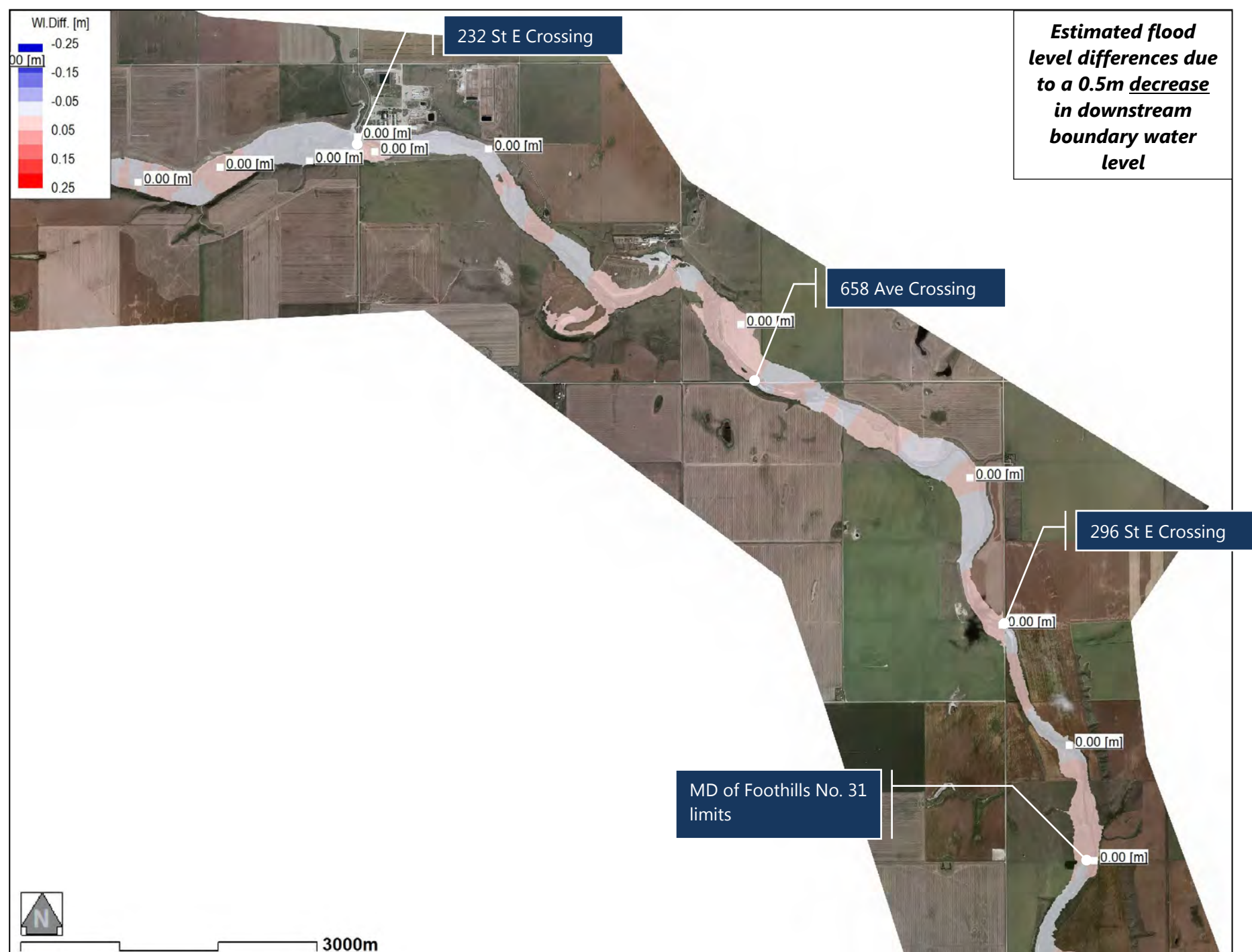
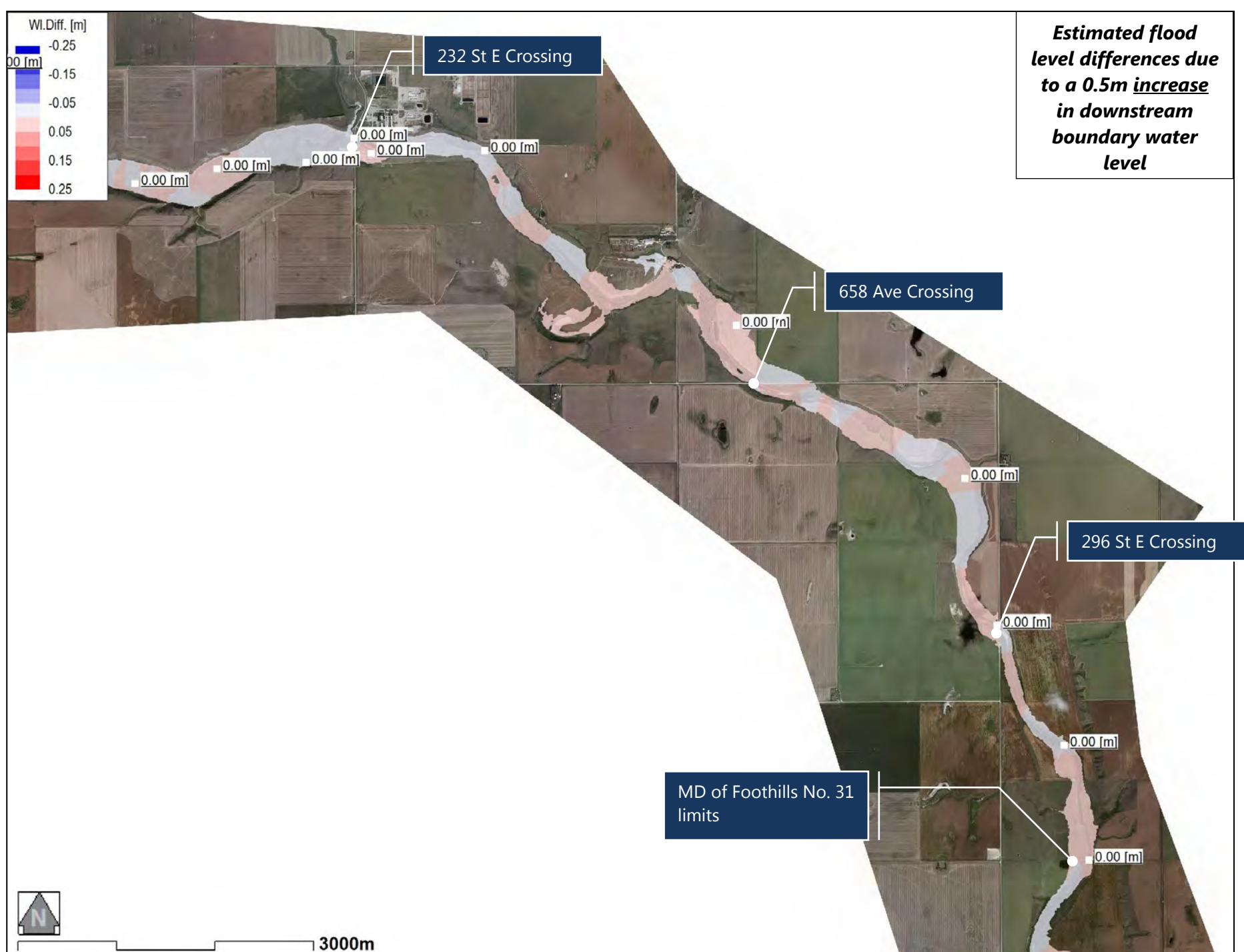
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
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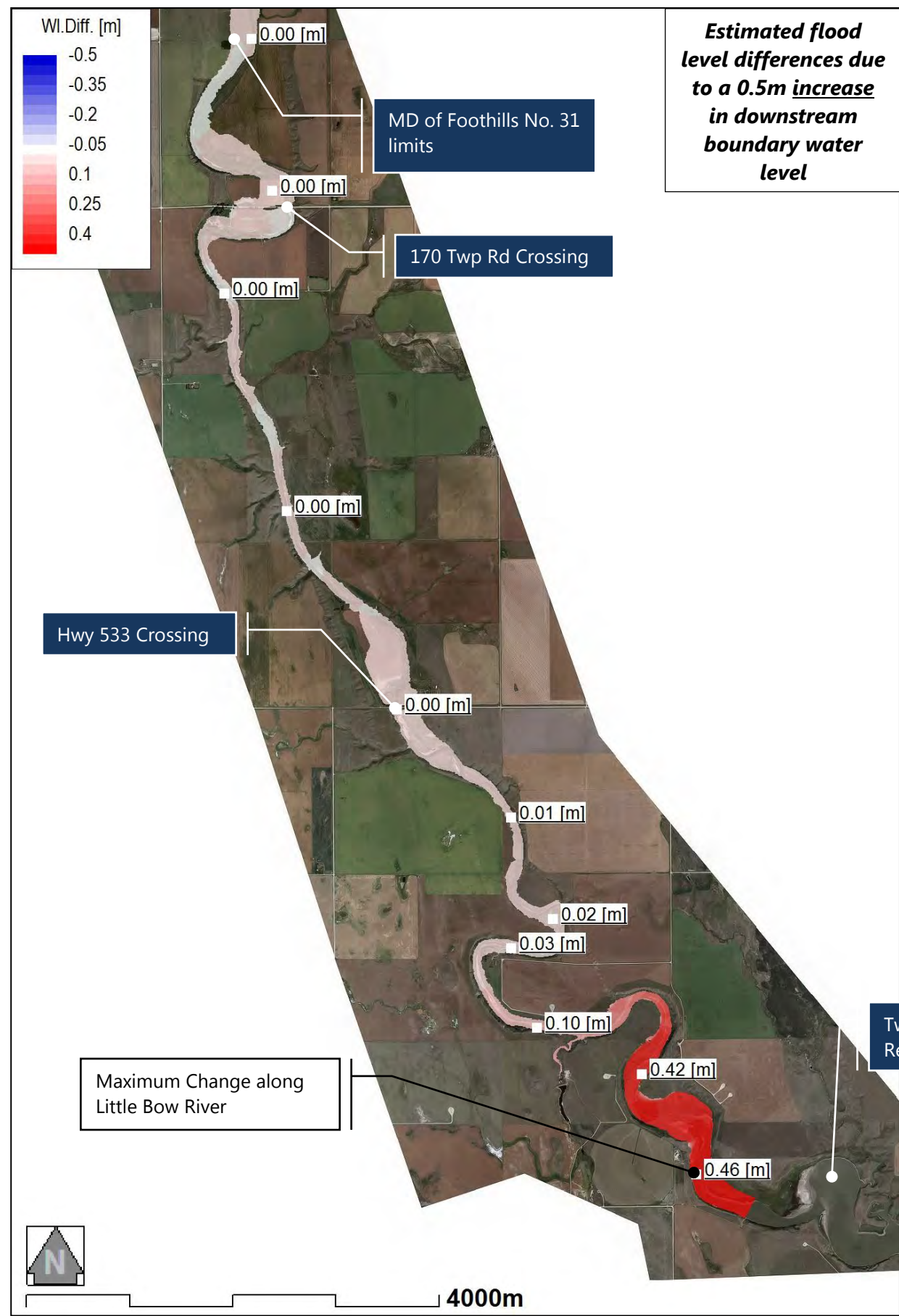
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 0.5m Increase or Decrease in Downstream Water Level (1 of 3)				
Date:	Jan 30, 2017	File Path:	U:\CAL\GBS\307076-07348\12_0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-21
Created By:	AP	Reviewed By:	JB	Rev: 0
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		<div>Estimated Changes in Peak ‘June 2013 – 560 m³/s’ Flood Levels as a Result of a 0.5m Increase or Decrease in Downstream Water Level (2 of 3)</div>			
<div>Created By: AP</div>		<div>Date: Jan 30, 2016</div>	<div>File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures</div>	<div>Figure No: 5-22</div>	<div>Rev: 0</div>
<div>Reviewed By: JB</div>		<div>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.</div>			



Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 560 m³/s' Flood Levels as a Result of a 0.5m Increase or Decrease in Downstream Water Level (3 of 3)



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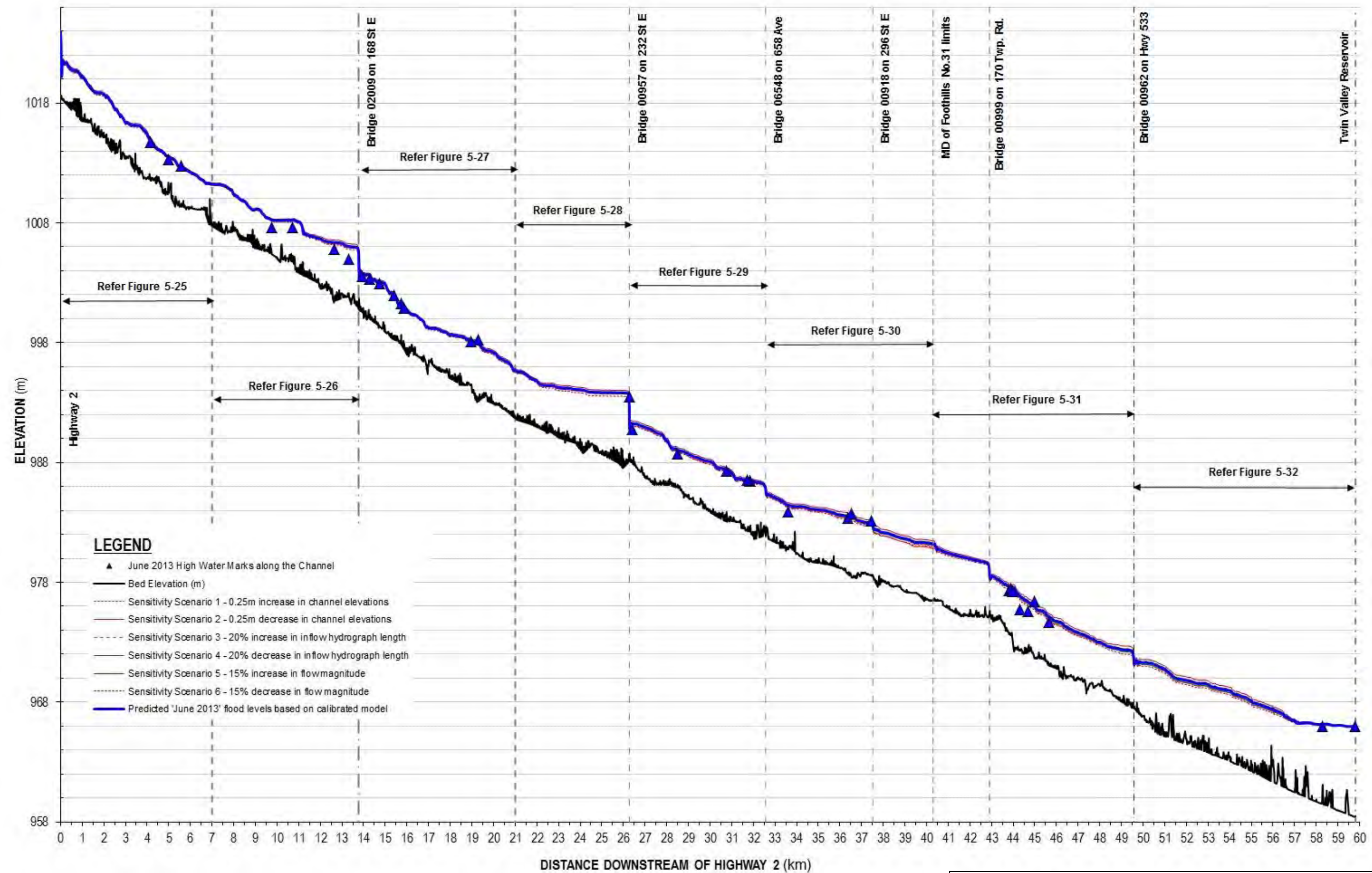
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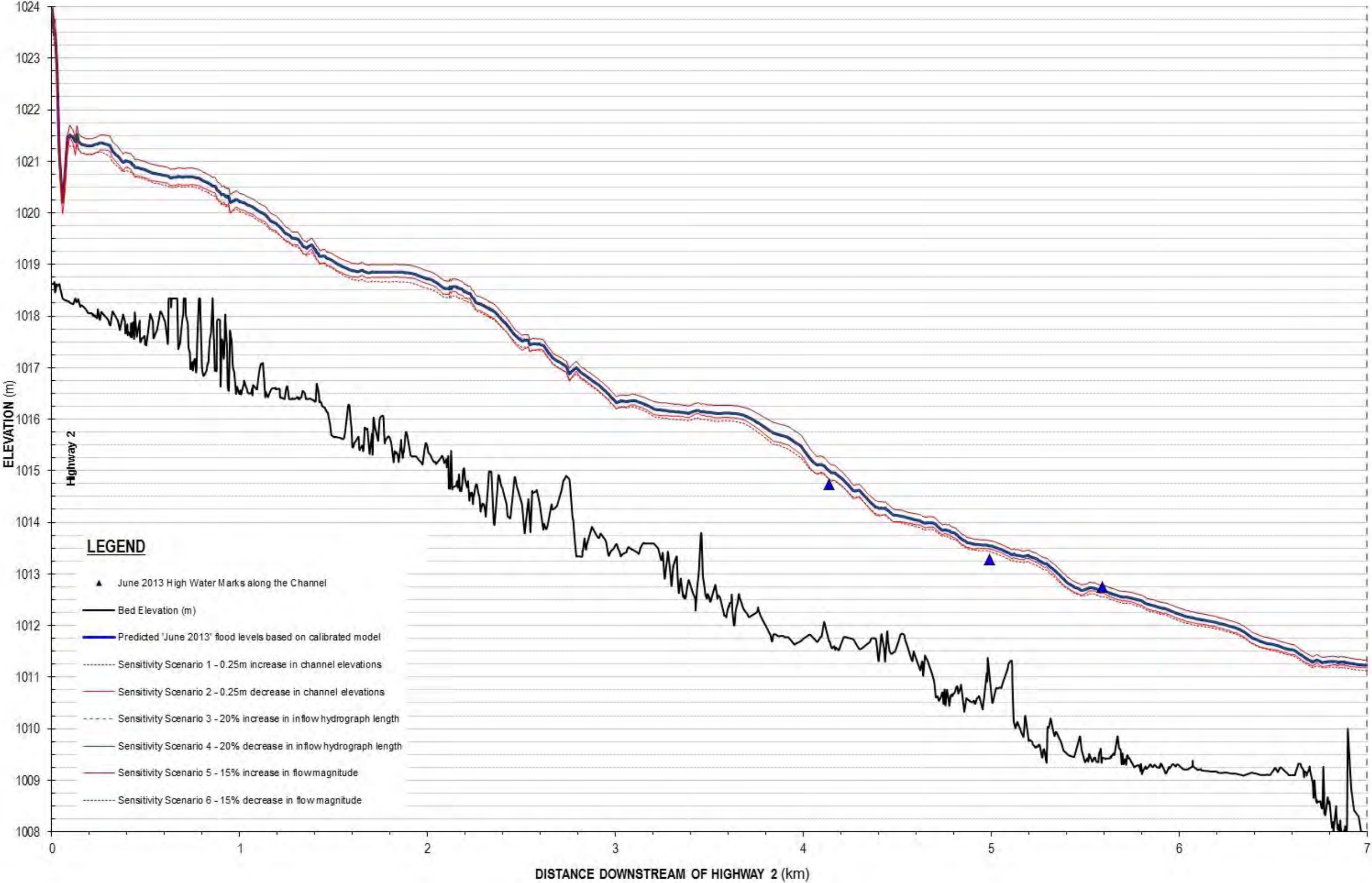
Figure No: 5-23

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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Overview)				
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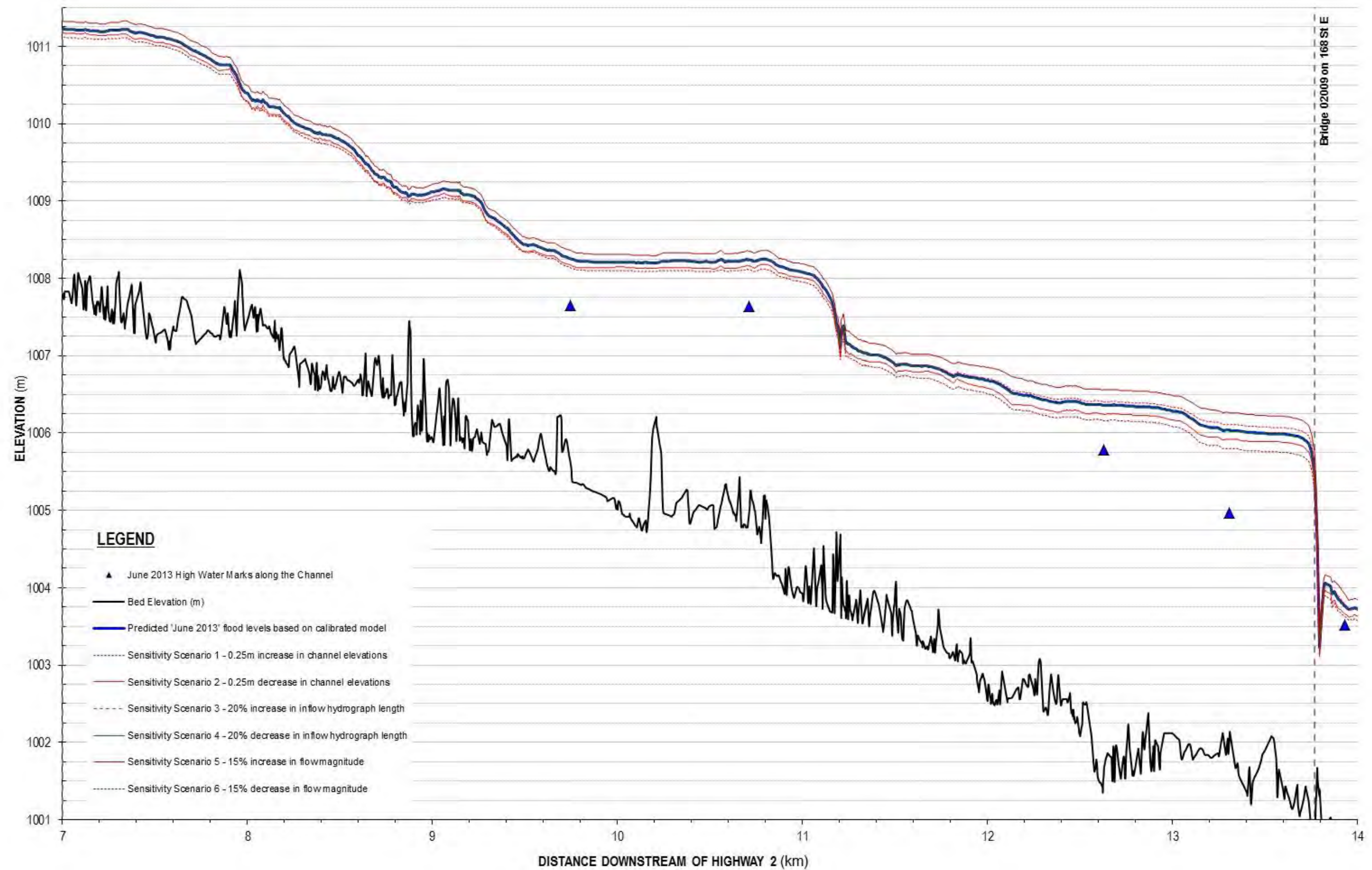


Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 1 of 8)				
Date: Jan 30, 2017		File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures		Figure No: 5-25
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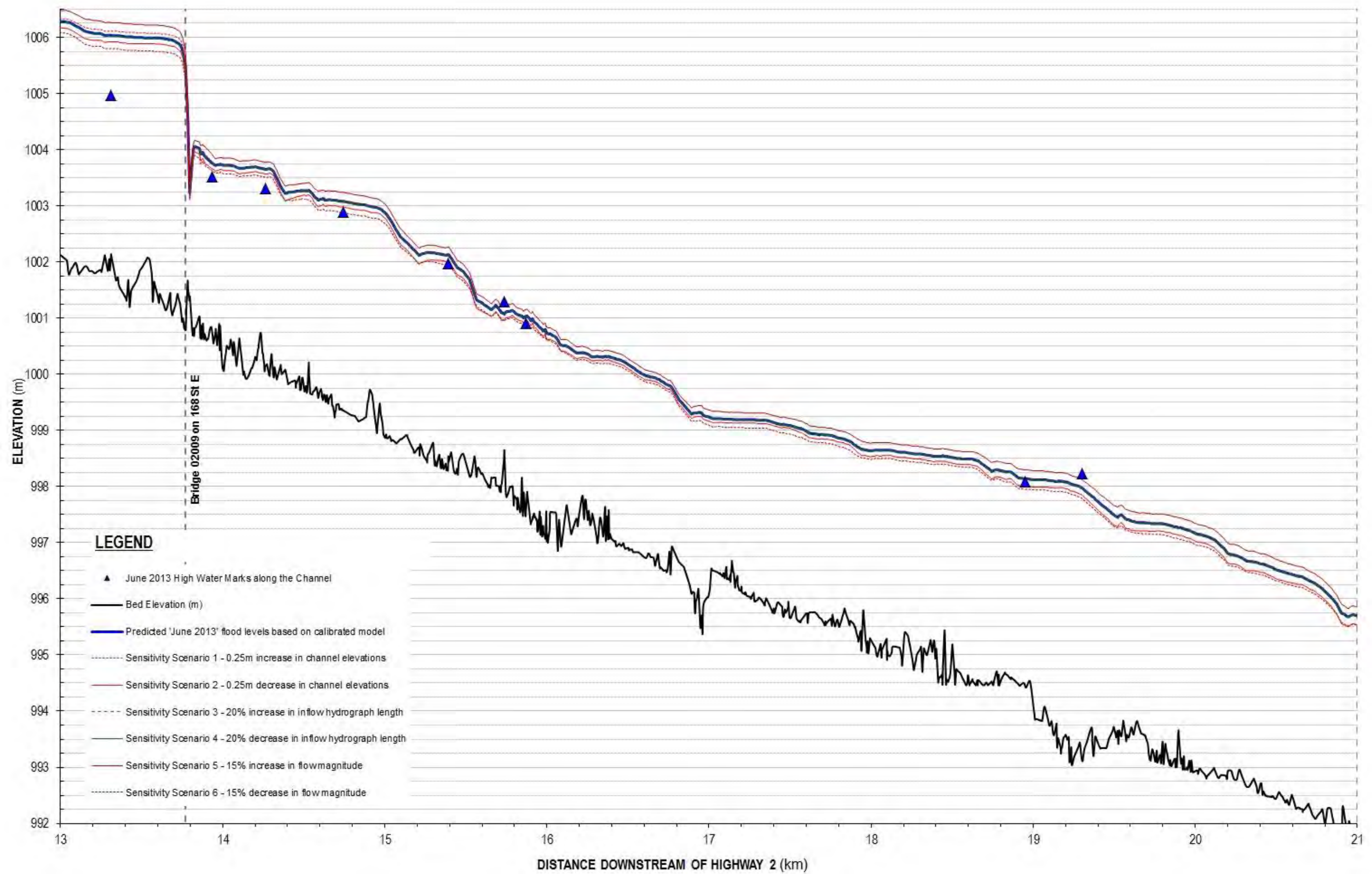


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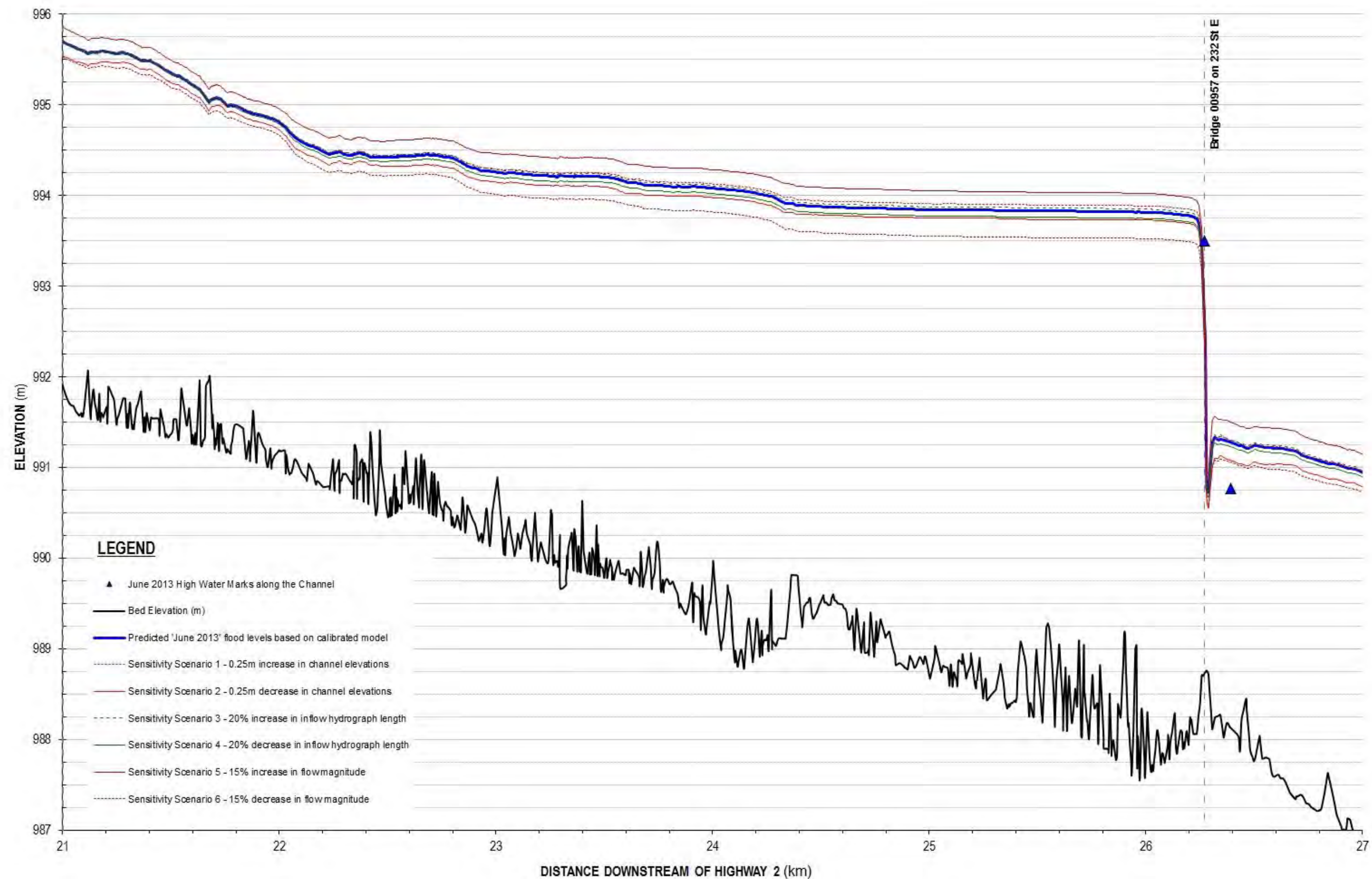
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 2 of 8)				
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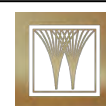


Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 3 of 8)				
Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-27	Rev: 0
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.		



Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 4 of 8)



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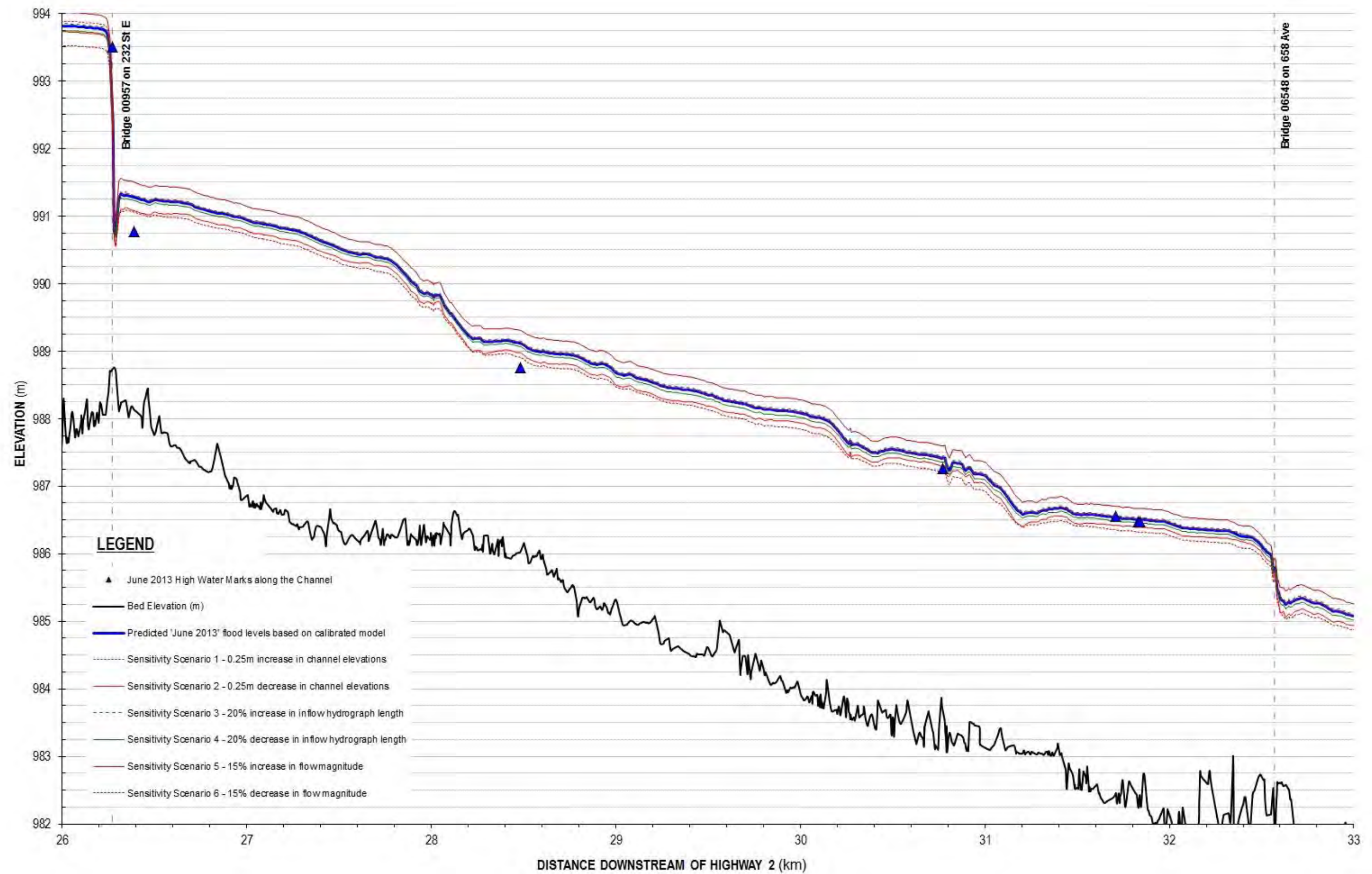
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Figure No: 5-28

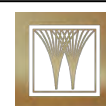
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 5 of 8)



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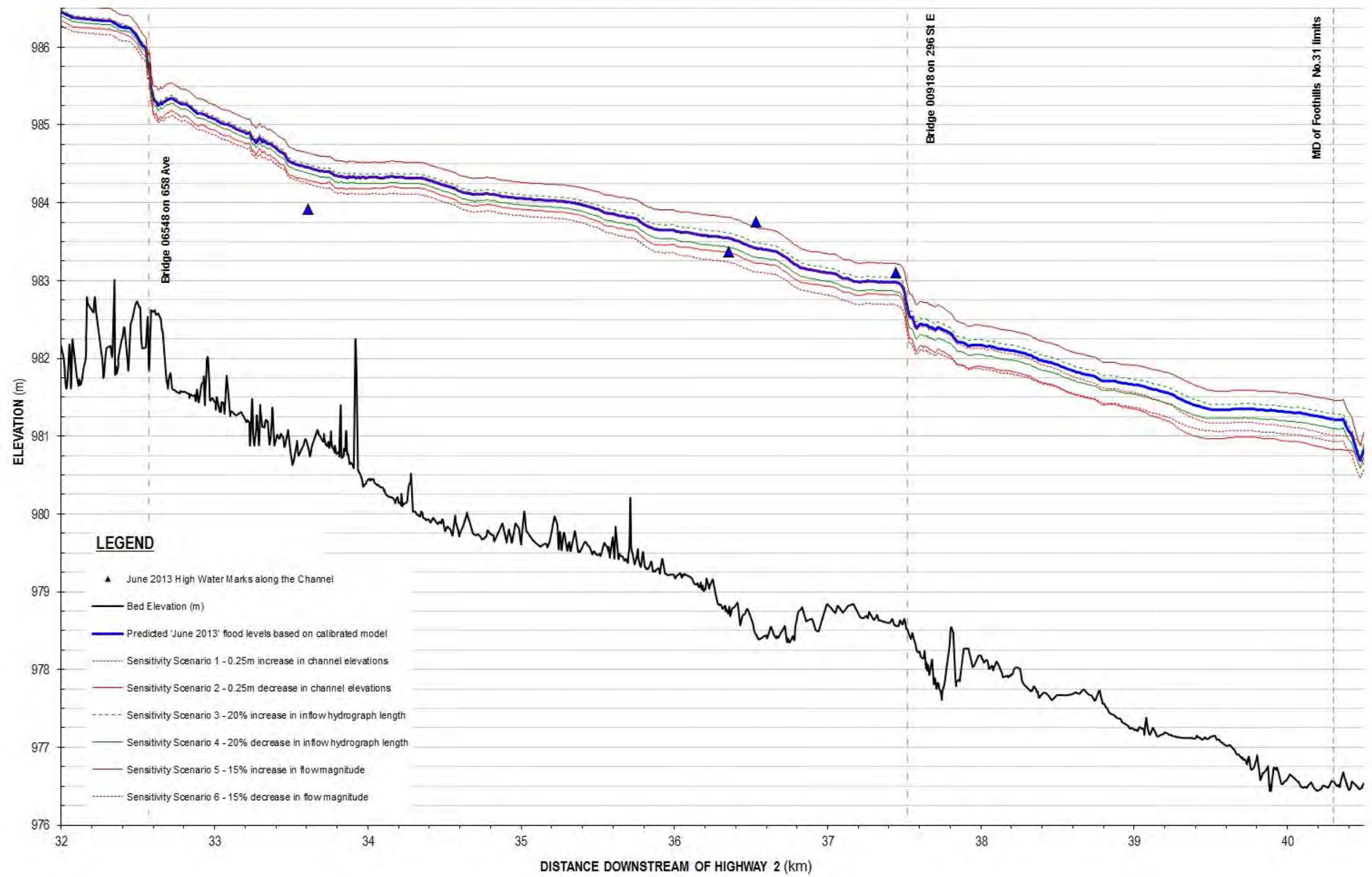
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Figure No: 5-29

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LEGEND

- ▲ June 2013 High Water Marks along the Channel
- Bed Elevation (m)
- Predicted 'June 2013' flood levels based on calibrated model
- - - Sensitivity Scenario 1 - 0.25m increase in channel elevations
- - - Sensitivity Scenario 2 - 0.25m decrease in channel elevations
- - - Sensitivity Scenario 3 - 20% increase in inflow hydrograph length
- - - Sensitivity Scenario 4 - 20% decrease in inflow hydrograph length
- - - Sensitivity Scenario 5 - 15% increase in flow magnitude
- - - Sensitivity Scenario 6 - 15% decrease in flow magnitude

Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 6 of 8)



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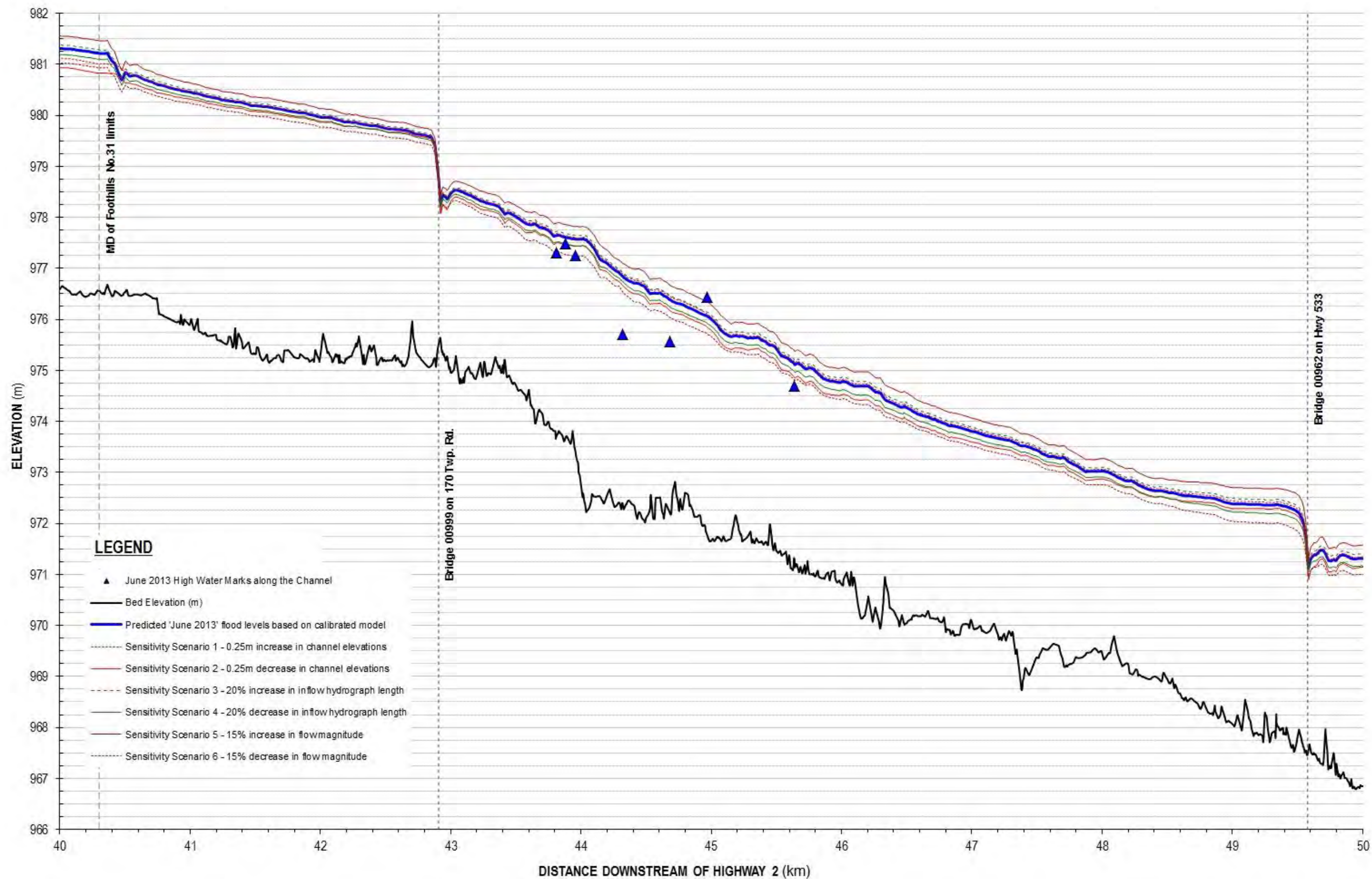
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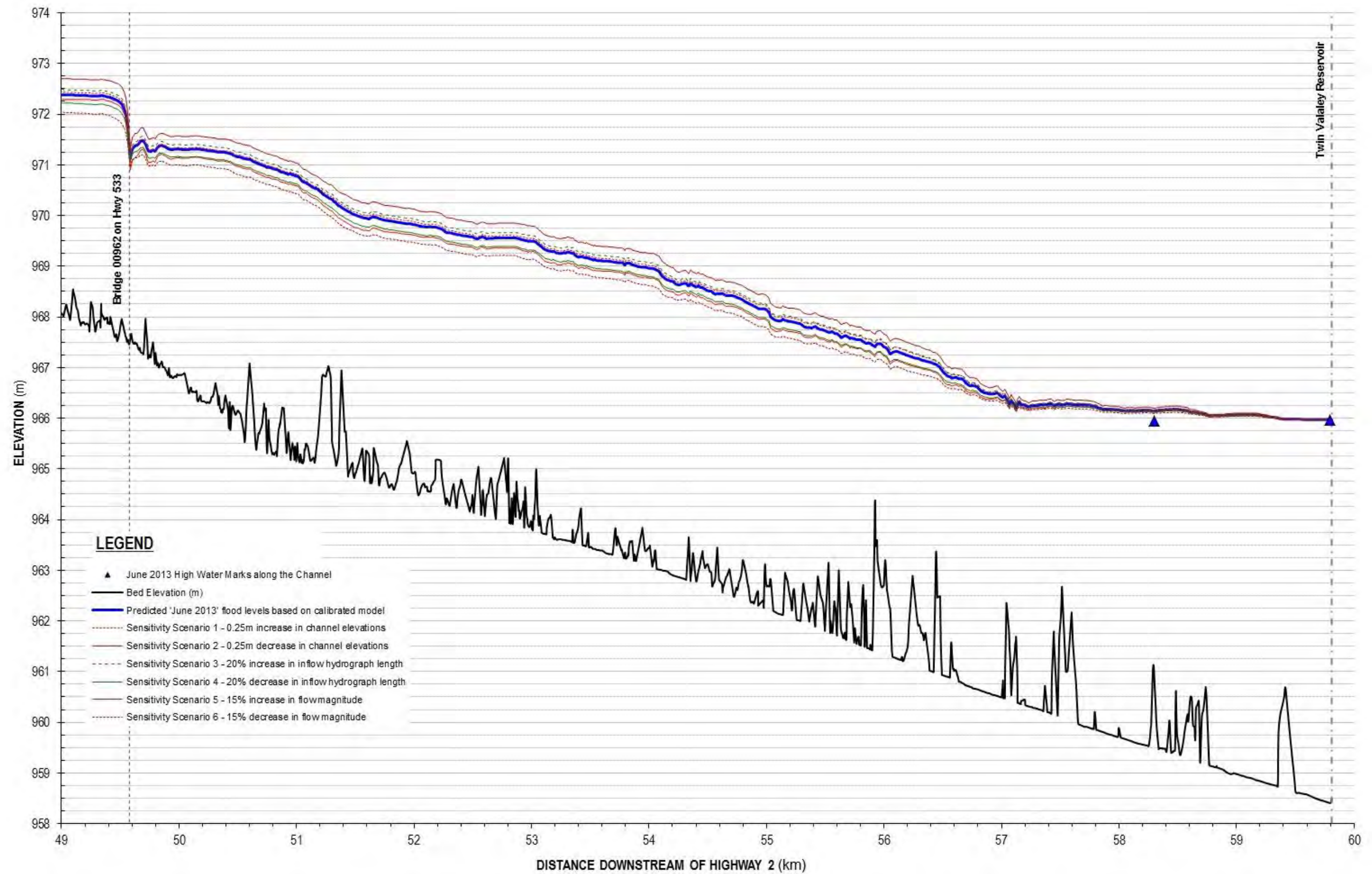
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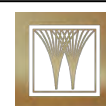


Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 7 of 8)				
Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-31	Rev: 0
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 (Extent 8 of 8)



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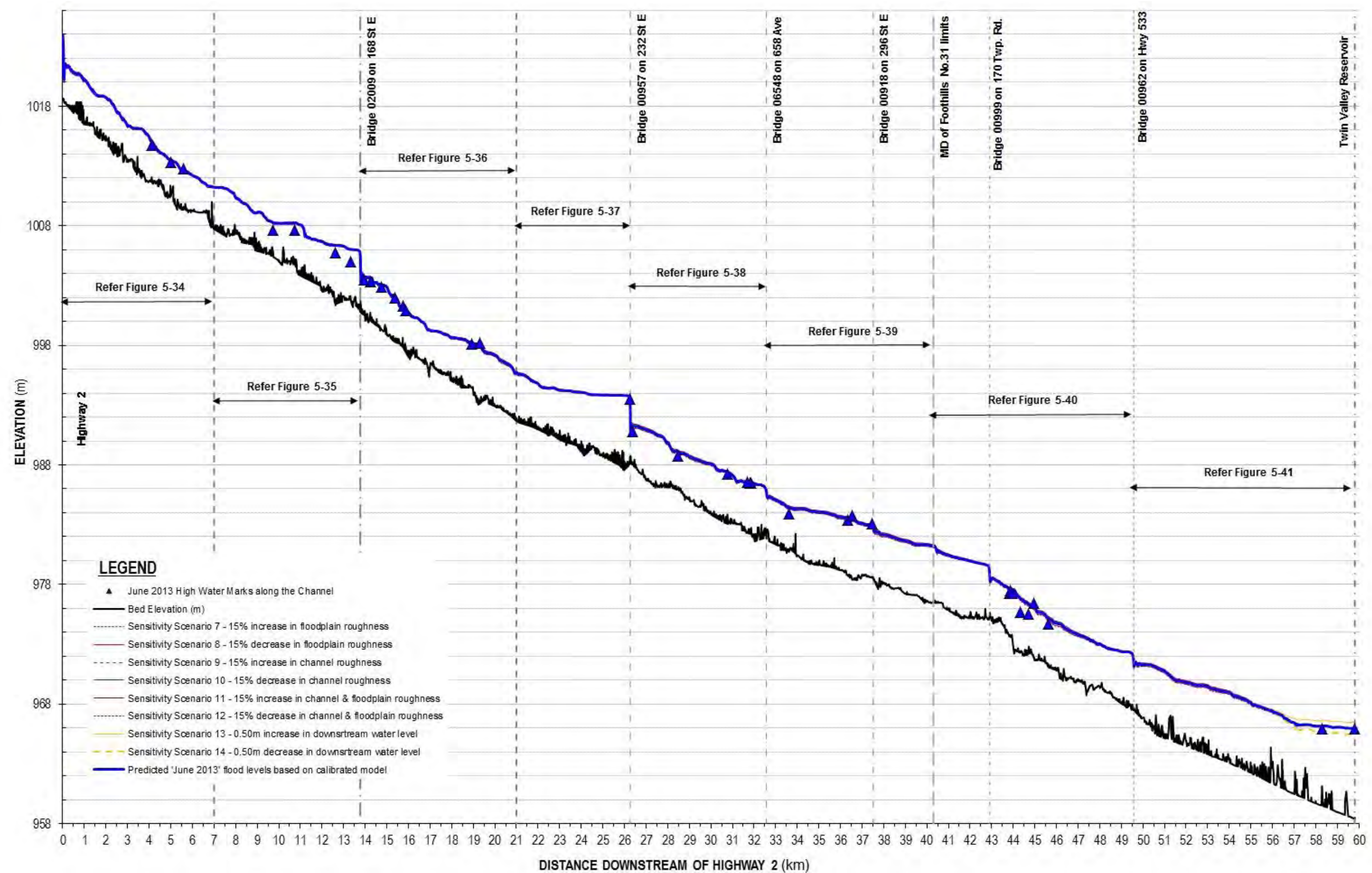
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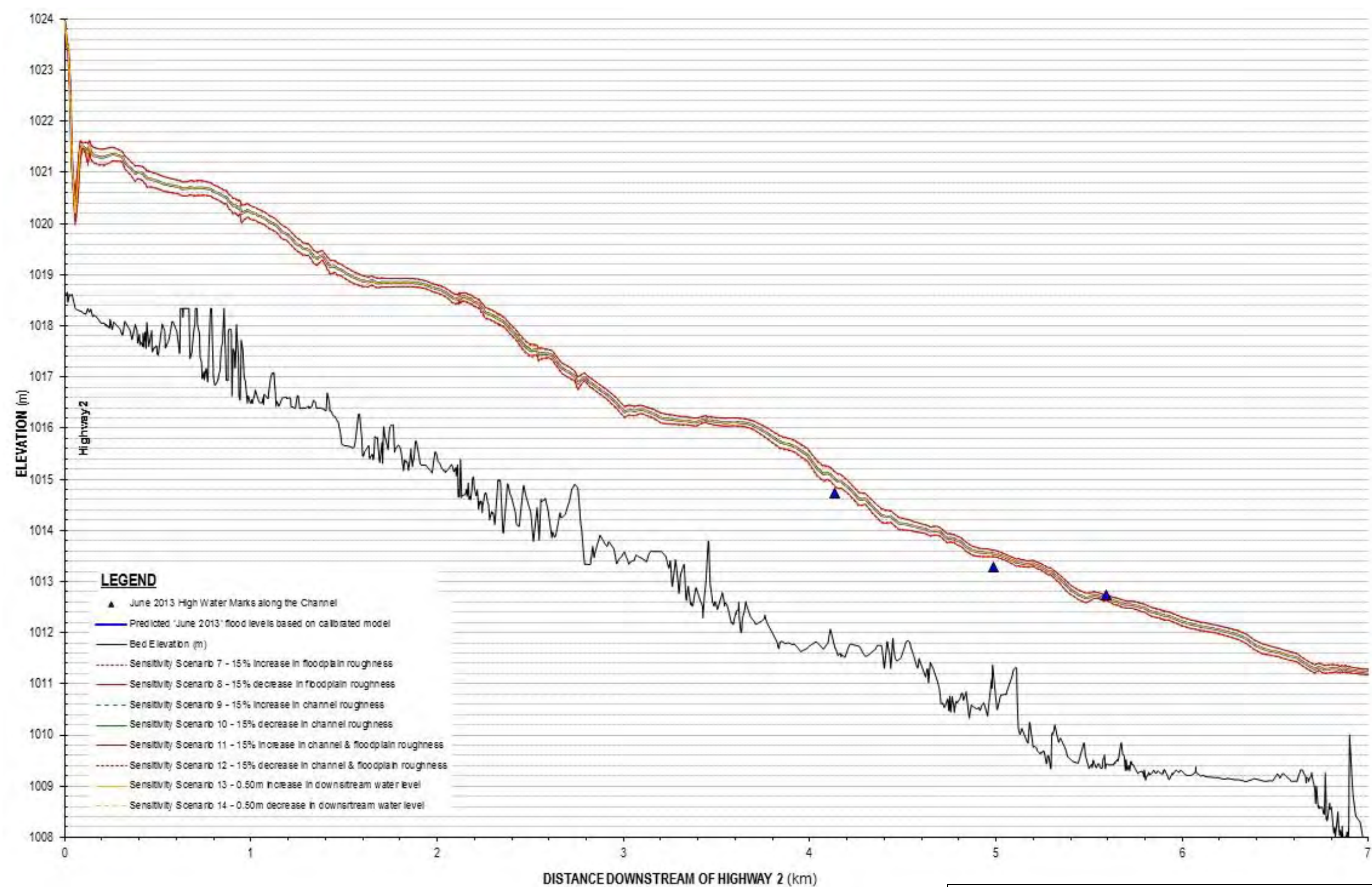
Figure No: 5-32

Rev: 0

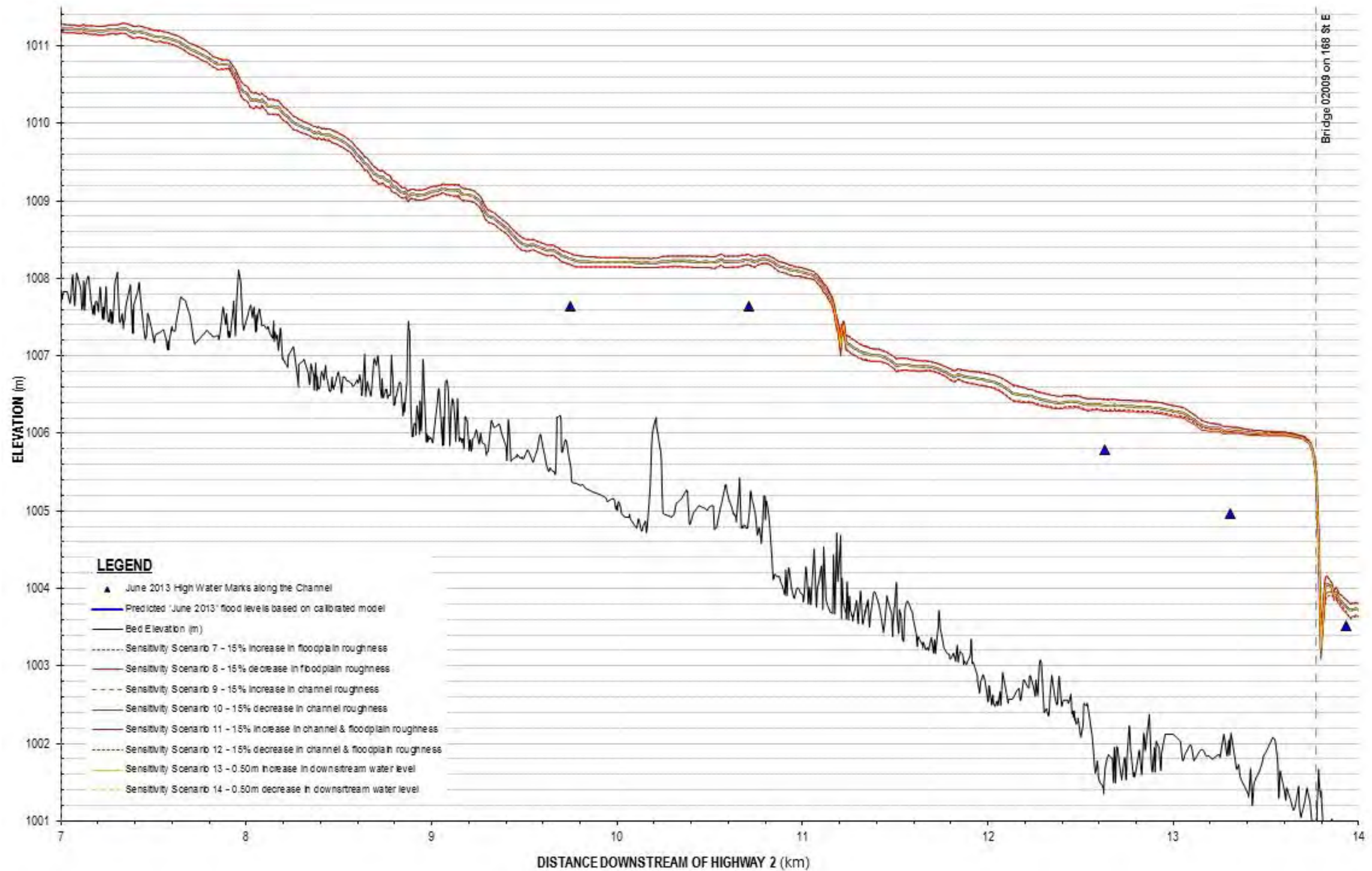
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Overview)				
Date:	Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-33	Rev: 0
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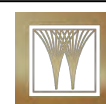


Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 1 of 8)				
Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-34	Rev: 0	
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 2 of 8)



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Reviewed By: JB

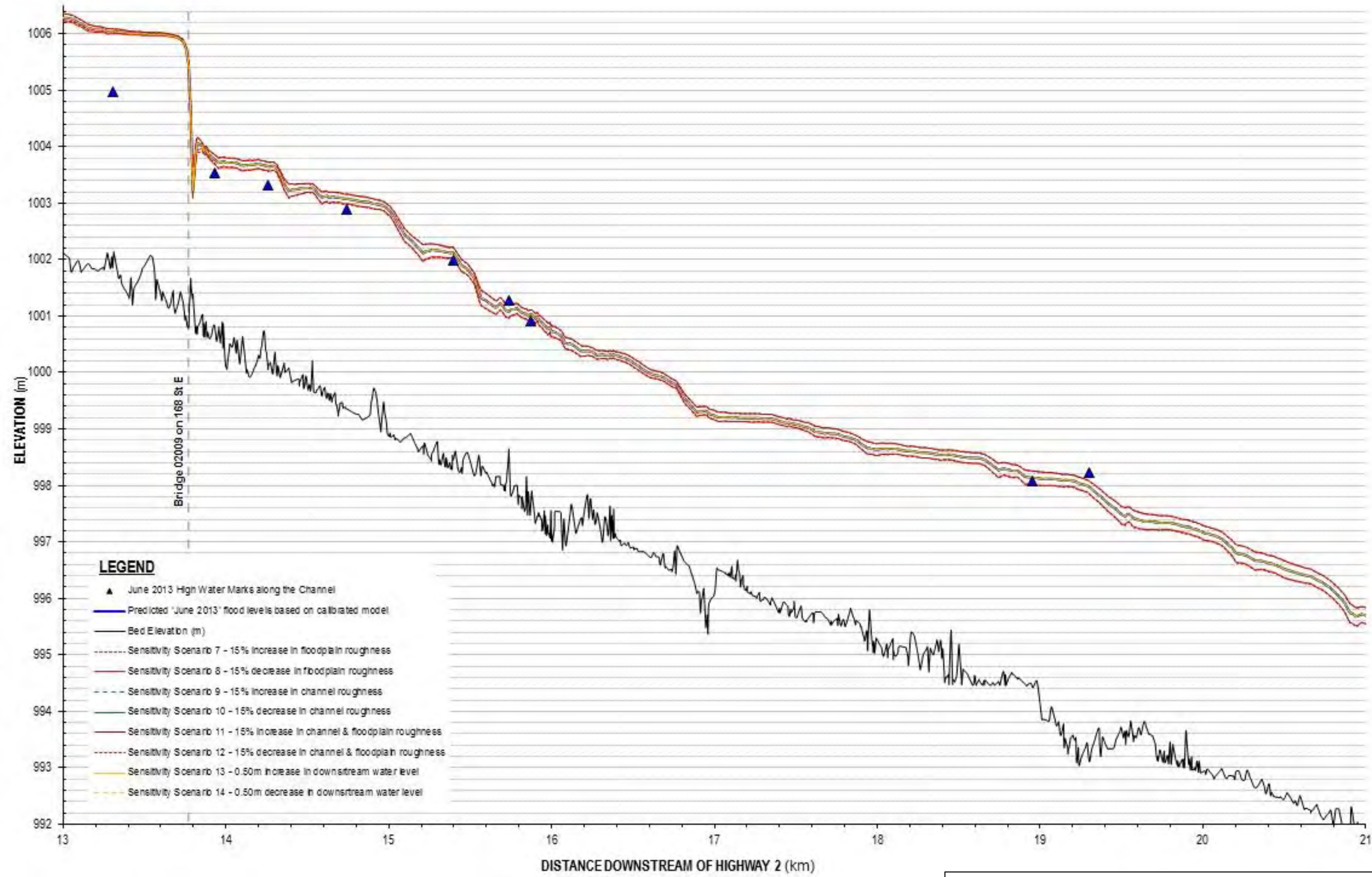
Date: Jan 30, 2017

File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures

Figure No: 5-35

Rev: 0

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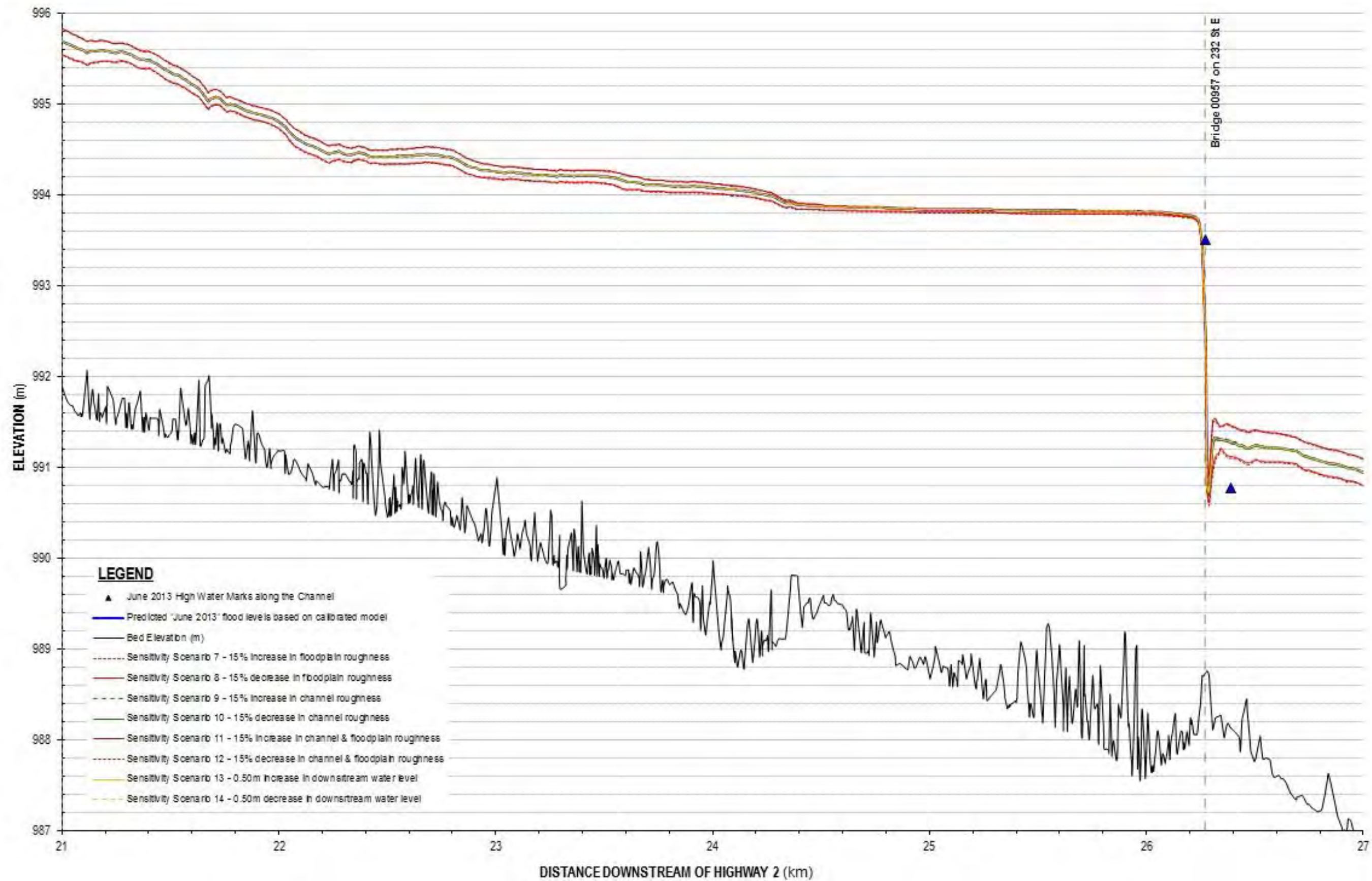


Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 3 of 8)				
Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-36	Rev: 0
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.		



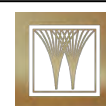
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 4 of 8)



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Reviewed By: JB

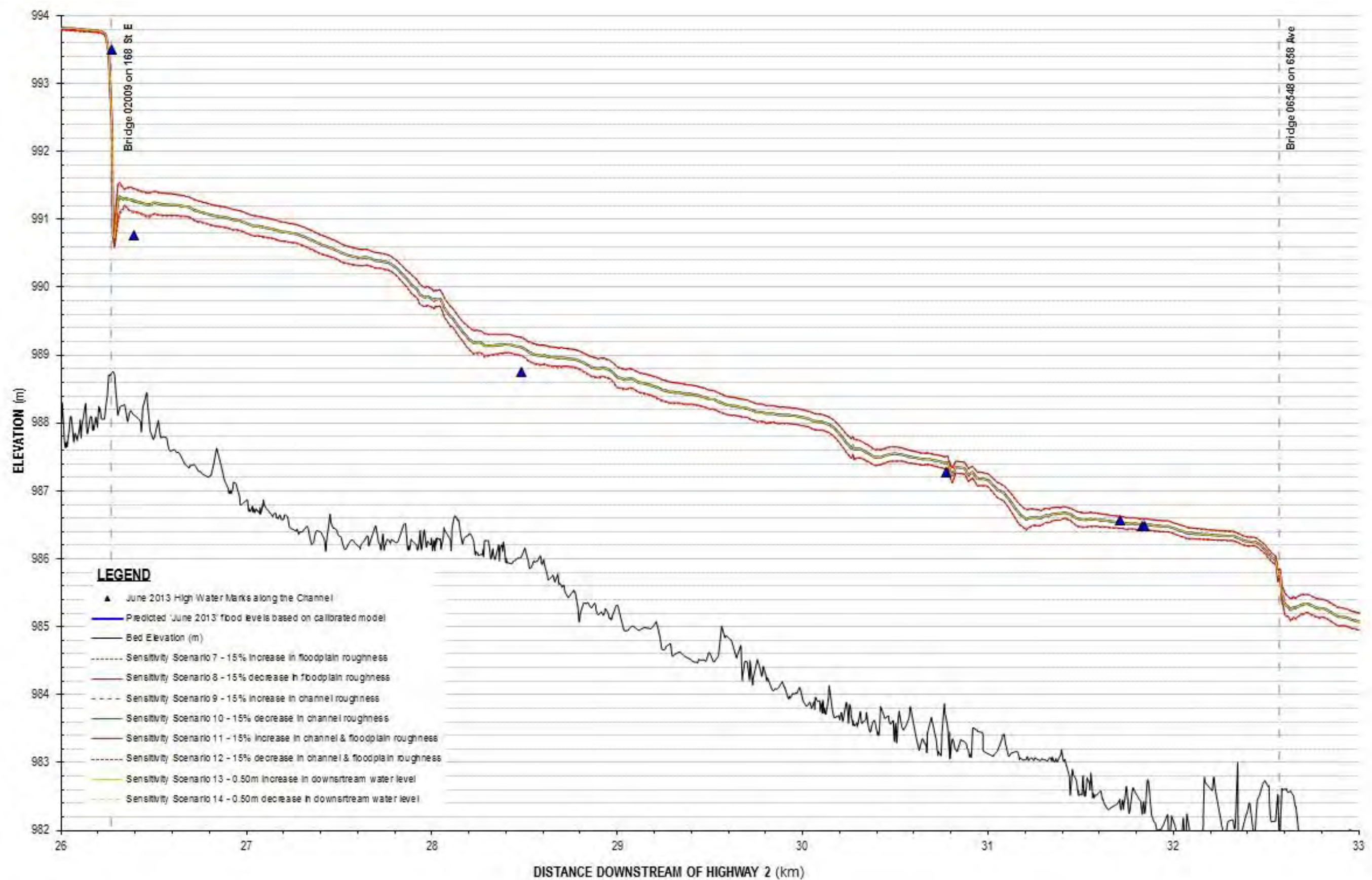
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Figure No: 5-37

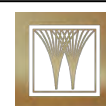
Rev: 0

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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 5 of 8)



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Reviewed By: JB

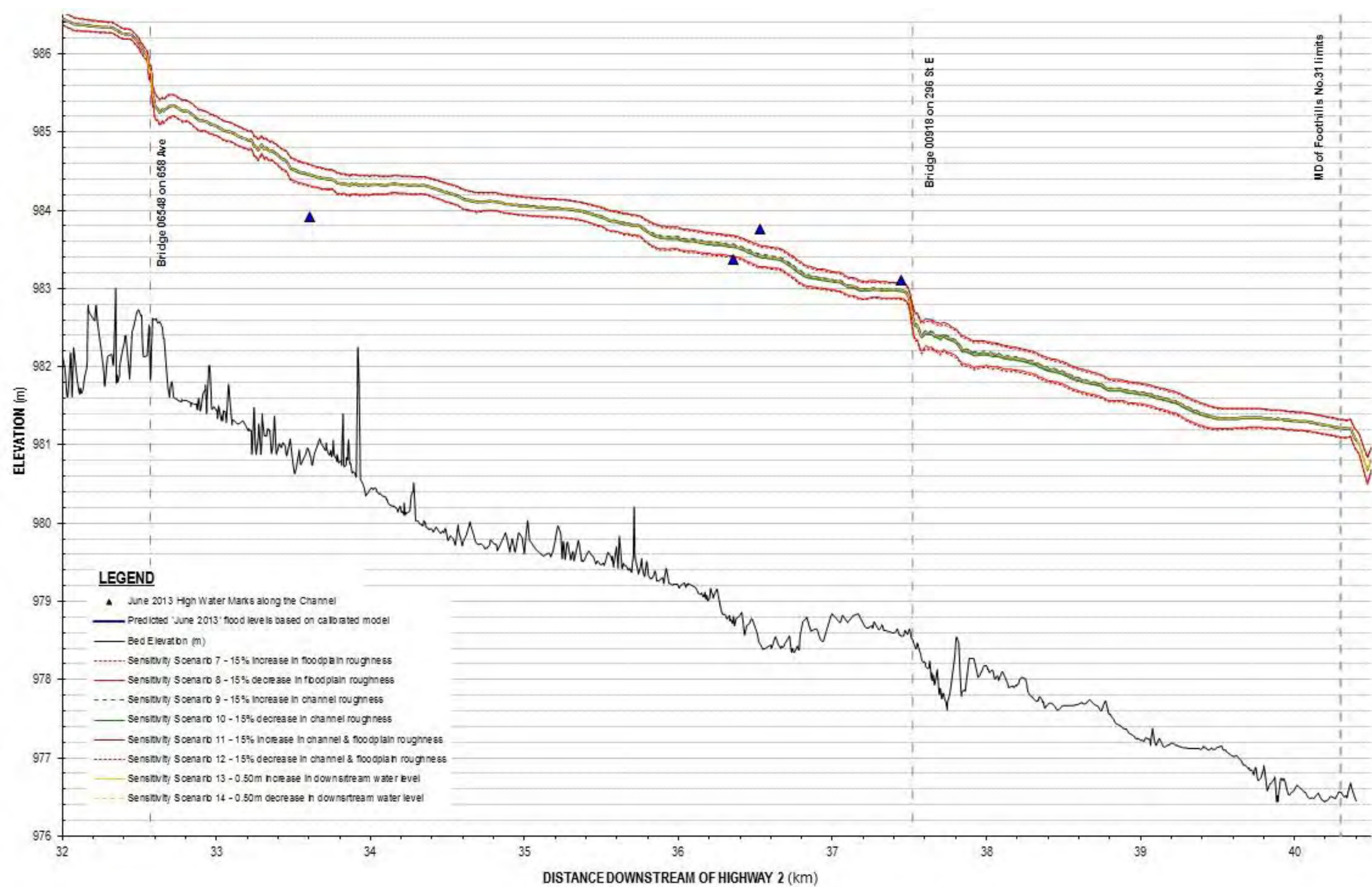
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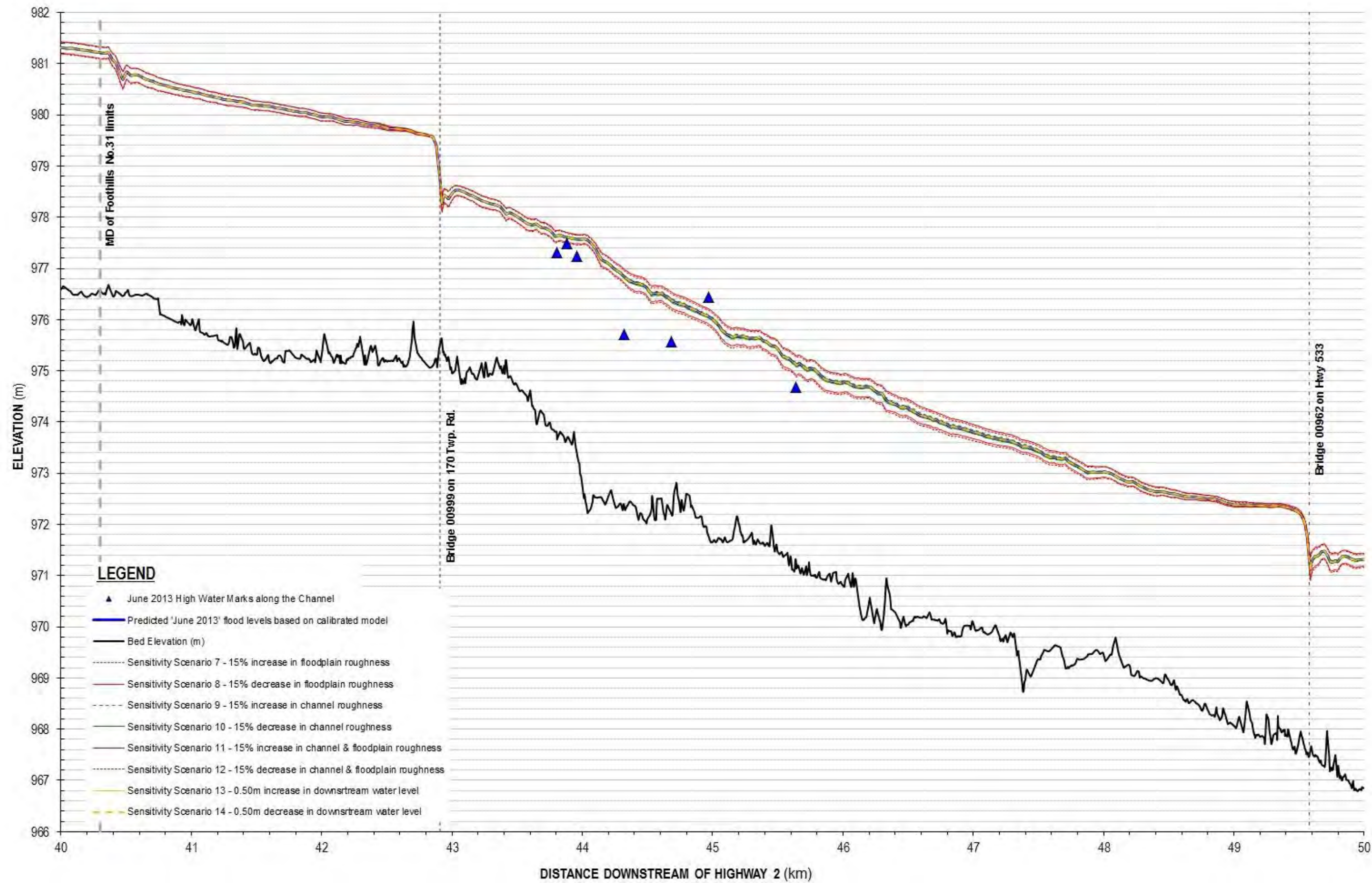
Figure No: 5-38

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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 6 of 8)				
Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-39	Rev: 0
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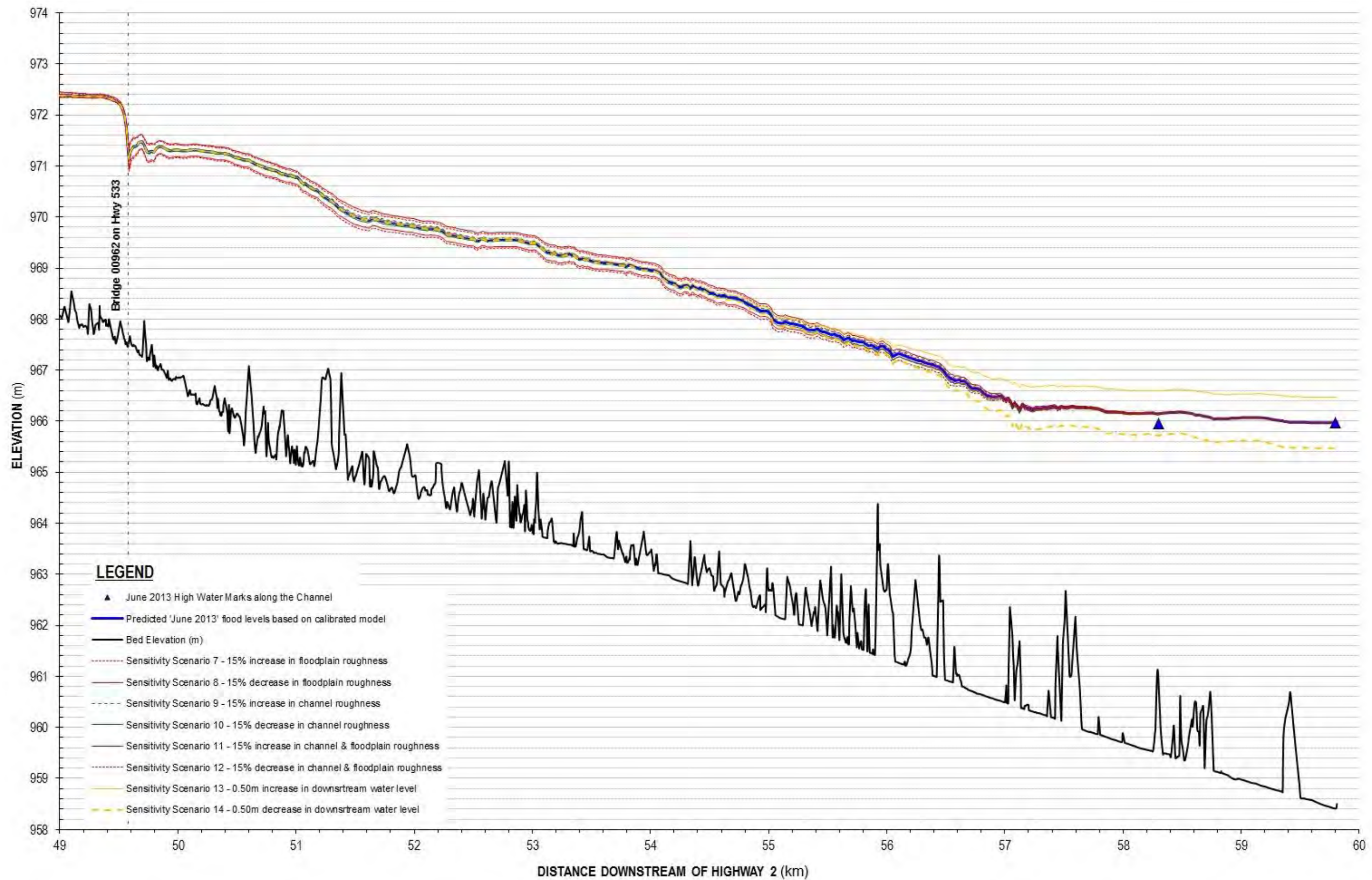



Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 7 of 8)				
Date: Jan 30, 2017		File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-40	Rev: 0
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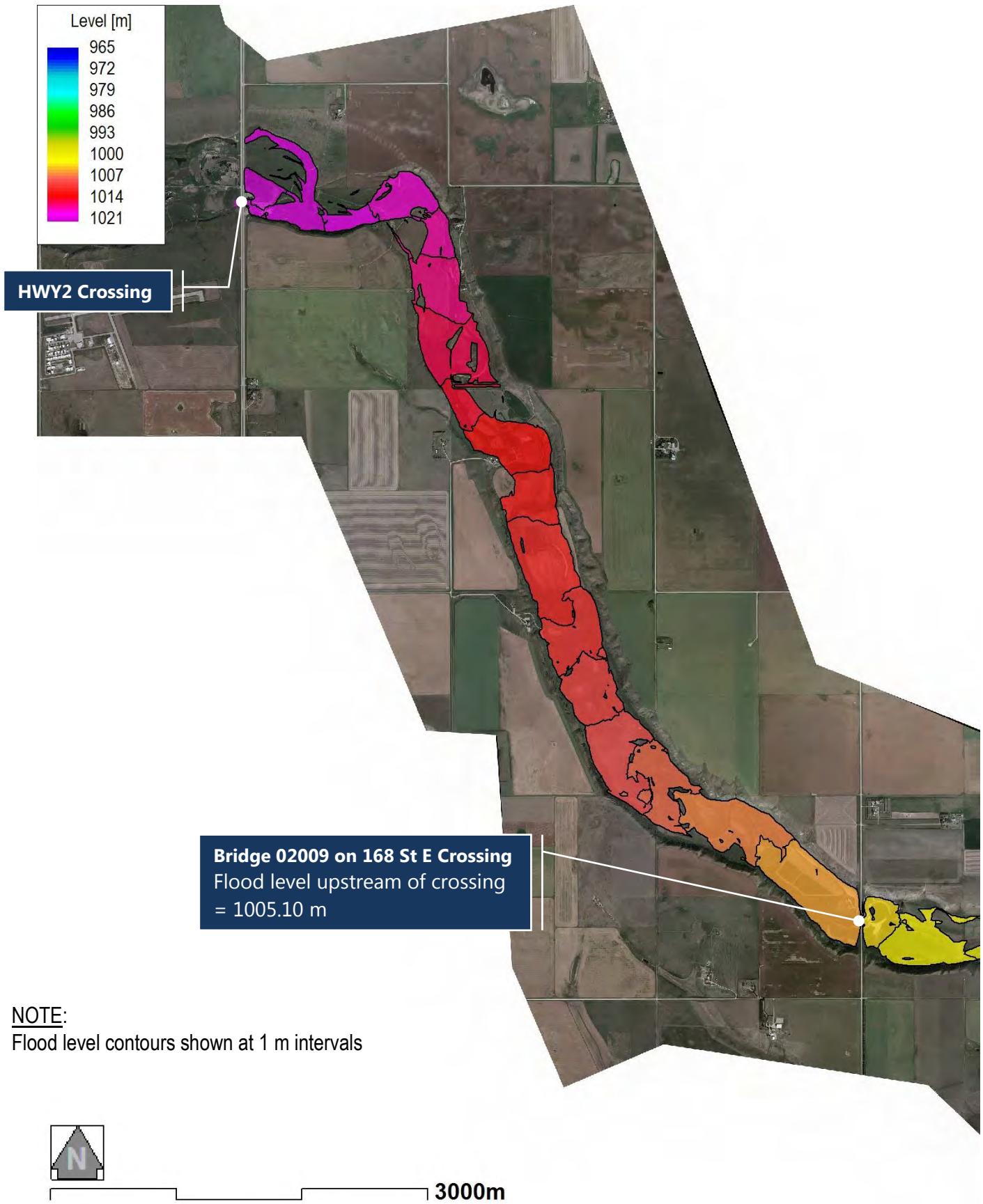
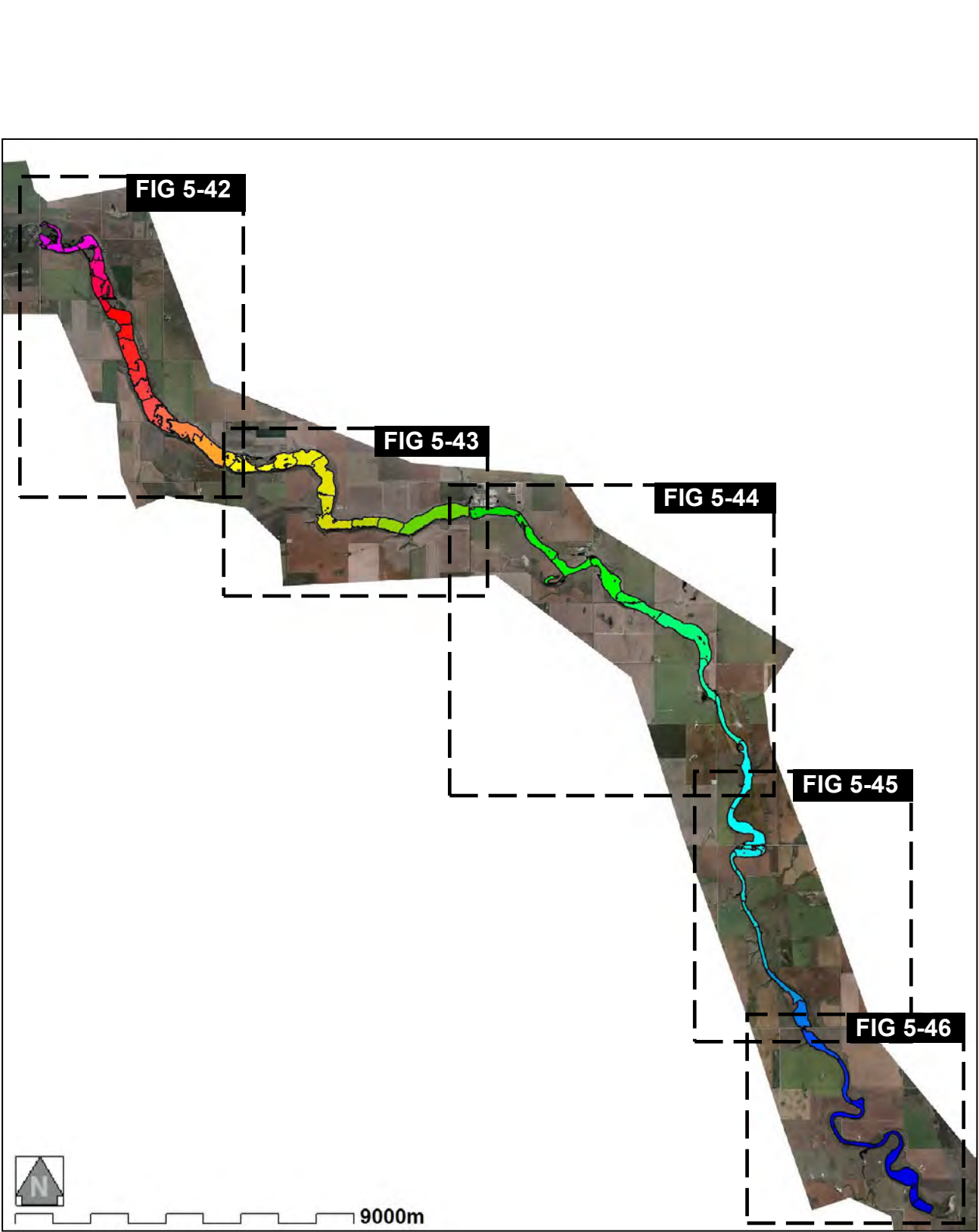


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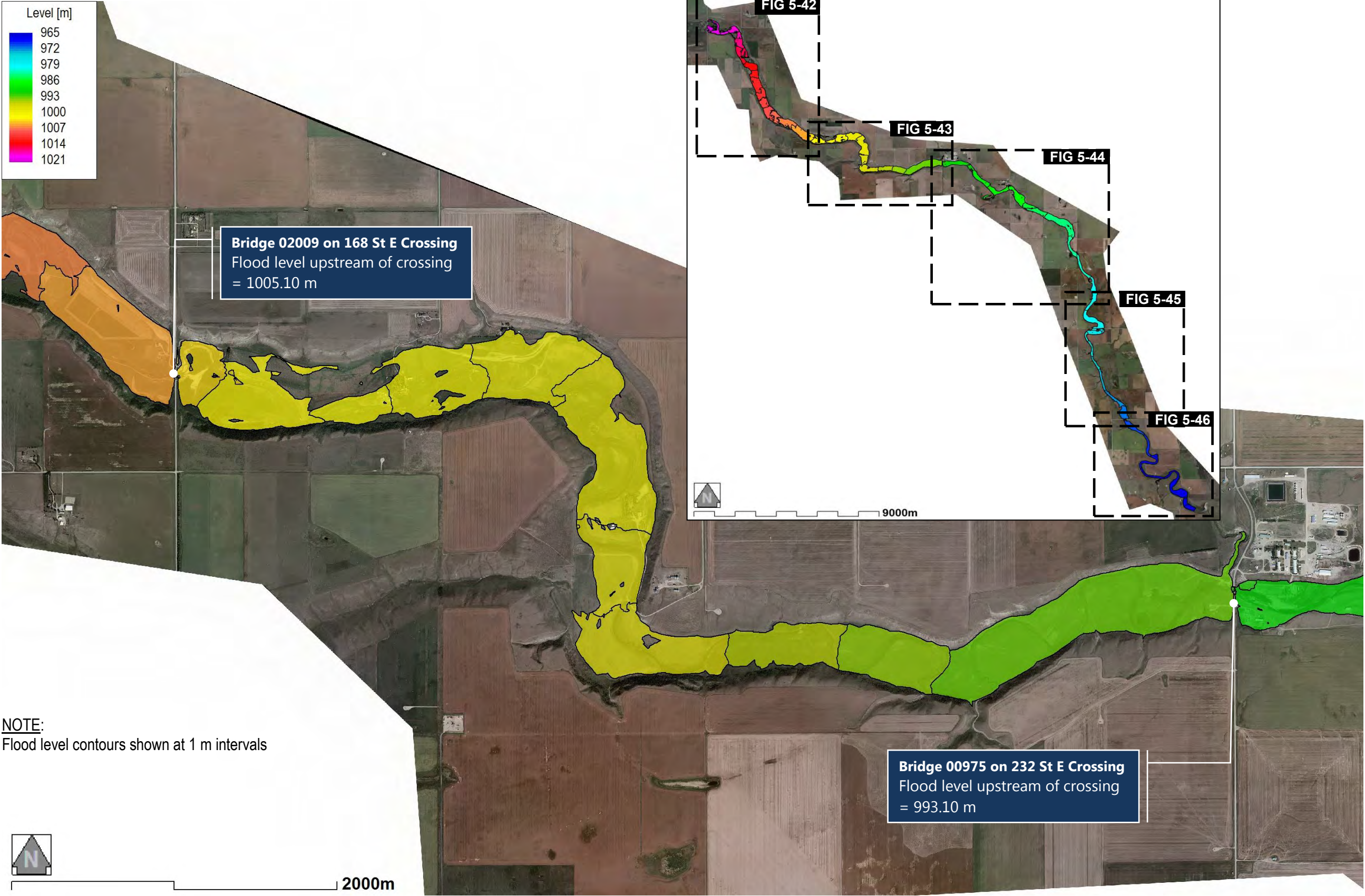


Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 14 (Extent 8 of 8)				
 <div>Advisian WorleyParsons Group</div>	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-41
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.		



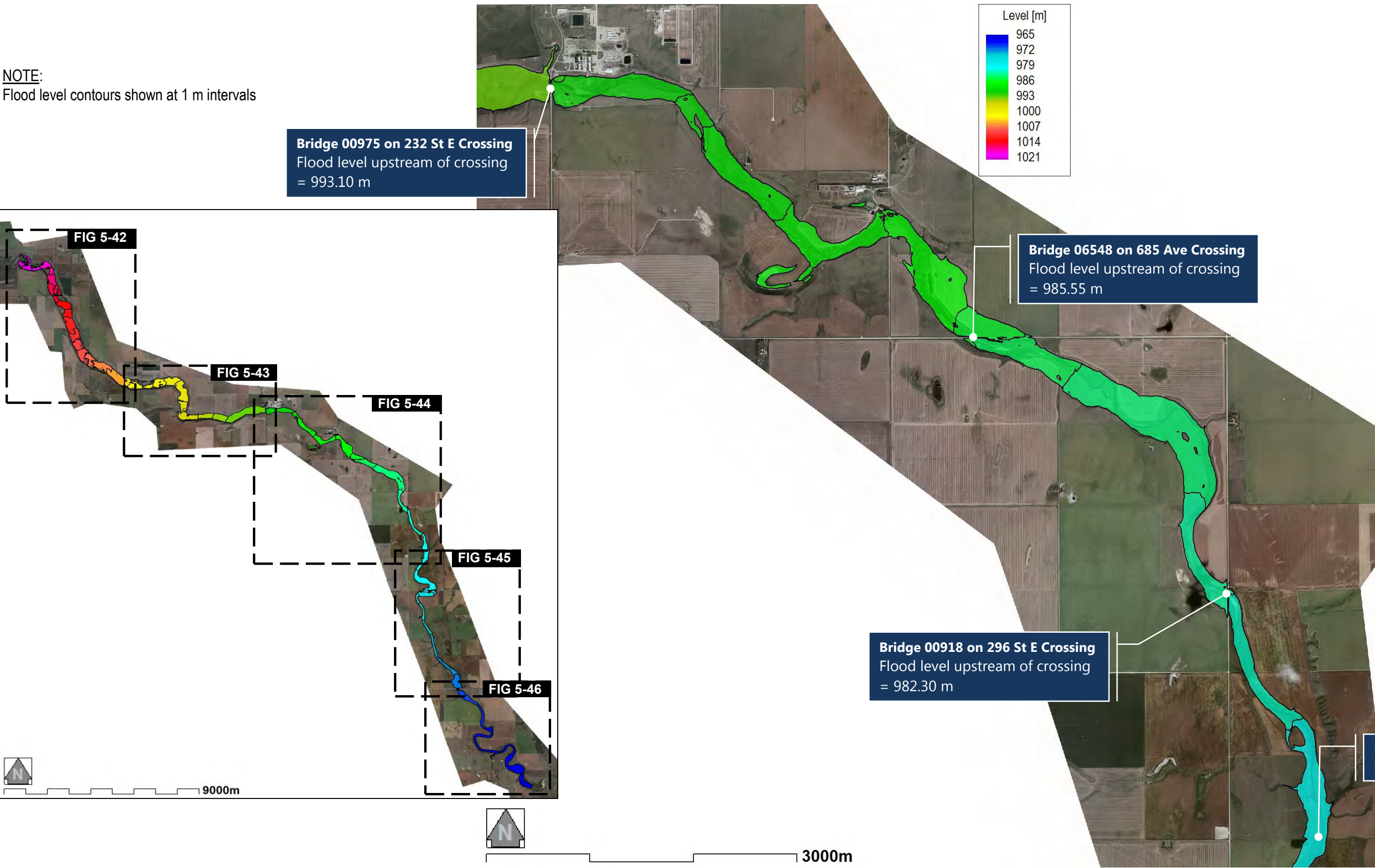
NOTE:
Flood level contours shown at 1 m intervals

 <div>Advisian WorleyParsons Group</div>		Municipal District of Foothills No. 31 – Little Bow River Modelling			
		Estimated Flood Levels at the Peak of a ‘June 2013 – 410 m³/s’ Flood under Post Mitigation Scenario 28A (1 of 5)			
Created By: AP		Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-42	Rev: 0
Reviewed By: JB		This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.			



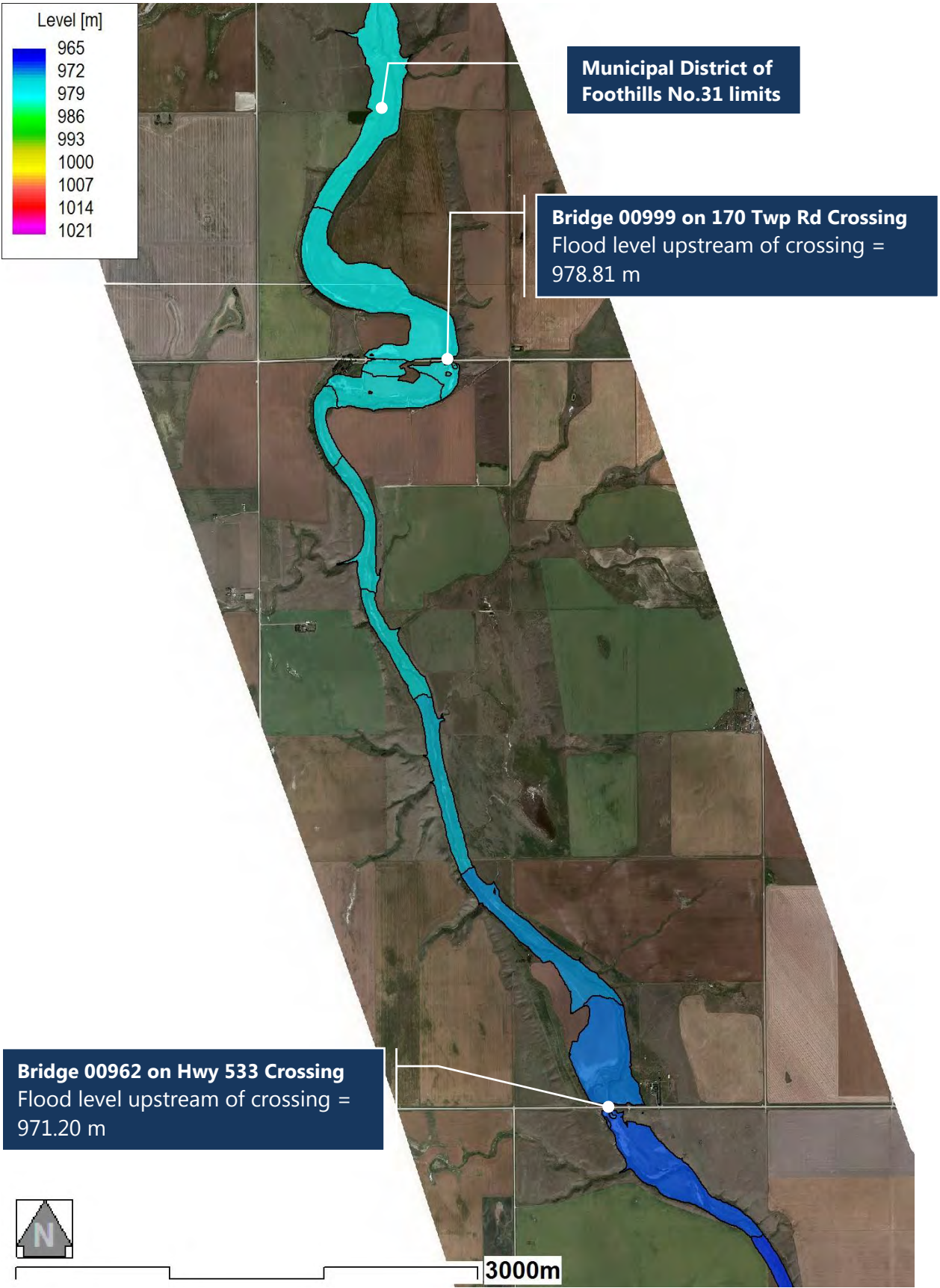
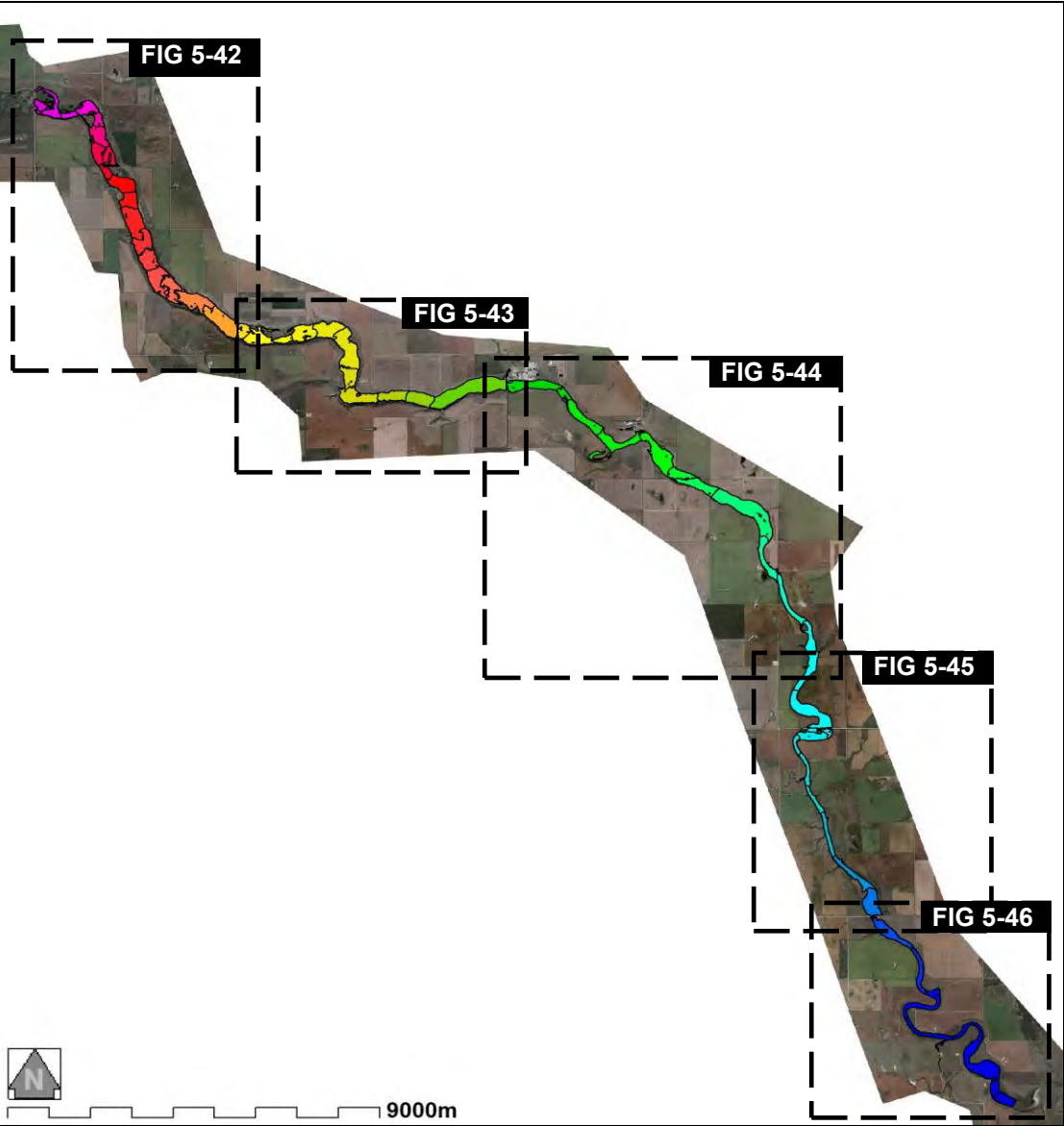
Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Flood Levels at the Peak of a ‘June 2013 – 410 m³/s’ Flood under Post Mitigation Scenario 28A (2 of 5)				
Date:	Jan 30, 2017	File Path:	U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-43
Created By:	AP	Reviewed By:	JB	Rev: 0
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NOTE:
Flood level contours shown at 1 m intervals



Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Flood Levels at the Peak of a ‘June 2013 – 410 m³/s’ Flood under Post Mitigation Scenario 28A (3 of 5)				
Date:	Jan 30, 2017	File Path:	U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-44
Created By:	AP	Reviewed By:	JB	Rev: 0
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NOTE:
Flood level contours shown at 1 m intervals



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Reviewed By: JB

Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Flood Levels at the Peak of a ‘June 2013 – 410 m³/s’ Flood under Post Mitigation Scenario 28A (4 of 5)

Date: May 1, 2017

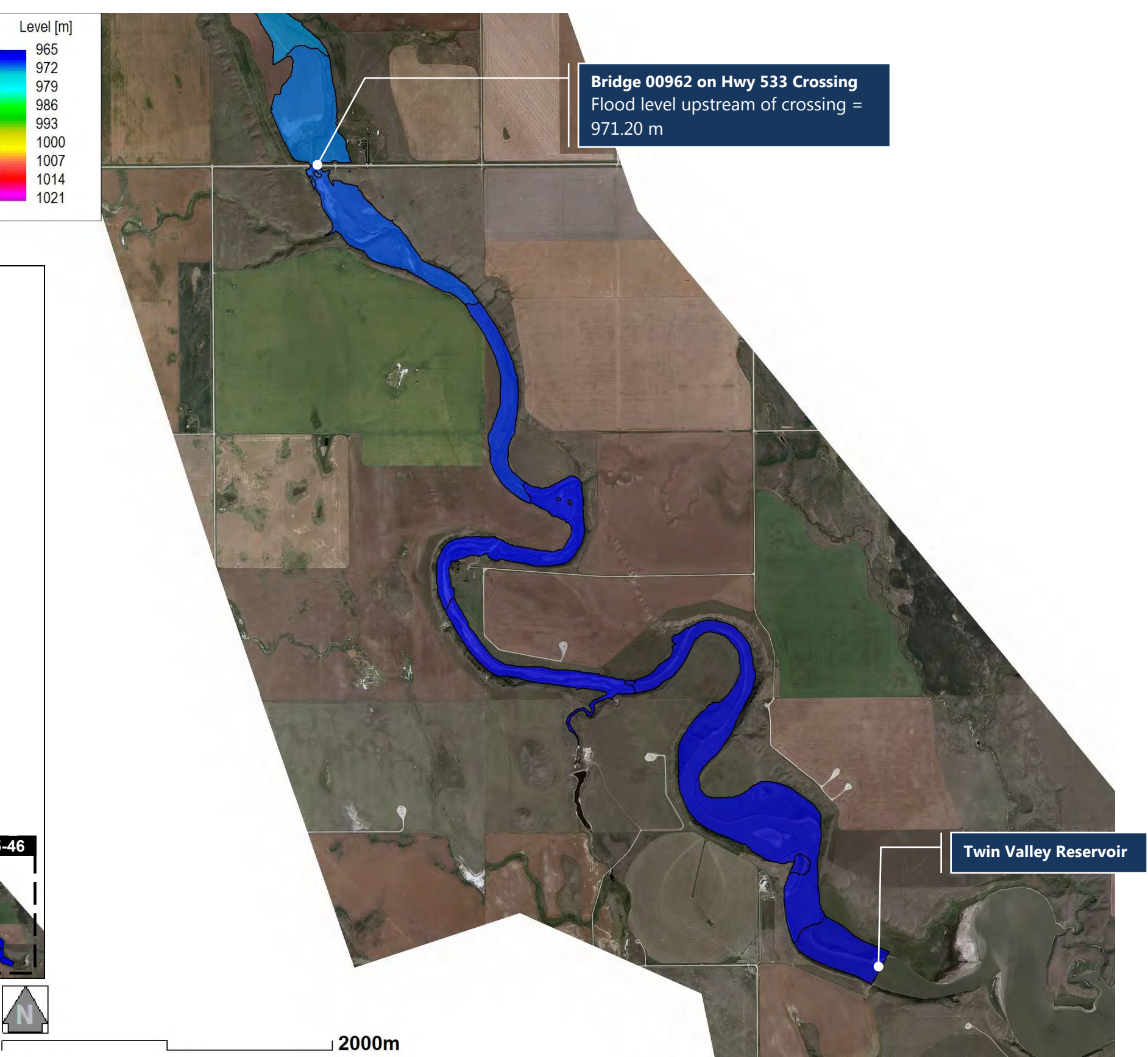
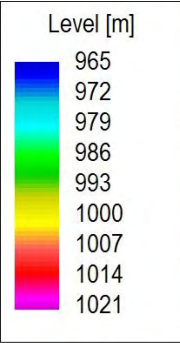
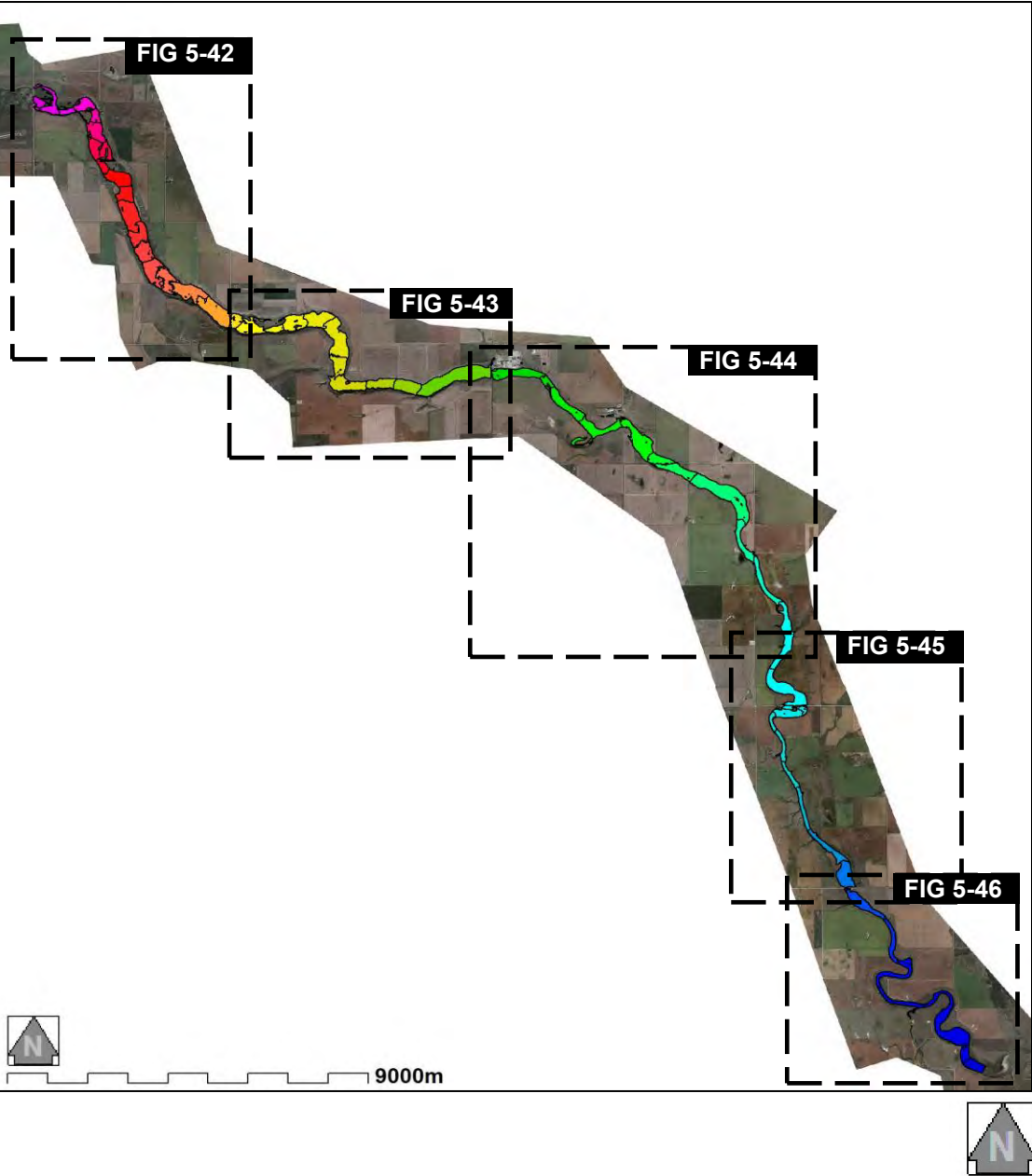
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Figure No: 5-45

Rev: 1


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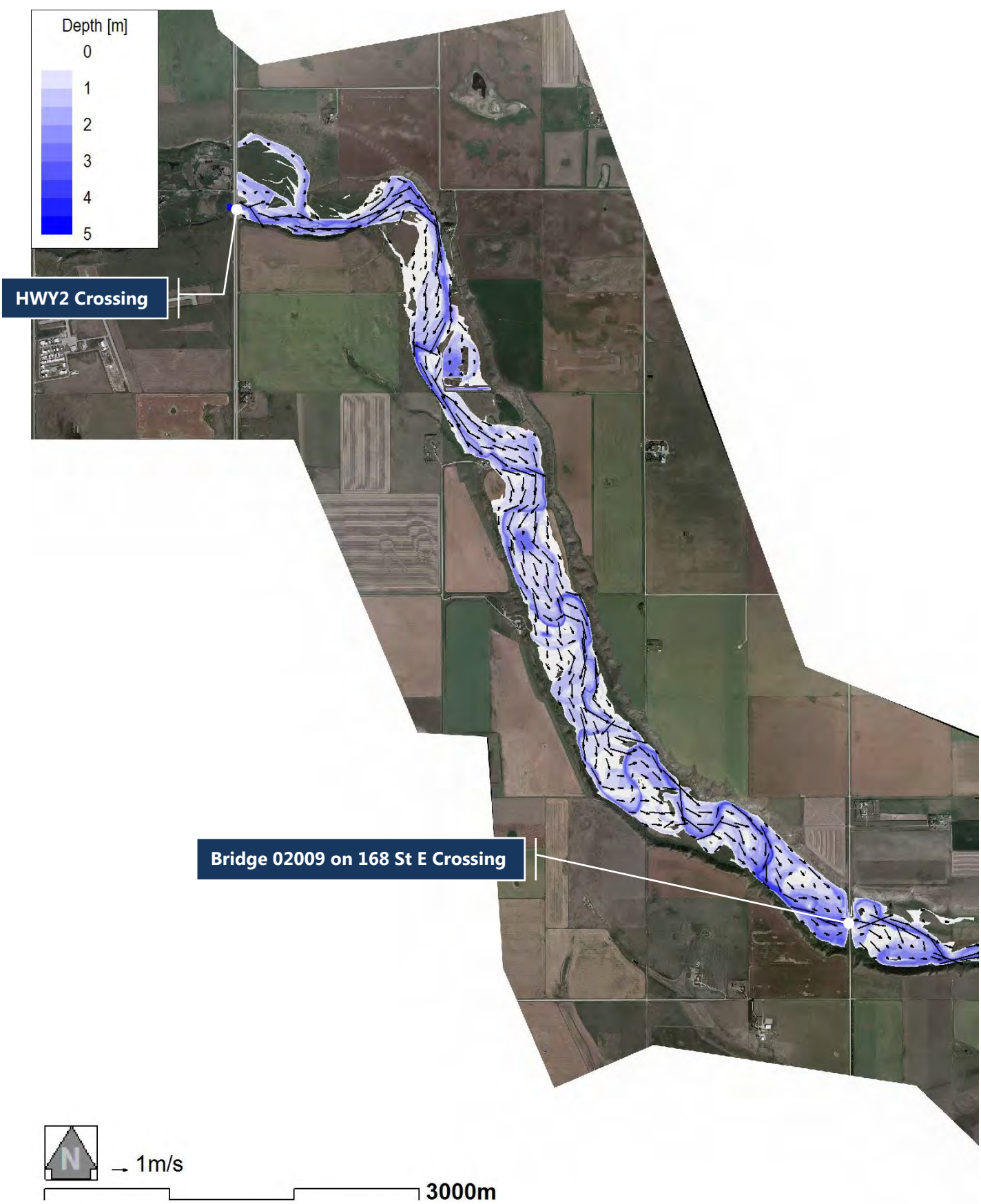
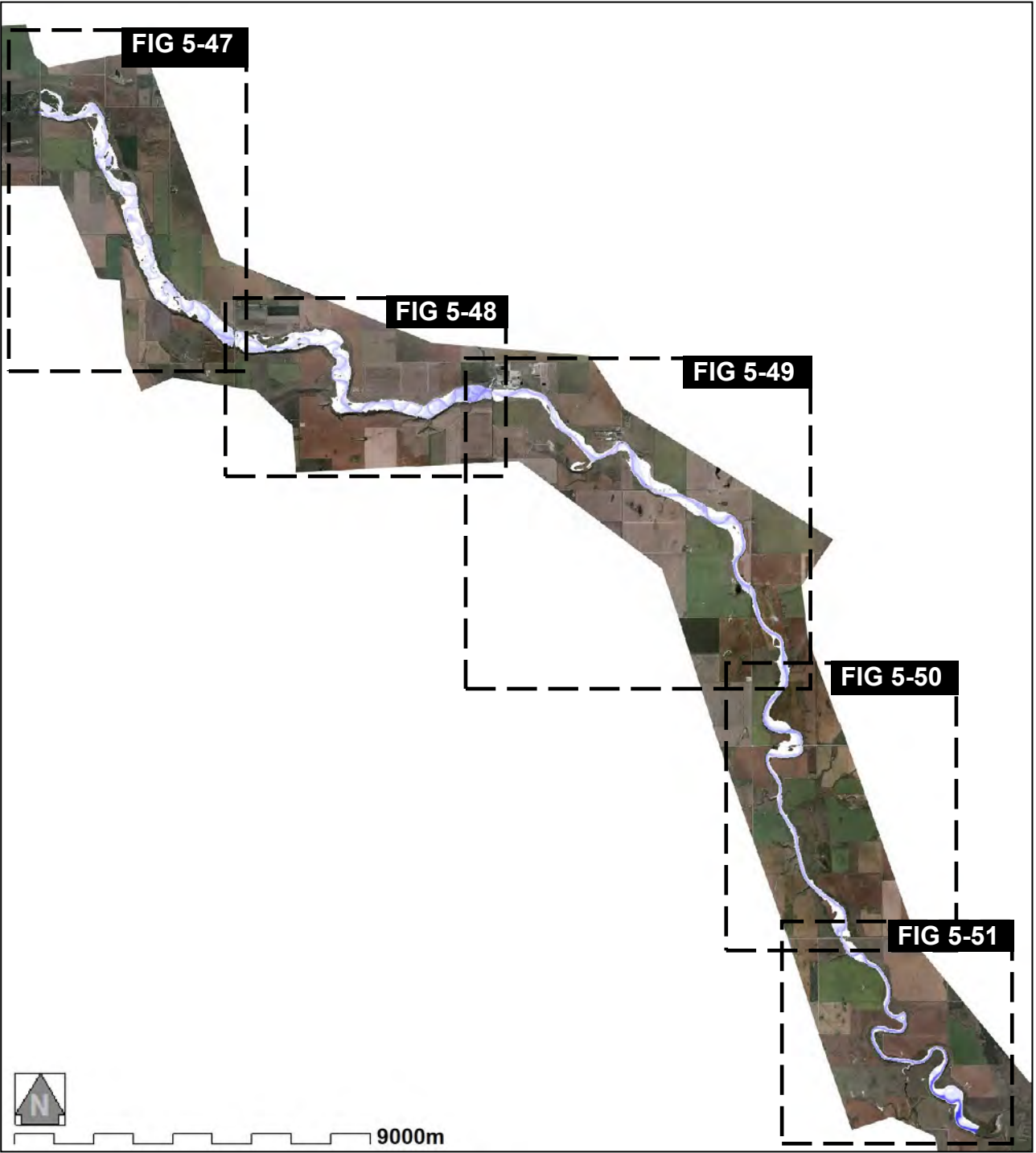
NOTE:
Flood level contours shown at 1 m intervals




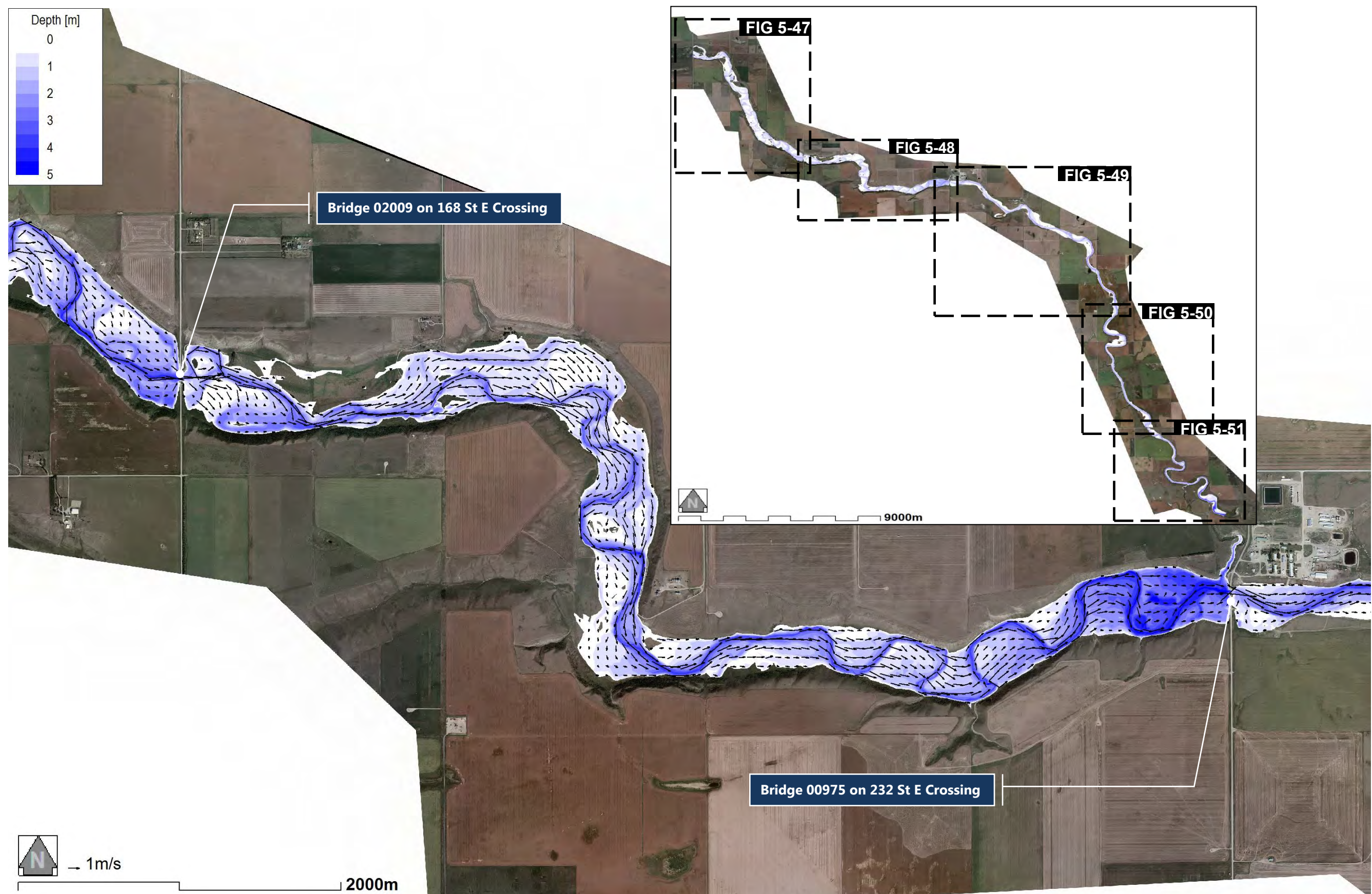
Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Flood Levels at the Peak of a ‘June 2013 – 410 m³/s’ Flood under Post Mitigation Scenario 28A (5 of 5)

 <div>Advisian WorleyParsons Group</div>	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-46	Rev: 1
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.			




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	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.			

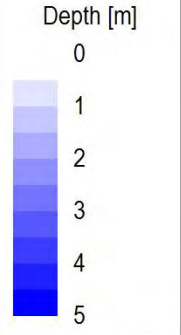


Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Depths and Velocities at the Peak of a 'June 2013 – 410 m³/s' Flood under Post Mitigation Scenario 28A (2 of 5)

 Advisian WorleyParsons Group	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-48	Rev: 0
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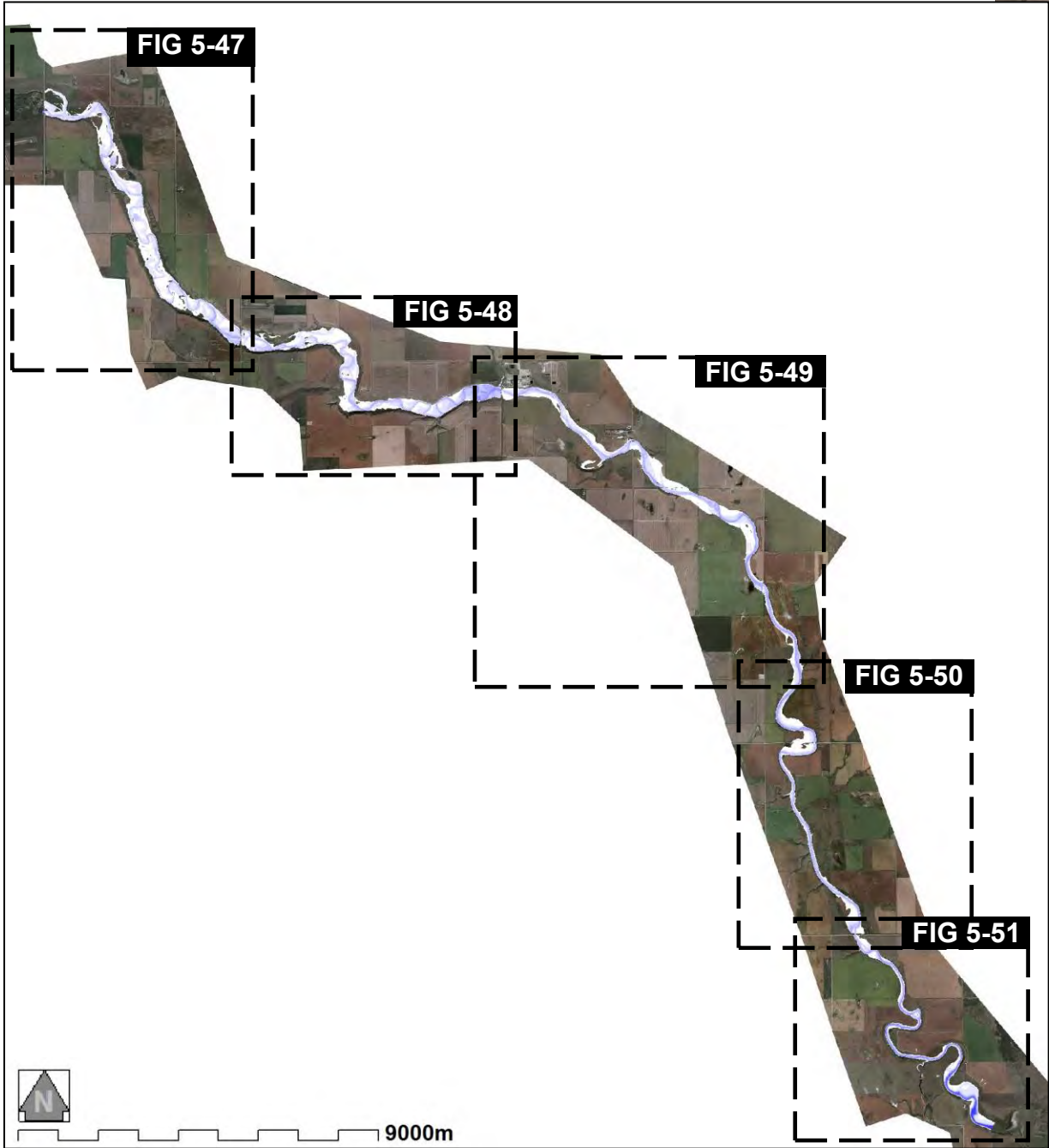
Bridge 00975 on 232 St E Crossing



Bridge 06548 on 658 Ave Crossing

Bridge 00918 on 296 St E Crossing

Municipal District of Foothills
No.31 limits



1m/s

3000m

Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Depths and Velocities at the Peak of a 'June 2013 – 410 m³/s' Flood under Post Mitigation Scenario 28A (3 of 5)



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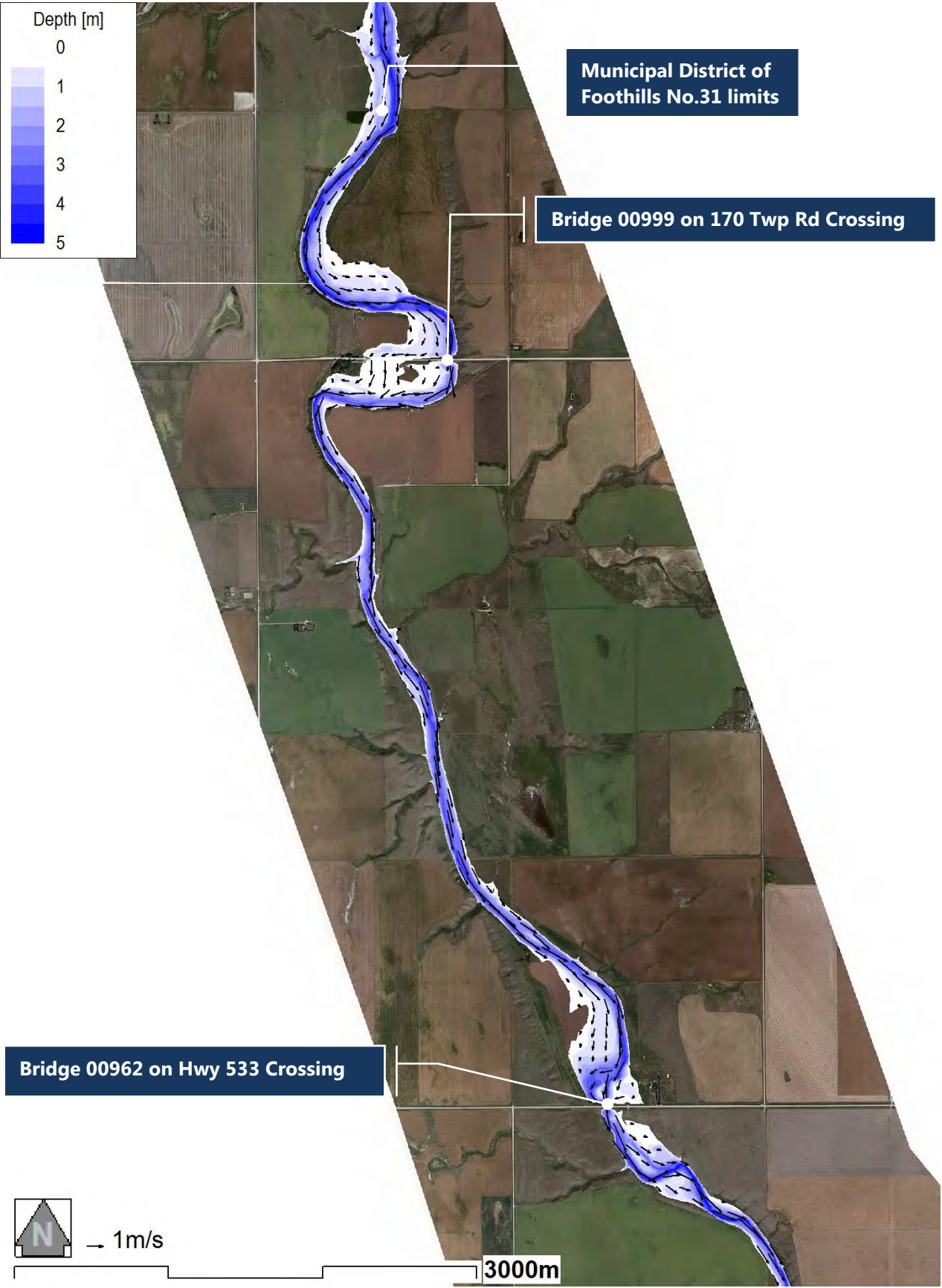
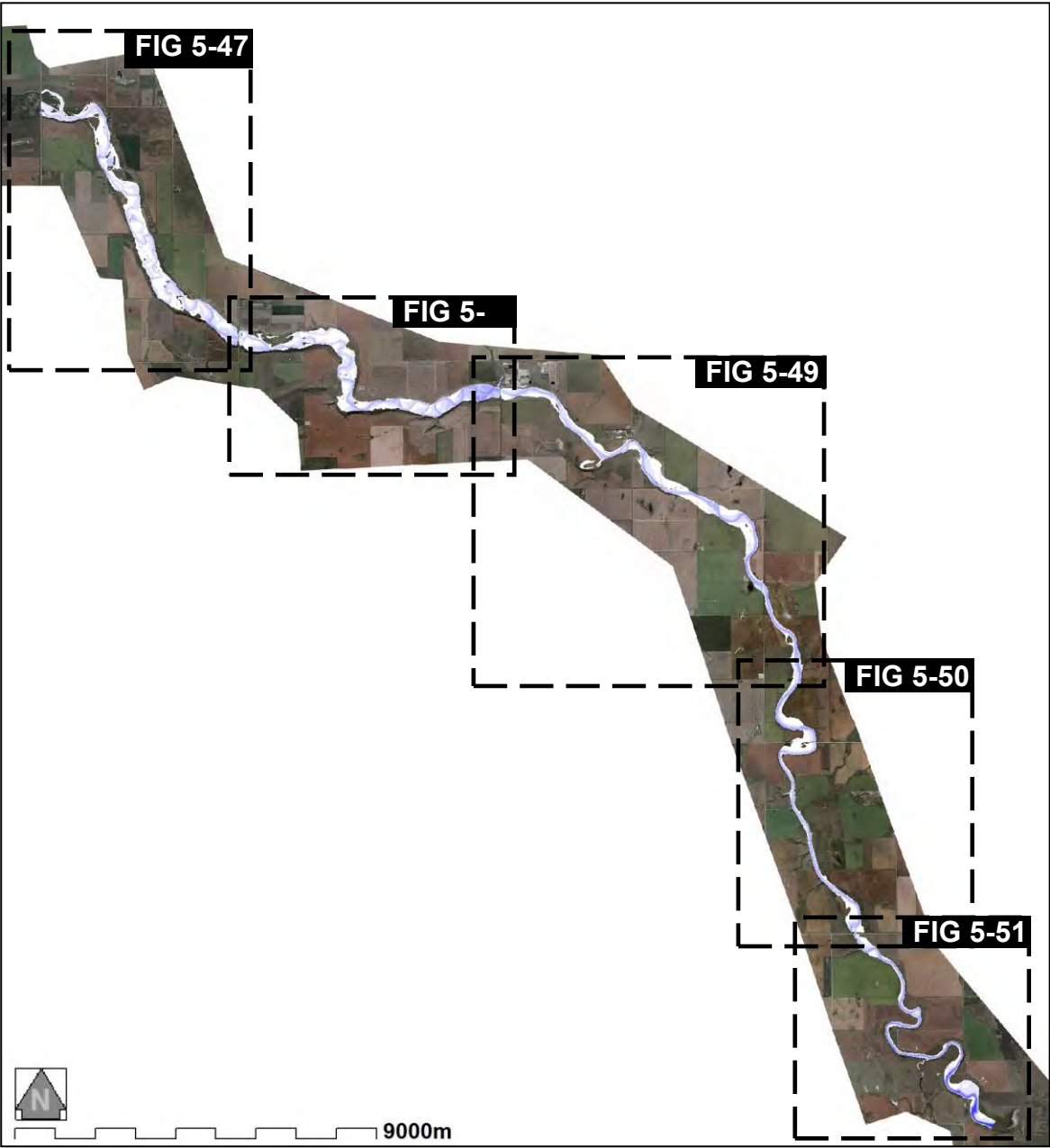
Date: Jan 30, 2017

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Figure No: 5-49

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Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Depths and Velocities at the Peak of a 'June 2013 – 410 m³/s' Flood under Post Mitigation Scenario 28A (4 of 5)

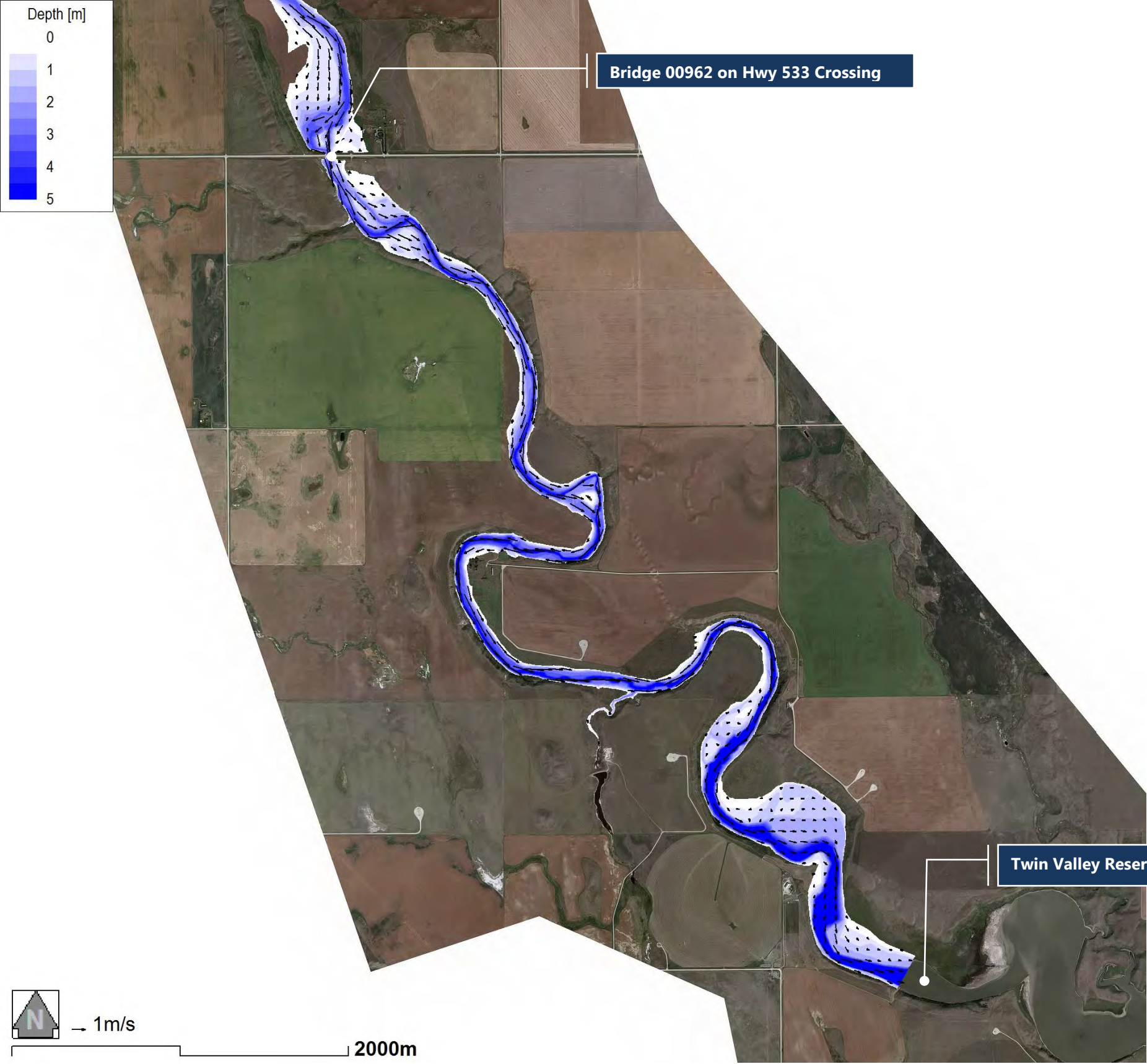
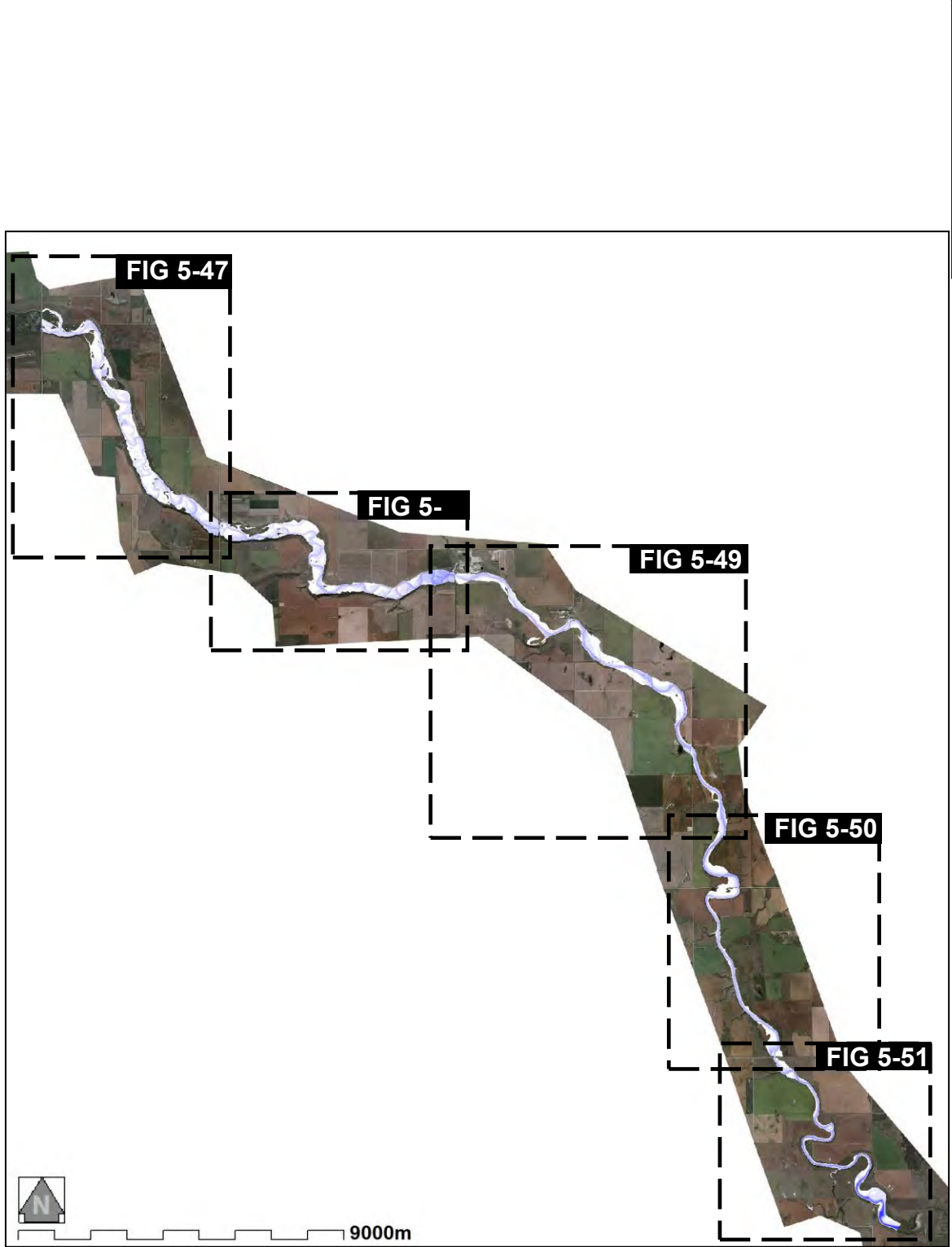
Date: **May 1, 2017**

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Figure No: 5-50

Rev: 1

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Municipal District of Foothills No. 31 – Little Bow River Modelling			
Estimated Depths and Velocities at the Peak of a ‘June 2013 – 410 m³/s’ Flood under Post Mitigation Scenario 28A (5 of 5)			
Date: May 1, 2017	File Path: U:\CAL\IGBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-51	Rev: 1
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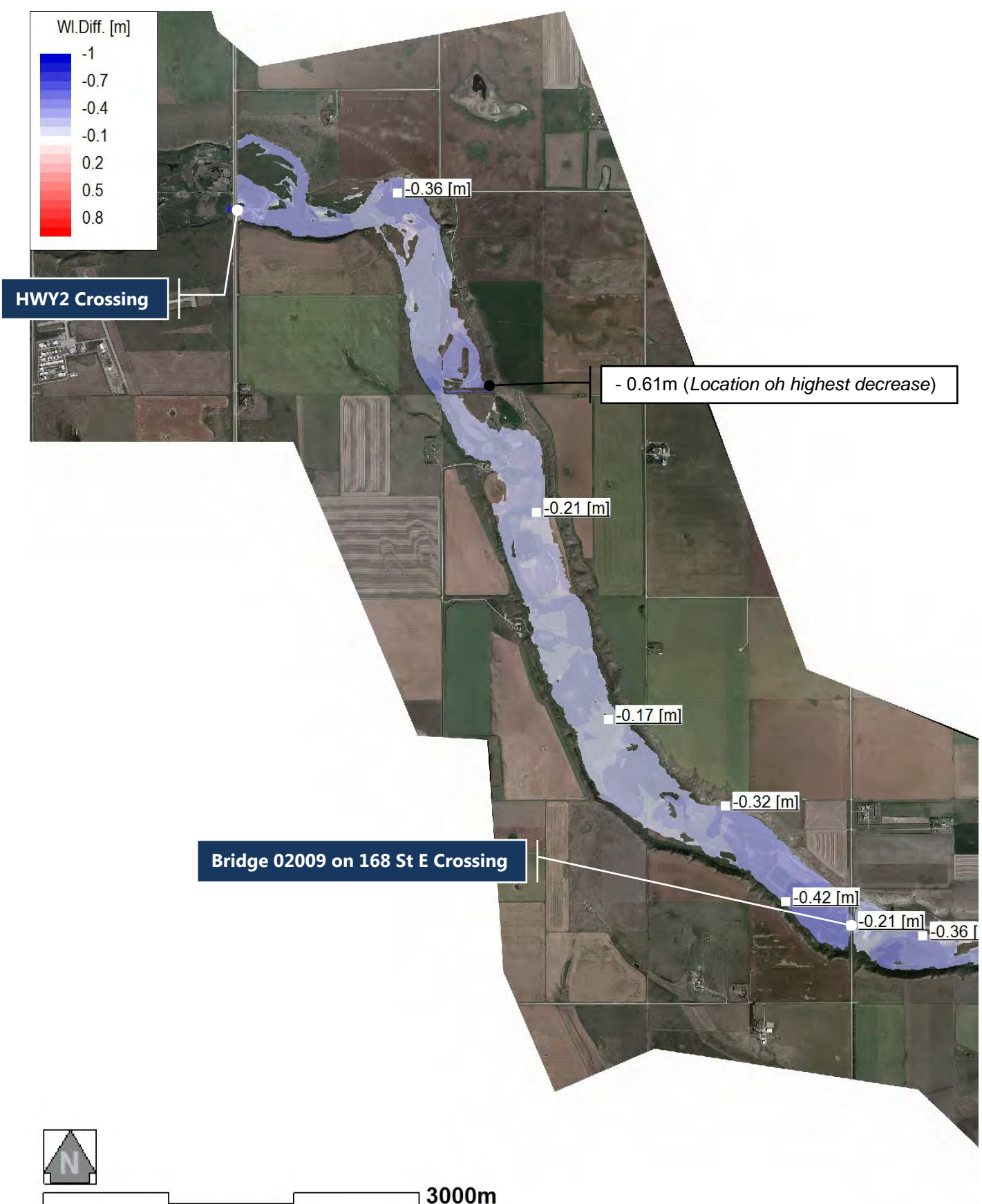
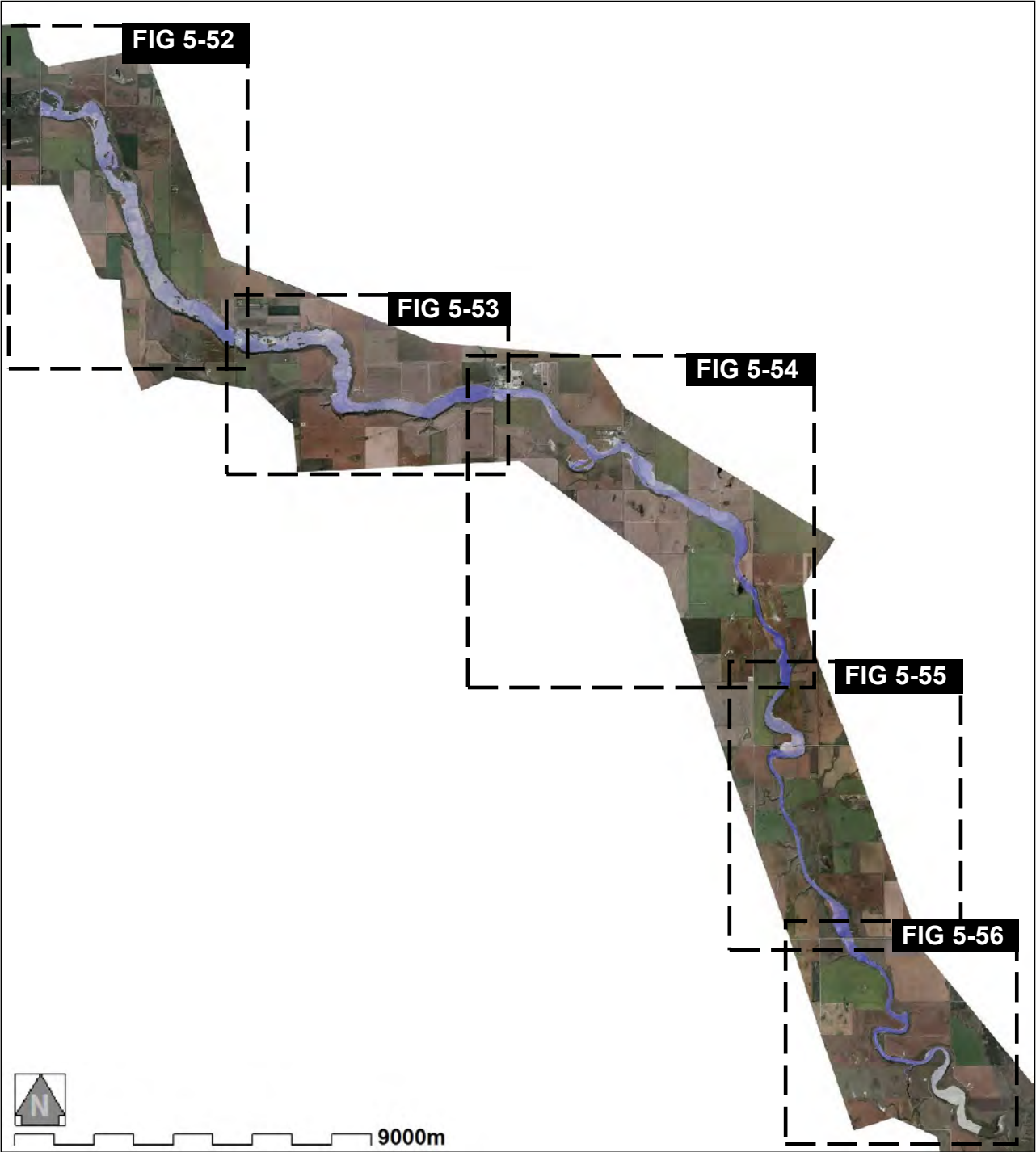



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Reviewed By: **JB**




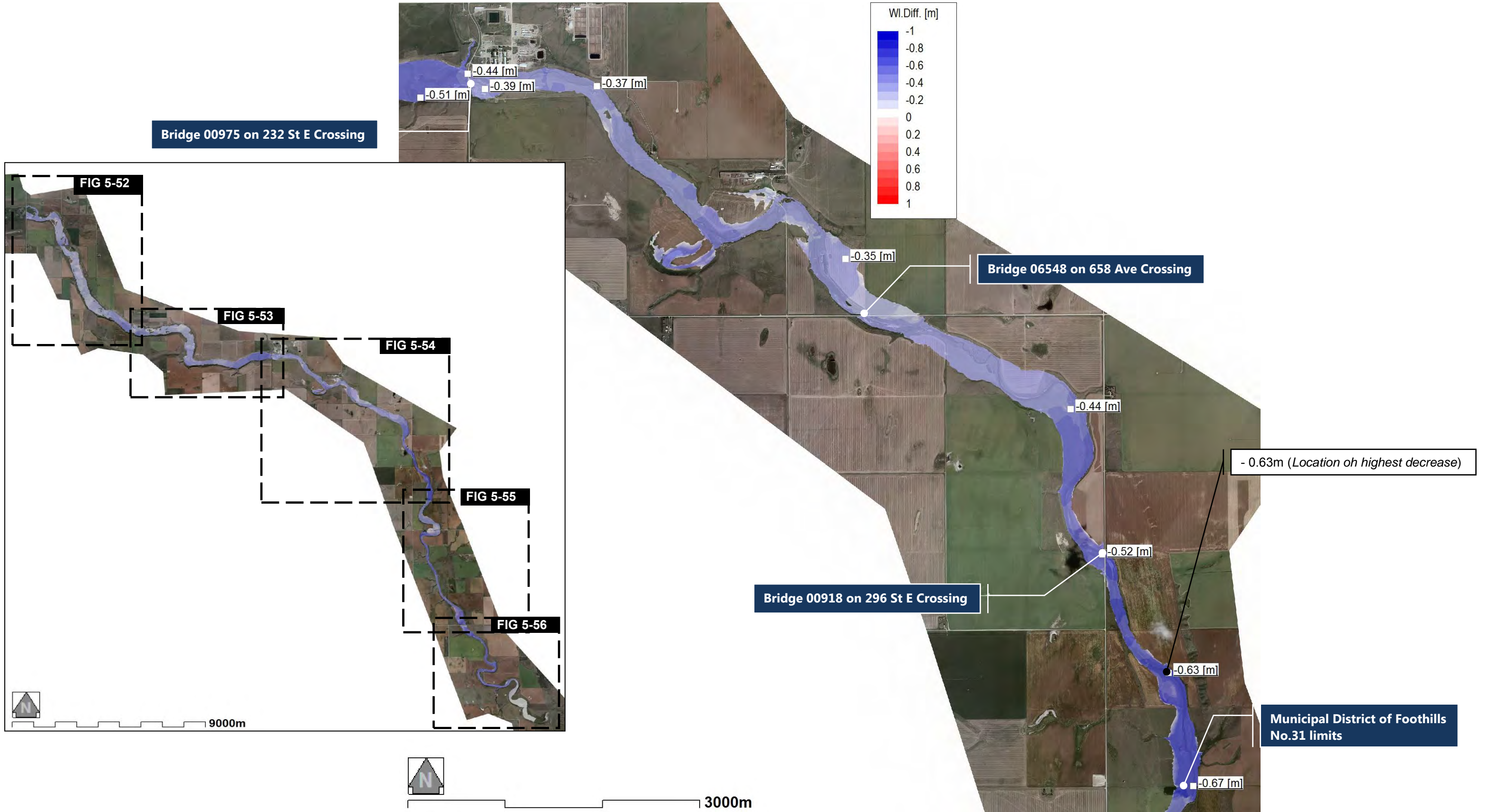
 <div>Advisian WorleyParsons Group</div>	Created By: AP	Municipal District of Foothills No. 31 – Little Bow River Modelling		
	Reviewed By: JB	Estimated Changes in Peak ‘June 2013 – 410 m³/s’ Flood Levels under Post Mitigation Scenario 28A (1 of 5)		
	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-52	Rev: 0
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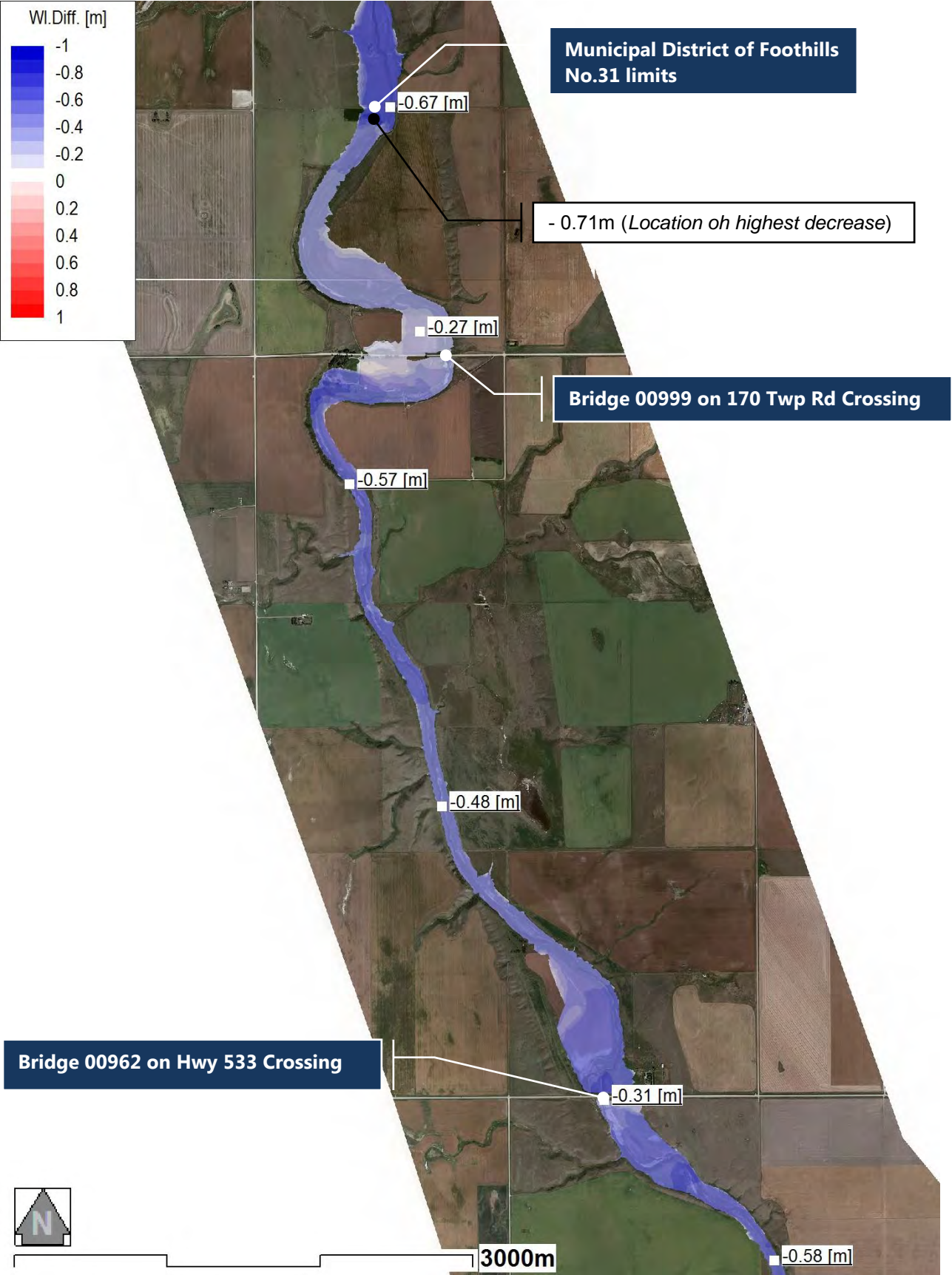
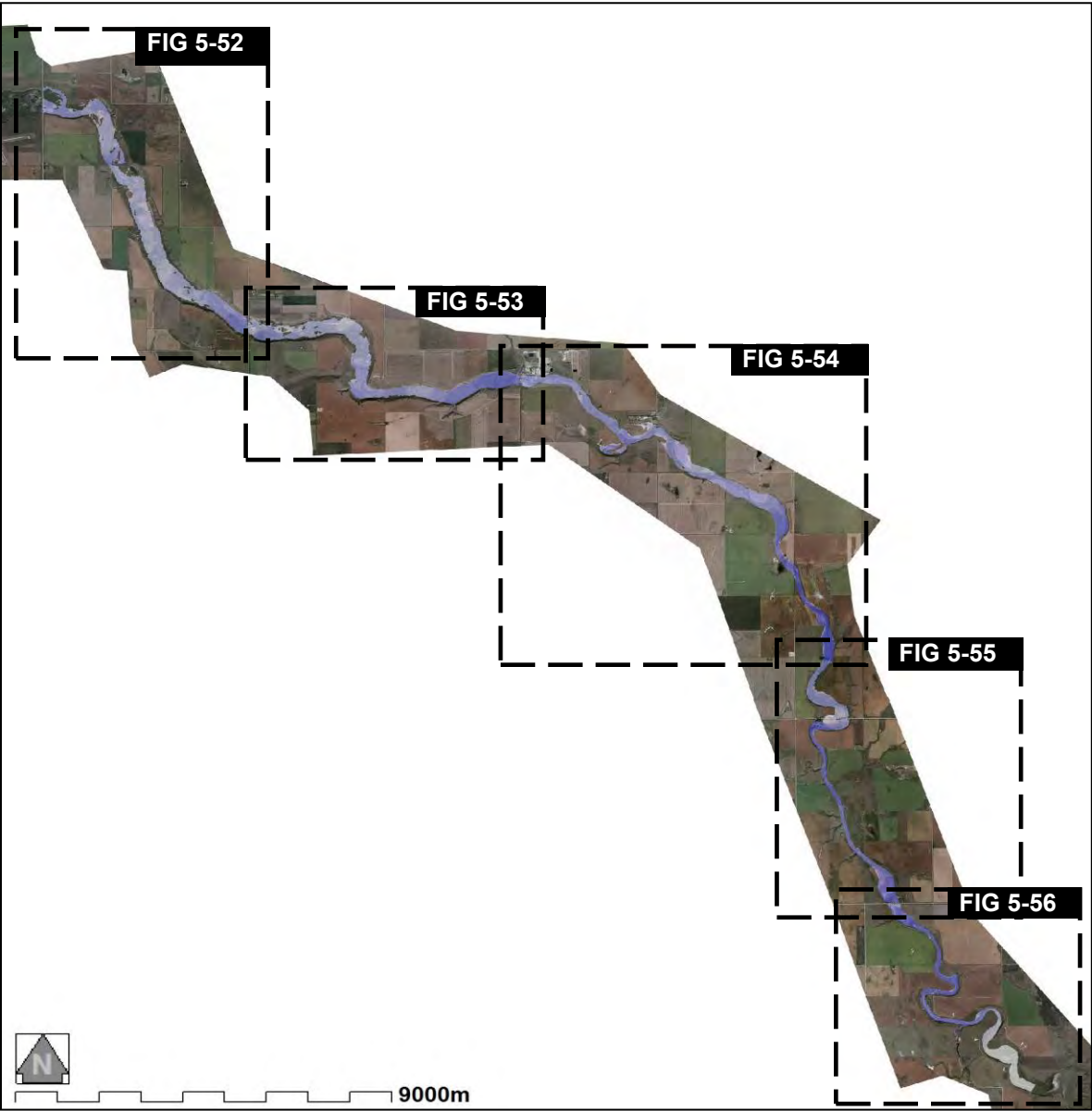
Municipal District of Foothills No. 31 – Little Bow River Modelling


Estimated Changes in Peak 'June 2013 – 410 m³/s' Flood Levels under Post Mitigation Scenario 28A (2 of 5)

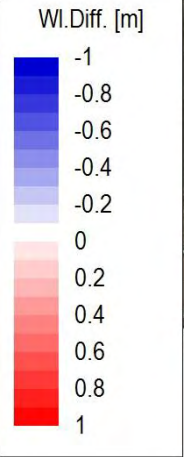
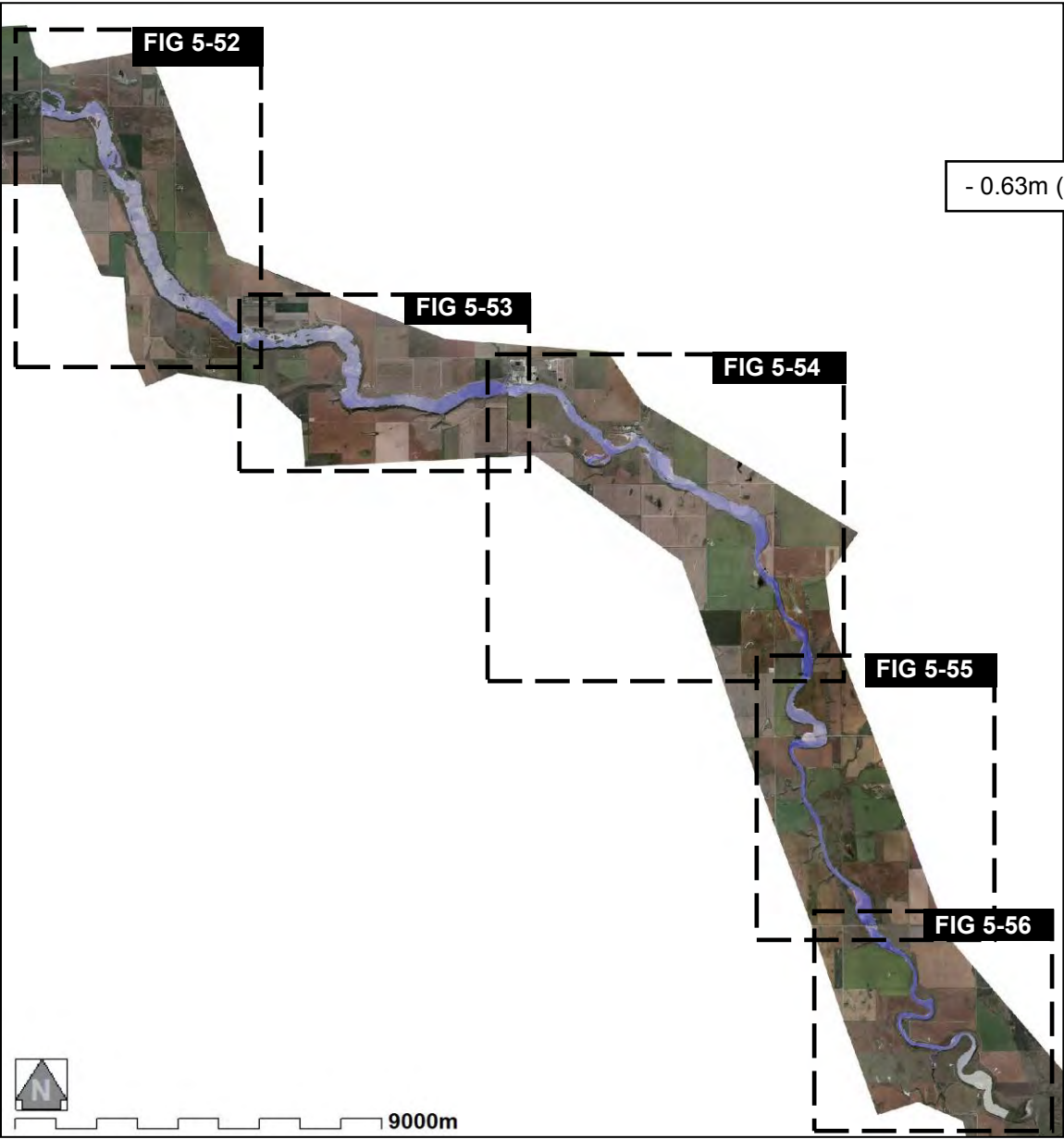
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	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.			



Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 410 m³/s’ Flood Levels under Post Mitigation Scenario 28A (3 of 5)				
Date:	Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-54	Rev: 0
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Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 410 m³/s’ Flood Levels under Post Mitigation Scenario 28A (4 of 5)				
 <div>Advisian WorleyParsons Group</div>	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-55
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.		
		Rev: 1		



- 0.63m (Location of highest decrease)



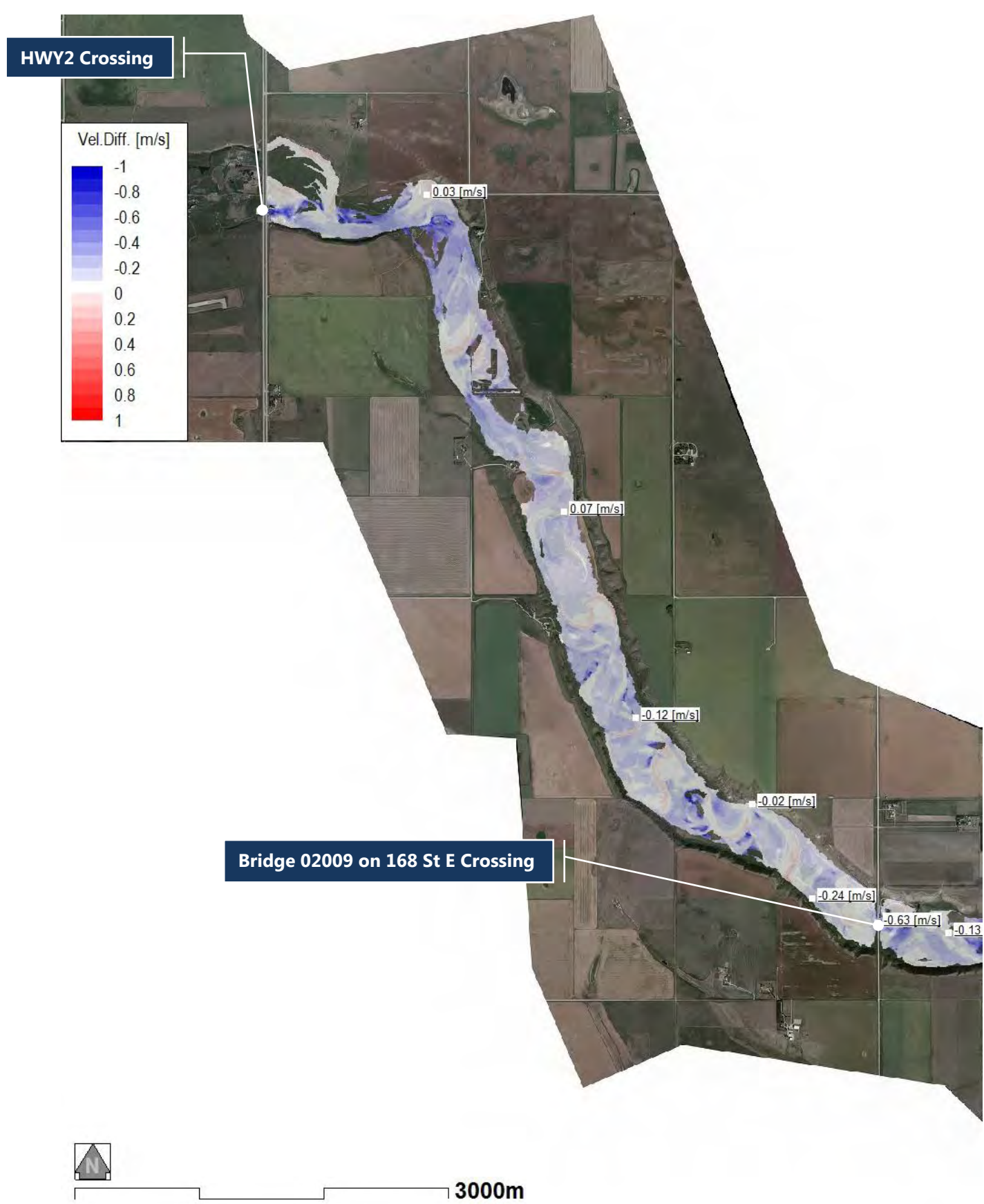
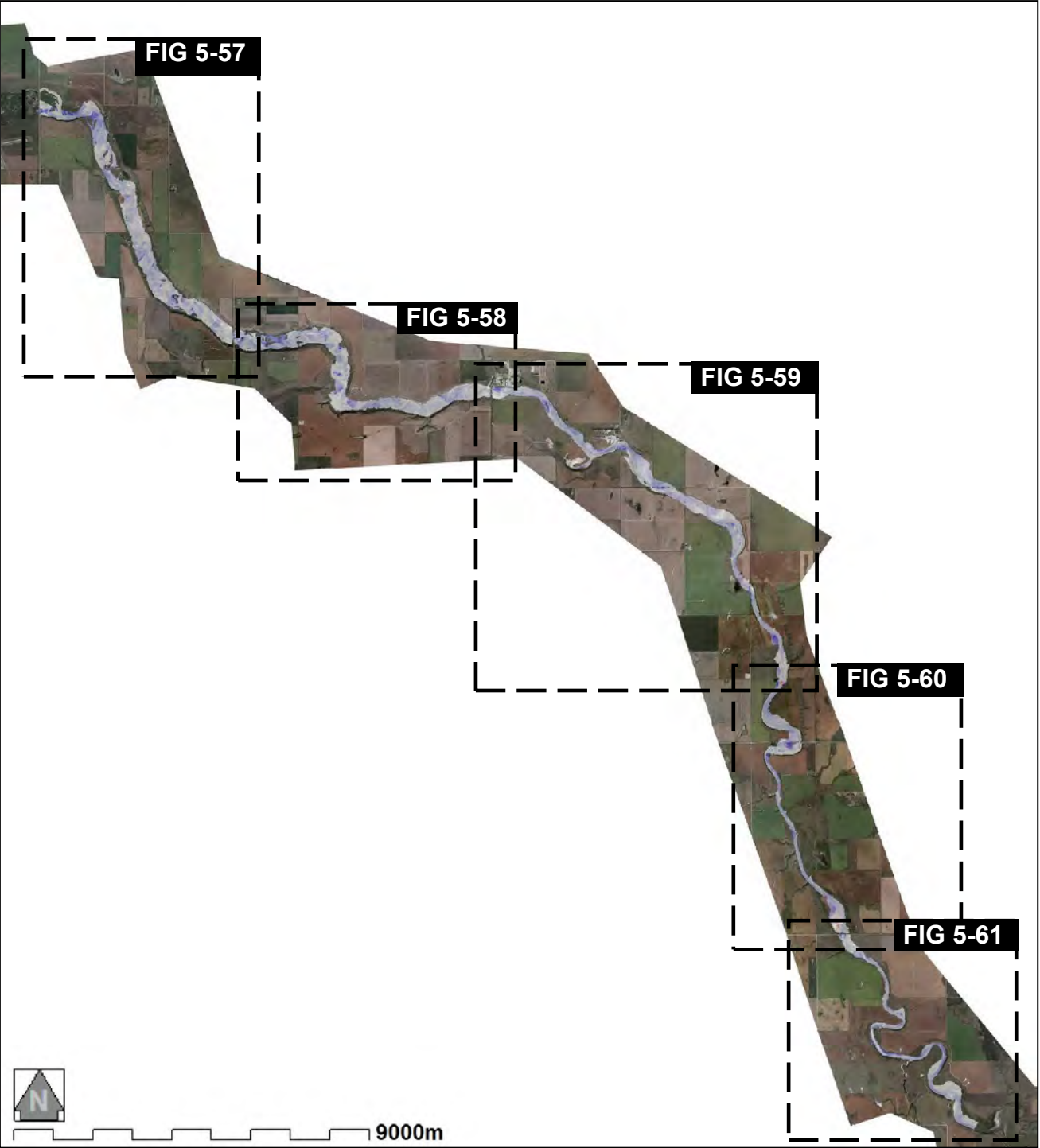
2000m



Municipal District of Foothills No. 31 – Little Bow River Modelling				
Estimated Changes in Peak ‘June 2013 – 410 m³/s’ Flood Levels under Post Mitigation Scenario 28A (5 of 5)				
Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-56	Rev: 1	<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.</i>



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Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 410 m³/s' Flood Velocities under Post Mitigation Scenario 28A (1 of 5)

Date: Jan 30, 2017

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Figure No: 5-57


Rev: 0

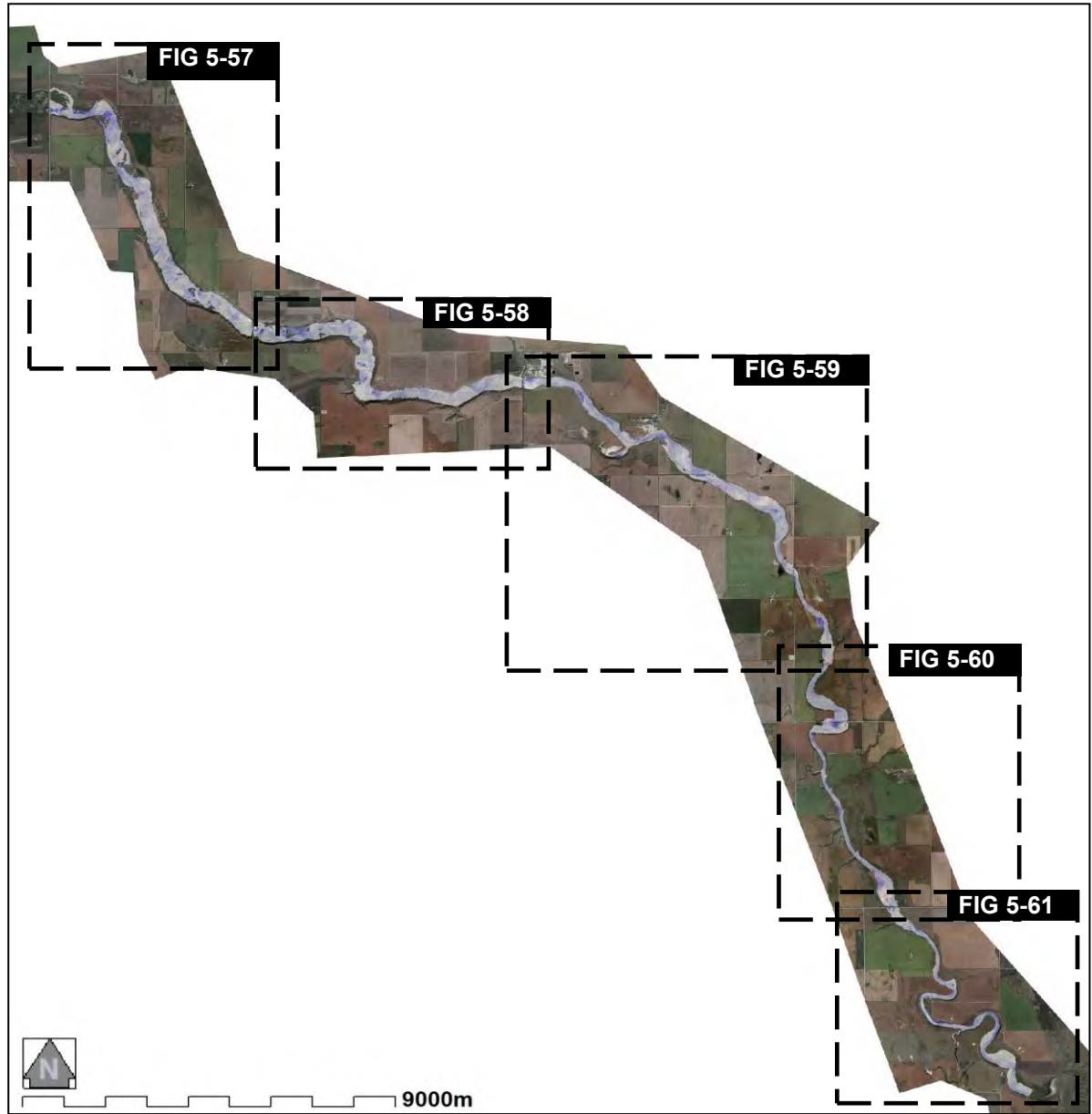
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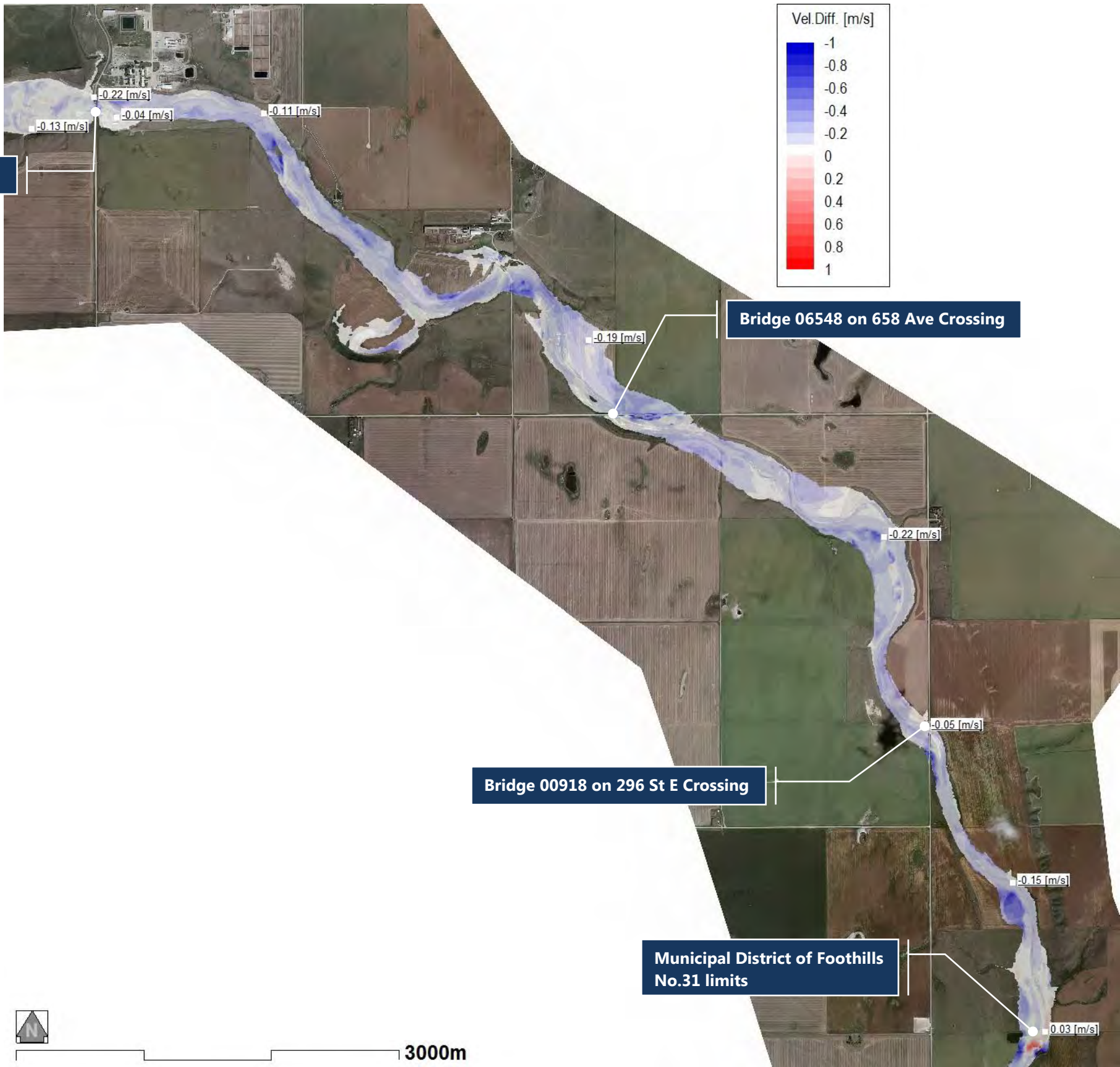
Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 410 m³/s' Flood Velocities under Post Mitigation Scenario 28A (2 of 5)

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Bridge 00975 on 232 St E Crossing



Municipal District of Foothills No. 31 – Little Bow River Modelling

Estimated Changes in Peak 'June 2013 – 410 m³/s' Flood Velocities under Post Mitigation Scenario 28A (3 of 5)



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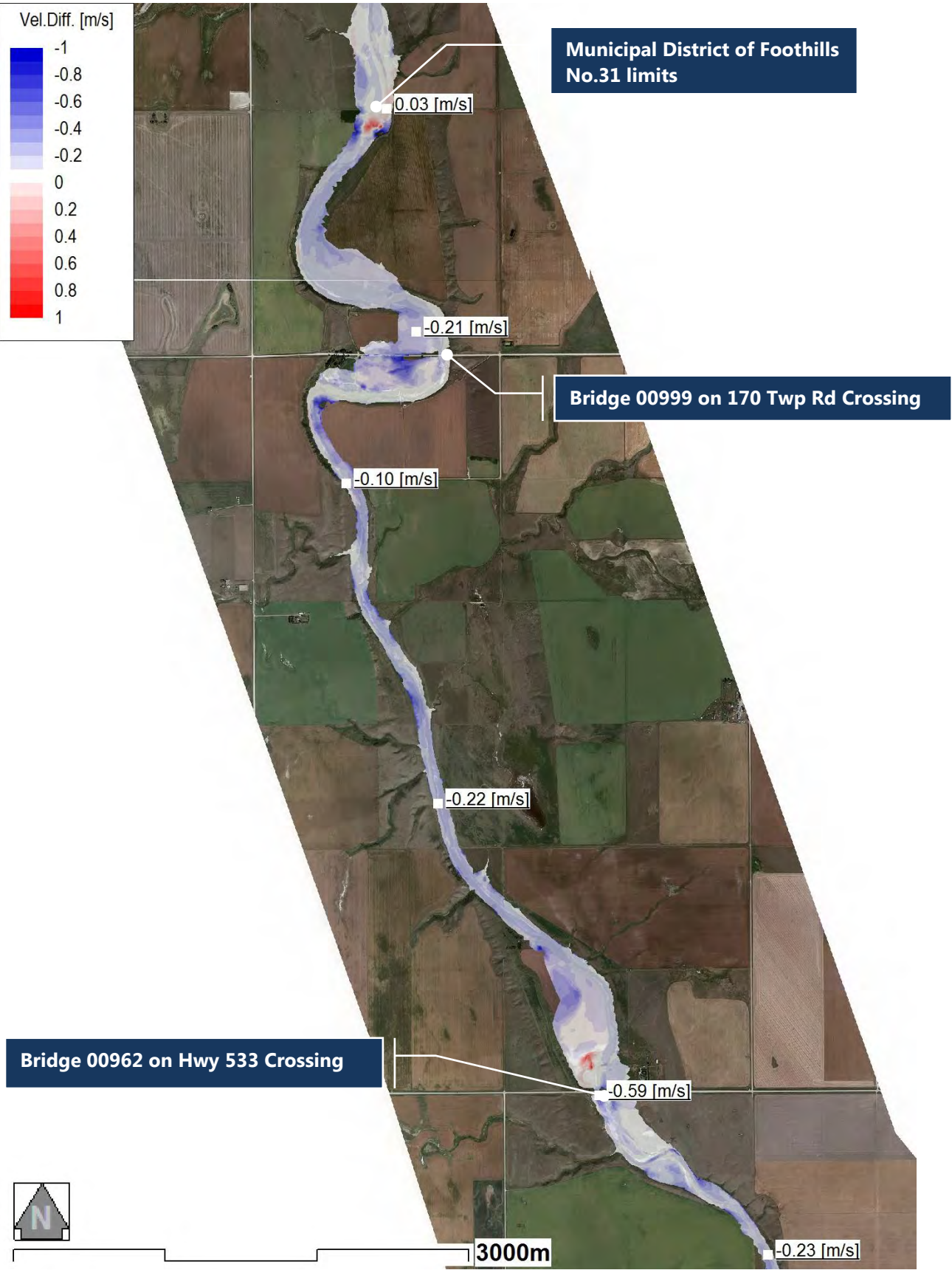
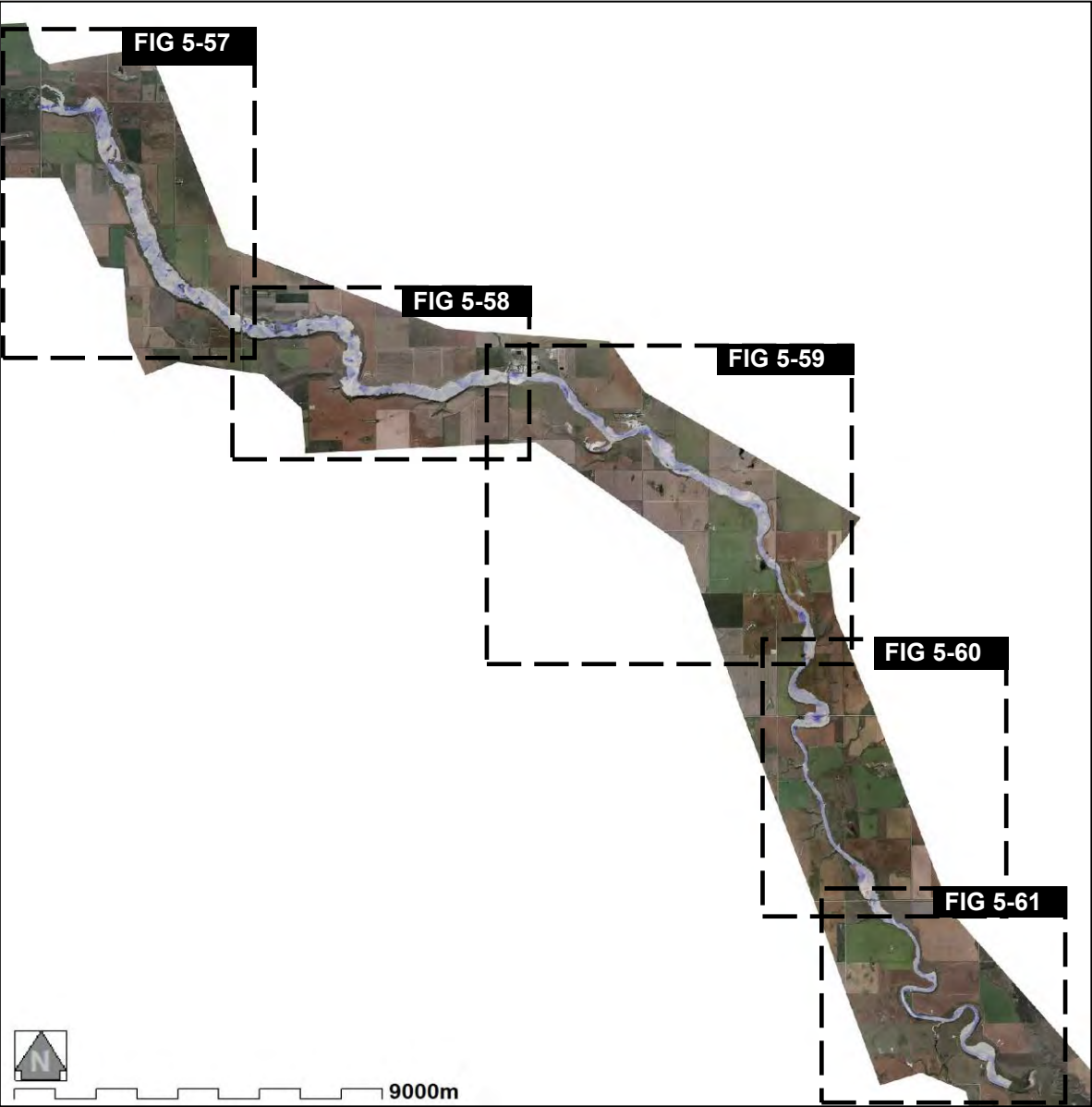
Date: Jan 30, 2017


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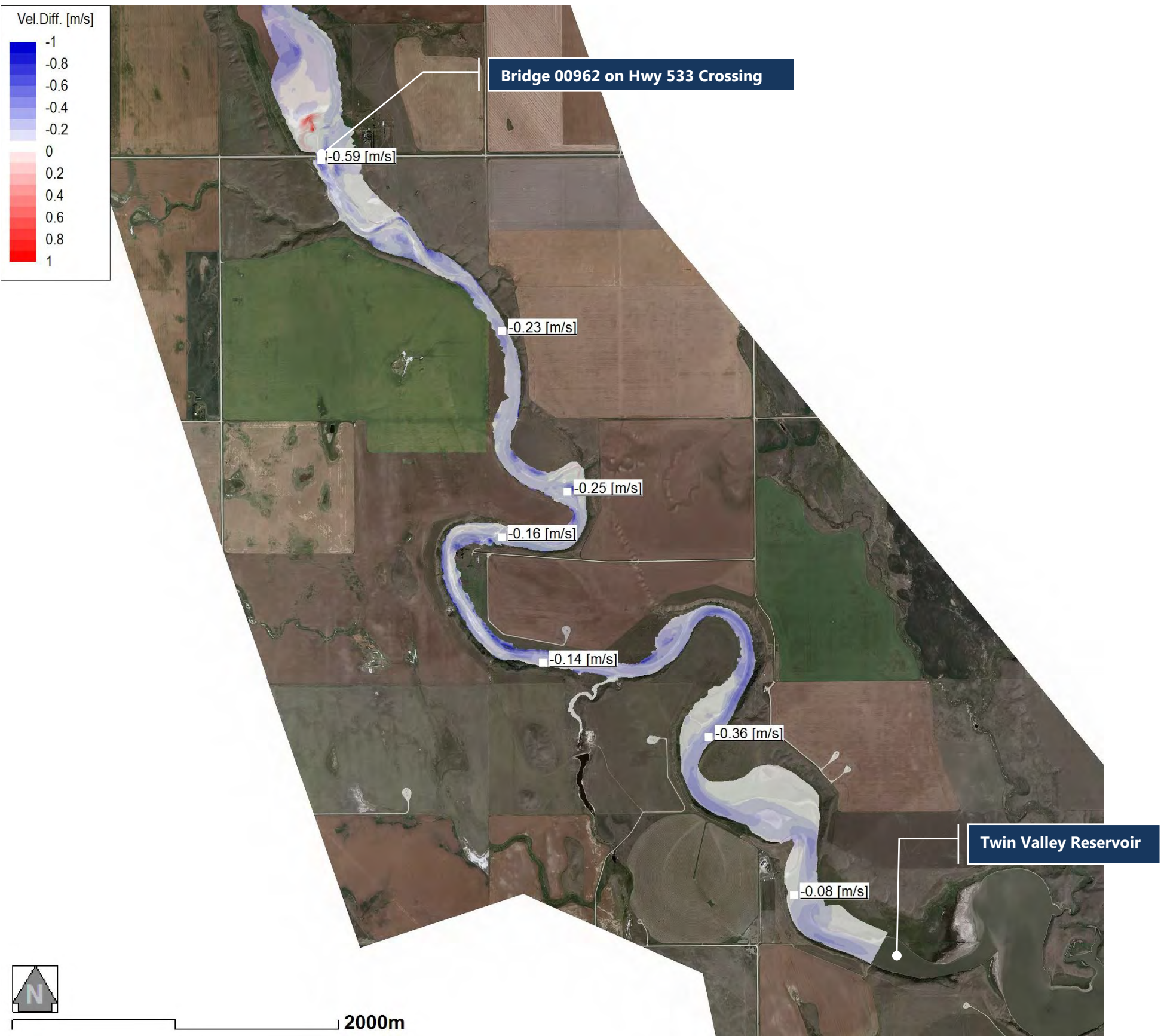
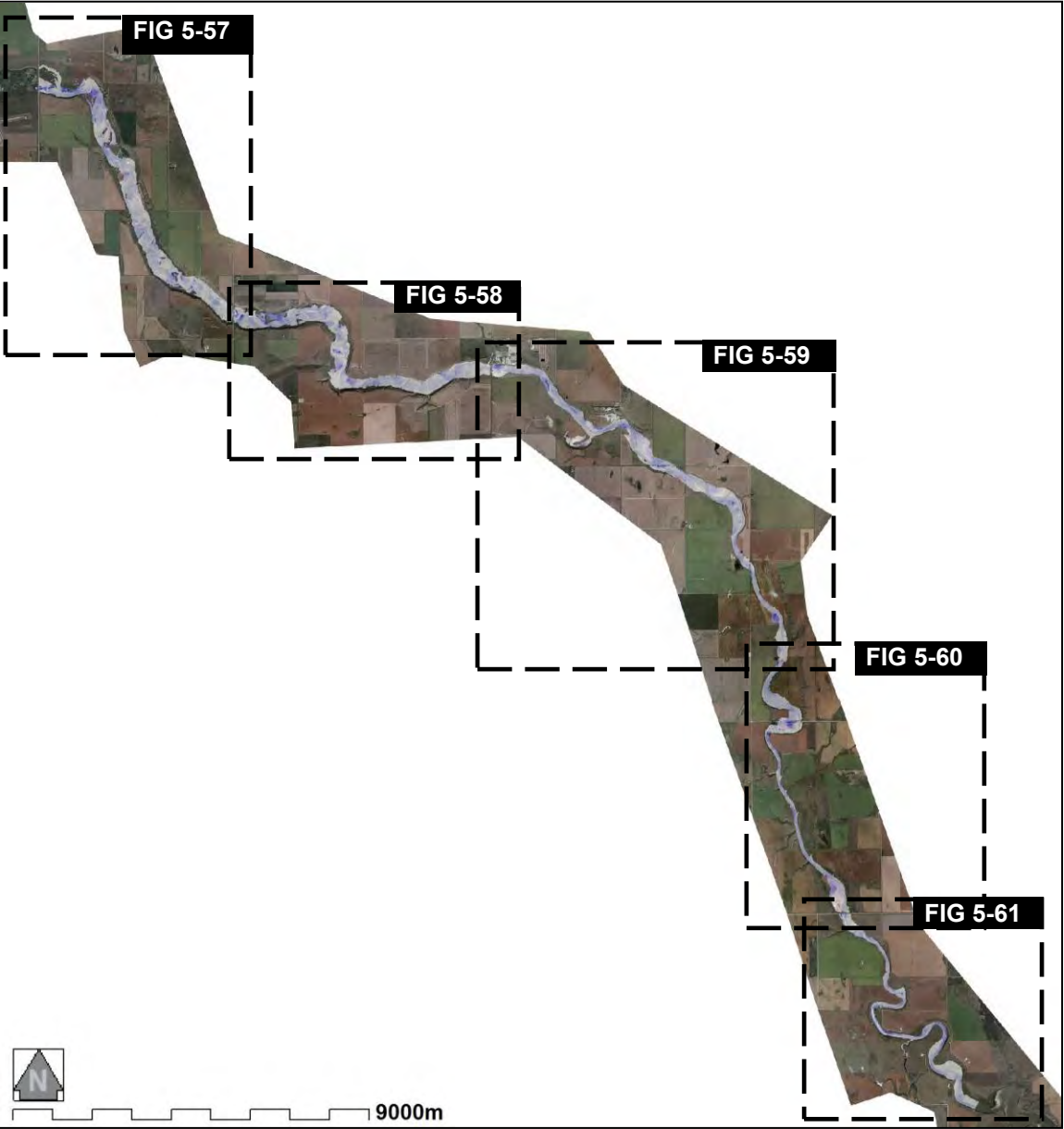
Figure No: 5-59

Rev: 0

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Estimated Changes in Peak ‘June 2013 – 410 m³/s’ Flood Velocities under Post Mitigation Scenario 28A (4 of 5)				
 <div>Advisian WorleyParsons Group</div>	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-60
	Reviewed By: JB	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.		
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Estimated Changes in Peak ‘June 2013 – 410 m³/s’ Flood Velocities under Post Mitigation Scenario 28A (5 of 5)

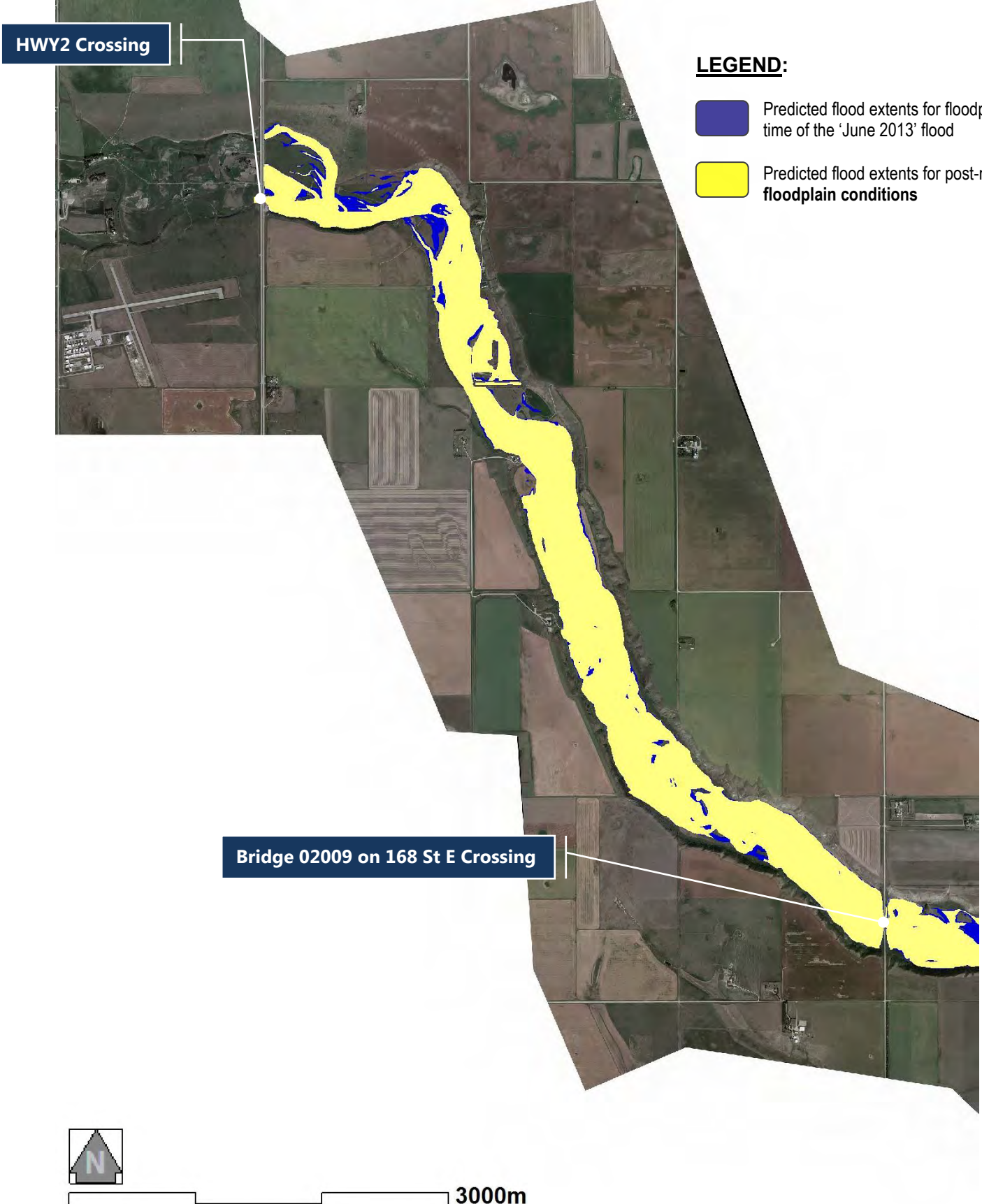
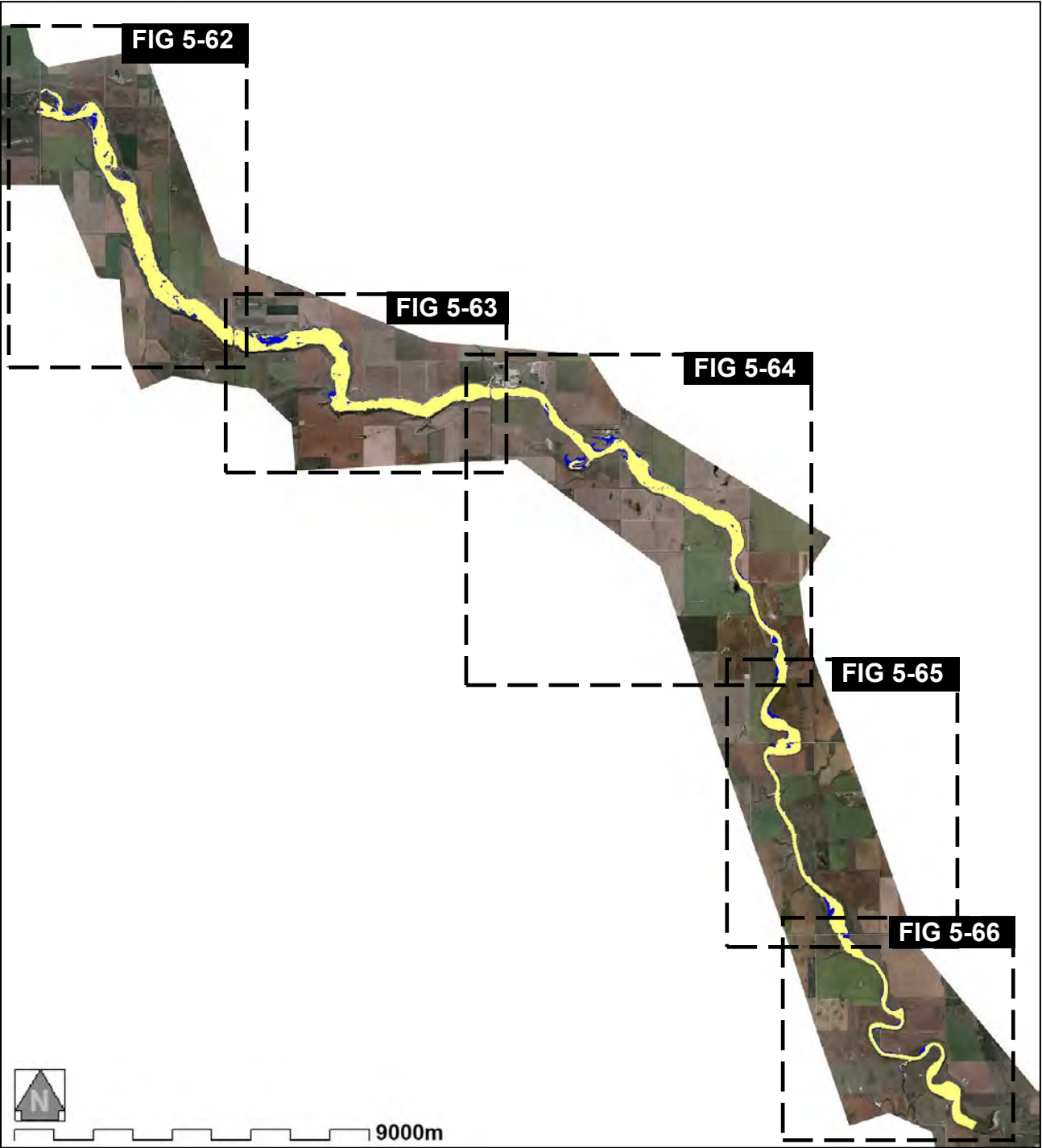
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Figure No: 5-61

Rev: 1

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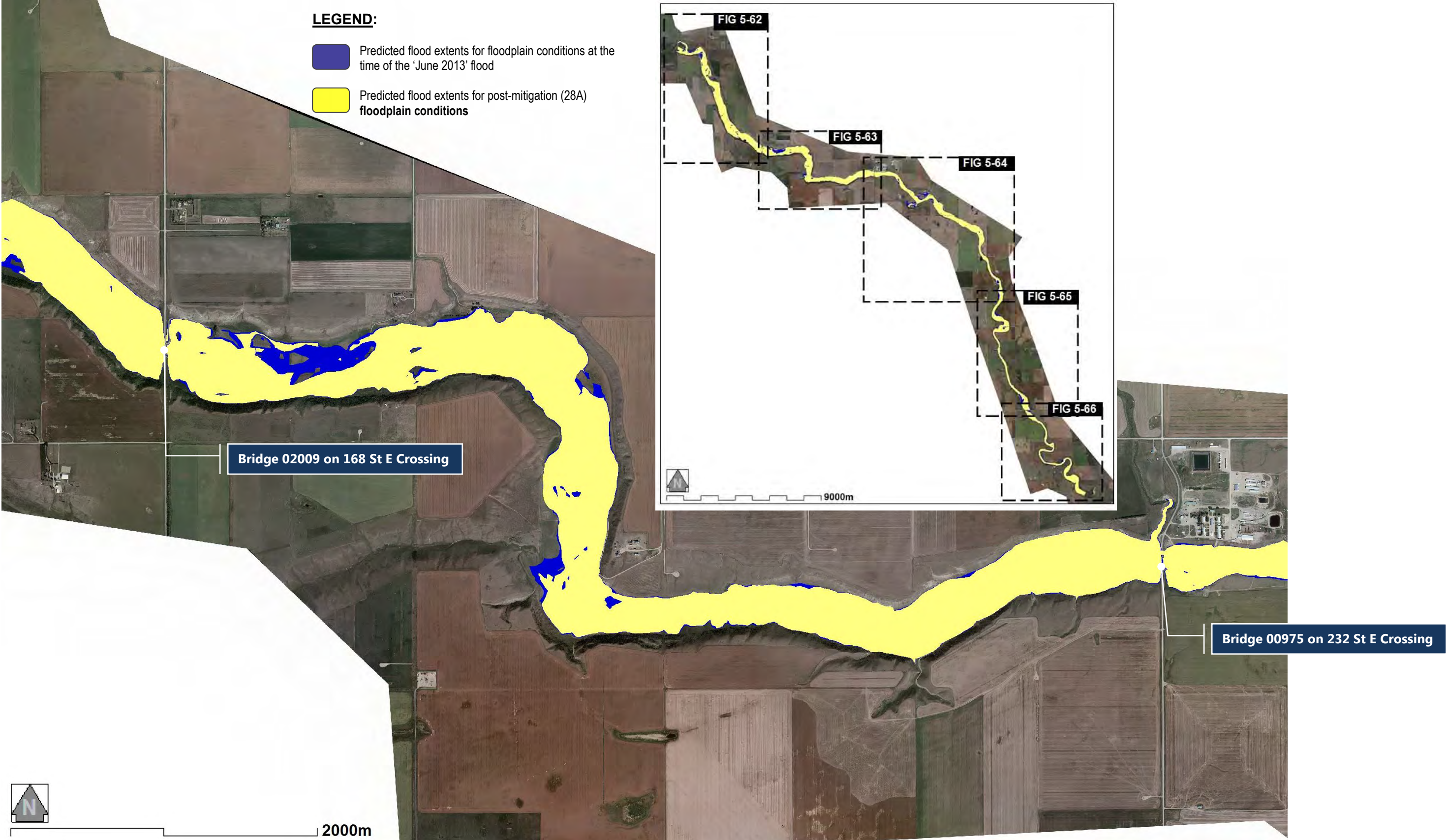


LEGEND:

Predicted flood extents for floodplain conditions at the time of the 'June 2013' flood

Predicted flood extents for post-mitigation (28A) floodplain conditions

<div><div></div><div>Advisian</div><div>WorleyParsons Group</div></div>	Created By: AP	Municipal District of Foothills No. 31 – Little Bow River Modelling		
	Reviewed By: JB	Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 560 m³/s vs. 410 m³/s' Flood Extents (1 of 5)		
		Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-62 Rev: 0
		This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons). WorleyParsons has exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantees or warranties as to the accuracy or completeness of this information. WorleyParsons assumes no liability to any other party for any representations contained within.		



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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 560 m³/s vs. 410 m³/s' Flood Extents (2 of 5)

Date: Jan 30, 2017

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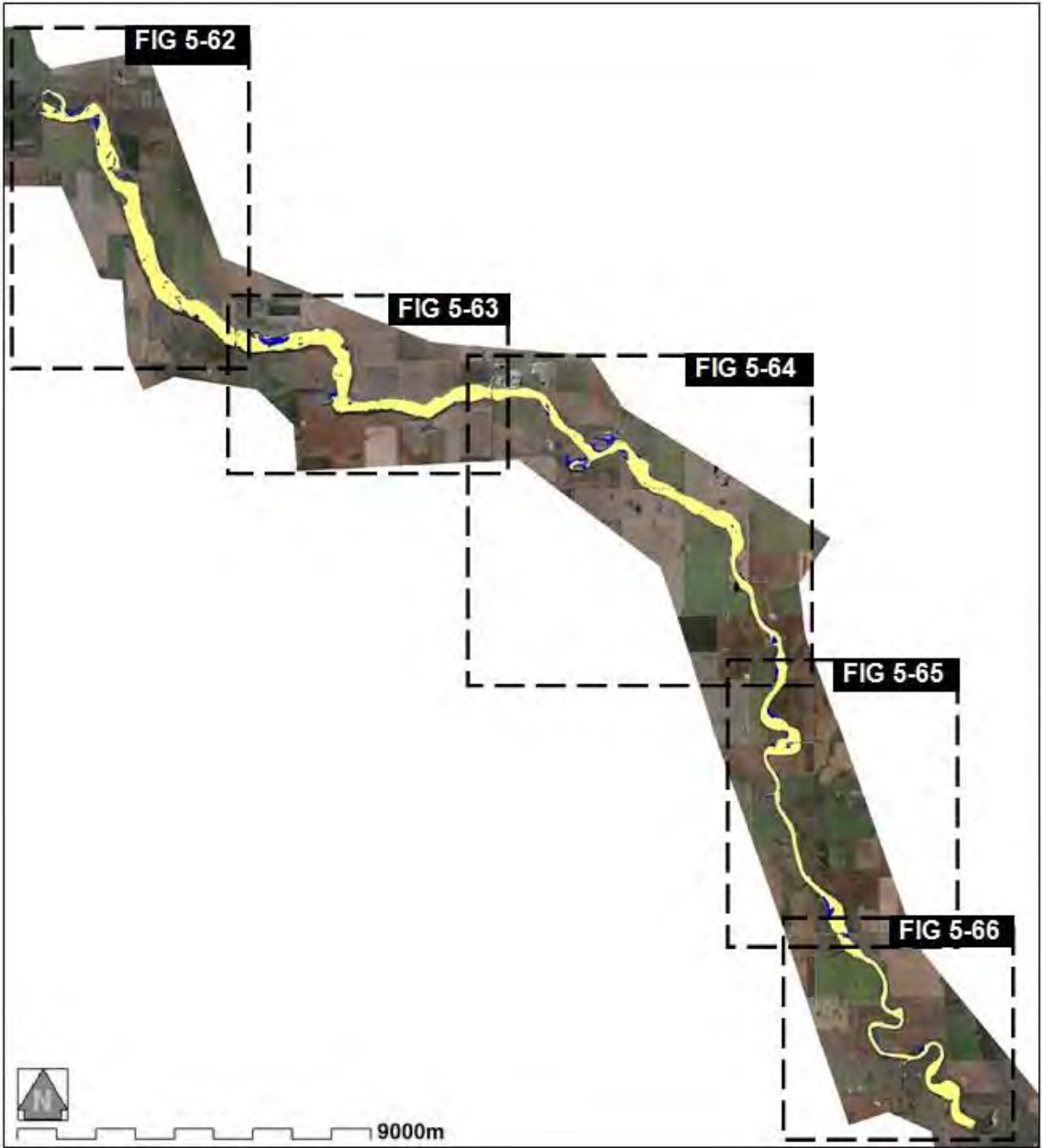
Figure No: 5-63

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LEGEND:

- Predicted flood extents for floodplain conditions at the time of the 'June 2013' flood
- Predicted flood extents for post-mitigation (28A) floodplain conditions



Municipal District of Foothills No. 31 – Little Bow River Modelling				
Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 560 m³/s vs. 410 m³/s' Flood Extents (3 of 5)				
Date:	Jan 30, 2017	File Path:	U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-64
Created By:	AP	Reviewed By:	JB	Rev: 0
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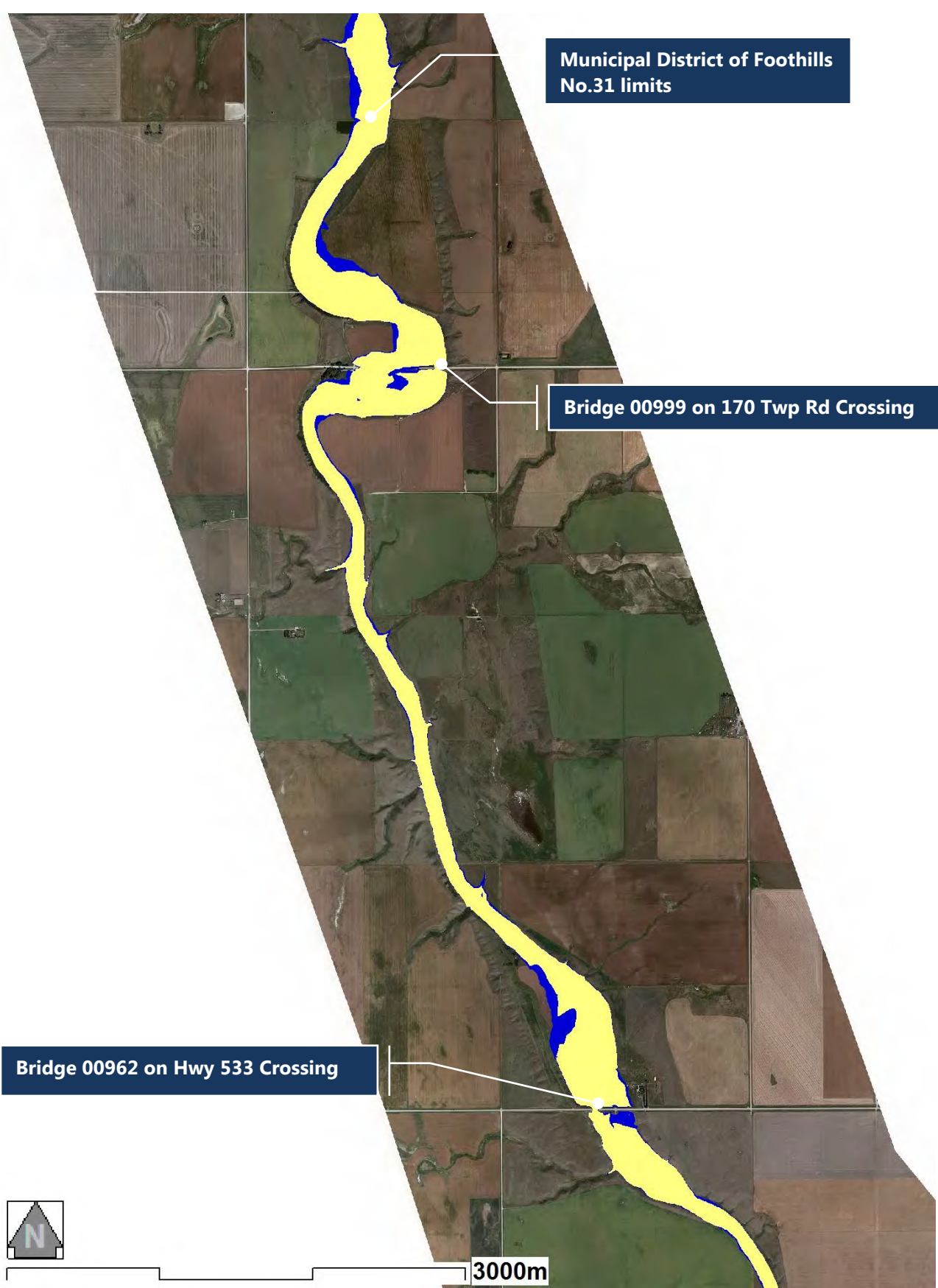
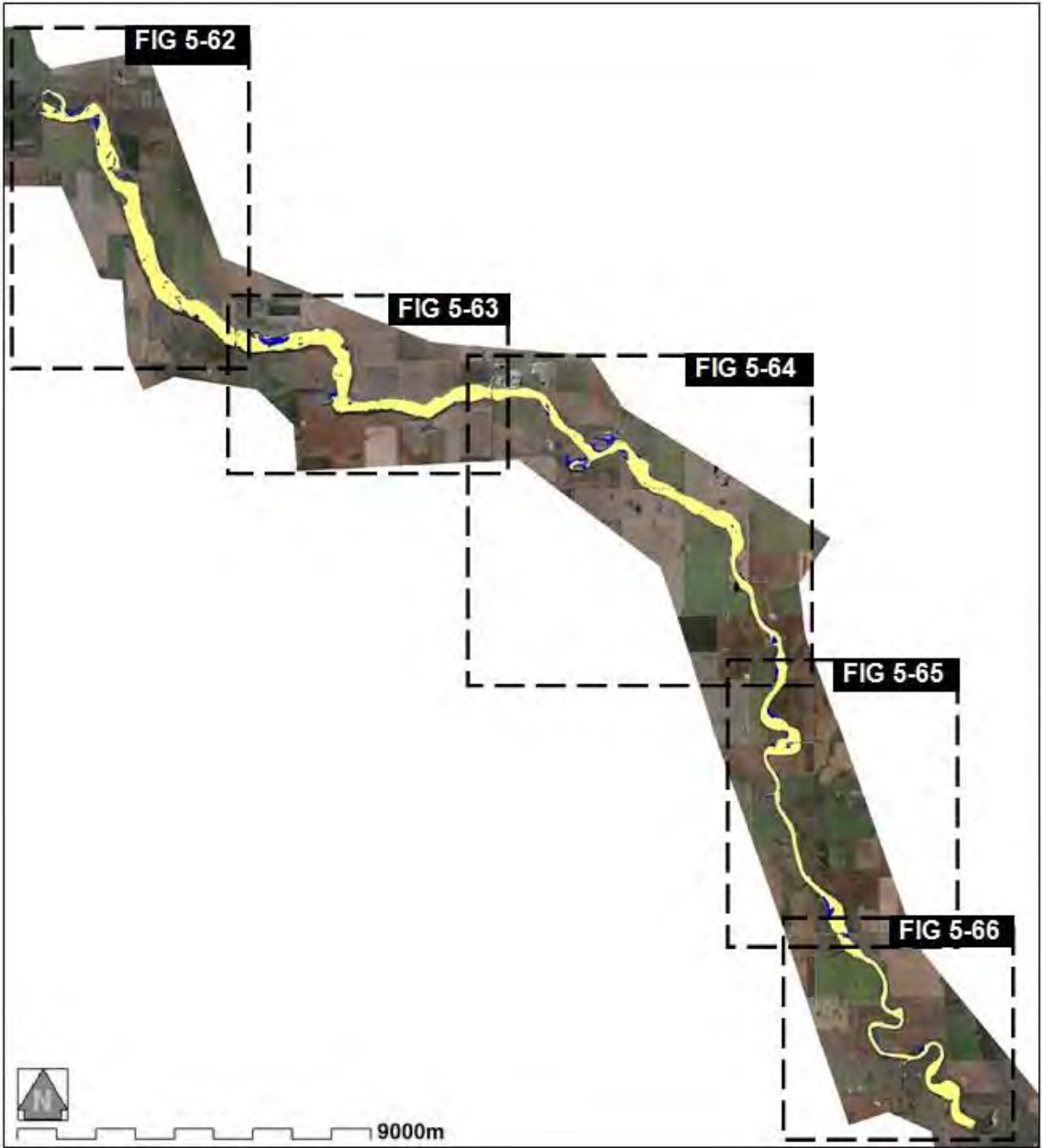



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LEGEND:

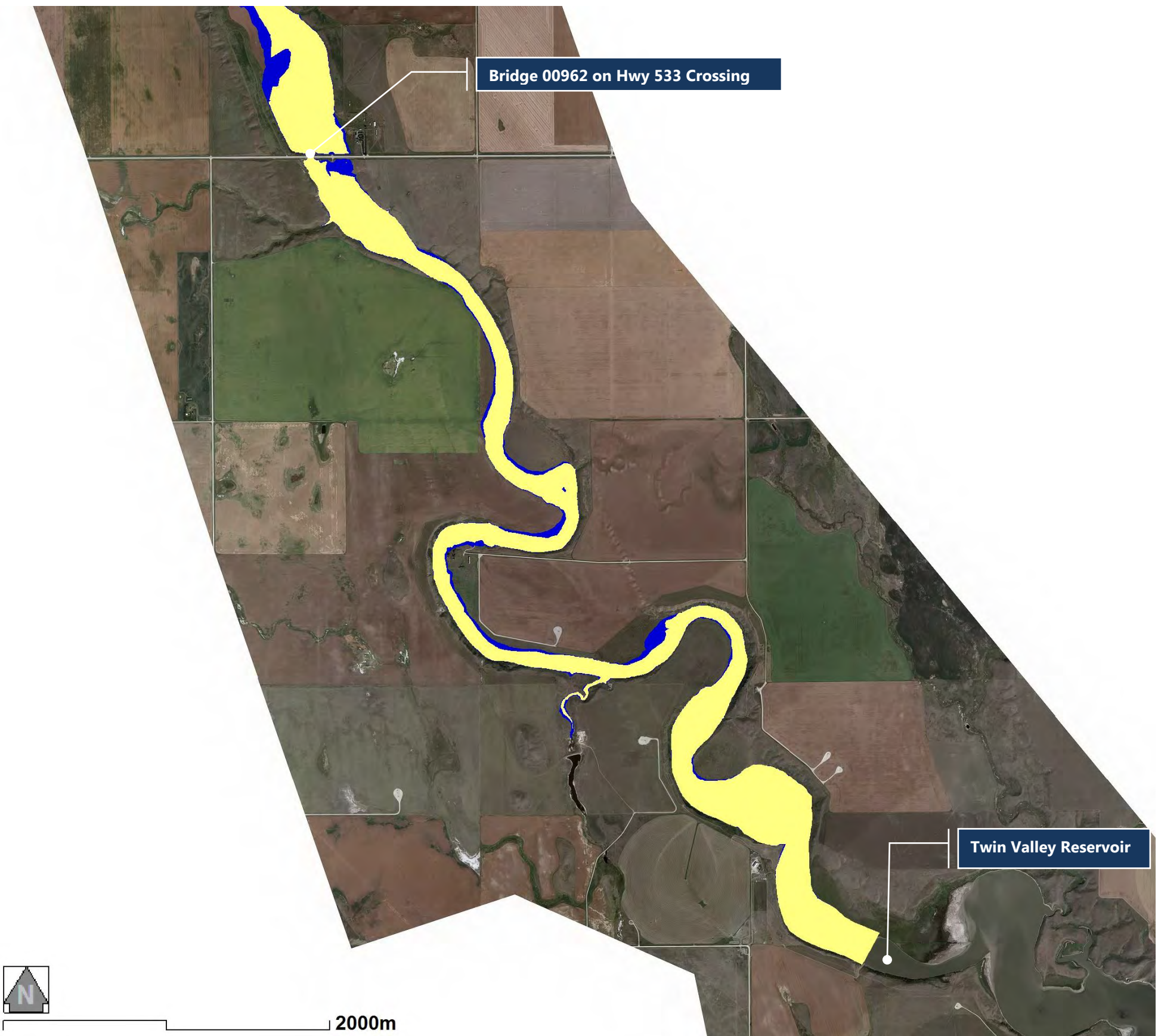
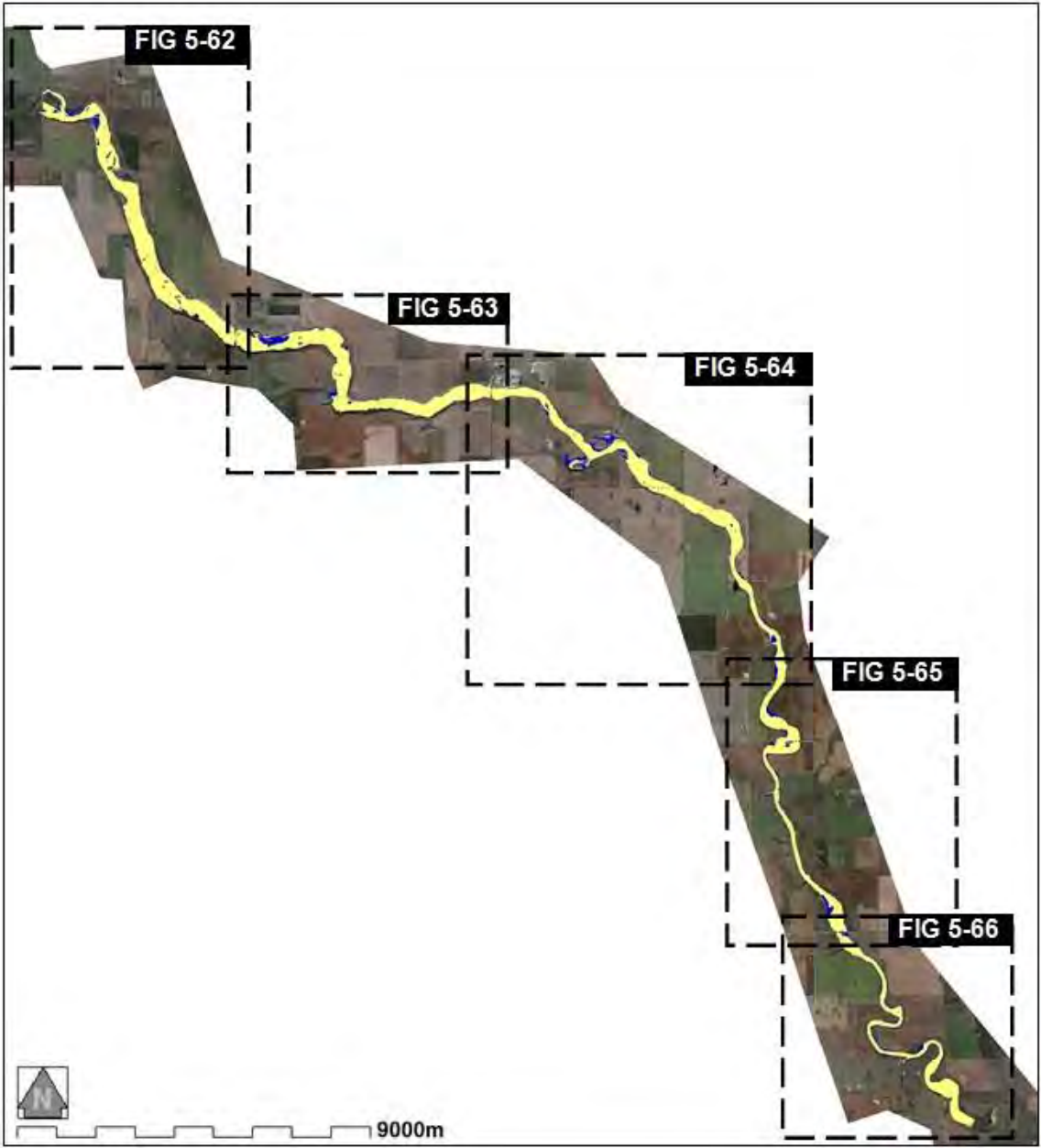
- Predicted flood extents for floodplain conditions at the time of the 'June 2013' flood
- Predicted flood extents for post-mitigation (28A) floodplain conditions



		Municipal District of Foothills No. 31 – Little Bow River Modelling			
		Comparison of Pre and Post-Mitigation (28A) ‘June 2013 – 560 m³/s vs. 410 m³/s’ Flood Extents (4 of 5)			
	Created By: AP	Date: May 1, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-65	Rev: 1
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LEGEND:

- Predicted flood extents for floodplain conditions at the time of the 'June 2013' flood
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Municipal District of Foothills No. 31 – Little Bow River Modelling

Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 560 m³/s vs. 410 m³/s' Flood Extents (5 of 5)

 <div>Advisian WorleyParsons Group</div>	Created By: AP	Date: Jan 30, 2017	File Path: U:\CAL\GBS\307076-07348\12.0_Reports\12.3_Backend\Little Bow River Modelling\Figures	Figure No: 5-66	Rev: 0
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Appendices

Appendix 1 Field Data Collection. Landowners High Water Marks Survey for Highwood River and Little Bow River Modelling

NOTE: Appendix 1 has been removed due to confidential information.

