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MUNICIPAL DISTRICT OF FOOTHILLS

Highwood River Modelling

Flood Mitigation Effects Assessment

307076-07349 – WW-REP-0001

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PROJECT 307076-07349 - HIGHWOOD RIVER MODELLING

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1. INTRODUCTION

WorleyParsons Canada Services Ltd., operating as Advisian, was retained by the Municipal District of Foothills (MD) to undertake Phase 1 Highwood River Modelling: Flood Mitigation Effects Assessment (HR-FEA). The Study Area for the HR-FEA includes MD lands potentially affected by flooding of the Highwood River along the river segment starting at Highway 2 and continuing downstream to the confluence with the Bow River (Figures 1-1, 1-2, 1-3, 1-4 and in the profile of Figure 1-5).

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 (or have the potential to) change to flood hazard level over this segment of the river. The MD has identified the need to assess downstream effects of these works on residents, infrastructure and agricultural lands adjacent to the Highwood River. The Study Area is downstream of existing coverage of previous modelling extents (i.e. the High River Flood Model as shown in Figure 1-6) 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 HR-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 HR-FEA are provided below. The purpose and scope are similar to the Little Bow River Modelling: Flood Mitigation Effects Assessment (LBR-FEA), which is a parallel study covering the Little Bow River from Highway 2 downstream to the MD's boundary (Advisian 2016).The methodology and results of Phase 1 of the HR-FEA are presented herein.

Phase 2 of the HR-FEA and LBR-FEA, if required, includes 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 by the Government of Alberta (GoA) and review of the Phase 1 report.

1.1 Purpose and Scope of Work

The overall purpose of HR-FEA is to characterize the change in flood hazard and effects associated with MD residential lands and infrastructure in the context of the 2013 flood under both pre and post-flood conditions. The post-2013 flood conditions will be integrated into the HR-FEA model. This integration includes adding all flood mitigation measures and mitigations that have been constructed or are planned for construction in and around the Town (Figure 1-7). The high-level scope of work to achieve this purpose is as follows:

- review available reports and data;
- collect high water marks (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 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 HR-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 development 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 HR-FEA and Study Area in general. The discussion begins with an overview of the Highwood 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 Highwood River hydrology (including a description of the Highwood-Little Bow flow split) are discussed. The Highwood-Little Bow flow split during a flooding event on the Highwood is a unique historic, morphologic characteristic that underlies the changes to low frequency flooding within the Study Area. Lastly, key existing reports are summarized to provide additional context for the HR-FEA.

2.1 Highwood River Watershed

The Study Area is located at the downstream end of the greater Highwood River watershed which has an effective drainage area at the confluence of the Bow River of approximately 4,000 km^2 (Figure 2-1).

The Highwood River watershed originates in the Rocky Mountain physiographic region in the Elk, Highwood and Livingstone ranges, located in the Kananaskis Country area. The watershed divide approaches an altitude of 3,000 m in this area and the river channel begins at approximately 2,400 m. This area of the watershed is associated with park and undeveloped areas covered mainly with high-density conifer forests. Moving eastward from the Rocky Mountain physiography region, the watershed moves downgradient to the Foothills (Porcupine Hills) physiographic region which begins near the MD’s western boundary. Land use and cover for this part of the watershed is less forest and more private property. Forest cover is still dominant in some areas but deciduous forest stands and grass lands become much more common.

The watershed continues to the east were it eventually transitions to the Southern Alberta Uplands near Longview. The Southern Alberta Uplands region of the watershed sees the trend continue with decreasing forest cover. Open grass lands comprise the majority of cover for this area. Private property and overall population density (including small municipalities) also increases through this region). The Southern Alberta Uplands continue east until just downstream of Woman’s Coulee Canal inlet. Over this river segment, significant tributaries join the river including Pekisko and Stimson Creeks which represent approximately 30% of the watershed at this location (Figure 2-1).

Downstream from the Southern Alberta Uplands, the watershed transitions to the Western Alberta Plains physiographic region just west of the Town. The Western Alberta Plains physiographic region encompasses the eastern portion of the watershed and includes the Study Area. The Western Alberta Plains are associated with highest residential densities and mainly grasslands. Forests in this area are mainly found in riparian areas adjacent to the Highwood River and tributaries.

The transition point to the Western Alberta Plains along the Highwood River also includes another key feature of the watershed. This can be described as the Highwood River-Little Bow River drainage divide (Figure 2-2). The drainage divide can be described as the location along the southern flood plain of the Highwood River, upstream from the Town, where low frequency flood events with magnitudes greater than approximately 700 m^3/s on the Highwood River “spill” over to the Little Bow River watershed. Northwest Hydraulic Consultants (NHC 1992) provides rationale behind this mechanism:

> *It is believed that a broad gravelly outwash fan formed west and south of High River during retreat positions of the most recent continental ice sheet northeast of the town. Alpine meltwater during that period was forced to flow southeast across this fan, into the present day Little Bow River valley. With further retreat of the ice sheet, the Highwood River re-established itself along its pre-glacial path and present-day course downstream of the High River town. During low frequency floods, the present-day Highwood River is still able to overflow [towards the southeast] into the Little Bow River basin.*

The drainage divide is discussed further in Section 2.3.1.

The Highwood River catchment has a diversified land use, with recreational activities dominant in mountain areas where a number of parks are found. Agricultural and community developments become increasingly present in the downstream part of the basin. The two main communities here are the Town and the Village of Longview. Other communities include Eden Valley First Nations Community and a number of minor hamlets and localities (AECOM 2014).

2.1.1 Study Area Overview

The entire Highwood River channel is approximately 186 km in length from its origin to its confluence with the Bow River. The Study Area itself only includes potential flood-affected lands on the downstream 30 km segment of the overall river. This segment and its surrounding land use are discussed below.

The Study Area begins at the Highway 2 crossing of the Highwood River. This location coincides with the High River Town Flood Model downstream boundary (Figure 1-6). The river meanders north and then north-east for 30 km within a well-defined valley to the Bow River valley, which in line is located 18 km north of the Highway 2 crossing (Figure 1-1). The watershed area of the Highwood at the Highway 2 location is approximately 2,320 km^2. The Sheep River, a major tributary, joins the Highwood River approximately 14 km upstream from the Bow River confluence. The Sheep River watershed area is approximately 1,570 km^2 (or approximately 40% of the overall Highwood River watershed area of 4,000 km^2 as shown in Figure 2-1).

As mentioned above, the Study Area falls within the Western Alberta Plains physiographic region and consists mainly of grass lands. Riparian tree (Cottonwood and Balsam Poplar) and shrub stands are found sporadically within the Highwood River valley that defines the Study Area. The tree and shrub stands tend to be found adjacent to the river, on northern aspect valley slopes as well as in side valleys associated with small tributaries.

Land use is mainly a mix of rural residential and agriculture (cultivated, pasture and rangeland), although some commercial operations also seem to be apparent. Rural residential land use varies from large section holdings to small acreages found in two rural sub-divisions located outside of the Highwood River valley. In general, population density can be considered low adjacent to the river, likely due to the local valley feature.

2.2 Upstream River Segment Morphology

The section below discusses the river and valley morphology of the Highwood River just upstream of the Study Area. A sub-section is then provided that focuses on the Study Area in greater detail. The discussion begins near Woman's Coulee Canal inlet where the river exits a confined valley, discharging to a broad alluvial floodplain. The discussion then progresses to downstream segments until reaching the Study Area.

Woman's Coulee Inlet downstream to the Town Boundary: this segment of the Highwood River is in a more natural state when compared to the downstream segment through the Town. However, significant river training and diking works can be found in some reaches as shown in Figure 2-2. This segment of the river can be classified as wandering river. The sediment load and stream power are relatively high but transport capacity and channel form restrict braiding tendencies. The river has very low confinement as it leaves a more confined valley setting upstream. The river valley is approximately 1 km wide at the segments upstream end, increasing to a width of 2 km near the Town. The channel has minimal incision and can access its floodway at most flows above the median (2-year) flood event where diking is not present. The slope of this segment (0.32%), consistent with channel type, is greater than the other river segments downstream to Highway 2.

Upstream Town Boundary to 498th Avenue Crossing: historically, this segment of the river likely exhibited wandering characteristics potentially transitioning to braiding over some periods because of its sediment load and loss of transport capacity due to the lower slope apparent through the middle and lower portions of this river segment. However, river training works and the Centre Street crossing within the Town have created a confined channel with a meandering planform through much of this segment. Channel translation is limited, especially at the upstream portion, due to bank protection. Flood plain access is also limited in the upper portion of this segment due to diking on the southeast bank of the river. The channel has shown aggradational characteristics, mainly upstream of the Centre Street Bridge, which is consistent with an undersized crossing. Average slope of this segment is 0.16%. The confinement of the river through this area is only apparent 2.5 to 3.5 km to the south, within the Little Bow River watershed.

498th Avenue Crossing to the Highway 2 Crossing: the river through this segment has an irregular meandering planform through the downstream half and a straight reach through the upper half of the river segment. In general, the gradient (0.05%) is lower through this segment than both upstream and downstream river segments. The channel through this segment is incised within the surrounding floodplain although alluvial sediment can be observed as depositional layers in the upper areas of exposed bank. The floodplain is only accessed in most locations at low frequency flows above approximately 1,000 m^3/s. Bedrock, observed on bed of the upper boundary of this segment, may be limiting down-cutting and slope adjustment. However a detailed understanding of bedrock location and properties is beyond the scope of this study. This segment of river is not associated with valley confinement.

2.2.1 Study Area Overview

The morphology of the Study Area river segment, from Highway 2 to the Bow River, varies significantly from the segment upstream of Highway 2. The Study Area river segment is highly confined within a significant valley that increases in depth from 10-20 m just downstream of Highway 2 to 30-50 m near the Sheep River confluence to 50 to 70 m at the confluence with the Bow River. The river includes straight and irregular meandering reaches. Pool and riffle reach-scale geomorphic structure is prevalent throughout. Floodplain areas are scattered throughout the segment as the valley and upper terraces permit. The average 0.26%.gradient of this segment increases significantly compared to the upstream segment as the channel steepens to meet the Bow River. The significant depth of the Bow River valley and Highwood River valley in the study is likely influenced by glacial isostatic adjustment and long term river degradation. The following paragraphs discuss the morphology of local river reaches of the Study Area in detail from Highway 2 to the Bow River, making reference to the maps in Figure 1-2, 1-3, 1-4 and the chainage starting from Highway 2 bridge (0 km) and ending downstream at the Bow River confluence (30 km) as shown in the longitudinal profile of Figure 1-5.

Reach 1 (see Figure 1-2), River Chainage 0 km (Highway 2 bridge crossing) to River Chainage ~6 km (Highway 547 bridge crossing): The river over this reach has a slightly lower slope (0.13%) when compared to the overall average slope (0.26%) of the river to the confluence with the Bow River (see Figure 1-5). This is likely a transitional area, with slope adjustments migrating upstream over time. This reach of river has an irregular meandering planform with some straight local sections. The upstream portion of this reach is relatively unconfined but becomes more confined by valley walls (15-20 m above the river) near the Highway 547 bridge. The channel is slightly incised throughout the reach with the floodplain only being accessed during low frequency flood events on the inside of most meander bends and two floodplain areas. The flood plain areas occur on the RDB (right downstream bank) at the upstream end of the reach and on the LDB (left downstream bank) located approximately two-thirds down below the Silvertip neighbourhood. Local geomorphic features include pools and riffles interspersed between point and side bars. There is also occurrence of random longitudinal bars. Sediment deposition and bar formation appears relatively consistent throughout the reach. The channel width of this reach ranges from 45-65 m.

Reach 2 (see Figure 1-2), River Chainage ~6 km (Highway 547 bridge crossing) to ~16 km (just upstream of the Sheep River confluence): This reach of the Highwood has a slope consistent or slightly greater than the average slope of Study Area river segment of 0.26% (Figure 1-5). Again, the reach has an irregular meandering planform with straight sections occurring between meanders. The valley confinement for this reach becomes more defined as significant flood plains are almost non-existent. The valley is 15-20 m deep at the upstream end increasing to 35-50 m just upstream of the Sheep confluence, at the downstream end of the reach. The channel through this area is likely incised because of its lack of a floodplain. For the upstream half of this reach, geomorphic features are similar to the upstream reach and include pools and riffle. However bar morphology changes in that there are significant diagonal (dissected) and longitudinal bars in addition to point and side bars. In the downstream portion of this reach, the quantity of coarse material depositional features appears to increase substantially with diagonal (dissected) and longitudinal bars becoming more prevalent moving downstream. This bar morphology is associated with local channel widening in some areas. The channel width of this reach ranges from 45-65 m in the upper half of the reach to 50-75 m in the lower half of the reach. Relatively depths of Reach 2 appear to be less than those observed in Reach 1, 3 and 4.

Reach 3 (see Figure 1-3), River Chainage ~16 km (just upstream of the Sheep River confluence) to ~23.5 km (Highway 552 bridge crossing): This reach is similar to Reach 2, with a 0.3% slope consistent or slightly greater than the 0.26% average slope of Study Area river segment (Figure 1-5). This reach has lower meander sinuosity and more straight sections than the upstream reaches. The overall valley confinement decreases at the confluence, as the Sheep River valley has significant mid-level terracing at the mouth. These mid-level flood terrace features are also apparent on the Highwood River downstream of the confluence, alternating between LDB and RDB. Mid-level terracing is not accessible by modern-day low frequency flooding, being approximately 10-20 m above the river level. The upper valley level is 40-60 m from the river through the reach. The channel through this area is likely incised because of its lack of a floodplain. Sediment deposition is significant just downstream of the confluence with a major channel junction side bar occurring on the LDB of the Highwood. Downstream of this feature several longitudinal bars are present. There are also occurrences of point, side and diagonal bars moving downstream. Approximately half way down Reach 3, bar occurrence and sediment deposition in general appears to decrease as channel depths increase. Increasing depths are consistent with the flow increase from the Sheep River coupled with channel incision and valley confinement. Local-scale geomorphic features include the pools, riffles and runs. The channel width of this reach ranges from 60-90 m, however just downstream of the confluence, near the channel junction bar, the width approaches 120 m for a short section. Relatively depths of Reach 3 appear to be greater than those observed in Reach 1 and 2. One other interesting geomorphic feature of this reach, which occurs approximately 150 m upstream of the Highway 552 bridge crossing, is a bed rock outcrop that occurs approximately perpendicular to the main channel. This feature acts as a significant local hydraulic control.

Reach 4 (see Figure 1-4 and 1-5), River Chainage ~23.5 km (Highway 552 bridge crossing) to 30 km (Bow River confluence): The downstream reach of the Study Area has a slope consistent or slightly lower than the average slope of Study Area river segment. This reach, similar to Reach 3, has lower meander sinuosity and more straight sections than upstream Reach 1 and Reach 2. The valley confinement is fairly consistent through this reach with depths ranging from 50-70 m and width (at the top of the valley) ranging from 700 to 1200 m. The Highwood River valley gives way to the broader Bow River valley approximately 3.5 km upstream form the confluence. Mid-level terrace features found upstream are replaced by lower terraces and flood plains ranging from 5 to 15 m above the river. The flood plains are access during low frequency flood events. The channel through this area is likely less incised than the upstream reaches because of the active floodplains. Sediment deposition appears to be relatively consistent through the reach. Bar types are mainly point and side bars with a random diagonal and longitudinal bars scattered throughout. There is also is a significant delta sediment deposit at the confluence. Local-scale geomorphic features include the pools, riffles and runs. The channel width of this reach ranges from 70-120 m. Relatively depths of Reach 4 are consistent with Reach 3 and appear greater than those observed in Reach 1 and 2.

2.3 General and Flood Hydrology

The hydrology of the Highwood River is characterized by low late-summer, fall and winter base flows transitioning to an increased flow period driven by freshet (i.e. snow melt) and rain-on-snow runoff in the spring as well as rainfall-driven flow increases in the summer. During these increasing flow periods, significant peak flows (one or more per year) can be experienced. Freshet, rain-on-snow and rainfall driven floods events can be 20 to over 100 times greater than fall and winter base flows. 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. In dry years, however, in which little rain fall occurs, flows can be very low throughout summer also.

Local snow-melt in early spring in the uplands and plains physiographic regions of the Highwood River watershed result in local freshet events which produce flow increases in the lower portions of the watershed. This mechanism occurs before melting (and flow increases) begin in the foothills and mountainous portions of the watershed.

Flood hydrology for the upper portion of the Study Area, before the confluence with the Sheep River, for all but the most low frequency flood events (e.g. 2013 flood) can be characterized using data from the following stations (represented in Figure 2-1):

- 05BL003 Highwood River at High River;
- 05BL004 Highwood River below Little Bow Canal; and
- 05BL009 Highwood River near Aldersyde.

From an low-probability flood magnitude perspective (e.g. greater than 500 m^3/s), considering errors in flow estimates/measurements, timing of local runoff and canal operating procedures, the flows from these stations have been used interchangeably to characterize flood flow of the Study Area. This assumption is assumed valid as long as flood plain overflow to the east area of the Town (including the Hampton Hills, Sunshine, and Sunrise neighbourhoods) and storage associated with the flood plain between 498th Avenue north to the Highway 2 crossing are subtracted from the peak flows recorded at High River. This assumption is supported by a comparison of overlapping peak flows at the 05BL004 Highwood River below Little Bow Canal to 05BL009 Highwood River near Aldersyde. This station comparison did not provide a meaningful relationship of increasing peak flow with increasing watershed area based on seven overlapping years. In general the relationship indicated that peak flows tended to be slightly greater at the Little Bow Canal Station (approximately 7%). Considering uncertainty in peak flow estimates and the narrow range of peak flows for comparison (all peak flows were less than 270 m^3/s). Flow inputs from Tongue Creek (270 km^2), which enter the Highwood River just upstream of the Aldersyde station, do not appear to have a significant effect on peak flow magnitude based on review of historic Water Survey of Canada (05BL016) flow data in comparison to the greater Highwood watershed. For example, in 1923 the maximum daily flow in Tongue Creek was approximately 13.0 m^3/s versus approximately 500 m^3/s (representing less than 3% of the total flow) in the Highwood River at Aldersyde (i.e. just downstream of Tongue Creek's discharge location). Anecdotal and historical imagery evidence (Photo A), however, indicates that a dam in upper Tongue Creek watershed failed during 2005 flooding and hence flows emanating from this watershed may now be influential during freshet.

Photo A Imagery taken in 2005 of the dam failure in Tongue Creek

Additional assessment should be undertaken to assess the potential change in hydrology. It is also worth noting that significant flow to the Hampton Hills, Sunshine, and Sunrise neighbourhoods and storage in the flood plain north of 498th Avenue north to the Highway 2 has only been documented during the 2013 flood event. The approximate watershed area of the most upstream point within the Study Area can be estimate using the 05BL009 Highwood River near Aldersyde (discontinued) station, which has an effective watershed area of 2,310 km^2. The effective watershed area at the Highwood River below Little Bow Canal is 1,950 km^2.

Downstream from the Highway 2 crossing in the Study Area, flood hydrology is greatly influenced by Sheep River. The Sheep River near Aldersyde has an effective watershed area of approximately 1,570 km^2. The total effective watershed area downstream of the Highwood River-Sheep River confluence is 3,950 km^2 measured at station 05BL024 (Highwood River near the mouth). This station is located 6.5 km upstream of the Highwood River's confluence with the Bow River.

The low frequency flood hydrology of the Study Area is also influenced by the amount of spill-over from the Highwood River to the Little Bow River during flood events greater than approximately 650-700 m^3/s. Additional information pertaining to this mechanism is provided in Section 2.3.1.

Table 2-1 below summarizes the low frequency (greater than 500 m^3/s) flood instantaneous peak flows associated with the lower portion of the Highwood River including the Study Area as well as peak flows of the Sheep River where data exist.

Table 2-1 Low-Probability (greater than 500 m^3/s) Instantaneous Peak Flows related to the Study Area

Year	Highwood River at the Town of High River (05BL004) (Study Area - adjusted if required)	Sheep River at Okotoks (05BL012) (at Black Diamond, 05BL014)	Highwood River near Mouth (05BL024)
	Peak Flow (m^3/s)	Peak Flow (m^3/s)	Peak Flow (m^3/s)
2013	1,225[A] (960[A])	900 (750)	1,860[B] (2,320)[C]
1995	803	440[E] (366)	1,120
1932	740[D]	---	---
1942	708[D]	---	---
2005	671	460[E] (380)	1,340
1923	643[D]	---	---
1929	561[D]	---	---
1953	536[D]	---	---

Notes:

A – Preliminary estimate using High River Flood Model (flow upstream of Woman's Coulee Canal est. at 1,820 m^3/s by Water Survey of Canada (WSC)

B – Preliminary estimate using High River Flood Model results plus WSC Sheep River slope-area est. at Okotoks

C - Preliminary WSC flood estimate using slope-area methodology

D - Highwood River near Aldersyde (05BL009)

E – High-level estimated using ratio between 2013 flood WSC slope-area estimates and WSC peak estimates for the Sheep River at Black Diamond for 1995 and 2005

"---" Data not available

Peak flow data provided for Study Area was derived from numerous sources including WSC stations, Highwood River near Aldersyde (05BL009) and Highwood below Little Bow Canal (05BL004), WSC slope-area estimates and modelling estimates as outlined in Table 2-1. Overflow to the Little Bow Basin is not included in the values provided in Table 2-1. Overflow was observed for the years 1923, 1929, 1932, 1942, 1995 and 2013. The Highwood below Little Bow Canal (05BL004) station became operational in 1986 while the Aldersyde station was decommissioned in 1993 after being in operation since 1912. It is worth noting that the Highwood below Little Bow Canal (05BL004) station also operated from 1908 to 1915.

Sheep River flood magnitude data at near the confluent (i.e. Sheep River at Okotoks) is not available for the majority of high-flow years. As a surrogate, Sheep River data from the Black Diamond (1970 to present) station (05BL014) have been included and used to provide high-level estimates of potential flow magnitudes of the Sheep River at Okotoks through the use of simple peak ratios using the 2013 flood estimates. These estimates are provide to provide a feel for the expected flood magnitudes but should not be used for detailed assessment.

The period of record for the hydrometric station of Highwood River near the Mouth (05BL024) is 1970-present, with missing maximum instantaneous discharge data in the years 1991, 1993, 2002, 2006 and 2011 due to equipment malfunction, orifice damages or similar. Therefore only a limited number among the eight largest events in the area are recorded in the WSC database, as reported in Table 2-1. The station is still active. It is worth noting that two flow estimates are provided for the Highwood River at the Mouth: 1) 1,860 m^3/s estimated using the High River Flood model which included the WSC-estimated upstream flow boundary condition for the 2013 flood of 1,820 m^3/s plus WSC estimate for the Sheep River at Okotoks; and 2) 2,320 m^3/s WSC-estimated value. The High River Flood Model estimates flow losses due to flood plain storage (~100 m^3/s), overflow to the Little Bow River (560 m^3/s) and overflow to the east side of the Town (200 m^3/s) for a total of approximately 860 m^3/s. Based on these results and WSC's flow estimate of 900 m^3/s corresponding to the 860 m^3/s above, WSC's estimate for the 2,320 m^3/s appears to the on the high-side of the range for expected flows assuming low frequency flood flow estimates calculated using the slope-area method are accurate to +/-15%.

2.3.1 Highwood-Little Bow Flow Split

Low frequency flood hydrology of the Study Area is influenced by the amount of water that overflows to the Little Bow River during floods greater than approximately 650-700 m^3/s (i.e. the Highwood-Little Bow flow split). In particular, topographic changes (e.g. construction of dikes) that change the Highwood-Little Bow flow split can result 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 m^3/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 m^3/s in the early to mid-1900s. Upgrades to the diking systems (e.g. Town and Hoeh dikes) over the last half 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. This means that an increase in the peak flow magnitude in the Highwood is required upstream for overflow to the Little Bow to occur. Note the flow estimate of 650-700 m^3/s needed to initiate overflow to the Little Bow watershed is gauged above the Woman's Coulee Canal inlet upstream of where flow-splitting occurs.

Overflow from the Highwood River occurs when significant flood waters enter the 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, then continuing downstream until reaching the area just downstream of the Little Bow Canal inlet located within the Town (see Figure 2-2). During these flood events (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 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) appeared to 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 point 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 low frequency 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 (Town Dike [TD] and Little Bow Canal Dike) are designed to prevent overflow from the main channel for flood magnitudes below 1,820 m^3/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 floodways, 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 its 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 low frequency 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 m^3/s. The West Town Dike (WTD) has been designed and constructed to protect the south portion of Town (north of 12th Ave) from Baker Creek RDB overflow (Figure 1-7). The Town Dike (TD) and Lineham Canal Dike have been constructed to protect the Town from flooding originating from the main channel of the Highwood River (Figure 1-7). These structures, however, result in significant increases to low frequency 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 2013 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 High River during low frequency flood events greater than 650-700 m^3/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 low frequency flood events in the Highwood River.

Preliminary estimates of the effect of the two flow additions described above indicate an increase of approximately 180 m^3/s (from 1,225 during the 2013 flood to 1,405 m^3/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 m^3/s to 410 m^3/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 low frequency 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 low frequency floods (i.e. restoring pre-mitigation 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.
- WorleyParsons' (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 a review of 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

HR-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 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 collected and 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 provided by the GoA and acquired in 2015 provided the basis for digital elevation model (DEM) and subsequently model surface network development;
- Bridge Data: gleaned from the Alberta Transportation hydrotechnical database;
- Remote Imagery: Ortho-rectified air photographs of the Study Area were provided by the MD to provide background imagery for model development including assessment of land use. In addition, Google Earth imagery was used to refined and characterize the Study Area and other areas of the Highwood River watershed.
- Flow data: flow data for the Highwood River was estimated from the High River Model (WorleyParsons 2014, Advisian 2016) and flow data for the Sheep River and Bow River was gathered from Water Survey of Canada (WSC). Flow information for each watercourse was used 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 period January 20 to February 6, 2015 WorleyParsons completed a survey to gather HWM 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 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).

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 survey 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 61 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 essentially 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 HR-FEA was development of a hydrodynamic model of the Highwood River and its floodplain within the Study Area. This model is referred to herein as the Lower Highwood Flood Model. The Lower Highwood 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 general overall approach for development and execution of the Lower Highwood River 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 hydraulic roughness applied to the network mesh;
- Undertake a sensitivity analysis to better understand the 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 Lower Highwood Flood Model in RMA-2 model network mesh was based around the input/assessment of a number of data sources that were discussed 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 a 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 terrain 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 Lower Highwood Flood Model DEM. Standard modelling approaches require additional data to define the channel bathymetry. However, channel bathymetric data being collected by the GoA was not going to be available to meet MD schedule requirements for the Lower Highwood Flood Model. Therefore, the HR-FEA study was split into two phases to accommodate the absence of this information:

a) Phase 1: Undertake the modelling scope using only LiDAR and aerial imagery data. This approach meant that the bathymetry below the water surface would need to be estimated based on aerial photograph information and visual observations from the HWM survey. This approach was considered a reasonable starting point considering the following:

   i) LiDAR information was collected during the low water period (2015) and therefore provided significant information for in-channel areas where water was not apparent. The flow magnitude during LiDAR collection was estimated to be less than 6% of bank full flow and less than 1% of the 2013 flood magnitude (estimated flow of 1,820 m^3/s just upstream of Woman's Coulee Canal inlet).

   ii) Aerial photograph imagery was also available during the low water period. This permitted identification of riffles, pools and hydraulic controls (e.g. major bars, bedrock outcrops) that could be used to extend the LiDAR surface into the low-flow wetted sections of the stream.

   iii) The results could be reviewed and refined until good agreement was achieved between recorded HWMs and simulated flood levels; and

   iv) The sensitivity of the flood model results could be assessed by raising and lowering the of the wetted-width low-flow channel identified from the LiDAR and enhanced through aerial photograph interpretation.

b) Phase 2: Update the model using bathymetry provided by the GoA and re-assess the effects of the mitigation scenario with this updated model.

Once a DEM is available for the Study Area the next step of the modelling process is creating a finite element model 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' that covers 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 Lower Highwood 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 Lower Highwood River Flood Model was therefore constructed to realize the benefits of the flexible finite element model platform.

The low-flow channel portion of the model network was first developed using a trapezoidal channel of specific depth with a varying width based on observations of channel form including bars, riffles and pools. Multiple simulations with comparisons to recorded HWMs were undertaken to fine tune the channel geometry and bed elevations. This process was followed until good agreement was achieved between recorded and simulated flood levels. A final visual comparison was completed to review the channel geometry within the model to that shown in Aerial Photography.

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 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 Lower Highwood Flood Model were estimated from aerial photograph and field observations, as well as through comparison of vegetation and bed material characteristics with the existing Highwood River Flood Model. Additional information pertaining to DEM and network development of the Lower Highwood Flood Model is provided in Section 4.1.1.

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 end of a channel, a flow discharge boundary needs to be entered into the model. For the Lower Highwood Flood Model, flow discharges (boundary conditions) were provided for the Highwood River and Sheep River at their respective Highway 2 crossings.

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 Lower Highwood Flood Model is based on a conservative constant water level condition defined by normal flow level for the peak flow in the Bow River at the Highwood mouth. 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 Highwood River Flood Model scenarios have been used to define the inflows/scenarios for the two Lower Highwood River Models used in the HWR-FEA:

a) outflow from the Highwood River Flood Model - 2013 Flood Landscape Scenario (previously referred to as the Existing Condition Scenario) is used as the inflow boundary condition for the Lower Highwood 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 information and the proposed 12 Ave-Centre St. Dike required to protect southern boundary of the Town (see Figure 1-7) 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 Lower Highwood River 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 m^3/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 1-7. Scenario 28A incorporates all proposed and constructed mitigations measures throughout and surrounding 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 an important step in the model development purposes. However, verification data for the Lower Highwood Flood Model is not available and hence this step focused only on calibration to 2013 HWM levels only. If acceptable calibration of the model to recorded events can be achieved, it provides a higher level of certainty and reliability of future assessment results.

Calibration of the Lower Highwood River Flood model 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 described in Section 3.2.3. Calibration most often focuses on adjustment of hydraulic roughness values. Roughness values were mainly adopted from equivalent land covers in the High River Flood Model (WorleyParsons 2014).

As the High River Flood Model had already undergone an extensive calibration and validation process the material types and roughness values used in that model were adopted for the Lower Highwood River Flood model. Given land use types and vegetation types were very similar between model extents the material types and roughness values were considered suitable and hence calibration of roughness was not required.

Because the bathymetry of the low-flow channel was unknown, calibration focused on scrutinizing aerial photographs and adjusting generic trapezoidal low-flow channel bathymetry to more closely match bar, riffles and pool morphology and hydraulic controls found within the low-flow portion of the channel. Additional information pertaining to the results of the calibration exercise for the Lower Highwood Flood Model 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 modelling parameters. Sensitivity analysis also helps assess and characterise 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 Lower Highwood River Flood model was completed following calibration. Sensitivity analysis incorporated changes to the inflow boundary conditions (magnitude and shape of the inflow hydrograph) and changes to the downstream boundary conditions and roughness (channel, floodplain and combined). However, because bathymetric data was not available for the low flow 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 HR-FEA. Effects assessment focused on characterizing the effects of flooding in the Study Area as a result of the flood mitigation measures modelled in Scenario 28A (*as described in Section 3.2.3*) at a flood equivalent in magnitude to the 2013 flood event (1,820 m^3/s). Scenario 28A for the Study Area including changing the inflow/upstream boundary conditions of the calibrated Lower Highwood River Model (i.e. the 2013 Flood Landscape Scenario) to those that are output from the High River Flood Model under Scenario 28A. That is, the inflow/upstream boundary conditions of the Lower Highwood River Model were changed to the flow conditions defined by the outflow of the existing High River Flood Model-28A Scenario.

Following simulation of the Lower Highwood River Model-Scenario 28A as described above, the results of the model were interrogated to determine various hydraulic variables including water level, depth, 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 within the Study Area due to flood mitigation works taken within the Town.

4. THE LOWER HIGHWOOD RIVER FLOOD MODEL

The Lower Highwood River Flood Model network was developed in the following three stages:

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

Once the network is completed conditions need 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

As discussed in Section 3.2.2, the Phase 1 flood model and associated modelling has been based on a DEM developed from LiDAR survey. LiDAR data were collected in 2015 by Airborne Imaging and provided by the MD. They have a 15 cm vertical accuracy 95% of the time (95^{th} 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 the network detail with respect to the DEM.

For the base network there is very little detail incorporated to define the Highwood River channel. This is shown in Figure 4-2 with only a single element covering the base of the river channel and an element either side of it to define the embankments. This simplification of the channel recognises the limitations of LiDAR to penetrate the water surface to '*pick-up*' channel bathymetry.

4.1.2 Incorporating the River Bathymetry

The network mesh discussed in Section 4.1.1 and shown in Figure 4-1 was refined in order to incorporate additional detail to define the Highwood River channel. In particular, additional nodes and elements were added to define variations in channel bathymetry and in-channel features such as pools and riffles.

This additional detail was incorporated into the model based on a detailed review of available aerial photography combined with on-site observations. Figure 4-2 shows an example of the network refinement completed for the Highwood River channel during this process.

Due to limitations in available bathymetric survey bed elevations for the Highwood River, Sheep River and Bow River were assumed to be 1.5 metres below the water level picked-up by the LiDAR survey. This assumption was tested during model calibration and sensitivity analysis which is discussed further in Section 5.1 and Section 5.2, respectively.

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 channel and floodplain vegetation density. The adopted roughness values were based on those adopted for the Town 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 flood model are shown in Figure 4-3 and Figure 4-4.

Table 4-1 Adopted RMA-2 Element Roughness Values

RMA-2 MODEL ELEMENT TYPE^	DESCRIPTION	ROUGHNESS PARAMETER VALUE	MATERIAL COLOUR *(Refer Figure 4-3 and Figure 4-4)*
2	Vegetated bars and banks (light)	0.050	
4	Pasture / Grassland	0.040	
7	Brush / Forest (dense)	0.140	
8	Brush / Forest (light)	0.080	
9	Brush / Forest (medium)	0.120	
10	Pavement / Cut grass	0.030	
14	Clear overbank areas	0.030	
35	Highwood River channel	0.023	
38	Vegetated bars and banks (dense)	0.080	

^ *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 in the model were represented with a focus on properly replicating the conveyance of the control section. This was achieved via the calibration process by selecting the most suitable combination of elements number, size and roughness for the section of the crossing.

4.2 Model Boundary Conditions

4.2.1 Upstream Boundary Conditions

The Lower Highwood River RMA-2 model has three upstream boundaries that are located along the Highwood River and Sheep River at the respective HWY2 crossings and along the Bow River approximately 3 km upstream of the mouth of the Highwood River. The location of these boundaries is shown on Figure 4-5.

The discharge hydrograph adopted for the Highwood River was generated directly from the flow output of the High River model. As no detailed two-dimensional model is available for the Sheep River the inflow hydrograph was generated by '*factoring*' the Highwood River hydrograph to match the peak flow magnitude recorded for the Sheep River during the 2013 flood. No changes were made to the time length of the hydrograph.

A flatter hydrograph shape was adopted for the Bow River inflow hydrograph with a peak flow magnitude that matched recorded data. The flatter hydrograph recognised the significantly larger catchment size of the Bow River which would result in a more drawn out and less 'peaky' hydrograph.

4.2.2 Upstream Boundary Conditions

The RMA-2 flood model has one downstream boundary that is located along the Bow River approximately 3.5 km downstream of the mouth of the Highwood River. The location of this boundary is shown on Figure 4-5.

The downstream boundary adopts a constant water level condition that has been inferred from nearby recorded HWM elevations. The constant value of water level simplifies and speeds-up model run times and was adopted as the results focus on the peak conditions during the overall simulation span. The downstream boundary has also been located a sufficient distance downstream of the Highwood River to ensure it would have no impact on flood behaviour within the Study Area.

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 predict flood conditions, in particular flood levels and extents, which are in good agreement to those conditions 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 Lower Highwood River flood model, calibration has been undertaken relative to the June 2013 flood HWM information that was surveyed in January and February 2015. In total, 105 HWMs were collected throughout the Study Area along the Highwood, Sheep and Bow Rivers. Further information on the HWMs and the collection process is provided in Section 3.1.2.

As discussed in Section 3.2.4, the Lower Highwood River model was predominantly calibrated by fine-tuning the models representation of the Highwood River channel. This included model refinements to incorporate more realistic bed elevations and features such as pools and riffles identifiable from aerial photography. No calibration was required of the material roughness values as these were adopted directly from the High River flood model which was extensively calibrated to over 350 June 2013 flood HWMs, and also validated by comparison to the 1995, 2005 and 2008 floods. Notwithstanding, some fine-tuning of the spatial distribution of each material type corresponding to a different hydraulic roughness was undertaken based on an iterative review of the modelling results.

The results of the model calibration to the June 2013 flood are shown in Figure 5-1, Figure 5-2 and Figure 5-3. The calibration figures show a comparison of the flood levels predicted by the RMA-2 model to the recorded flood levels recorded at each of the HWMs.

The Figures report both the confidence assigned to the RMA2 estimation of water level at each HWM (Excellent, Good, Average or Poor) based on how closely the modelled value is to the surveyed one: green colour 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 105 to 95.

As shown in Figures 5-1 to 5-3, the RMA-2 model predicts peak flood levels for the June 2013 event that are generally in good agreement with the recorded HWM. Although there are HWMs where the modelled and recorded levels were in disagreement (i.e. considered to be differences greater than 0.4 metres) these generally appear to be localised discrepancies with other nearby HWMs showing a much closer calibration. 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; and uncertainty in boundary conditions.

Local disagreements are also likely the results of lack of detailed or updated bathymetry for the River's channel. In that regard, it is considered likely that the calibration could be improved if recent post June 2013 bathymetric data was available and incorporated into the model.

A basic statistical analysis of the calibration results over the 95 confirmed HWMs from the June 2013 flood is shown in Table 5-1.

The calibration results summarised in Table 5-1 indicate that the model was successfully calibrated to a mean difference of +/-0.225 metres. This statistic in conjunction with a median difference of 0.030 metres indicates that the model predicts flood behaviour that is comparable to the HWM data. This is a particularly favourable result given the limitations with the current Highwood River channel geometry in the model due to a lack of bathymetric data.

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

Statistic	Calibration Result ^
Minimum Difference	-0.69
Maximum Difference	1.2
Median Difference	0.030
Mean Difference	0.225
Percentage of Differences between +/-0.10 metres	37%
Percentage of Differences between +/-0.20 metres	64%
Percentage of Differences between +/-0.30 metres	78%
Percentage of Differences between +/-0.40 metres	87%

^ *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.*

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 Highwood River RMA-2 model to establish the potential for changes in flood level predictions due to changes to a number of model parameters and inputs. This stage is often completed to determine which inputs or adopted parameters get an indication of what inputs or adopted parameters 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
Inflow Boundary Conditions	10% decrease in inflow magnitude	Scenario 1
	10% increase in inflow magnitude	Scenario 2
	10% decrease in inflow hydrograph length	Scenario 3
	10% increase in inflow hydrograph length	Scenario 4
River Bed Elevations	0.25m decrease in channel elevations	Scenario 5
	0.25m increase in channel elevations	Scenario 6
	0.50m decrease in channel elevations	Scenario 7
	0.50m increase in channel elevations	Scenario 8
Roughness Parameters	15% decrease in channel roughness	Scenario 9
	15% increase in channel roughness	Scenario 10
	15% decrease in floodplain roughness	Scenario 11
	15% increase in floodplain roughness	Scenario 12
	15% decrease in channel and floodplain roughness	Scenario 13
	15% increase in channel and floodplain roughness	Scenario 14
Downstream Boundary Condition	0.5m decrease in downstream boundary water level	Scenario 15
	0.5m increase in downstream boundary water level	Scenario 16

Each of the Sensitivity Scenarios shown in Table 5-2 was set-up in the RMA-2 model by modifying the boundary conditions, roughness parameters or channel elevations for each respective scenario. Each of the 16 scenarios was then simulated for the June 2013 flood hydrograph.

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

5.2.1 Model Sensitivity Results

The results for the Sensitivity Scenarios are shown as flood level difference mapping in Figure 5-4 to Figure 5-15**.**

The results for each of the Sensitivity Scenarios are also shown as Water Surface Profile (*WSP*) plots in Figure 5-16 to Figure 5-29. The WSP plots have been prepared as two figures sets each containing six Sensitivity Scenarios in order to make each profile more legible. Each set of WSP plots contains seven figures that combined cover the entire length of the Highwood River within the Study Area.

The Sensitivity Scenarios 3, 4 (10% increase or decrease in inflow hydrograph length) and 15, 16 (0.5 m increase or decrease in downstream boundary water level) did not produce flood level differences relevant enough to be represented in the mapping or the WSP Figures.

The HWMs have also been included on the plots to show the model sensitivity 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 overbank areas where localized topographic features may influence the predicted flood levels.

5.2.2 Model Sensitivity Findings

Due to the large number of Sensitivity Scenarios and associated figures we have completed a statistical analysis to summarise the overall findings. The analysis has been completed for the entire reach of the Highwood River in the Study Area, and also for the following four sub-sections of the Highwood River:

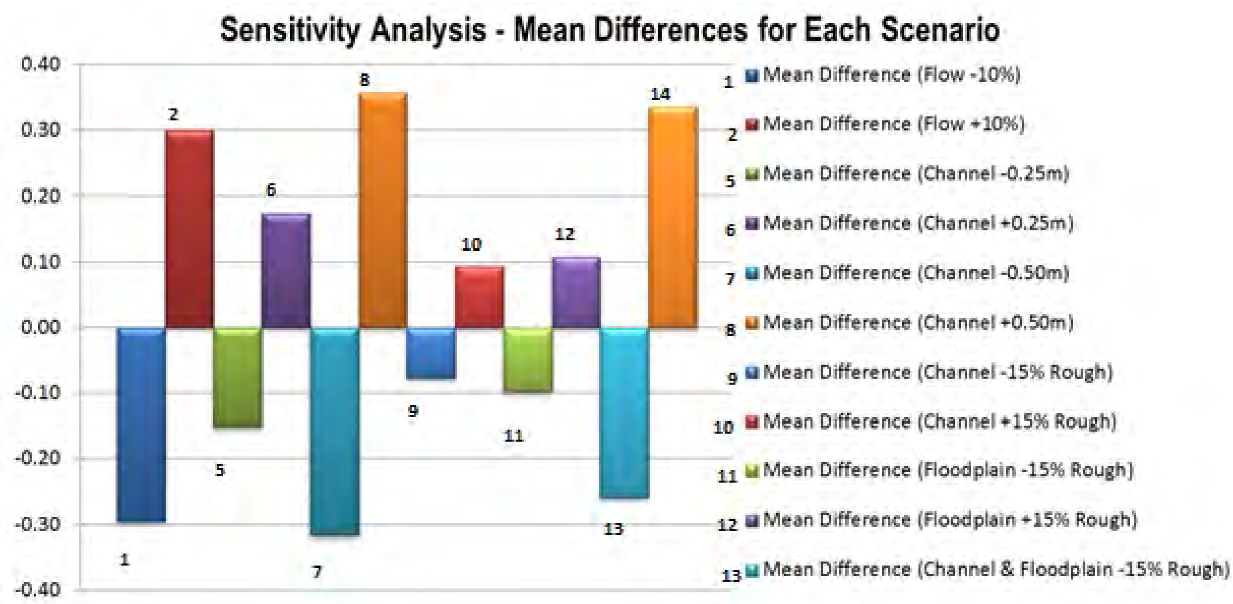
- Sub-Section 1 spanning from Highway 2 to Highway 547,
- Sub-Section 2 spanning from Highway 547 to Confluence with Sheep River,
- Sub-Section 3 spanning from Sheep River Confluence to Highway 552, and
- Sub-Section 4 spanning from Highway 552 to Bow River.

The peak water levels differences between each scenario and the calibrated model (Base Case) are measured along the River's centerline at chainage along the river which are generally variable between 5 and 50 m to represent segments of the River with different sinuosity.

The predicted mean differences in water levels are shown in Figure A below for the entire stretch of the River. The results of the overall analysis are shown in Table 5-3.

The yellow shaded cells in Table 5-3 highlight the general statistics for the entire Study Area for each Sensitivity scenario. The cells below this shading are focused on each of the four river segments outlined above. The purpose of analysing the results of the Sensitivity Analysis separately for these sub-sections was to establish which segment of the River in the Study Area can be associated with the higher sensitivity to each particular parameter.

Figure A Comparison of Mean Differences in Water Levels for Each Sensitivity Scenarios (Entire Model)



Review of the difference mapping, WSP plots and statistical analysis indicates the following key findings:

- The sensitivity scenarios testing +/-15% changes to material roughness values for the channel and for the floodplain have shown the least change in peak June 2013 flood levels. As shown in Table 5-3, these scenarios have a maximum mean difference of 0.09 metres.
- The model was most sensitive to the increase/decrease in channel elevations of 0.5 metres. As shown in Table 5-3, this scenario resulted in a maximum mean difference of 0.34 metres.
- The majority of minimum and maximum differences in flood levels occurred within the two middle sub-sections. This indicates that the model is most sensitive to the hydraulic parameters selected for the Highwood River between Highway 547 and Highway 552.

No results are presented for the (+/-) downstream boundary sensitivity scenario and the (+/-) hydrograph length sensitivity scenario as they were confirmed to have no impact on predicted flood levels along the Highwood River. The flood model is therefore not sensitivity to these two parameters.

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) sensitivity will be utilized again in the Limitations and Accuracy Section 5.4.

Table 5-3 Adopted Sensitivity Scenarios

Section of Highwood River	Statistic	Difference in Peak Water Surface Level Compared to Base Case (m)											
	Sensitivity Test	Flows		Channel Elevations				Roughness					
								Channel		Floodplain		Channel & Floodplain	
		Scen. 1 -10%	Scen. 2 +10%	Scen. 3 -0.25m	Scen. 4 +0.25m	Scen. 5 -0.50m	Scen. 6 +0.50m	Scen. 7 -15%	Scen. 8 +15%	Scen. 9 -15%	Scen. 10 +15%	Scen. 11 -15%	Scen. 12 +15%
Highway 2 to Confluence with Bow River (All Data)	Mean	-0.30	0.30	-0.15	0.17	-0.32	0.36	-0.08	0.09	-0.10	0.11	-0.26	0.34
	Median	-0.30	0.29	-0.15	0.16	-0.31	0.34	-0.07	0.09	-0.09	0.09	-0.25	0.27
	Min	-0.12	0.04	-0.01	0.02	-0.06	0.06	0.00	-0.06	0.00	-0.07	-0.02	0.03
	Max	-0.51	1.25	-0.34	1.06	-0.76	1.24	-0.27	0.28	-0.23	0.24	-0.84	1.87
Highway 2 to Highway 547	Mean	-0.31	0.25	-0.13	0.13	-0.29	0.25	-0.07	0.07	-0.12	0.10	-0.29	0.23
	Median	-0.32	0.25	-0.12	0.11	-0.27	0.22	-0.06	0.06	-0.13	0.10	-0.27	0.23
	Min	-0.17	0.15	-0.05	0.06	-0.13	0.13	-0.03	0.03	-0.04	0.04	-0.14	0.13
	Max	-0.51	0.35	-0.26	0.21	-0.48	0.40	-0.16	0.12	-0.22	0.21	-0.51	0.37
Highway 547 to Confluence with Sheep River	Mean	-0.29	0.35	-0.19	0.24	-0.38	0.44	-0.08	0.10	-0.09	0.11	-0.27	0.33
	Median	-0.29	0.31	-0.19	0.21	-0.38	0.43	-0.08	0.10	-0.09	0.11	-0.27	0.32
	Min	-0.13	0.04	-0.09	0.05	-0.13	0.20	-0.01	-0.06	0.00	-0.07	-0.02	0.03
	Max	-0.43	1.10	-0.32	1.02	-0.76	1.20	-0.20	0.24	-0.20	0.30	-0.69	1.03
Confluence with Sheep River to Highway 552	Mean	-0.33	0.35	-0.15	0.19	-0.32	0.36	-0.09	0.14	-0.09	0.13	-0.26	0.32
	Median	-0.33	0.32	-0.15	0.17	-0.32	0.34	-0.08	0.11	-0.08	0.09	-0.25	0.28
	Min	-0.17	0.17	-0.01	0.04	-0.12	0.17	0.02	0.01	0.00	-0.01	-0.03	0.12
	Max	-0.50	1.25	-0.34	1.06	-0.53	1.24	-0.27	0.28	-0.23	0.24	-0.84	1.19
Highway 552 to Bow River	Mean	-0.25	0.23	-0.12	0.11	-0.25	0.36	-0.07	0.07	-0.09	0.09	-0.21	0.50
	Median	-0.26	0.24	-0.12	0.12	-0.25	0.25	-0.06	0.07	-0.09	0.09	-0.21	0.22
	Min	-0.12	0.12	-0.03	0.02	-0.06	0.06	0.01	-0.01	-0.03	0.04	-0.05	0.07
	Max	-0.36	0.32	-0.22	0.19	-0.45	1.13	-0.17	0.16	-0.18	0.19	-0.48	1.87

- Highlights section of Highwood River that is most sensitive to the relevant (-) test; i.e. where the Mean or Maximum difference equals or exceeds that for the entire section of the Highwood River

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

5.3 Effects Assessment

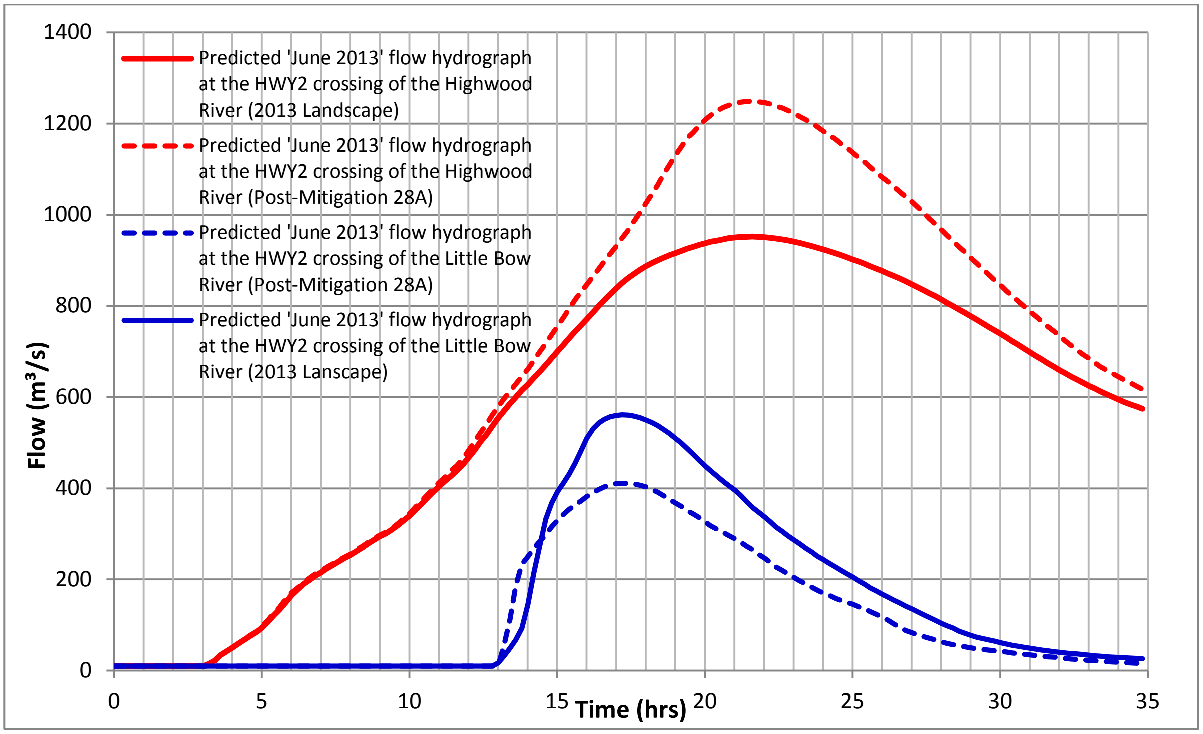
The effects assessment is focused on characterising the flood characteristics across the Study area due to the mitigation works that have been completed upstream of the Study Area to protect the Town. The assessment included a comparison of the flood behaviour for pre and post-mitigation conditions in order to determine where and to what magnitude the mitigation works have altered flow behaviour; i.e. peak flood levels and flow 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 Lower Highwood River model in Scenario 28A is derived from the High River Town Model under Scenario 28A mitigated conditions (see Figure 2-3 location 3, and Figure 4-5) with an incoming Highwood River flow magnitude above Woman's Coulee Canal Inlet of 1,820 m^3/s.

Detailed flood modelling completed by Advisian for the Town has shown that Post-Mitigation Scenario 28A will result in a change to the discharge of floodwaters throughout the Town. 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 along the Little Bow River as would have occurred during pre-mitigation conditions.

The mitigation works are predicted to result in an additional 297 m^3/s (approximately 31% increase from 952 to 1248 m^3/s) to continue flowing north along the Highwood River and a decrease of 149 cm (approximately 27% decrease) flowing south along the Little Bow River. Values are slightly modified in comparison to Table 1 of Figure 2-3 which is taken from the Town Flood Management Master Plan (WorleyParsons 2014) due to the re-run of the updated High River Flood model. Pre and post-mitigation flow hydrographs for the Highwood River and Little Bow River are plotted on Figure B.

The increase in flows along the Highwood River, and commensurate decrease along the Little Bow River, will have the potential to impact flood levels, flood extents and flow velocities downstream of the mitigation works. The following sections of this effects assessment will present the predicted flood characteristics under post-development conditions along the Highwood River downstream of Highway 2. The 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 documented.

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



5.3.1 Predicted Scenario 28A Flood Characteristics

Predicted flood levels at the peak of a June 2013 magnitude flood are shown in Figure 5-30 to Figure 5-33 for post-mitigation 28A conditions. The figures are also a representation of the flood extents.

Predicted flood depths at the peak of a June 2013 magnitude flood are shown in Figure 5-34 to Figure 5-37 for post-mitigation 28A conditions. Velocity vectors are superimposed on the figures to indicate the direction of flow and, by the arrow length, the magnitude of the peak flow velocities.

5.3.2 Predicted Changes to Flood Characteristics Due To Scenario 28A

Flood level, peak flow velocity and flood extent difference maps were generated to assess any changes in peak flood levels and/or velocities due to Post-Mitigation Scenario 28A. These flood level and flow velocity difference maps are provided as Figure 5-38 to Figure 5-41 and Figure 5-42 to Figure 5-45, respectively.

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

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

Flood Level Changes

As shown in Figure 5-38 to Figure 5-41, the increase in peak flows along the Highwood River associated with Post-Mitigation Scenario 28A has resulted in an overall increase in peak flood levels downstream of Highway 2. This is reflected by the red colour gradations which indicate flood level increases of varying magnitudes.

A statistical analysis of flood level differences between the June 2013 Landscape and Post-Mitigation Scenario 28A for a 'June 2013' magnitude flood is included below in Table 5-4. The mean, median, maximum and minimum changes in levels are provided for the Highwood River over the same four sub-sections of the Lower Highwood River adopted for the Sensitivity Analysis in Section 5.2.

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

Table 5-4 Statistical Analysis of Level Differences between Mitigated and June 2013 Results

Section of Highwood River	Statistic	Difference in Peak Water Surface Level Due to Increased Flows Associated with Mitigation Scenario 28A (m)
Highway 2 to Confluence with Bow River (All Data)	**Mean**	*0.66*
	Median	*0.67*
	Min	*0.19*
	Max	*1.66*
Highway 2 to Highway 547	**Mean**	*0.71*
	Median	*0.69*
	Min	*0.48*
	Max	*1.05*
Highway 547 to Confluence with Sheep River	**Mean**	*0.91*
	Median	*0.89*
	Min	*0.44*
	Max	*1.65*

Section of Highwood River	Statistic	Difference in Peak Water Surface Level Due to Increased Flows Associated with Mitigation Scenario 28A (m)
Confluence with Sheep River to Highway 552	Mean	*0.54*
	Median	*0.51*
	Min	*0.35*
	Max	*1.50*
Highway 552 to Bow River	Mean	*0.32*
	Median	*0.32*
	Min	*0.19*
	Max	*0.88*

As shown in Table 5-4, flood levels are predicted to increase by an average of 0.66 metres as a result of the flood mitigation measures in High River. This average is based on consideration of all flood level increases that are predicted to occur along the Highwood River channel from Highway 2 to the Bow River; the Study Area.

Flood level differences are predicted to be highest between HWY547 and the Sheep River confluence where an average increase in levels of 0.91 metres is predicted. The modelling indicates that flood level differences would be lowest towards the downstream end of the Study Area between Highway 552 and the Bow River. As shown in Table 5-4, the average increase in levels across this downstream section is 0.32 metres. It is likely that the increases are much lower near the Bow River due to the ‘drowning-out’ and backwater affects that the Bow River confluence would create.

The increased flows associated with Mitigation Scenario 28A along the Highwood River are shown in Figure 5-36 and Figure 5-39 to cause minor increases in flood levels along Sheep River and the Bow River, respectively. The increases in peak flood levels along the Sheep River are contained largely around the confluence extending approximately 500 metres upstream. The predicted increase in flood levels along the Bow River are typically less than 0.20 metres reflective of the ‘*drowning-out*’ that occurs when the small increase in Highwood River flows converges with the much larger Bow River flows.

Flow Velocity Changes

Changes to peak flow velocities during a June 2013 size flood as a result Mitigation Scenario 28A are shown in Figure 5-42 to Figure 5-45. Increases in velocities are shown to occur both in-channel and within overbank areas.

Velocity increases are predicted to be highest between Highway 2 and the Sheep River confluence where they exceed 1 m/sec at few localised locations but typically range between 0.2 to 0.4 m/sec (refer Figure 5-42 and Figure 5-43). The increases are highest across this reach as the percentage increase in flows is highest; i.e. the reach is upstream of the Sheep River confluence.

As expected, velocity increases are predicted to be lower downstream of the Sheep River confluence due to the increase in flows along the Highwood River and therefore a relative decrease in the percentage increase in flows. Figure 5-44 and Figure 5-45 indicate that velocity increases downstream of the Sheep River will typically range between 0.1 to 0.3 m/sec.

5.3.3 Comparison of Flood Extents

The predicted areal extents of flooding along the Highwood River for a June 2013 size flood have been superimposed on Figure 5-46 to Figure 5-49 for the June 2013 Landscape Scenario and Post-Mitigation 28A Scenario. Due to the confined valley of the Lower Highwood River (see Section 2.2 for discussion) there is very little change in flood extents throughout much of the Study Area.

The largest increases in flooded land is predicted to occur between Highway 2 and Highway 547 (refer Figure 5-46) and across areas upstream of the Bow River confluence (refer Figure 5-49). Elsewhere flood extents are predicted to be close between the two scenarios.

5.4 Limitations and Accuracy

The estimated average accuracy to which the 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 and the convergence parameters adopted for the simulations. Consideration of each of these items is typically required to reliably assess the confidence level assigned to the Flood Model predictions.

Although consideration of each of the above is ideal, it tends to result in an overly complicated approach. In an alternative, simplified approach the model accuracy can be defined based on consideration of the range of flood level differences predicted through the sensitivity analysis. This is considered appropriate 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 it is predicted that the Lower Highwood River RMA-2 model has a confidence level for peak flood elevation prediction of +/-0.36 m. This is based on the sensitivity analysis showing levels on average would not vary by more than +/-0.36 m for the adopted scenarios.

Although the sensitivity analysis predicted flood level changes that were significantly higher, these were localised occurrences and are unlikely to be a realistic representation of the model as a whole. For this reason it is considered more applicable to base the estimate of model accuracy on the average range of differences predicted from the sensitivity analysis.

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

- Limited existing information on the bathymetry of the Highwood River channel. Sensitivity analysis indicates that variations in the channel bed elevation can have a large impact on the flood level predictions. This is due to the confined floodplain downstream of Highway 2 along which the Highwood River channel conveys a significant portion of the peak flood flow.

- Additional peak flow and HWM information from another significant flood event is not available for model validation. This would help improve model uncertainty and robustness;
- Lack of a measured 2013 flow hydrograph shape (duration and overall volume) on the Sheep River and Bow River. The hydrograph used for modelling purposes for these two watercourses is based on recorded peak flow magnitudes factored to the Highwood River hydrograph shape. In addition, the upstream model (i.e. the High River Flood Model) also has uncertainty in terms of the upstream boundary condition (input flow hydrograph) as the magnitude was determined by the slope-area method and the hydrograph shape was estimated;
- Limited detail of the model domain and the large extent of the model. The Lower Highwood 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;
- 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 floodplain flow and routing. This is particularly a limitation when simulating relatively shallow flooding throughout a complex floodplain;
- 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 nearly 19 months following the flood event. The HWMs had to be estimated in many cases and very few were considered good to excellent in quality; and
- RMA-2 only provides results in the sub-critical 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.

6. SUMMARY AND RECOMMENDATIONS

A two-dimensional model of the Lower Highwood River between Highway 2 and the Bow River (Highwood 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 from LiDAR terrain data with localised refinement of elevations to incorporate an estimate of the channel bathymetry. 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) to develop the 2013 Landscape Scenario. 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 calibration against HWMs left by the 2013 event that were determined during high water survey campaign.

The model was predominantly calibrated by fine-tuning the models representation of the Highwood River channel (to incorporate pools and rifles identifiable from aerial photography) accompanied by fine-tuning of the spatial extent of floodplain roughness values. After calibration, the model predicted peak flood levels for the June 2013 flood event that had an average difference of 0.225 m compared to 95 recorded HWMs. This represents a fair outcome given the uncertainty over 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 scenarios aimed at obtaining statistical parameters on flood level variations derived from changes in flow magnitude and length, low flow channel and floodplain roughness, low flow channel elevations and downstream boundary conditions. The analysis indicated that the channel bathymetry has the most influence on the produced results, followed by roughness of the floodplain areas and the magnitude of the input flows. The results were much less influenced by hydrograph duration or downstream boundary conditions.

In addition to the 2013 Landscape Scenario, an additional model scenario was developed to determine the effects of mitigation measures constructed or planned for construction in and around the Town. This scenario has been labelled Scenario 28A. The system of dikes and other flood mitigation infrastructures completed on the Highwood River for protection of the Town (i.e. Scenario 28A) results in an increased flood volume and peak routed along the Highwood River downstream of Highway 2. For a flow equivalent to the 2013 flood magnitude, with an estimated peak of 1,820 m^3/s (above Woman's Coulee Canal Inlet), the flow magnitude predicted to continue along the Highwood River downstream of the Town is estimated to increase from 952 to 1,248 m^3/s.

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 increase substantially over the Study Area for an upstream flood magnitude on the Highwood River of 1,820 m^3/s. The modelling predicted that levels would increase on average by 0.7 m over the Study Area;

- Maximum and minimum increases have been estimated at 1.7 m and 0.20 m. Increases in flood levels greater than 1.0 m were generally found to be localized;
- Velocity increases typically ranging between 0.20 to 0.40 m/s with very occasional increases of approximately 1.0 m/s due to local hydraulic effects; and
- Due to the narrow and confined valley of the Lower Highwood River the modelling predicted very little change in flood extents throughout much of the Study Area.

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

- Collection of bathymetric survey to improve the definition of the Highwood River channel within the model;
- Refinement of the inflow hydrograph shapes and volumes adopted for Sheep River and the Bow River as information becomes available; and
- Verify/adjust the model performance for major event less low frequency than the June 2013 flood. This would require collection of additional HWM data.

The regional Flood Model produced for the Lower Highwood River can be a tool for planning and high-level design purposes which can be made more robust by incorporating additional detail to the model DEM in the area of interest and implementing any or all of the suggested recommendations. The regional model will always provide a base for the detailed DEM and boundary conditions as a minimum. It also provides an assessment of extreme water levels with an estimated accuracy of +/-0.35 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.

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APEGA Permit to Practice No. P00725

8. REFERENCES

Advisian, 2016, Little Bow River Modelling. Flood Mitigation Effects Assessment – Draft. Prepared for the Municipal District of Foothills No.31. July 2016

AECOM, 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 9, 2014

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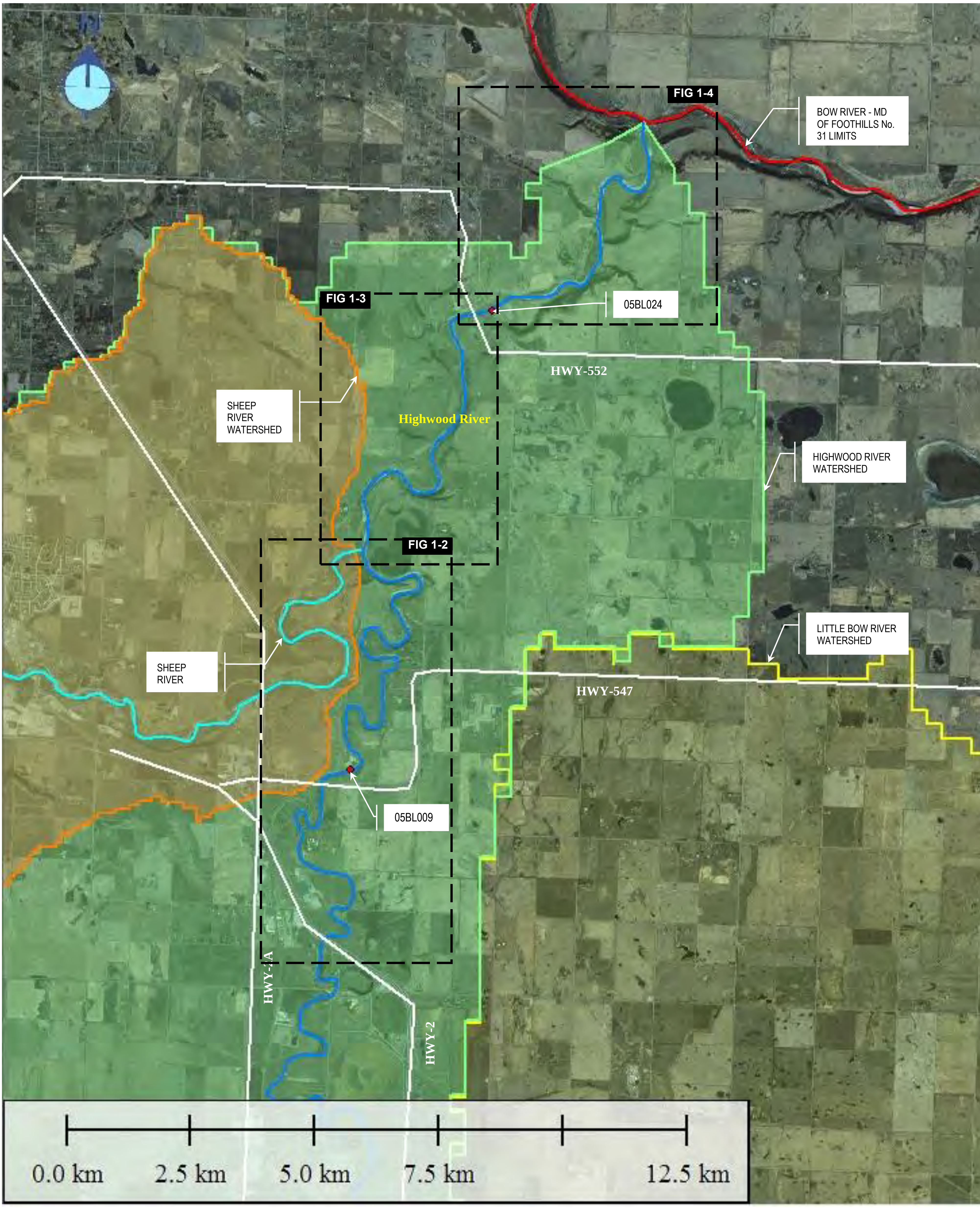
WorleyParsons (WorleyParsons Canada Services Ltd.), 2014. 2013 Flood Management Master Plan (Draft). Prepared for the Town of High River. Calgary, AB.

Figures



		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Study Area Overview			
Advisian WorleyParsons Group	**Created By:** AP	**Date:** Aug 31, 2016	**File Path:** U:\CAL\GBS\307076-07349\100 - Highwood Riv - Modelling\12.0_Reports\12.3_Backend\Highwood River Modelling\Figures	**Figure No:** 1-1	**Rev:** 0
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Municipal District of Foothills No. 31 – Highwood River Modelling

River Model Extents Map (1 of 3)

Advisian
WorleyParsons Group

Created By: AP

Reviewed By: JB

Date: Aug 31, 2016

File Path: U:\CAL\GBS\307076-07349\100 - Highwood Riv - Modelling\12.0_Reports\12.3_Backend\Highwood River Modelling\Figures

Figure No: 1-2

Rev: 0

Advisian WorleyParsons Group		Municipal District of Foothills No. 31 – Highwood River Modelling			
		River Model Extents Map (2 of 3)			
	Created By: AP	Date: Aug 31, 2016	File Path: U:\CAL\GBS\307076-07349\100 - Highwood Riv - Modelling\12.0_Reports\12.3_Backend\Highwood River Modelling\Figures	Figure No: 1-3	Rev: 0
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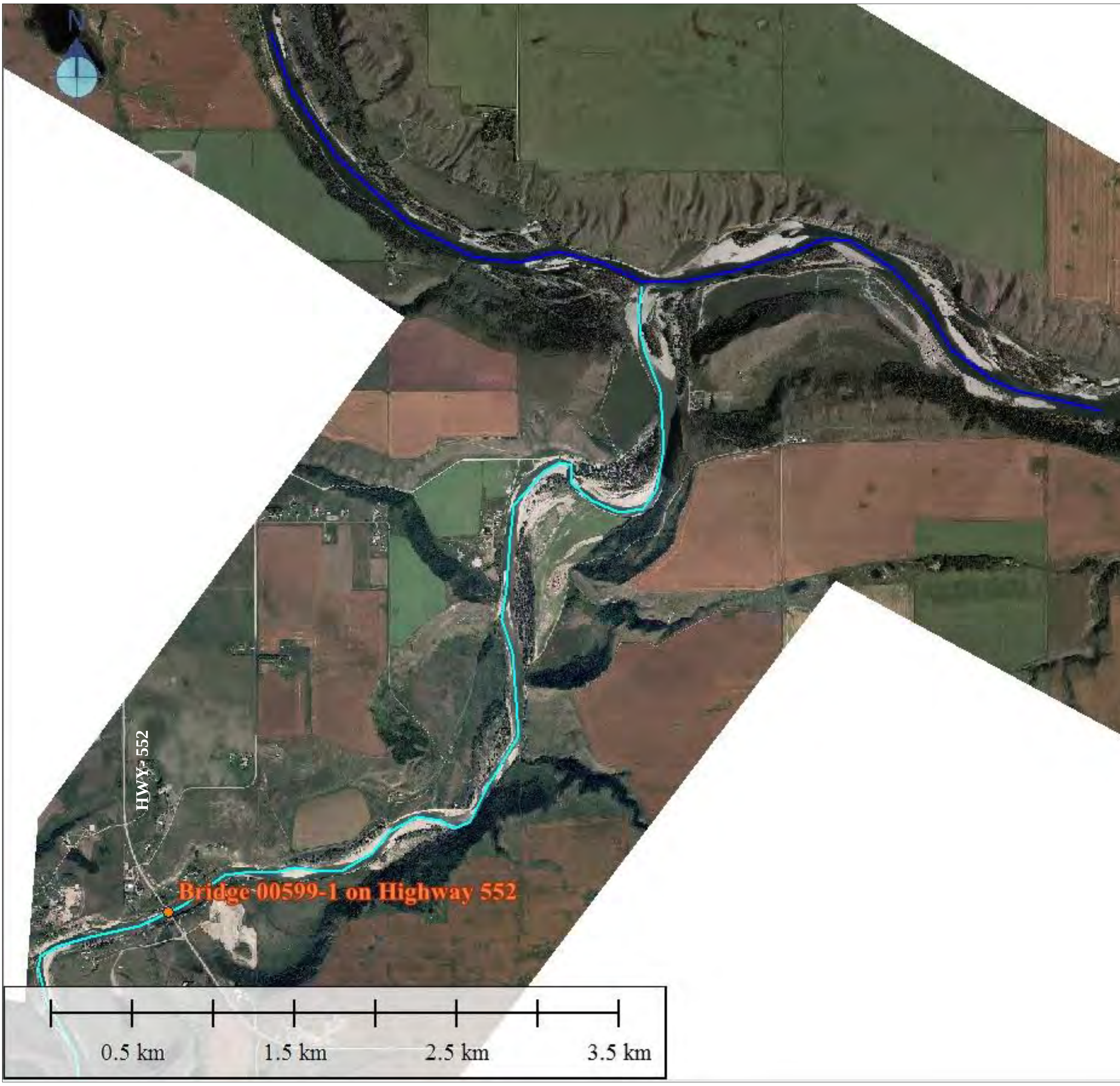

Municipal District of Foothills No. 31 – Highwood River Modelling			
River Model Extents Map (3 of 3)			
Date: Aug 31, 2016	File Path: U:\CAL\GBS\307076-07349\100 - Highwood Riv - Modelling\12.0_Reports\12.3_Backend\Highwood River Modelling\Figures	Figure No: 1-4	Rev: 0

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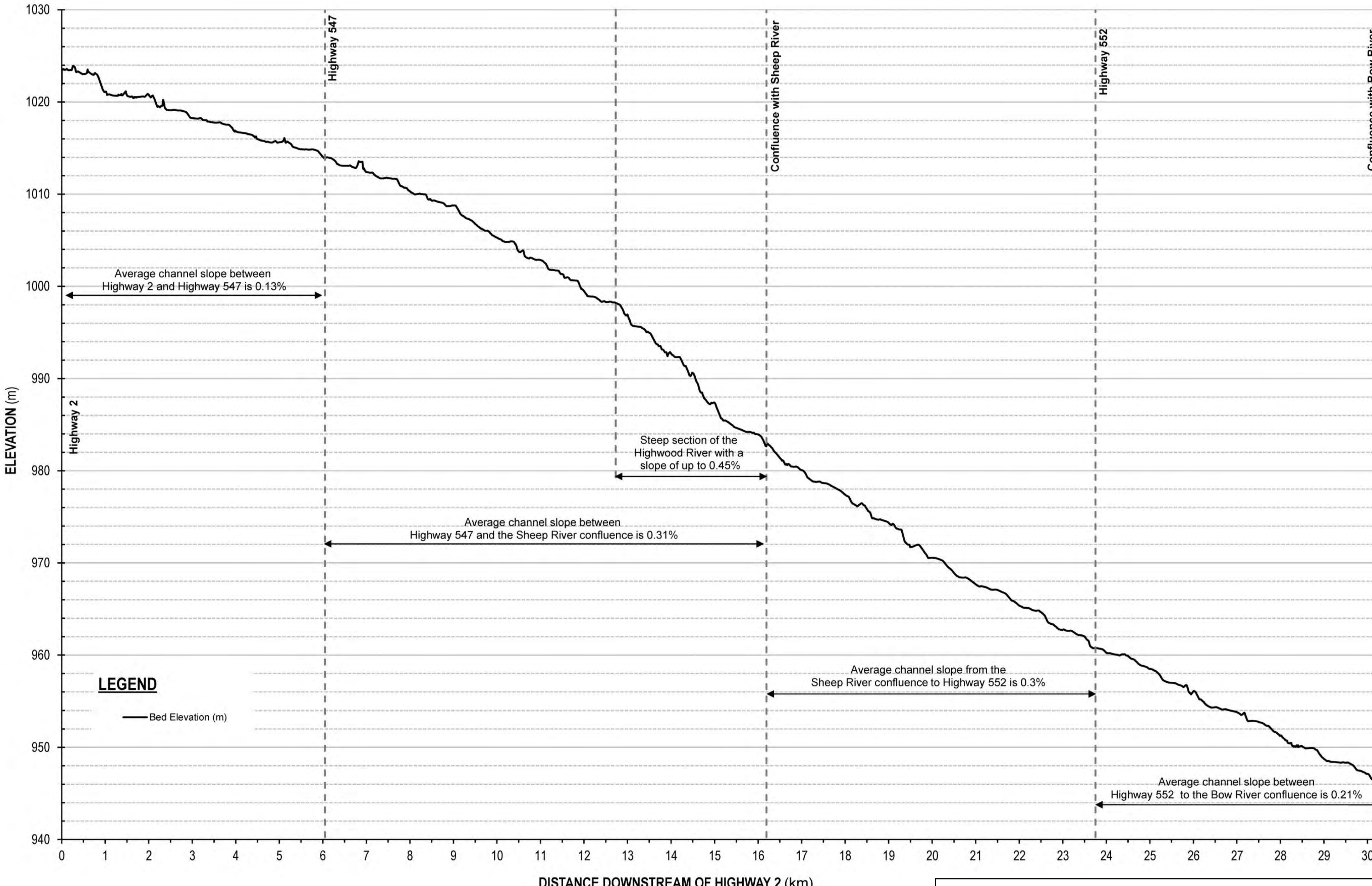

		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Highwood River Model Channel Profile			
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Municipal District of Foothills No. 31- Highwood River Modelling

Model Extents for High River Town Flood Model

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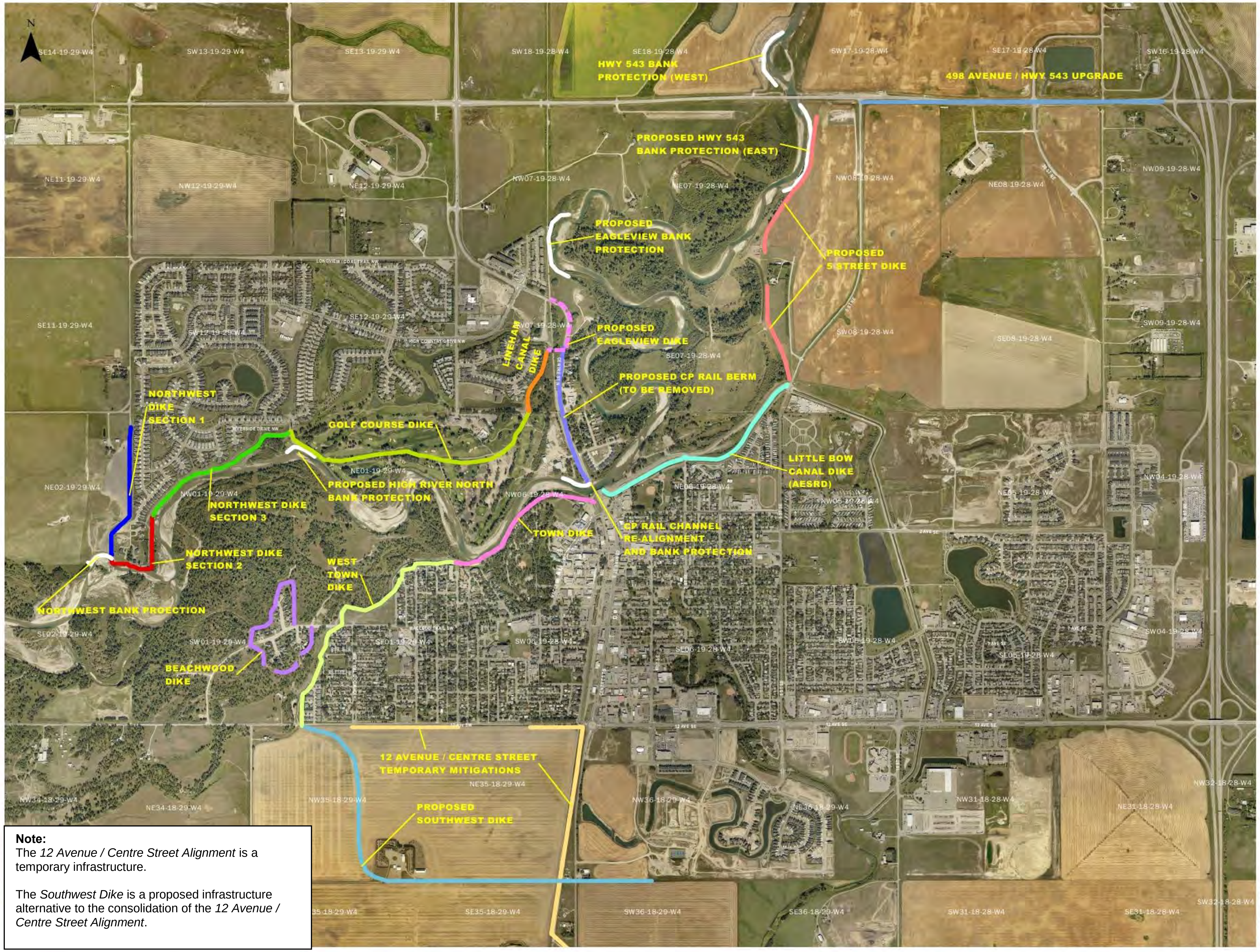

Note:
The *12 Avenue / Centre Street Alignment* is a temporary infrastructure.

The *Southwest Dike* is a proposed infrastructure alternative to the consolidation of the *12 Avenue / Centre Street Alignment*.

LEGEND

- NORTHWEST DIKE SECTION 1
- NORTHWEST DIKE SECTION 2
- NORTHWEST DIKE SECTION 3
- TOWN DIKE
- WEST TOWN DIKE
- PROPOSED EAGLEVIEW DIKE
- LINEHAM CANAL DIKE
- PROPOSED CP RAIL BERM (TO BE REMOVED)
- LITTLE BOW CANAL DIKE (AESRD)
- BEACHWOOD DIKE
- 12 AVENUE DIKE / CENTRE STREET TEMPORARY MITIGATIONS
- PROPOSED 5 STREET S.E. DIKE
- 498 AVENUE / HWY 543 UPGRADE
- BANK PROTECTION
- GOLF COURSE DIKE
- PROPOSED SOUTHWEST DIKE

0 125 250 500 750 1,000 M

Y:\HR\Projects\For_Flood_Related\Recreation of Worley Parsons Dike Map\DikeMap2016.06.mxd

Municipal District of Foothills No. 31 – Highwood River Modelling

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

Advisian
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Created By: AP	**Date:** Apr 28, 2017	**File Path:** U:\CAL\GBS\307076-07349\100 - Highwood Riv - Modelling\12.0_Reports\12.3_Backend\Highwood River Modelling\Figures	**Figure No:** 1-7	**Rev:** 1
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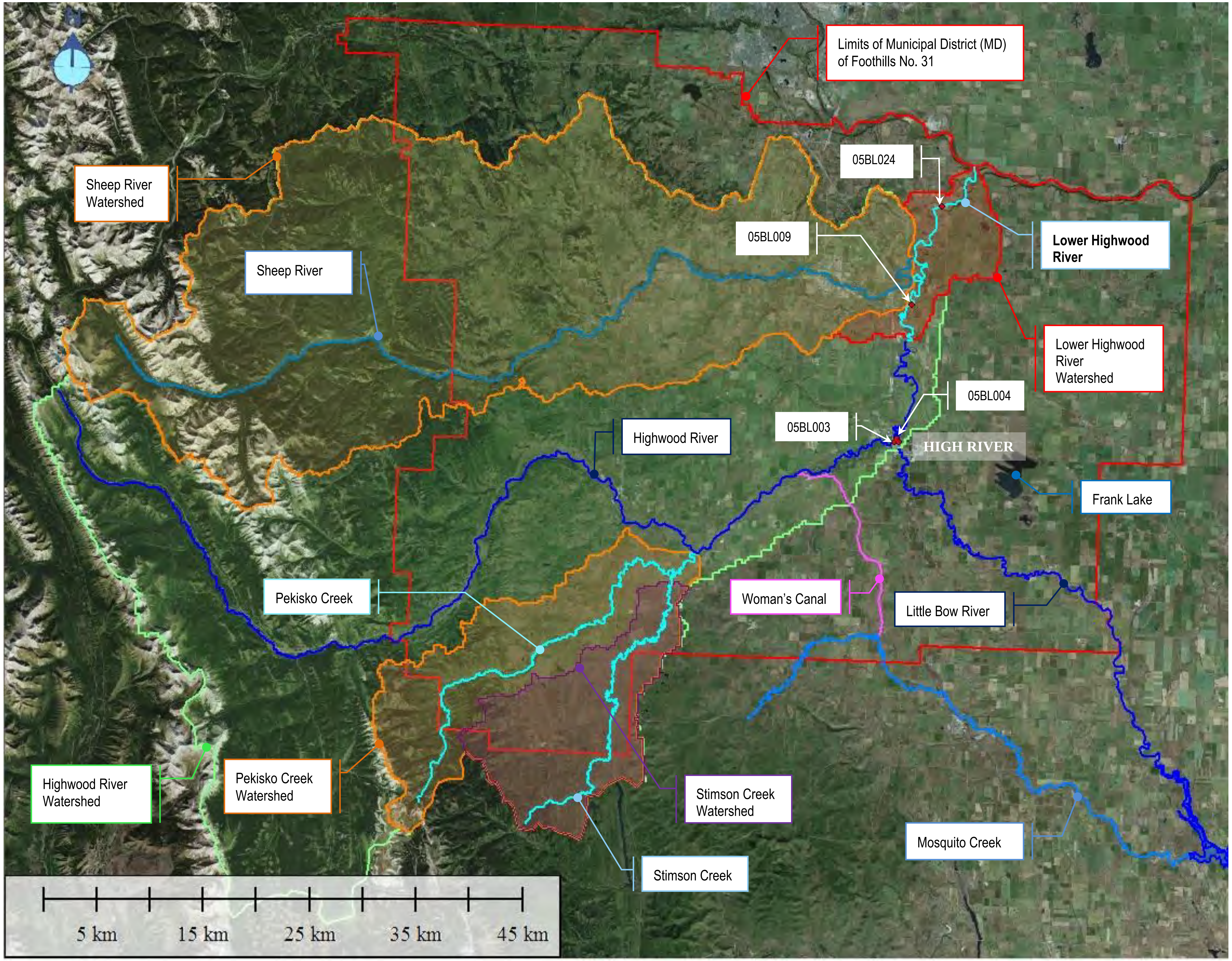

Municipal District of Foothills No. 31 – Highwood River Modelling				
Lower Highwood River Watershed				
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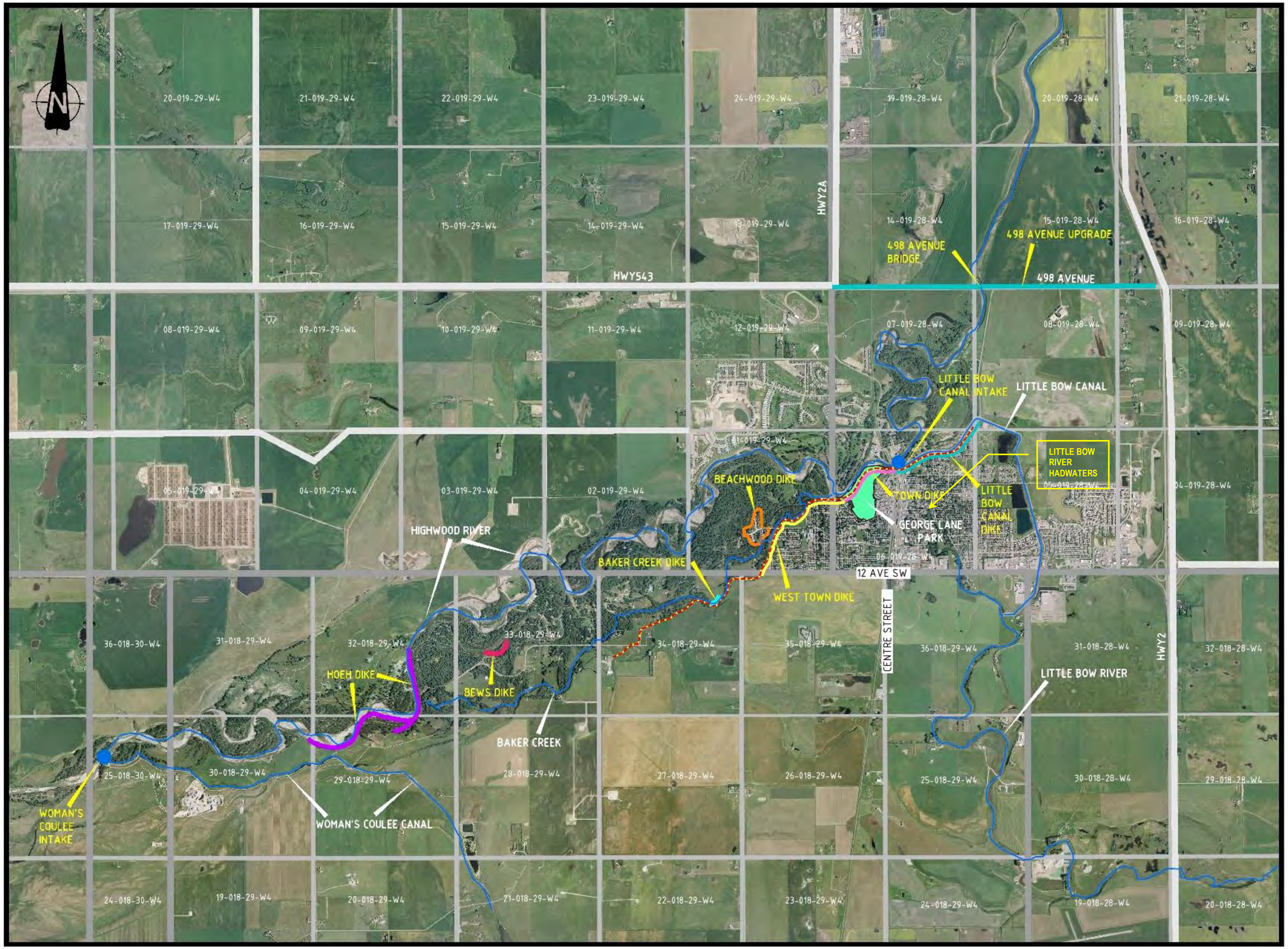

DATA SOURCE:

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

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Municipal District of Foothills No. 31 – Highwood River Modelling

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

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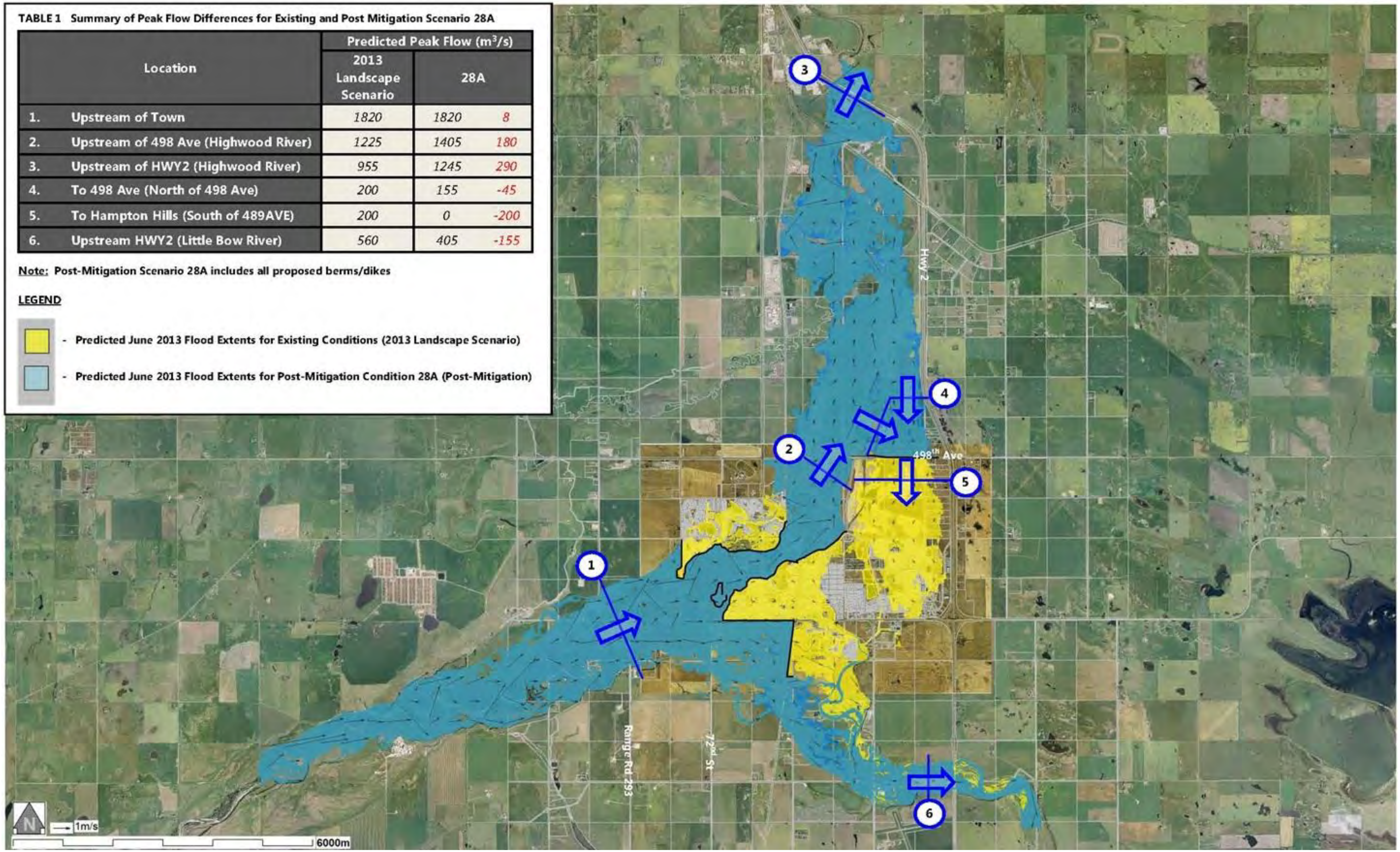
TABLE 1 Summary of Peak Flow Differences for Existing and Post Mitigation Scenario 28A

Location		Predicted Peak Flow (m^3/s)		
		2013 Landscape Scenario	28A	
1.	Upstream of Town	1820	1820	8
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	405	-155

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 – Highwood River Modelling				
Flow Split Summary for 2013 Flood Equivalent				
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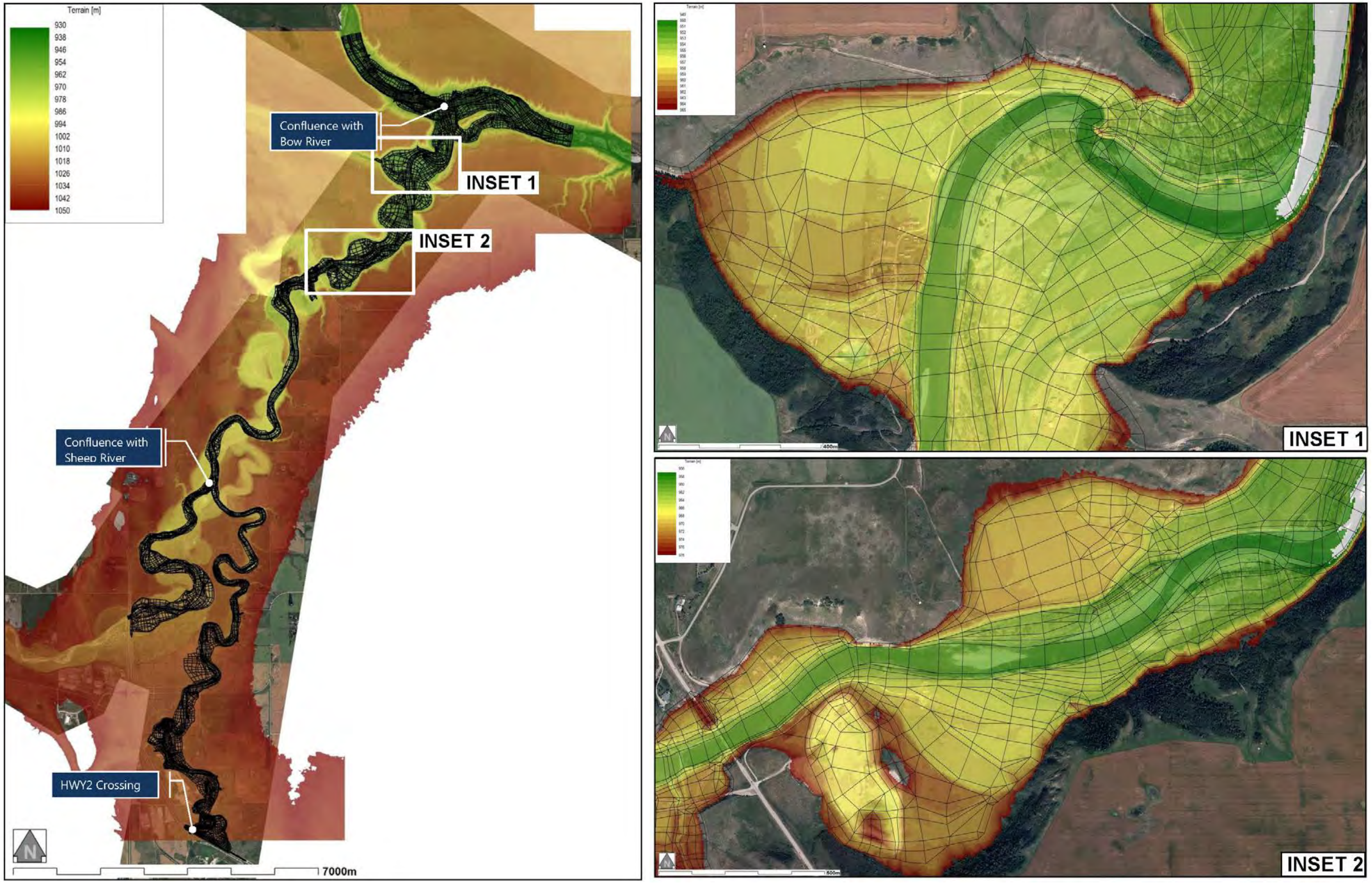

Municipal District of Foothills No. 31 – Highwood River Modelling

Overview of the Highwood River RMA-2 Model Network

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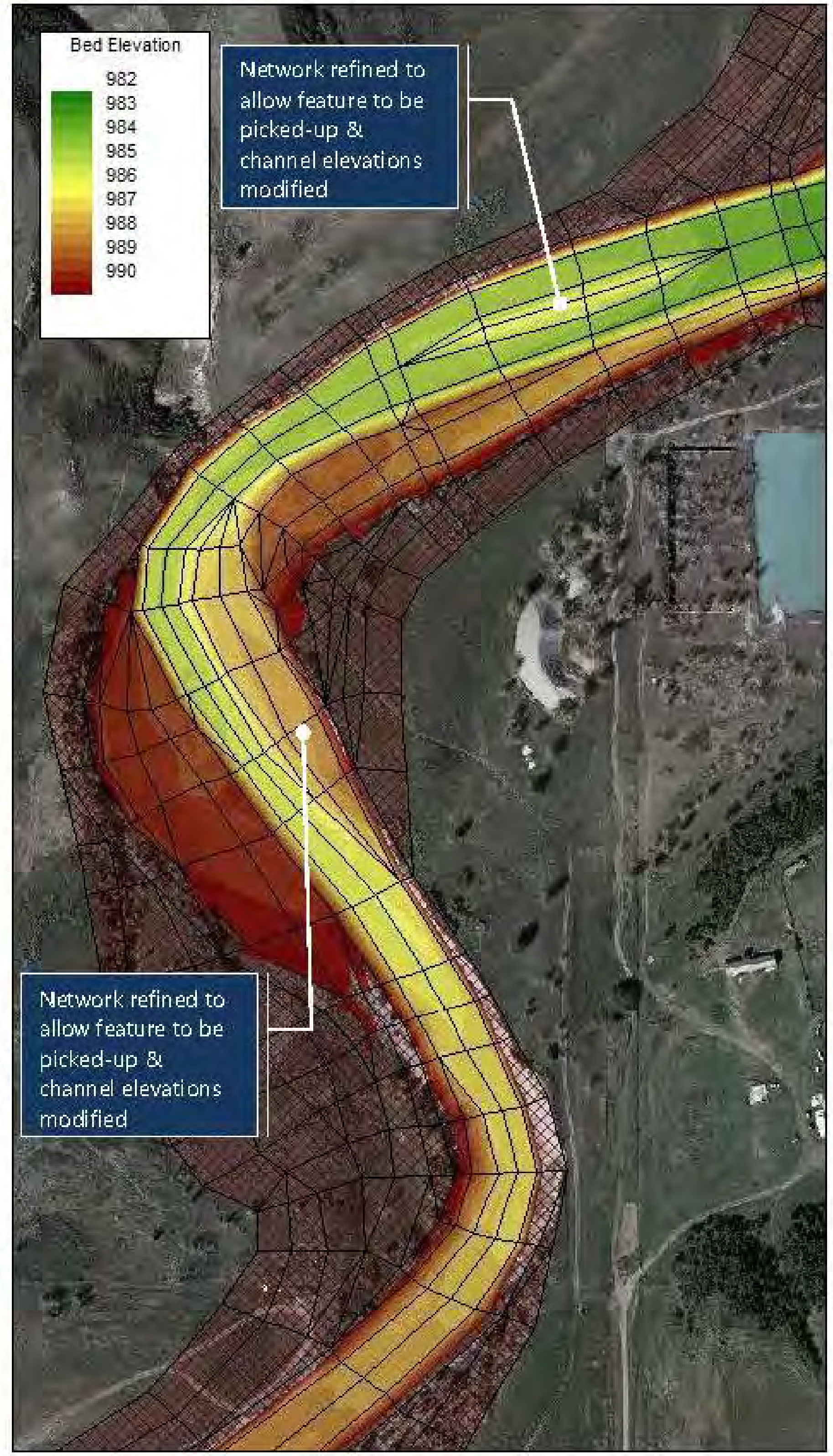
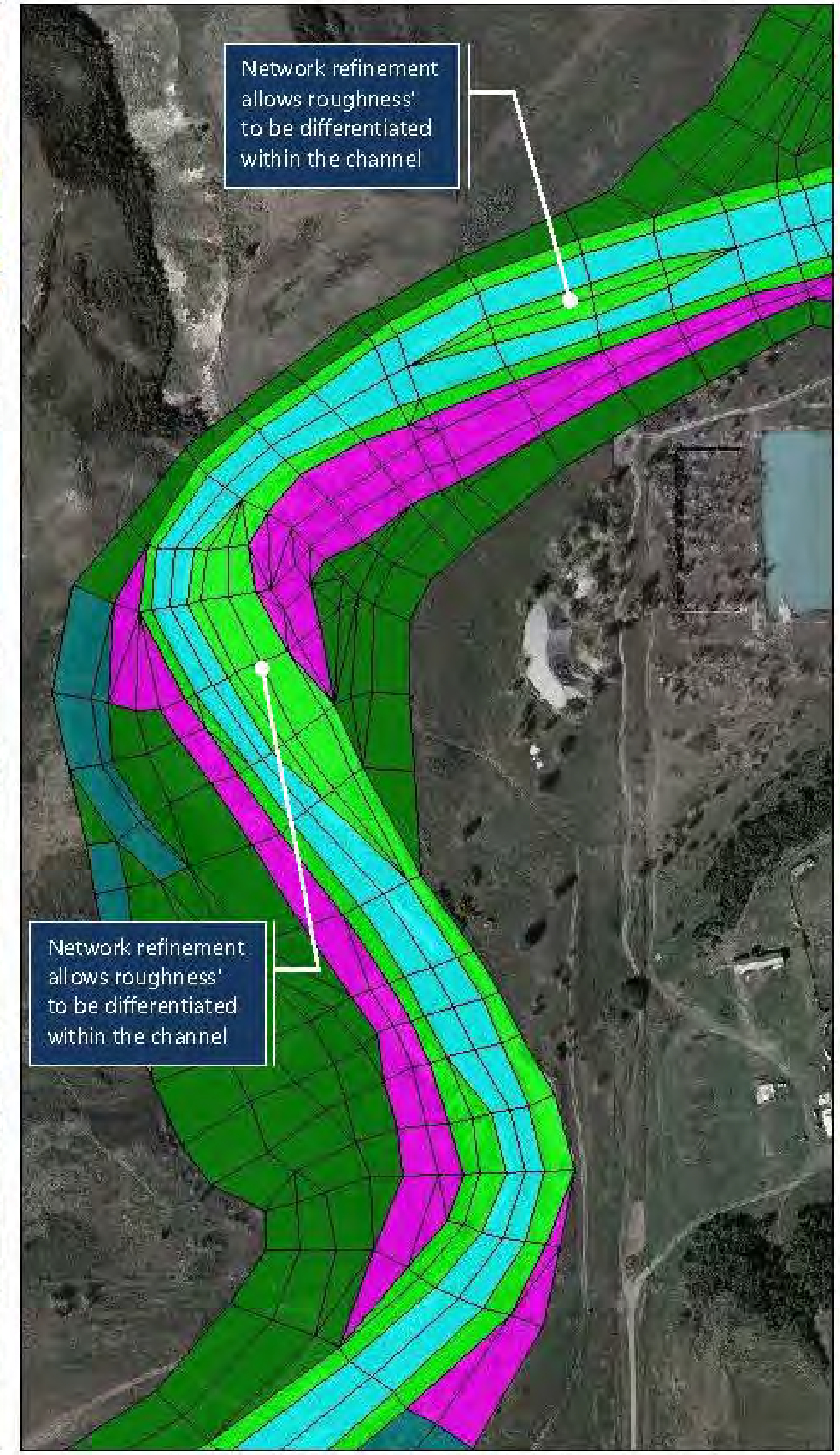
Inset 1 – Aerial Photograph



Inset 2 – RMA-2 Network & Model Topography



Inset 3 – RMA-2 Network & Model Roughness'

Municipal District of Foothills No. 31 – Highwood River Modelling

Channel Details incorporated into Highwood River RMA-2 Model

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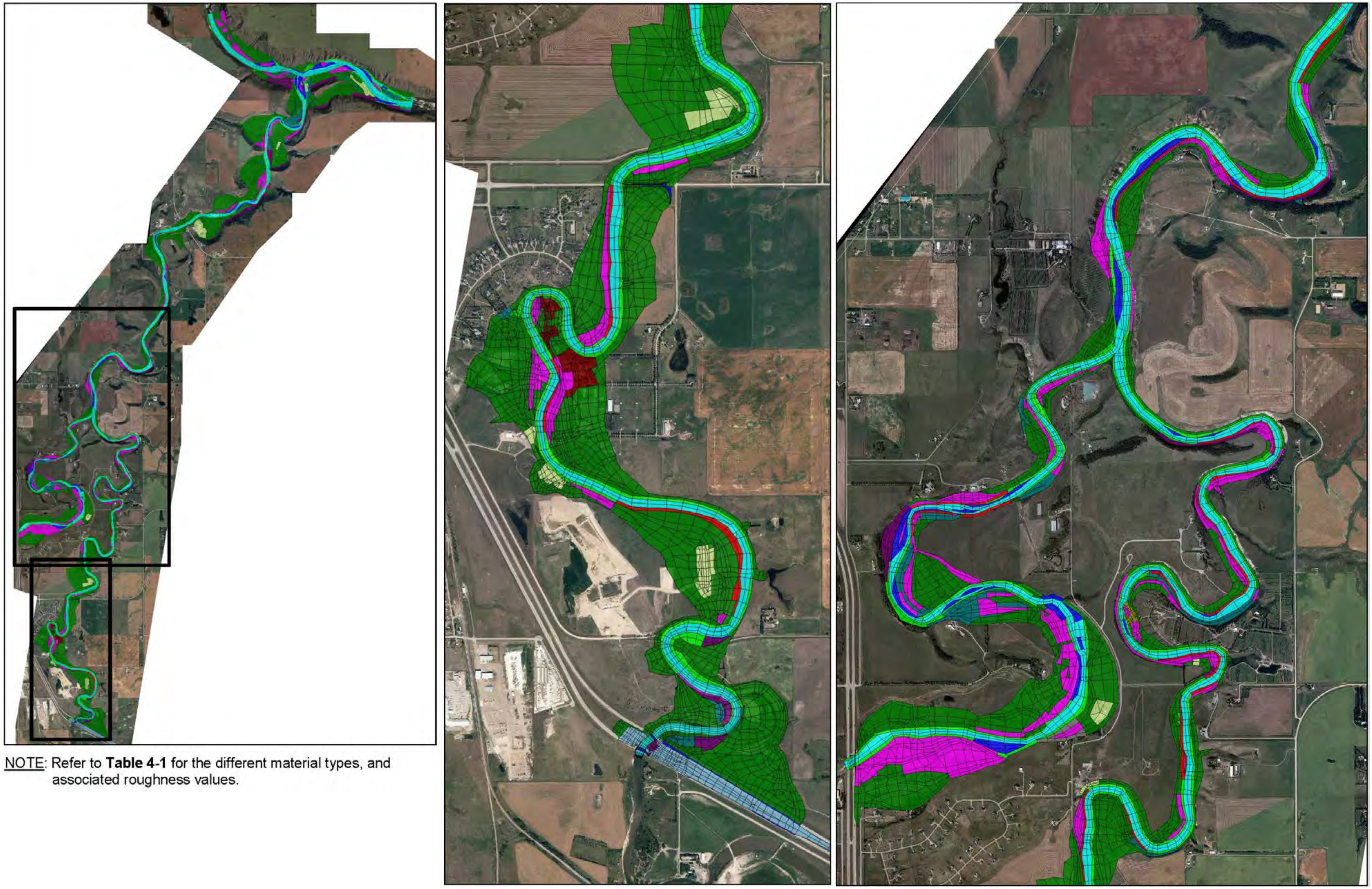

NOTE: Refer to **Table 4-1** for the different material types, and associated roughness values.

Municipal District of Foothills No. 31 – Highwood River Modelling

Adopted Roughness Distributions for the Highwood River RMA-2 Model (Figure 1 of 2)

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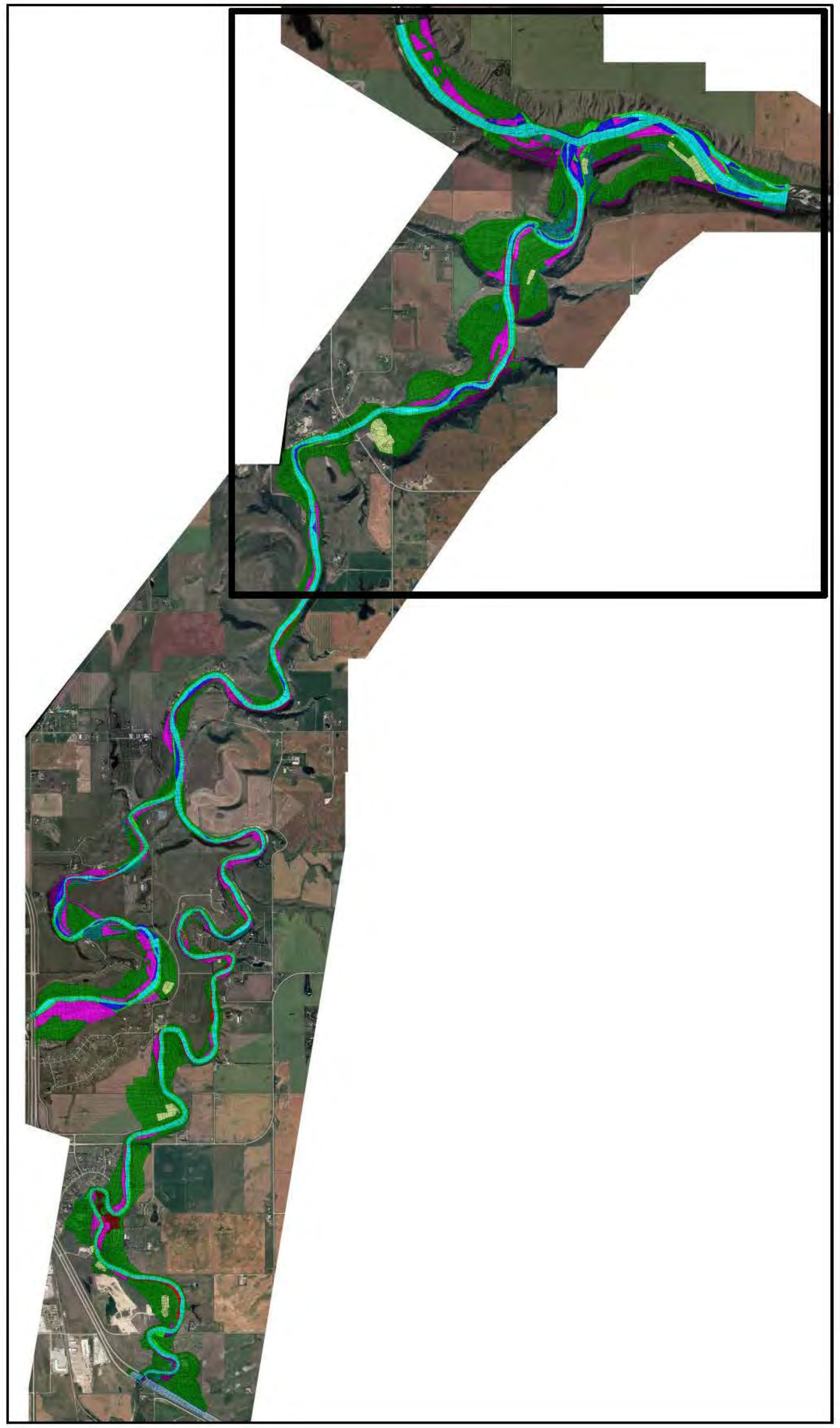

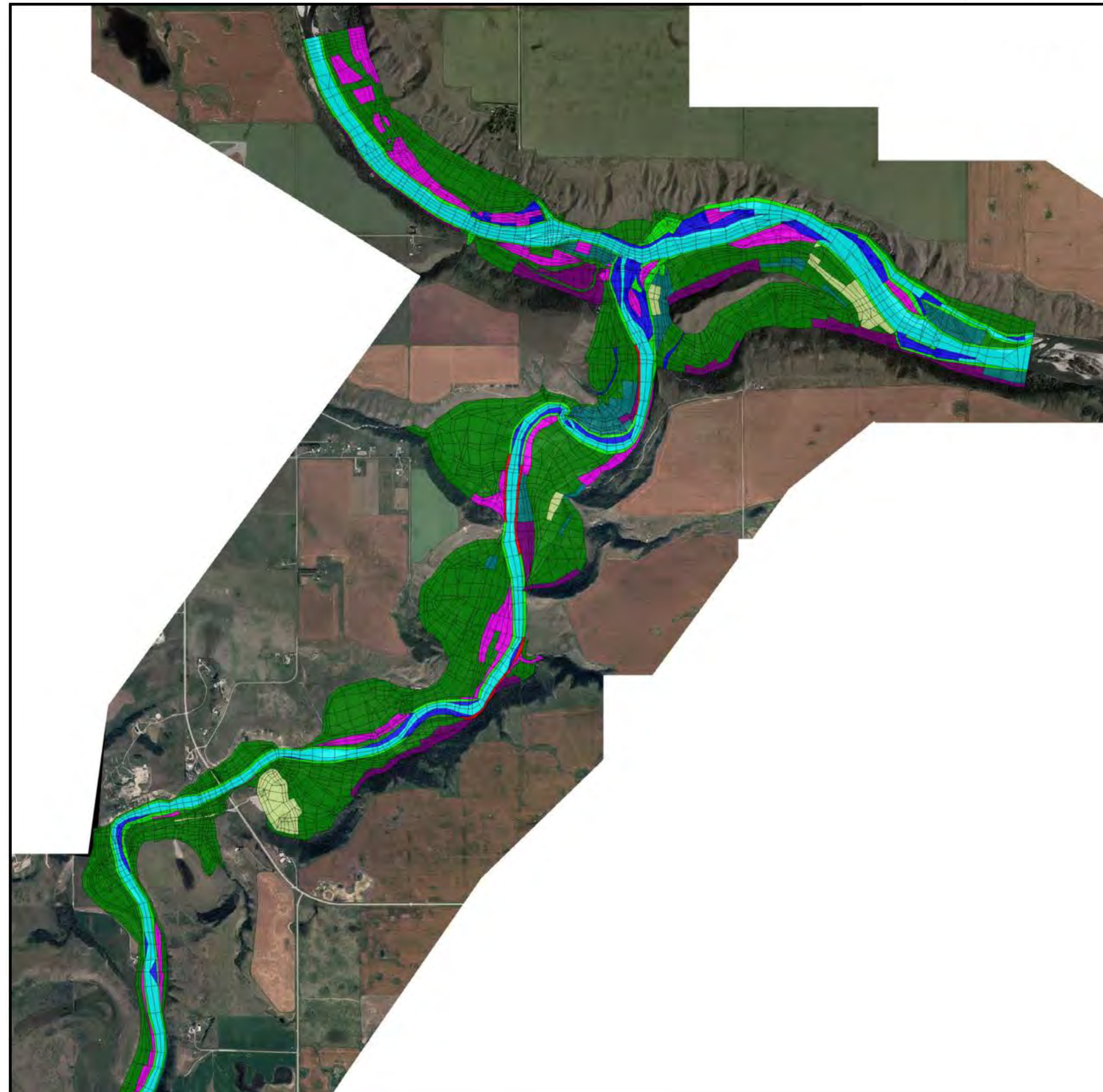

NOTE: Refer to **Table 4-1** for the different material types, and associated roughness values.

		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Adopted Roughness Distributions for the Highwood River RMA-2 Model (Figure 2 of 2)			
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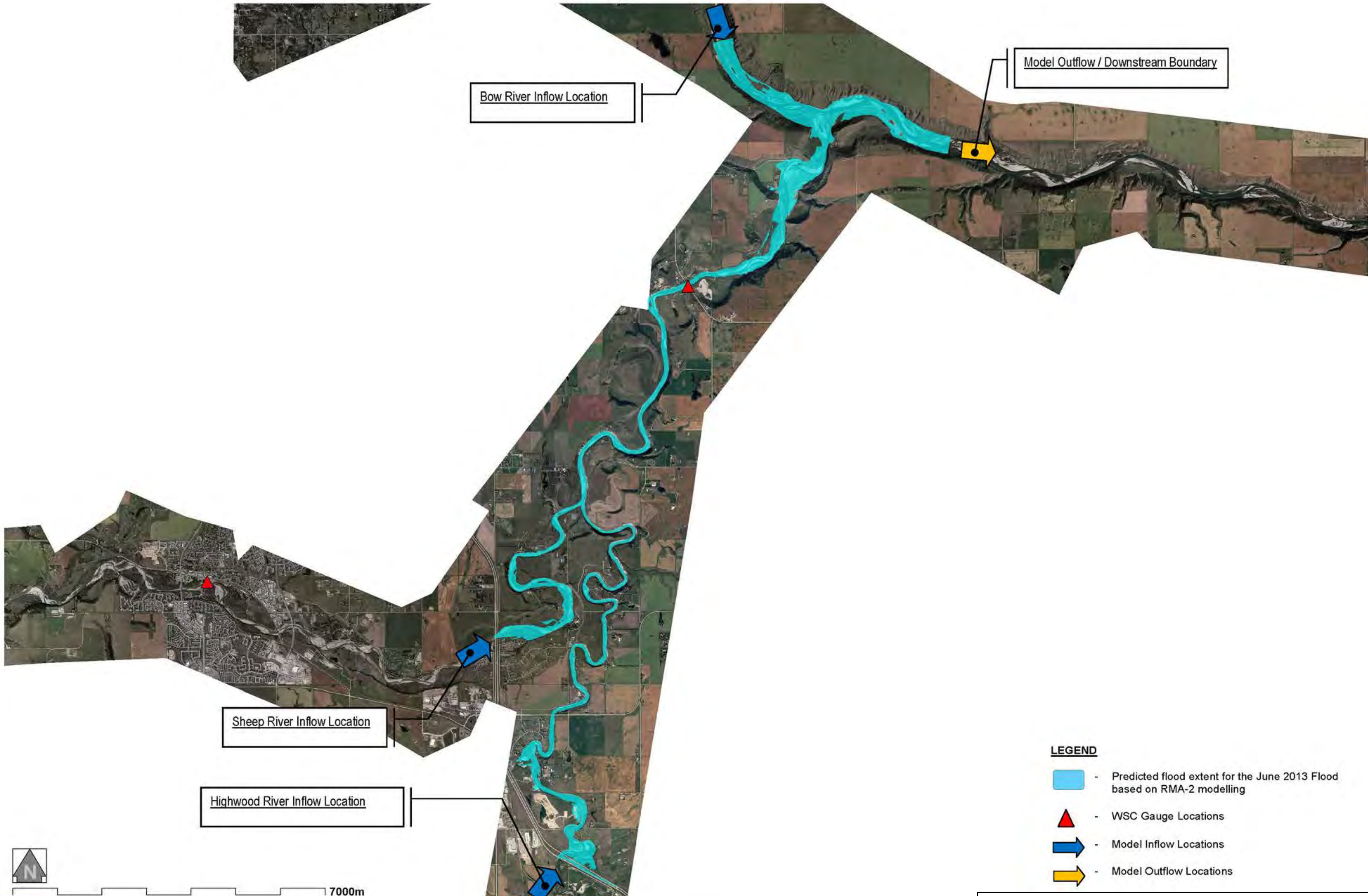

Municipal District of Foothills No. 31 – Highwood River Modelling

Location of Highwood River RMA-2 Model Boundaries

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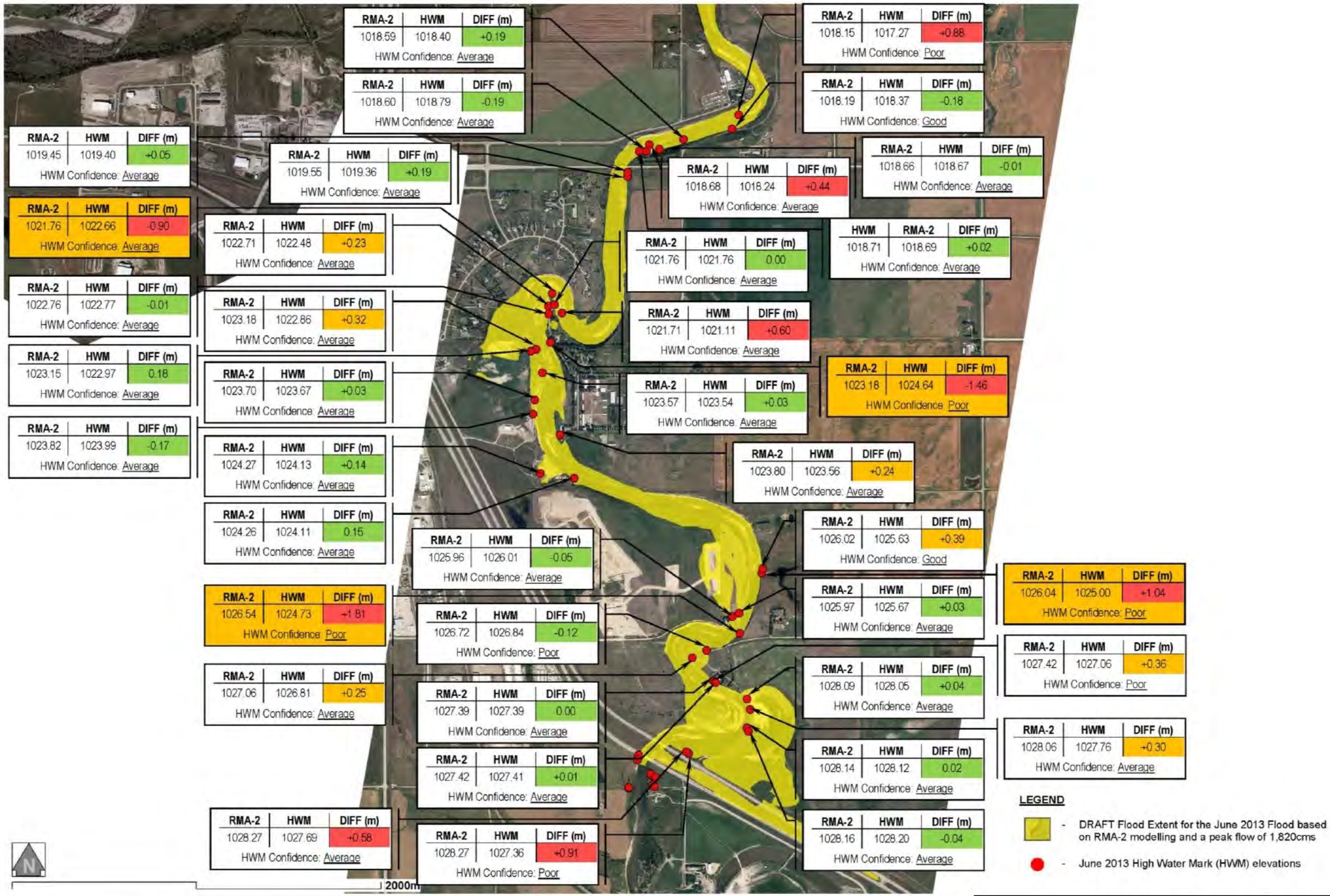

Note: Shading representative of magnitude of WL difference between observed and modelled flood levels. Green = 0 – 200 mm difference, Orange = 200 – 400 mm difference, Red = 400+ mm

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 – Highwood River Modelling

Comparison of RMA-2 Modelled Levels for the 'June 2013 – 1,820m³/s'Flood to Surveyed HWMs [Extent 1 of 3]

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Figure No: 5-1
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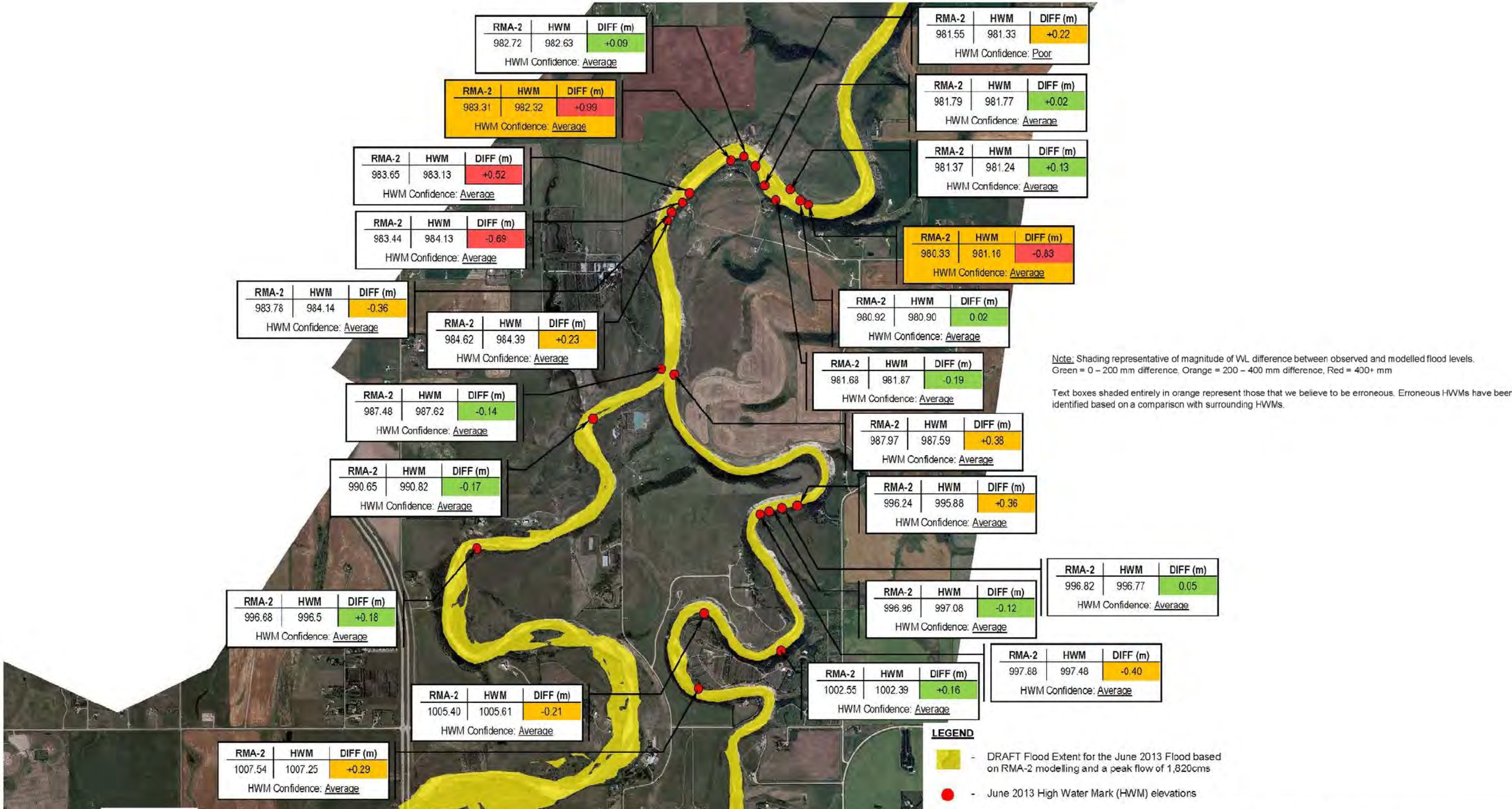

Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of RMA-2 Modelled Levels for the 'June 2013 – 1,820m³/s'Flood to Surveyed HWMs [Extent 2 of 3]

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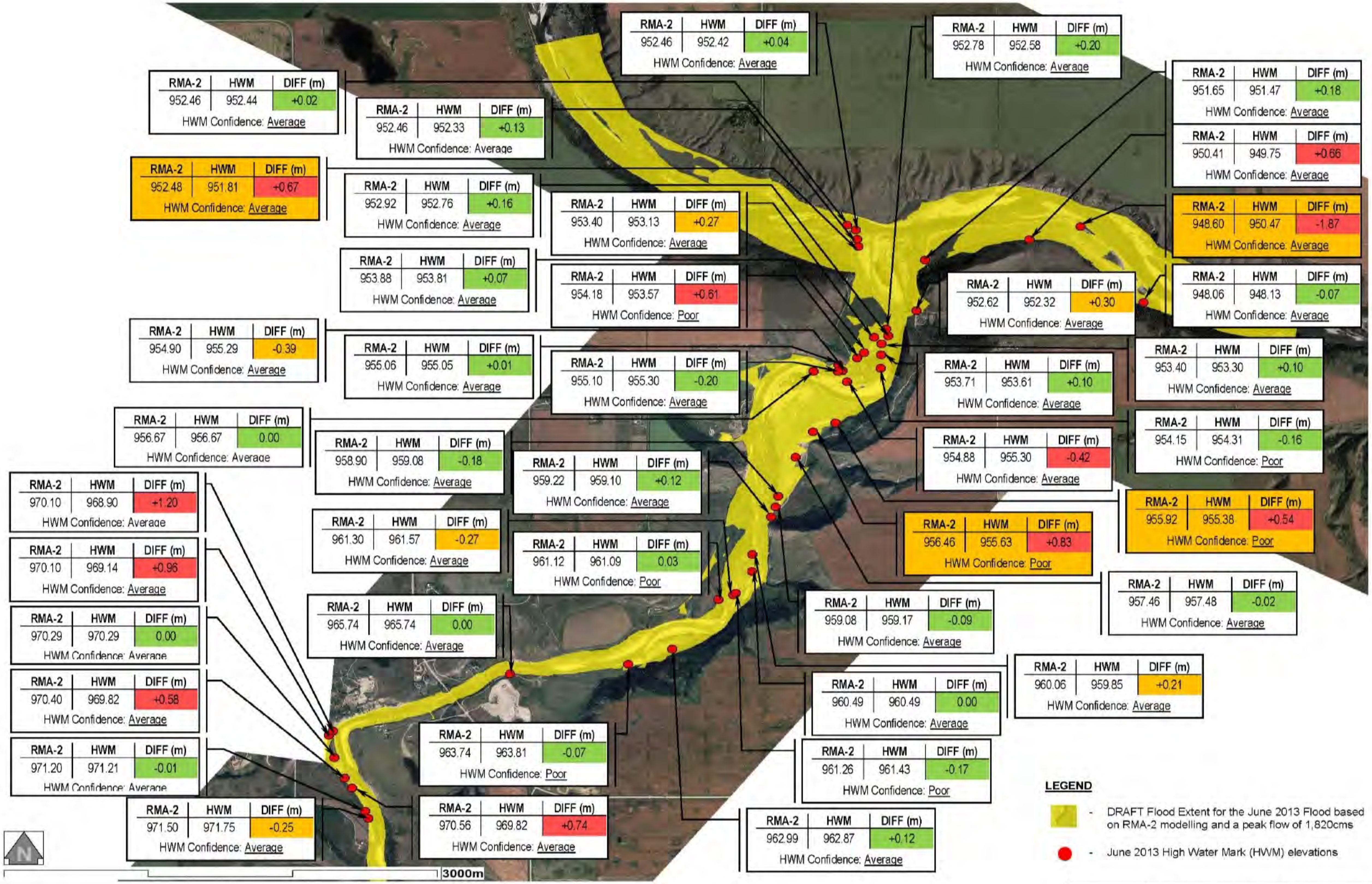

Note: Shading representative of magnitude of WL difference between observed and modelled flood levels.
Green = 0 – 200 mm difference. Orange = 200 – 400 mm difference. Red = 400+ mm

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 – Highwood River Modelling

Comparison of RMA-2 Modelled Levels for the 'June 2013 – 1,820m³/s'Flood to Surveyed HWMs [Extent 3 of 3]

Advisian
WorleyParsons Group

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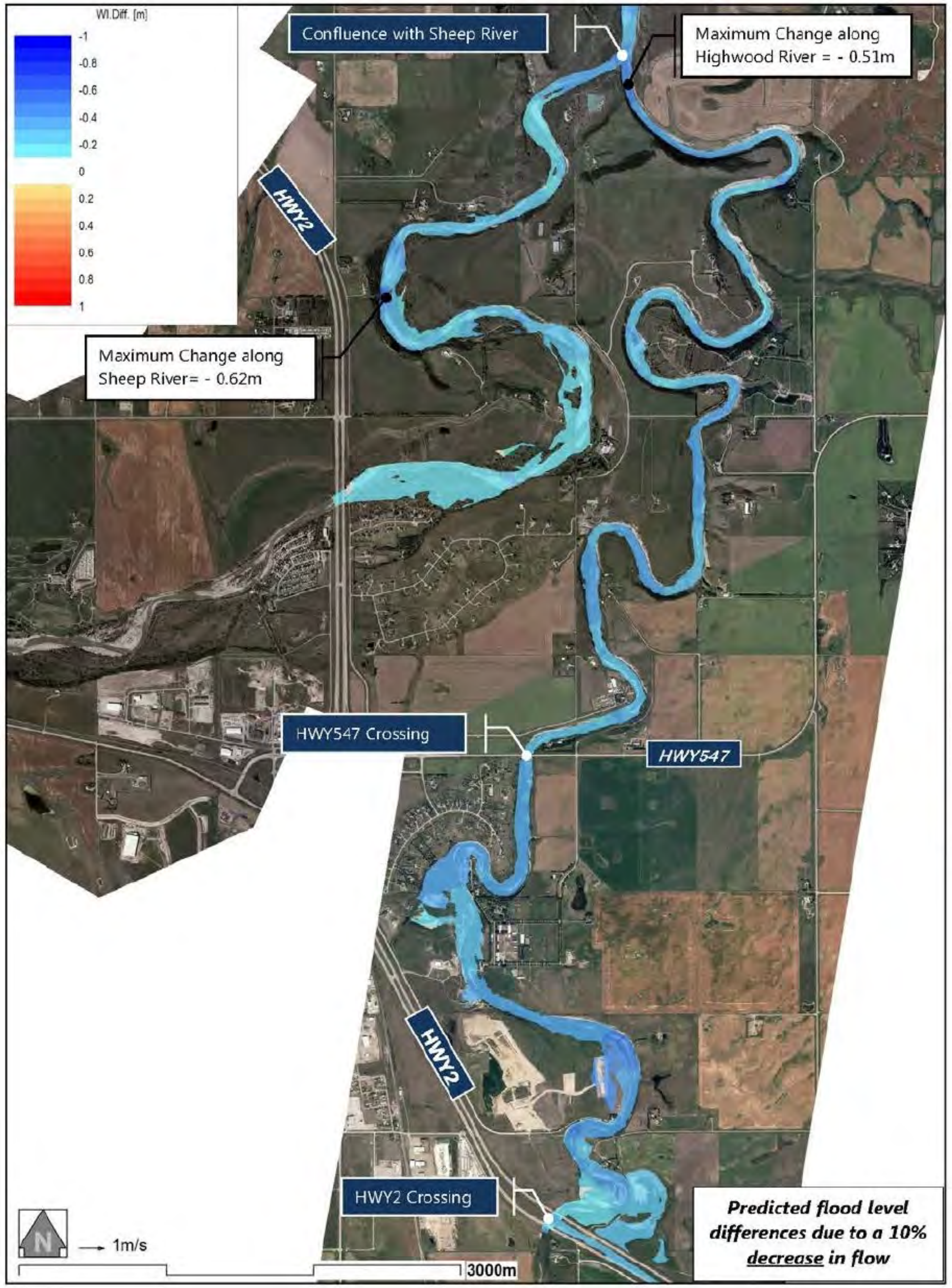
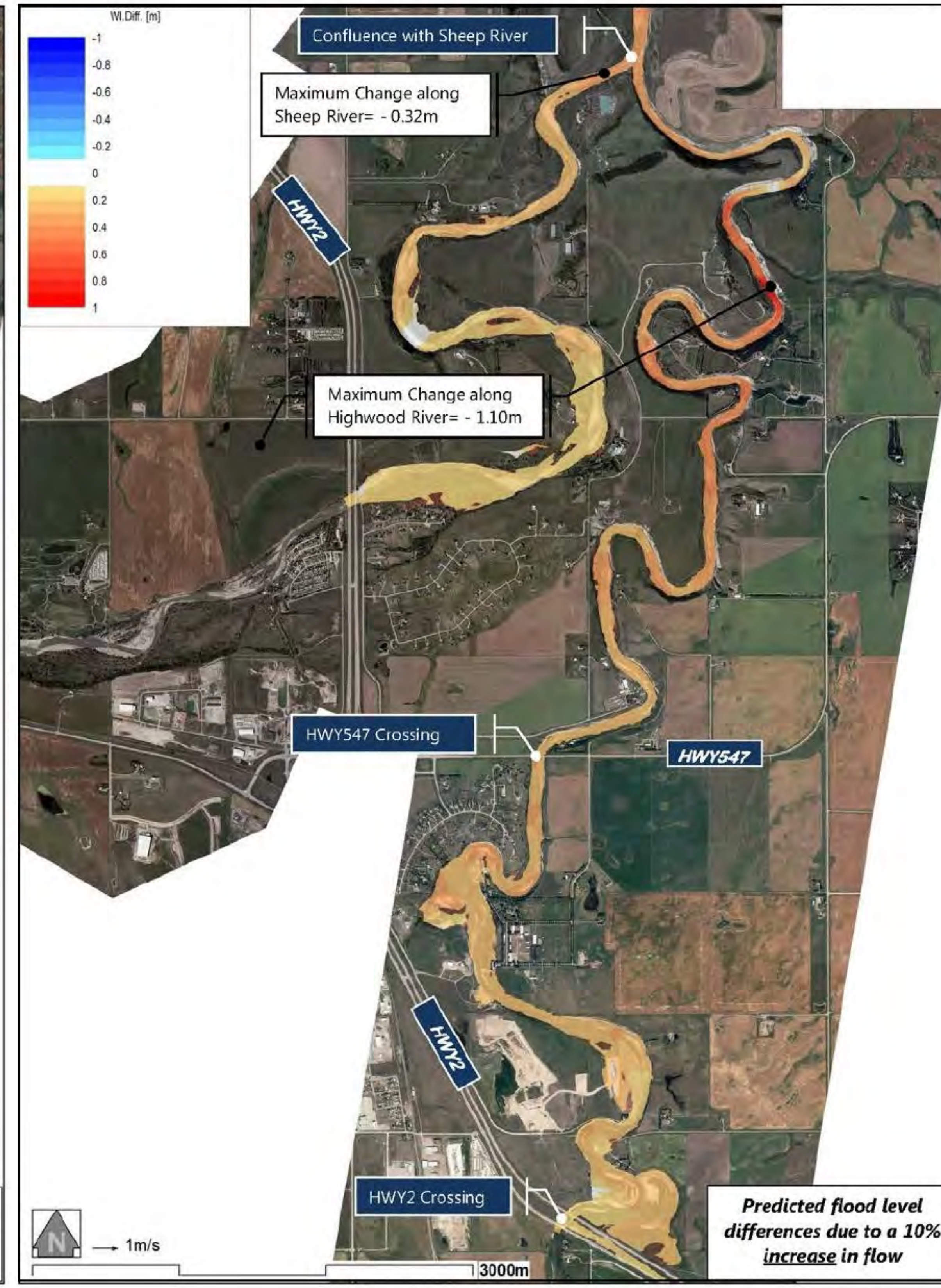
Reviewed By: JB					





Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s'Flood Levels as a Result of a 10% Decrease or Increase in Flow Magnitudes [Figure Extent 1 of 2]

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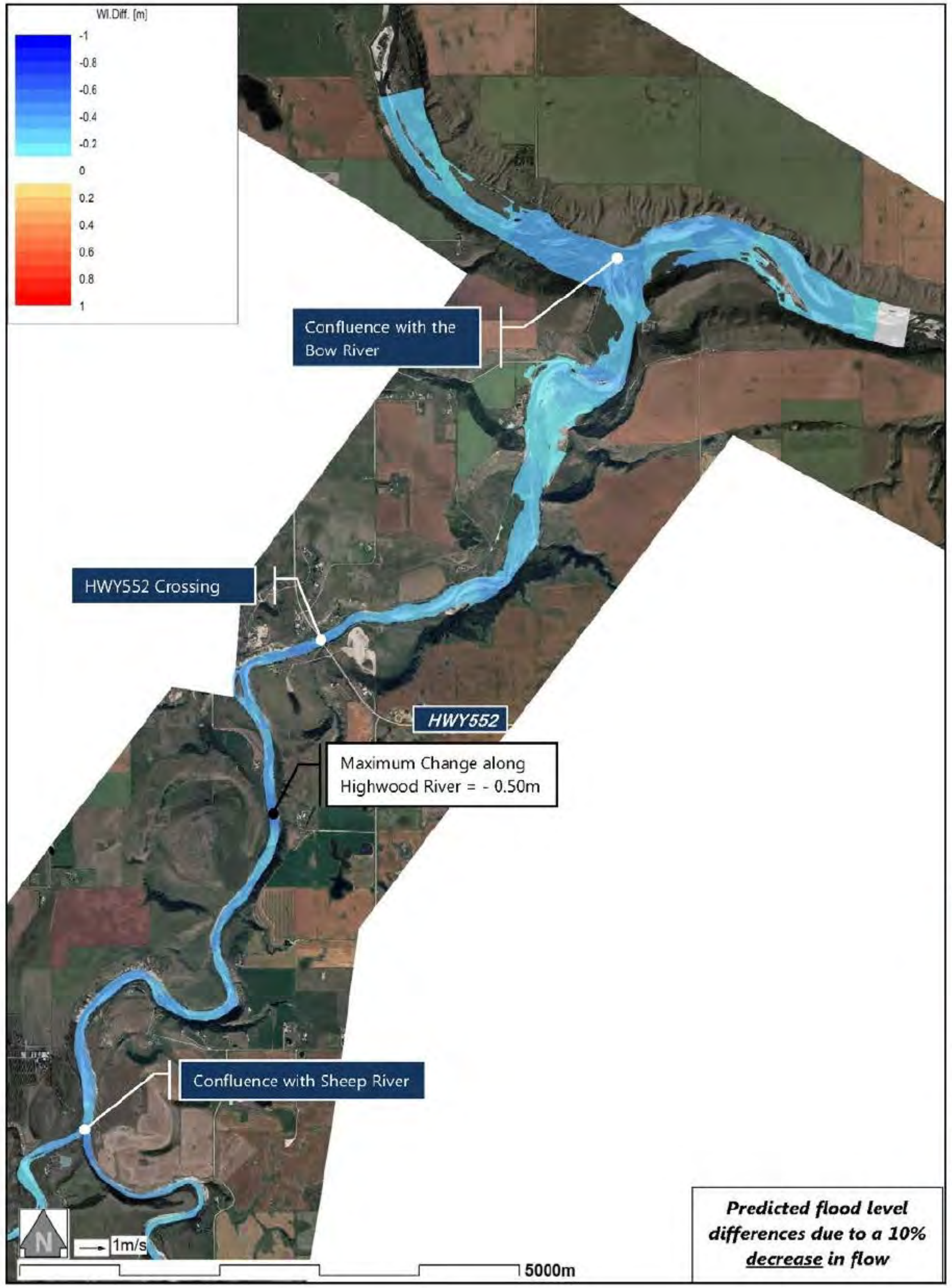

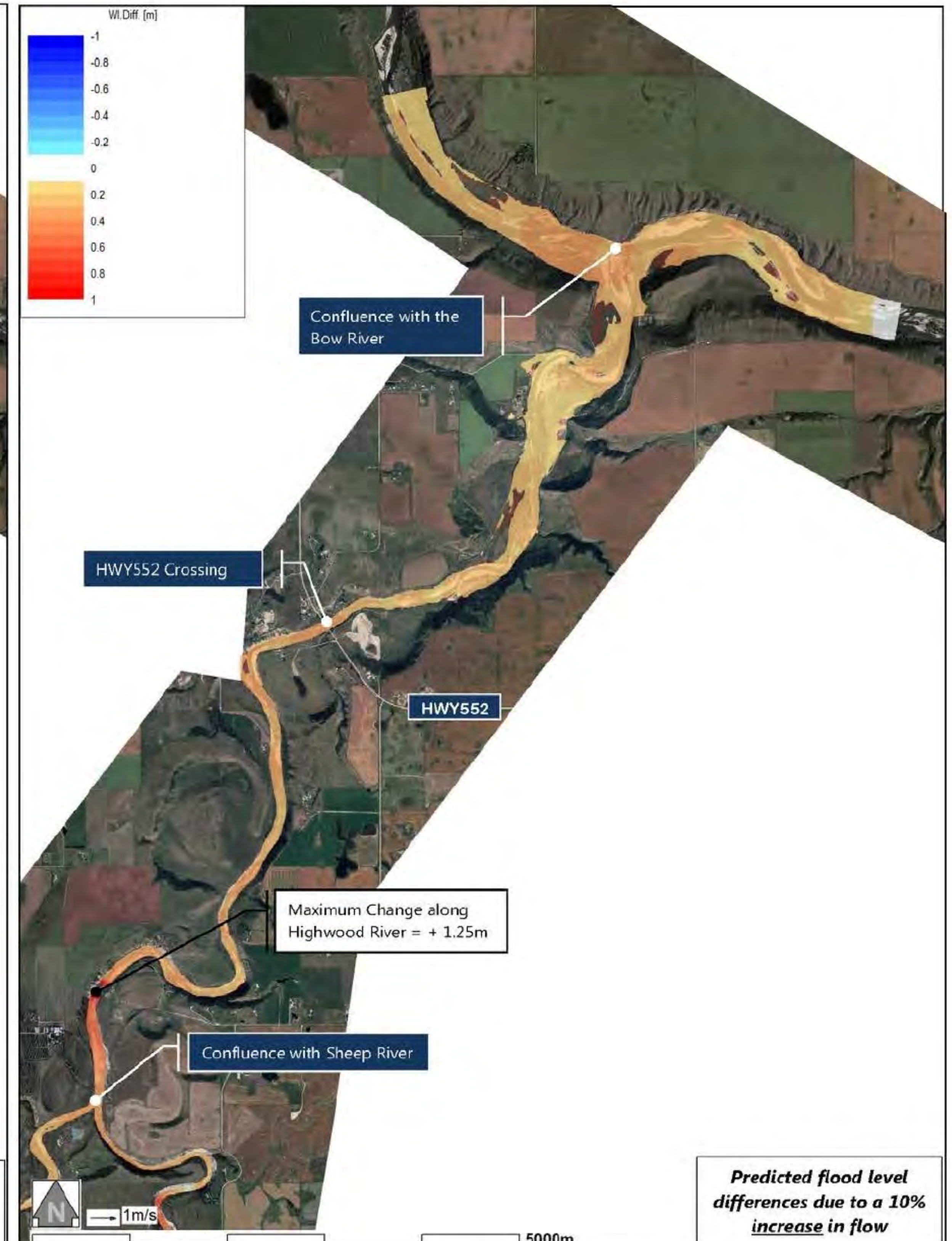

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s'Flood Levels as a Result of a 10% Decrease or Increase in Flow Magnitudes [Figure Extent 2 of 2]

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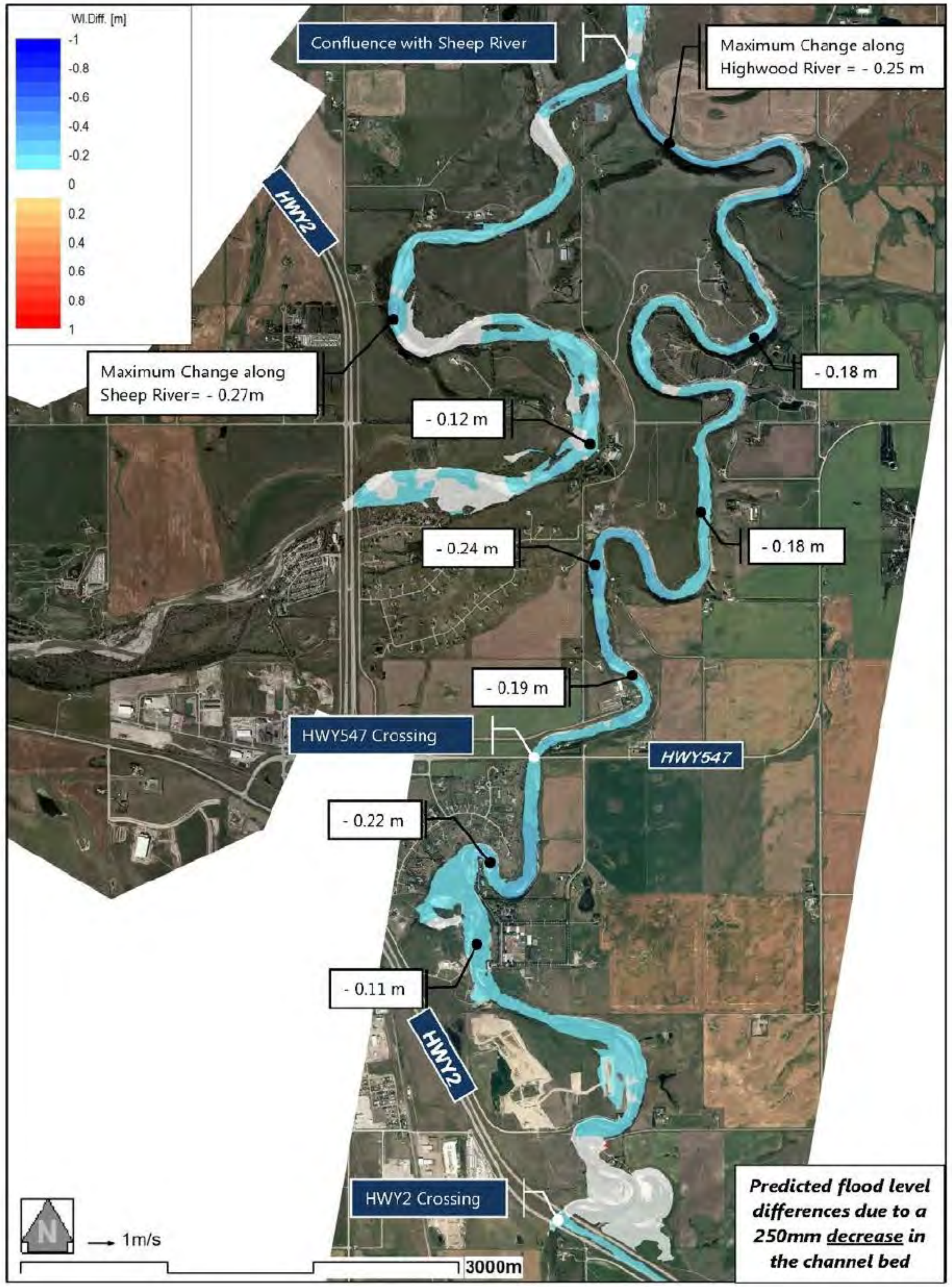

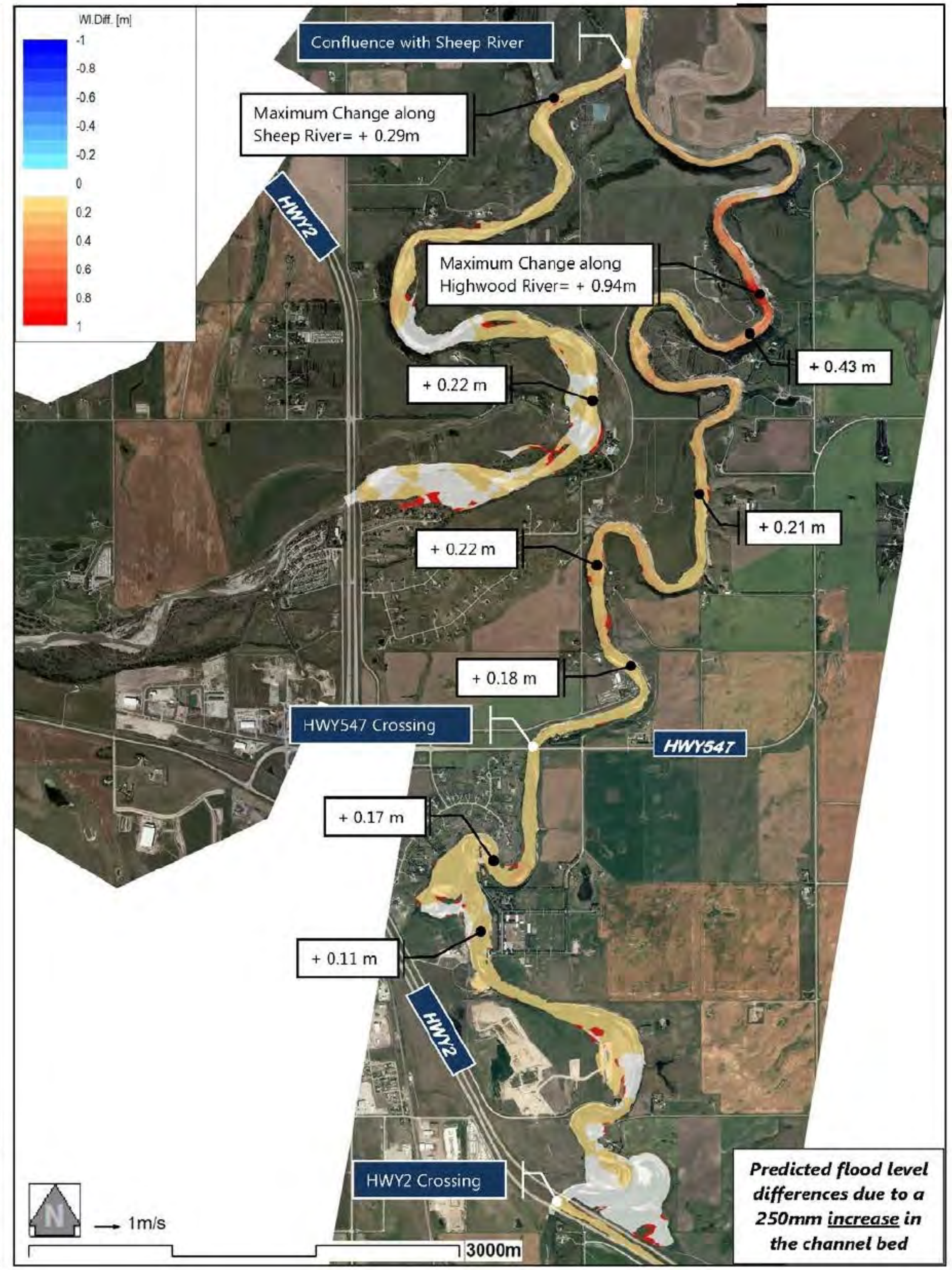

		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 250mm Decrease or Increase in Channel Levels [Figure Extent 1 of 2]			
Advisian WorleyParsons Group	**Created By:** RG	**Date:** July 5, 2016	**File Path:**	**Figure No:** 5-6	**Rev:** 0
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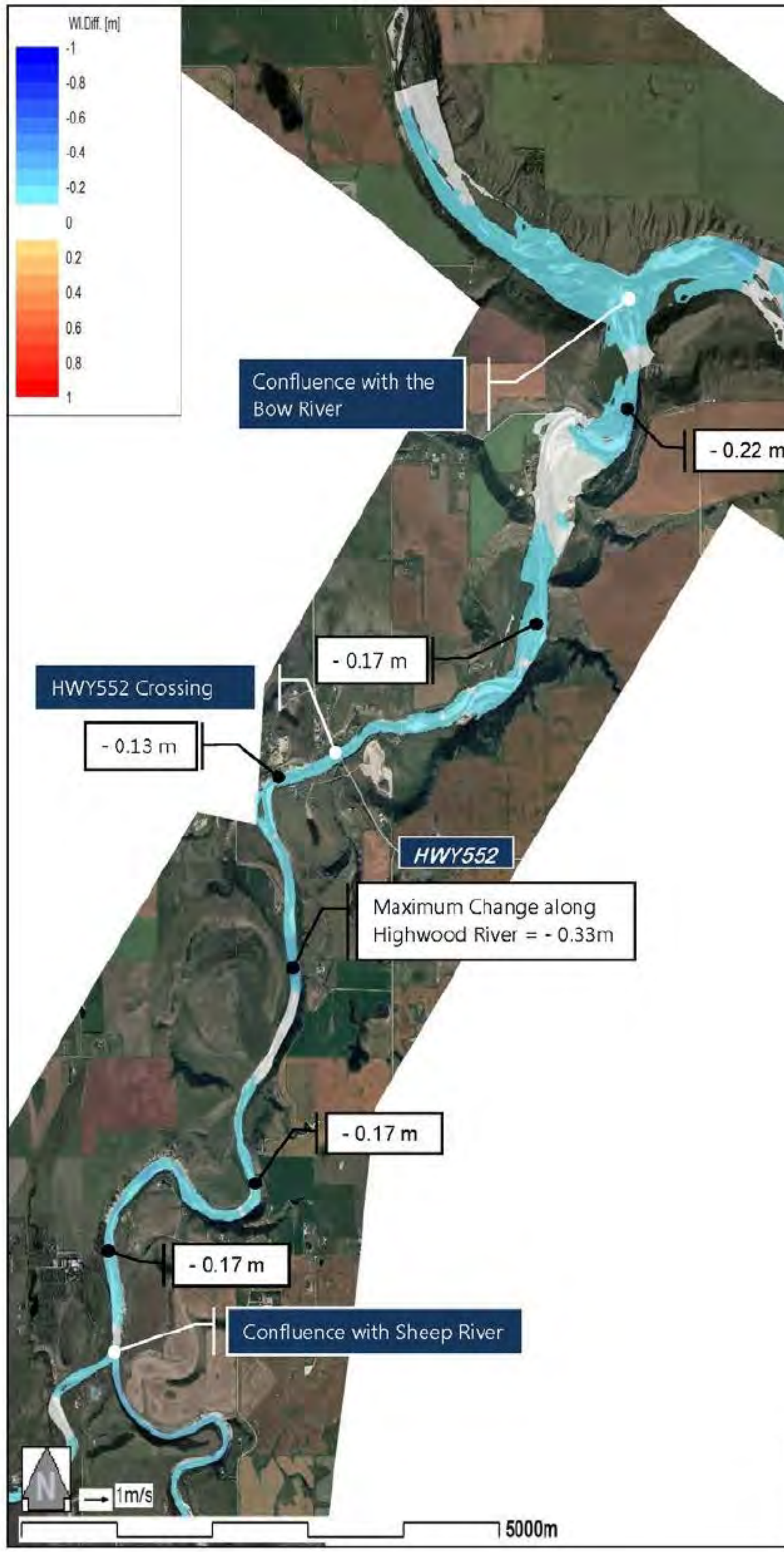


Predicted flood level differences due to a 250mm decrease in the channel bed

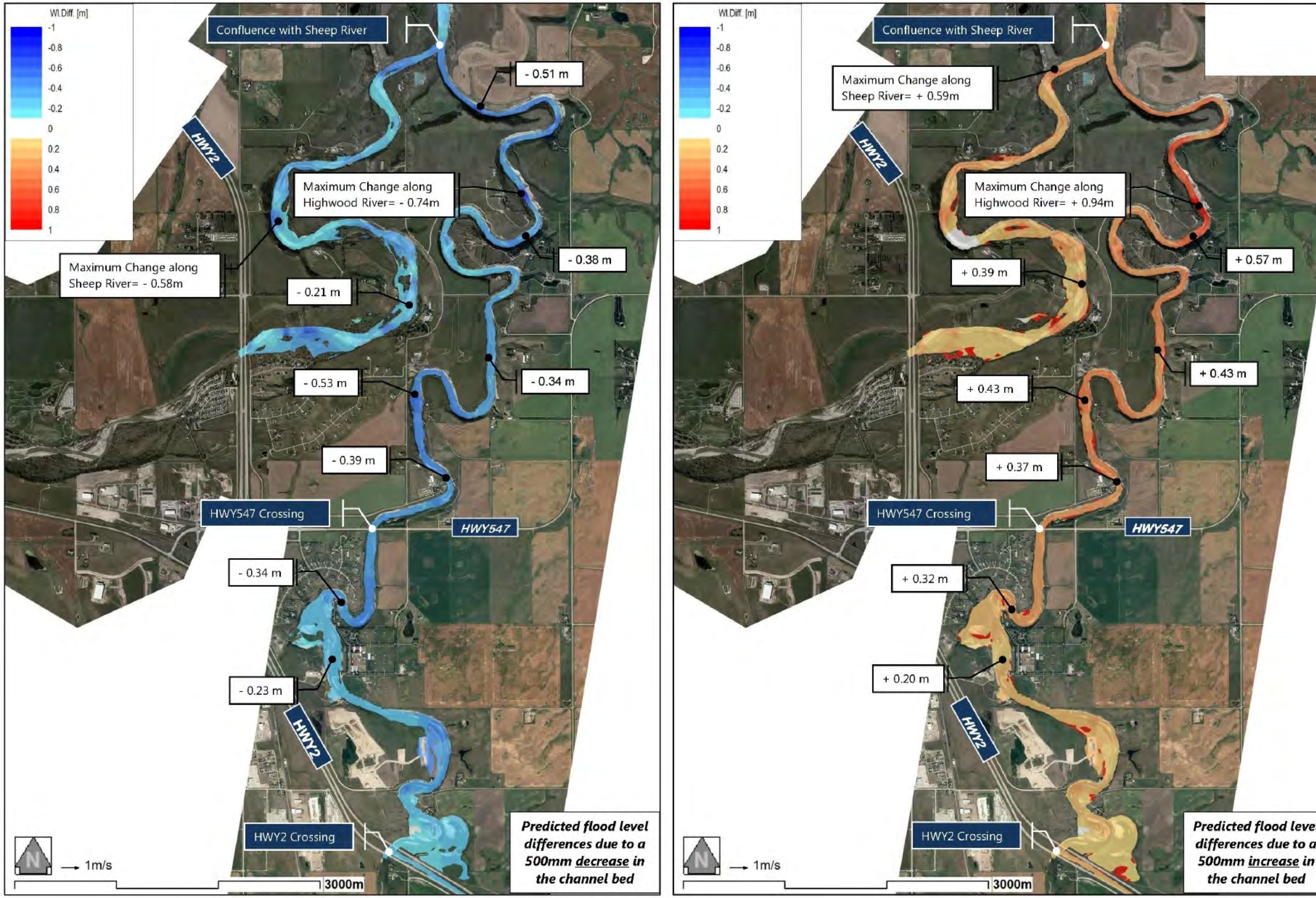
Predicted flood level differences due to a 250mm increase in the channel bed

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 250mm Decrease or Increase in Channel Levels [Figure Extent 2 of 2]

Advisian
WorleyParsons Group

Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-7	Rev: 0
Reviewed By: JB				



Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 500mm Decrease or Increase in Channel Levels [Figure Extent 1 of 2]

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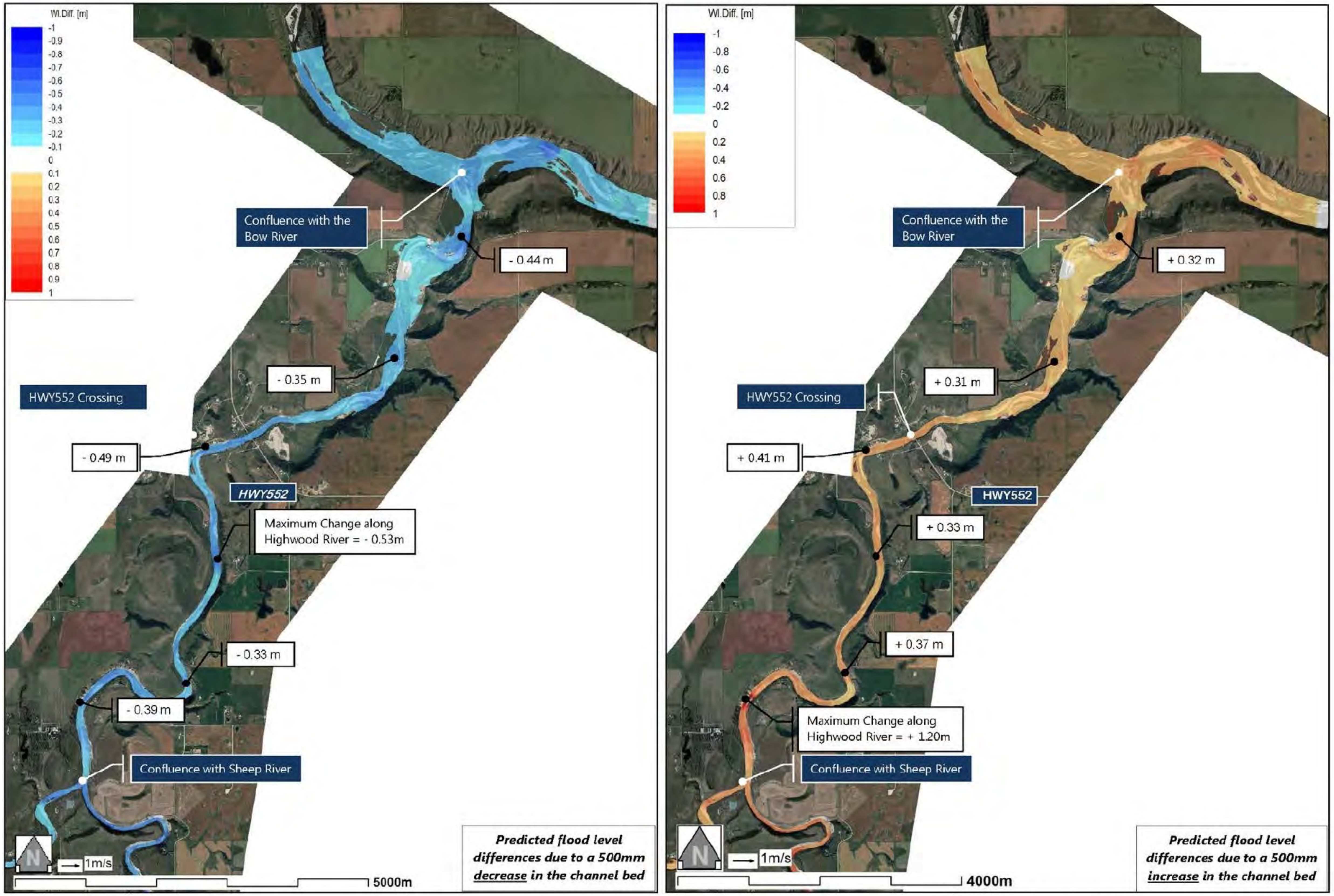
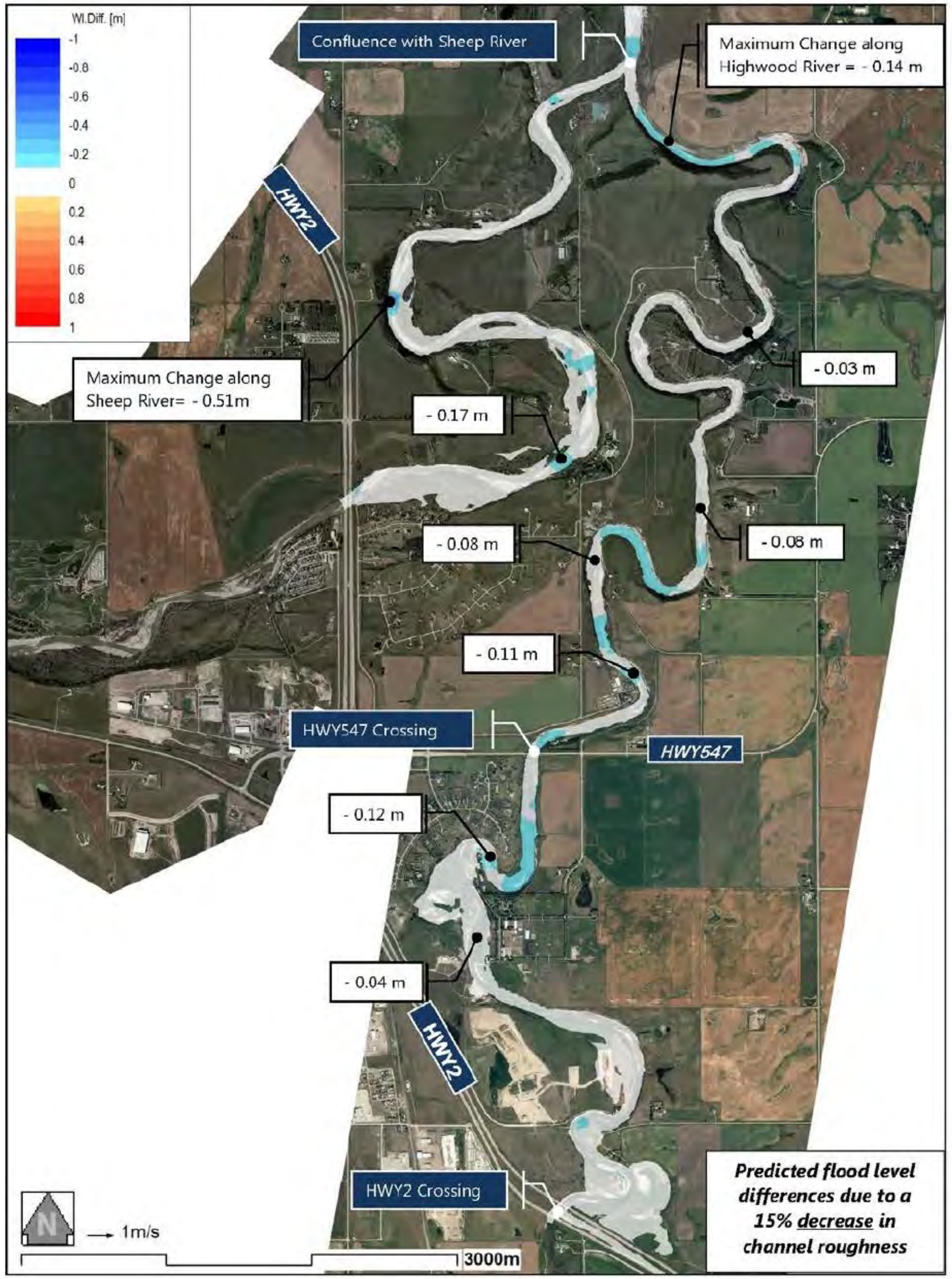
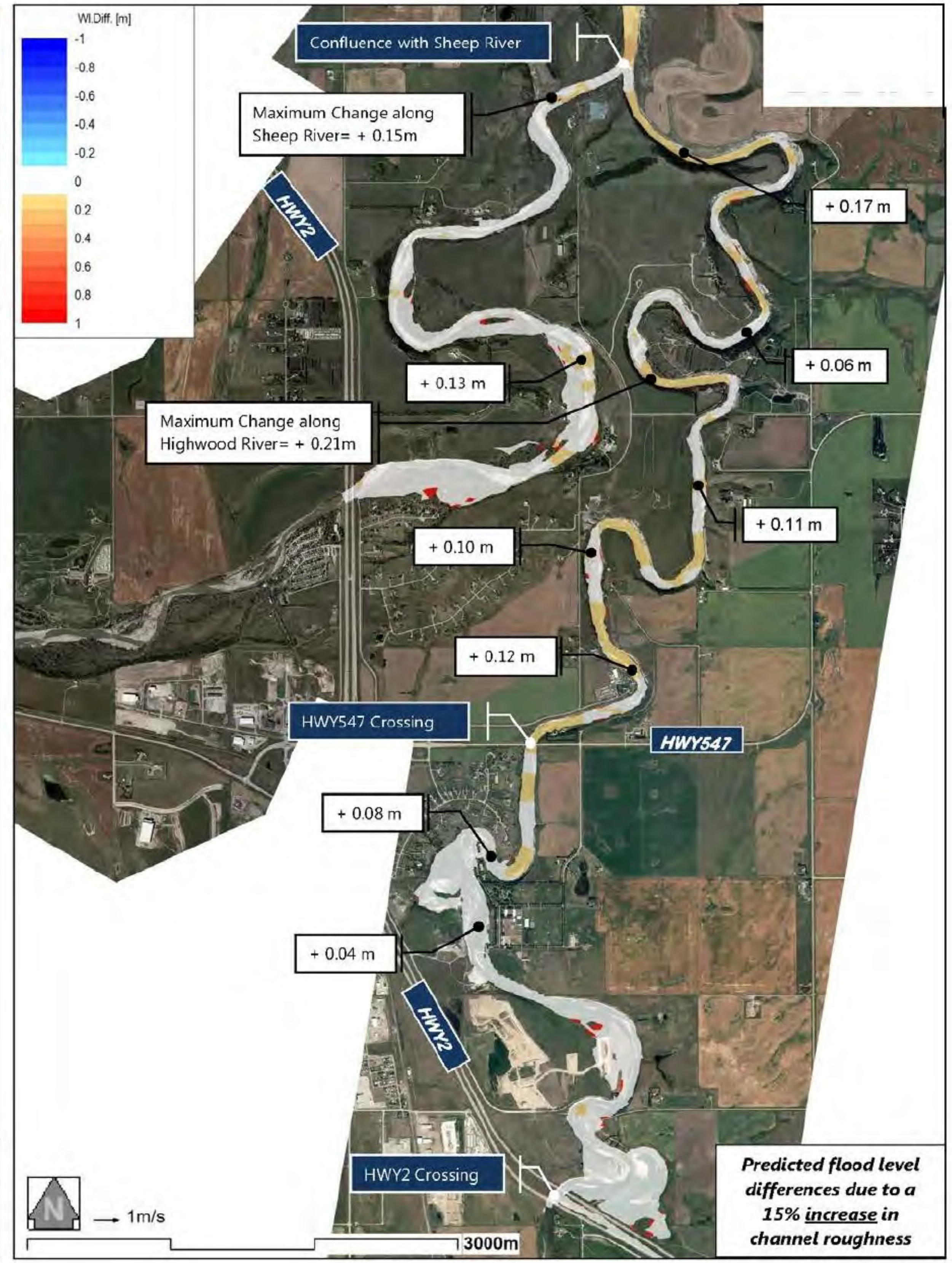


		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 500mm Decrease or Increase in Channel Levels [Figure Extent 2 of 2]			
Advisian WorleyParsons Group	**Created By:** RG	**Date:** July 5, 2016	**File Path:**	**Figure No:** 5-9	**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 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 15% Decrease or Increase in Channel Roughness [Figure Extent 1 of 2]

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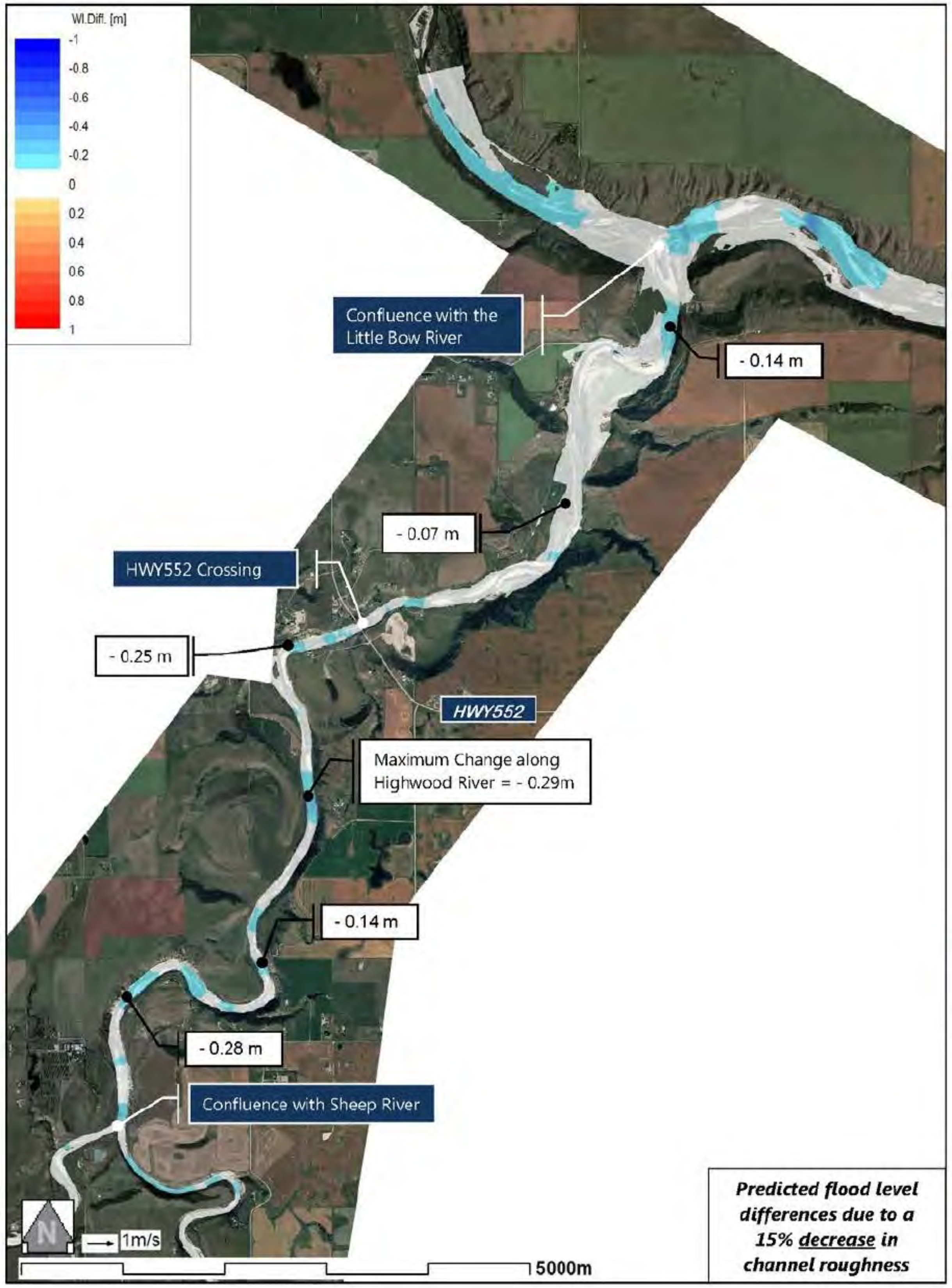

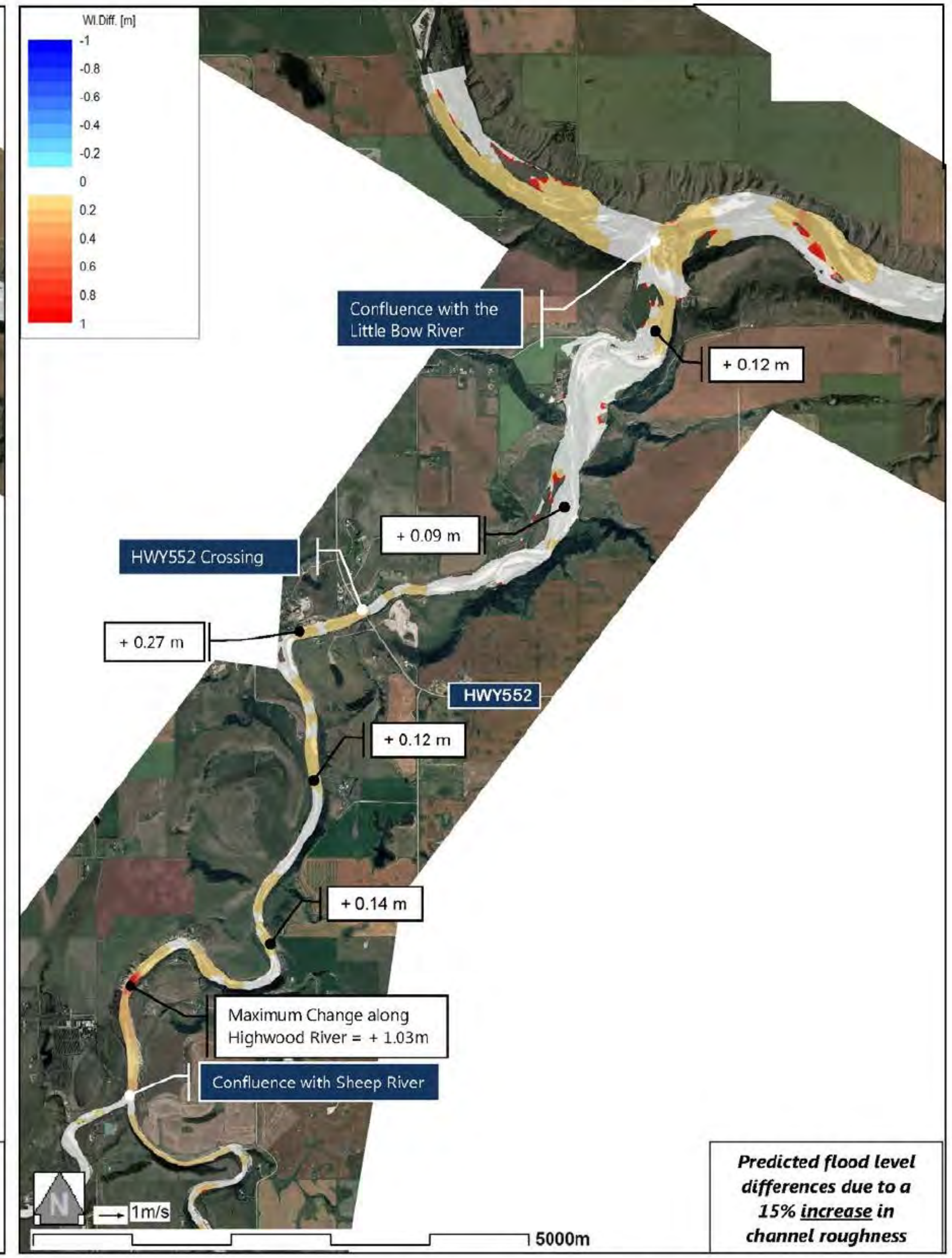

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 15% Decrease or Increase in Channel Roughness [Figure Extent 2 of 2]

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Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-11	Rev: 0
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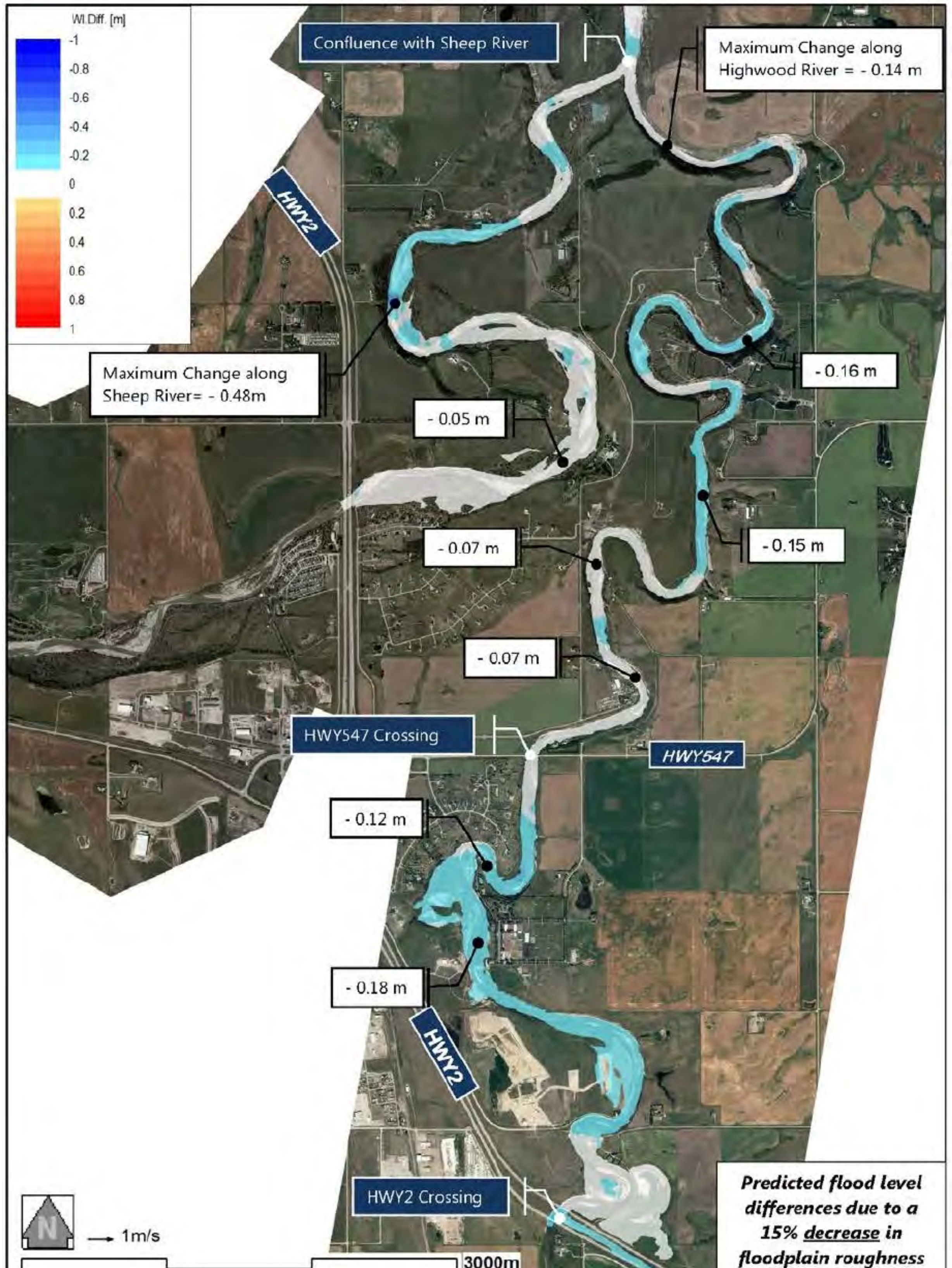
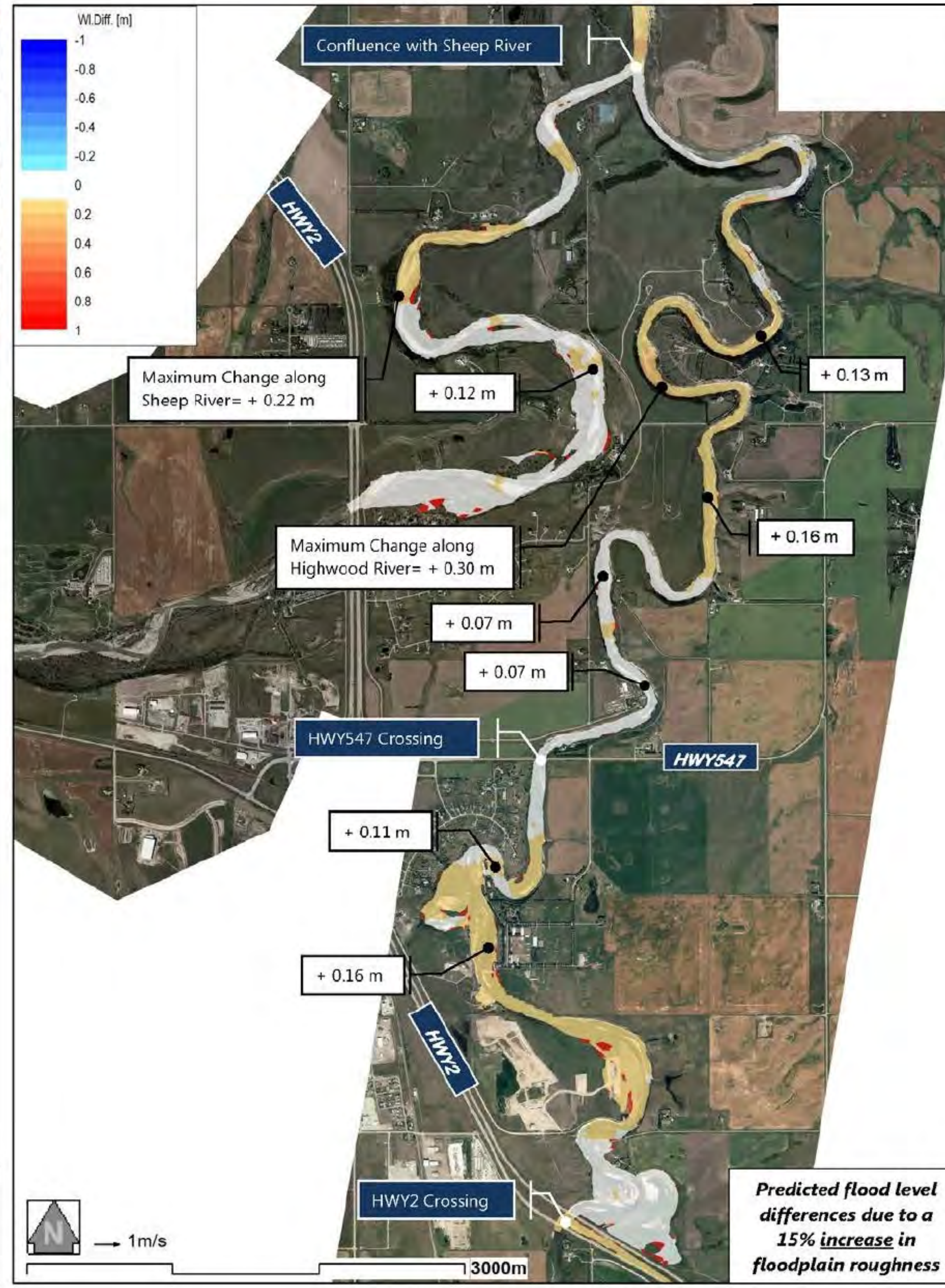
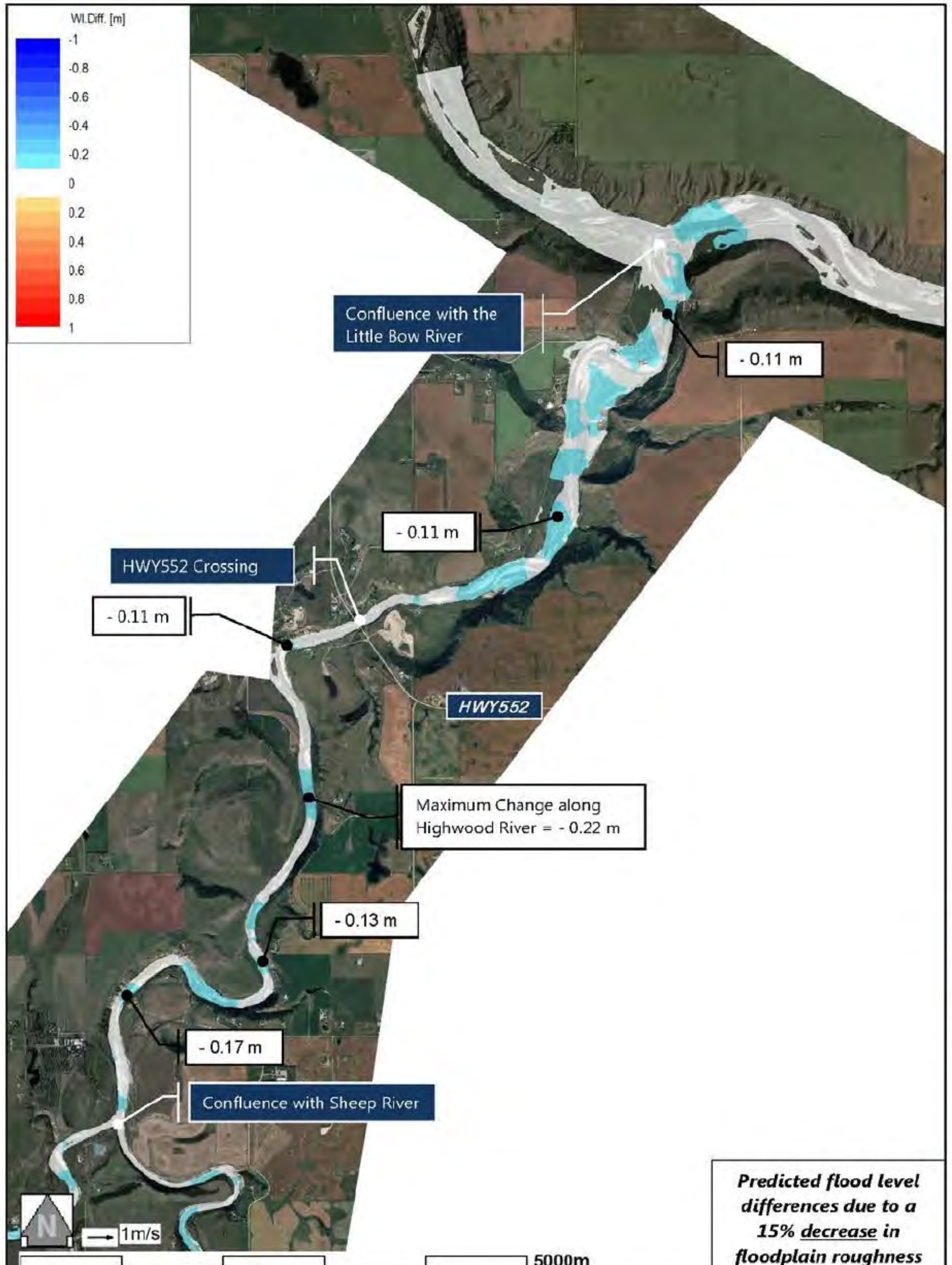
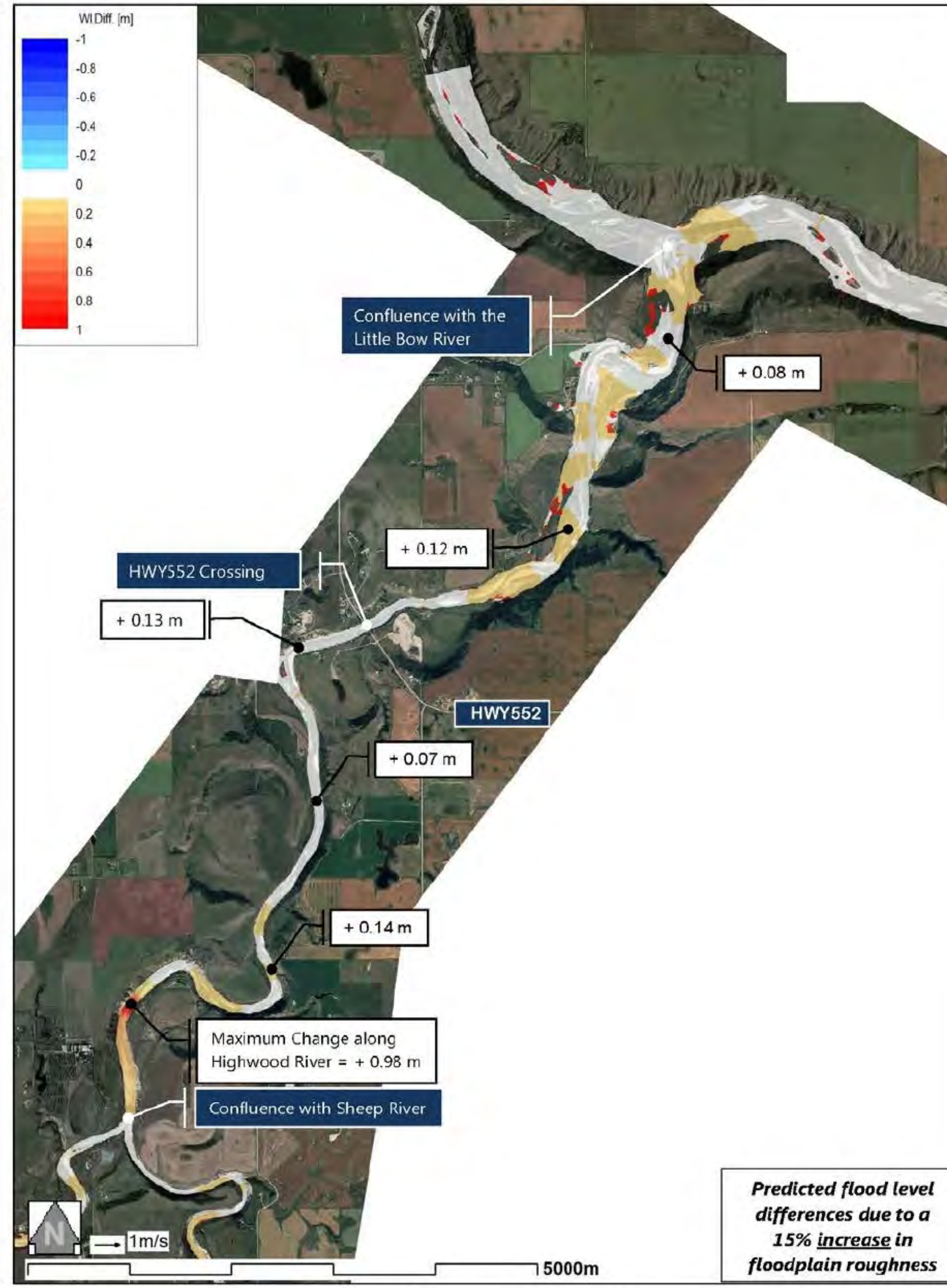




Municipal District of Foothills No. 31 – Highwood River Modelling				
Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 15% Decrease or Increase in Floodplain Roughness [Figure Extent 1 of 2]				
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-12 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.		



Predicted flood level differences due to a 15% decrease in floodplain roughness

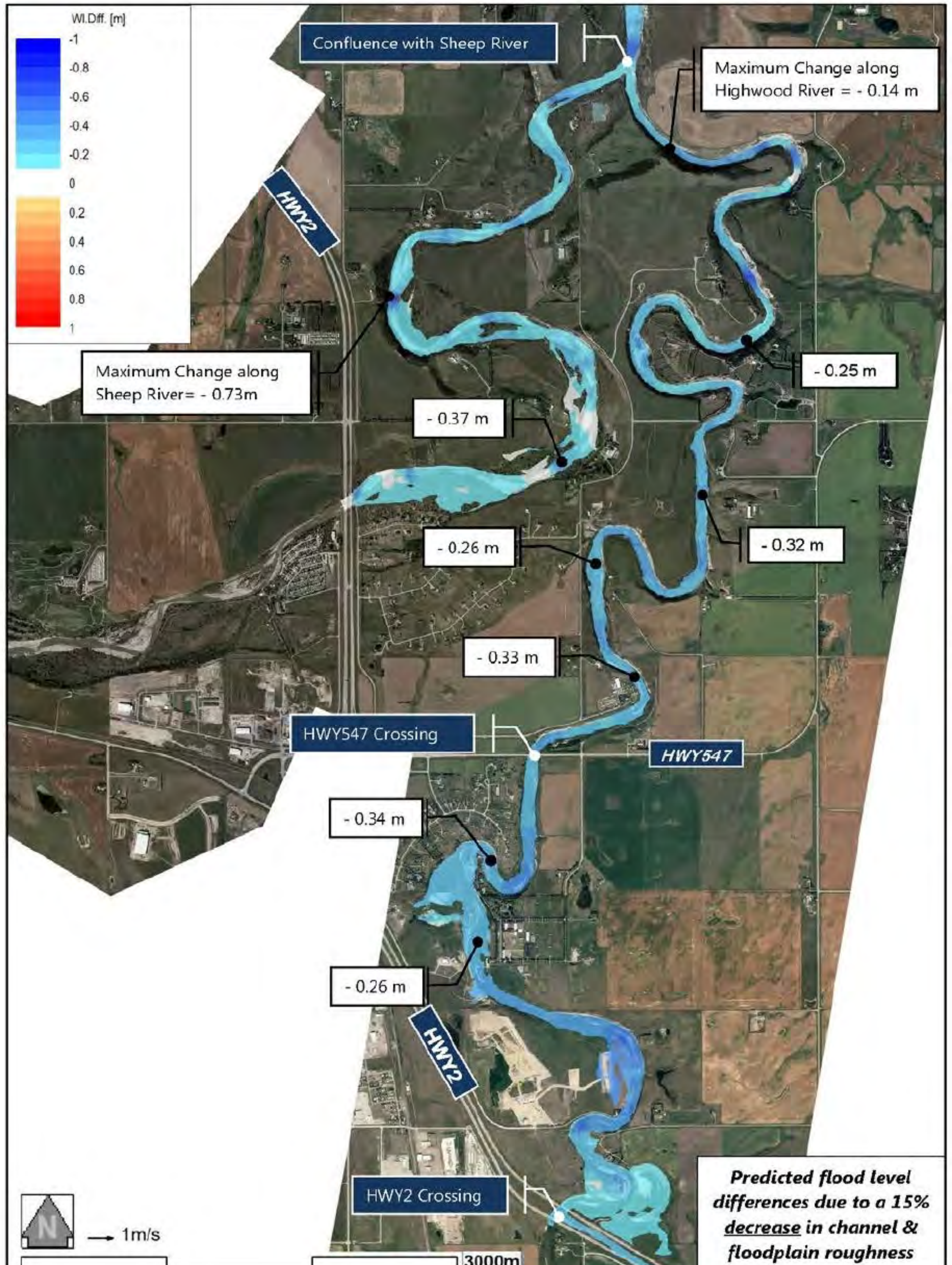


Predicted flood level differences due to a 15% increase in floodplain roughness

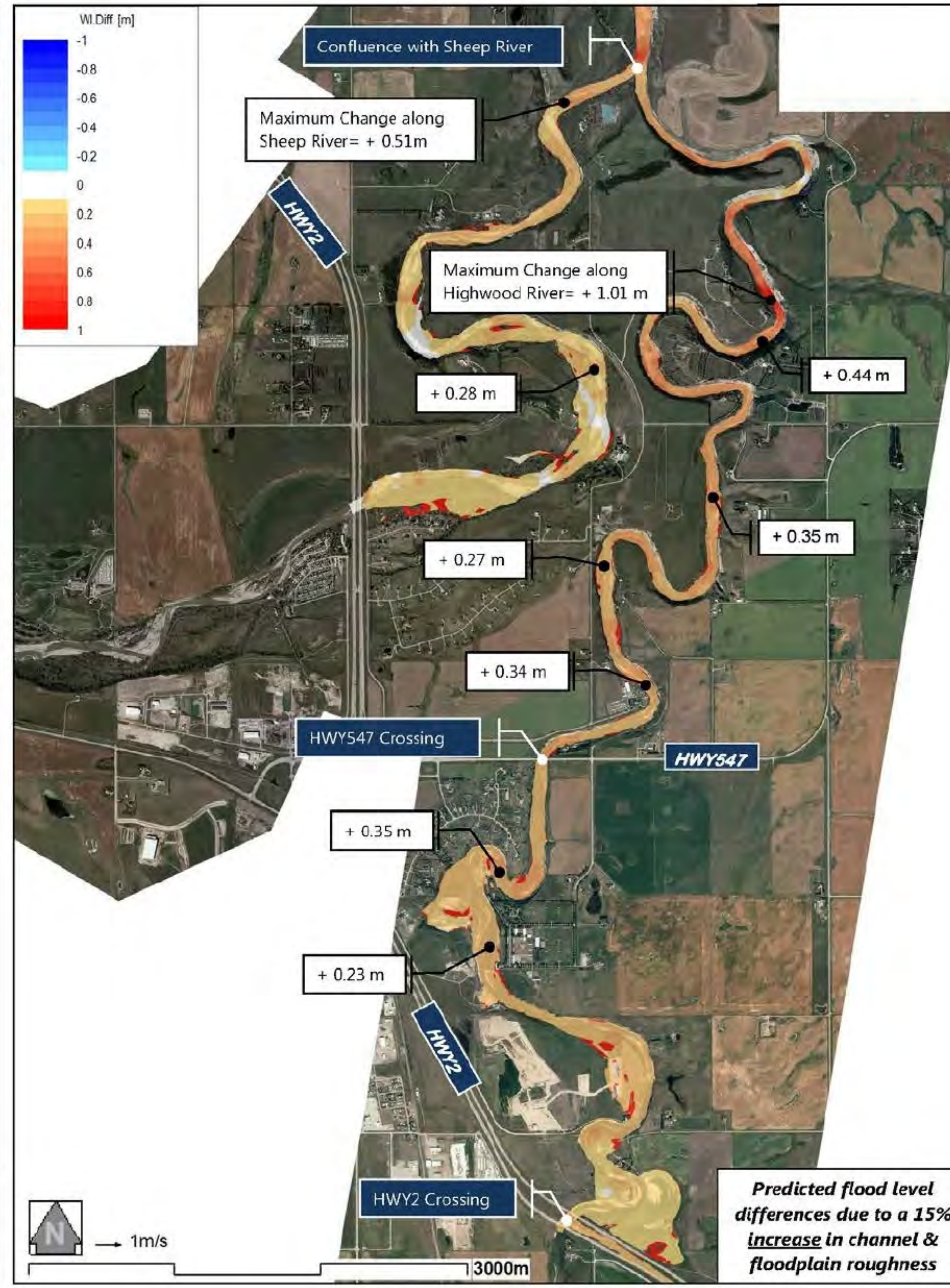
Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 15% Decrease or Increase in Floodplain Roughness [Figure Extent 2 of 2]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-13	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.			



Predicted flood level differences due to a 15% __decrease__ in channel & floodplain roughness



Predicted flood level differences due to a 15% __increase__ in channel & floodplain roughness

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of a 15% Decrease or Increase in Channel & Floodplain Roughness [Figure Extent 1 of 2]

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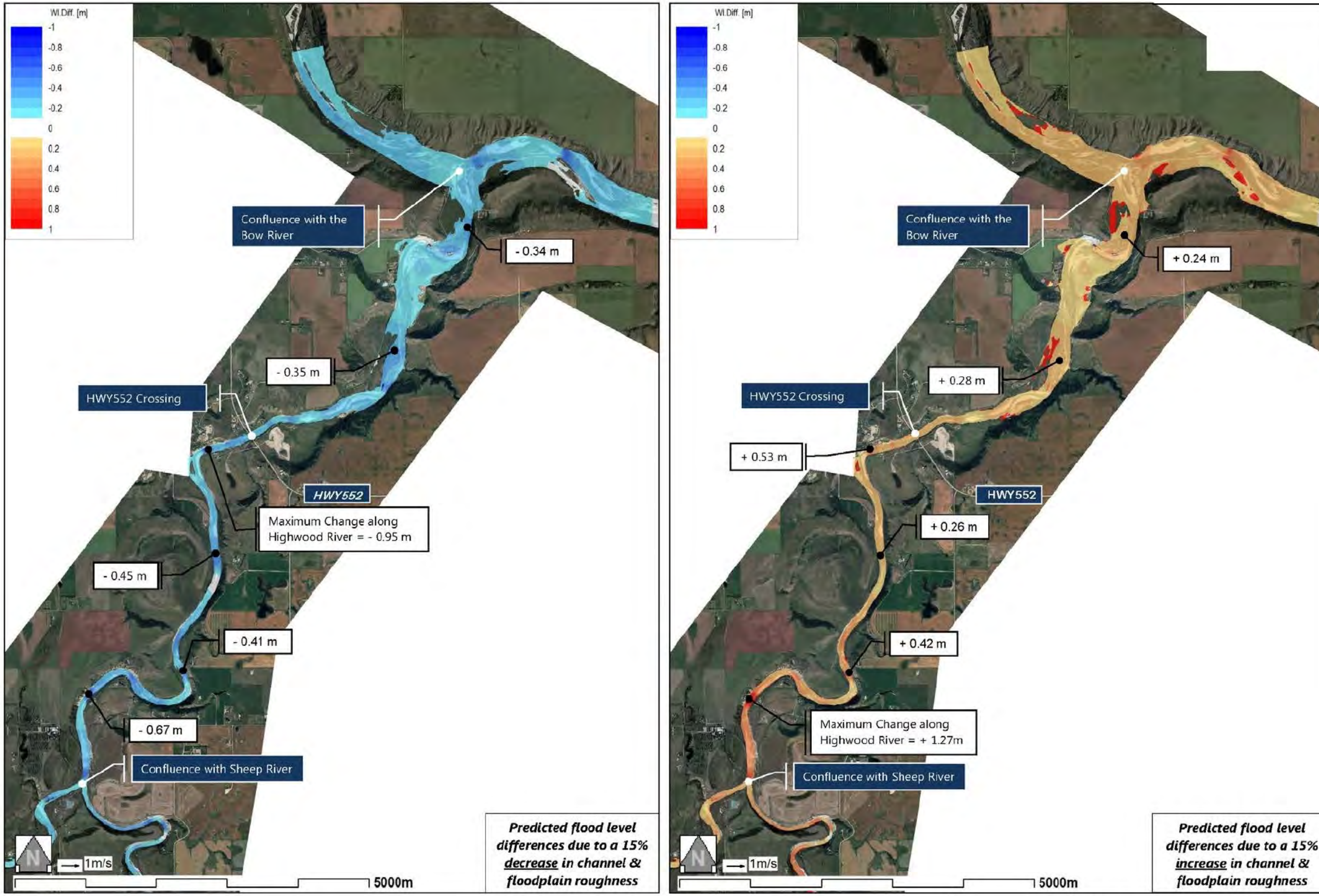

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m^3/s' Flood Levels as a Result of a 15% Decrease or Increase in Channel & Floodplain Roughness [Figure Extent 2 of 2]

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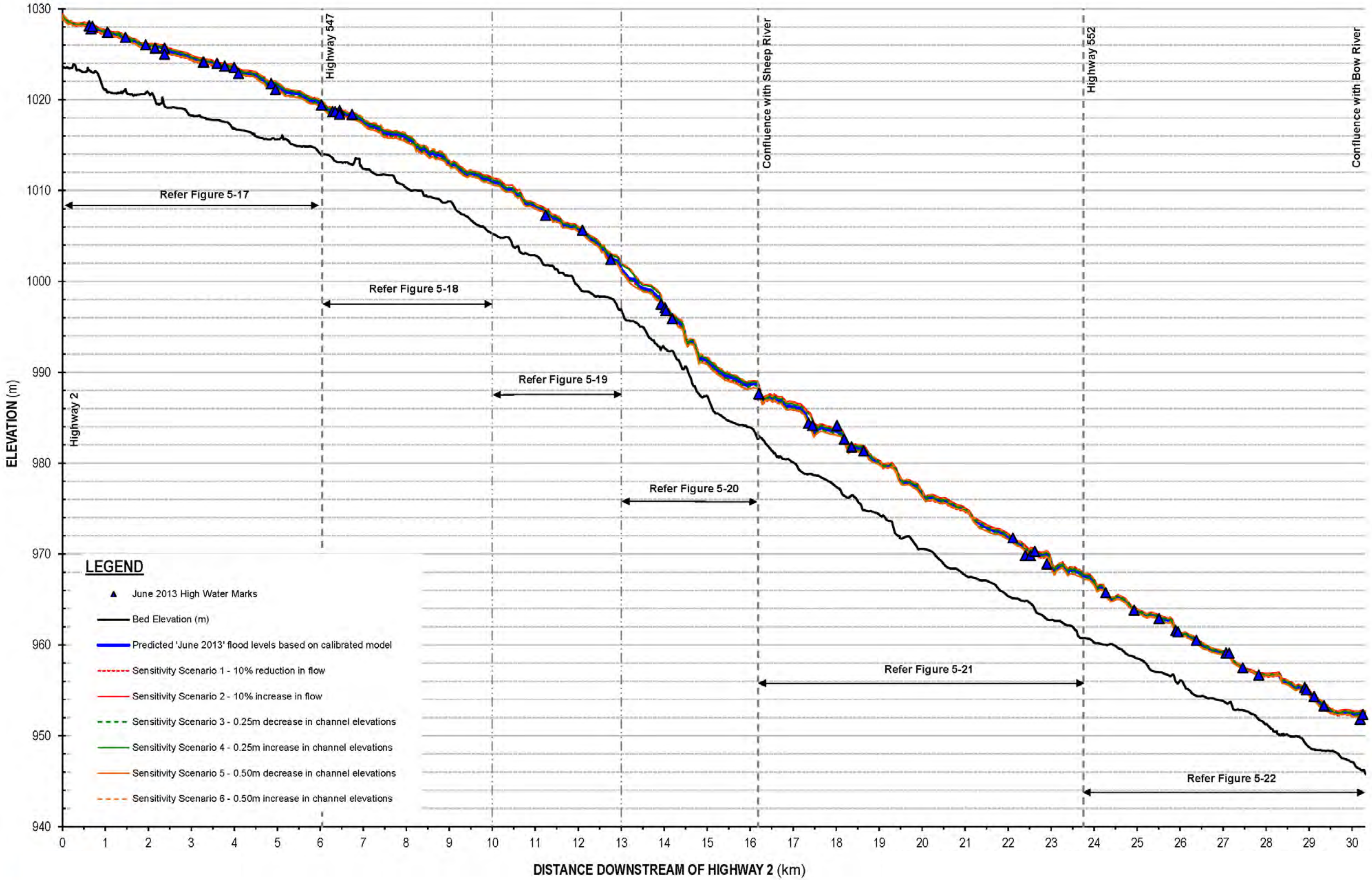
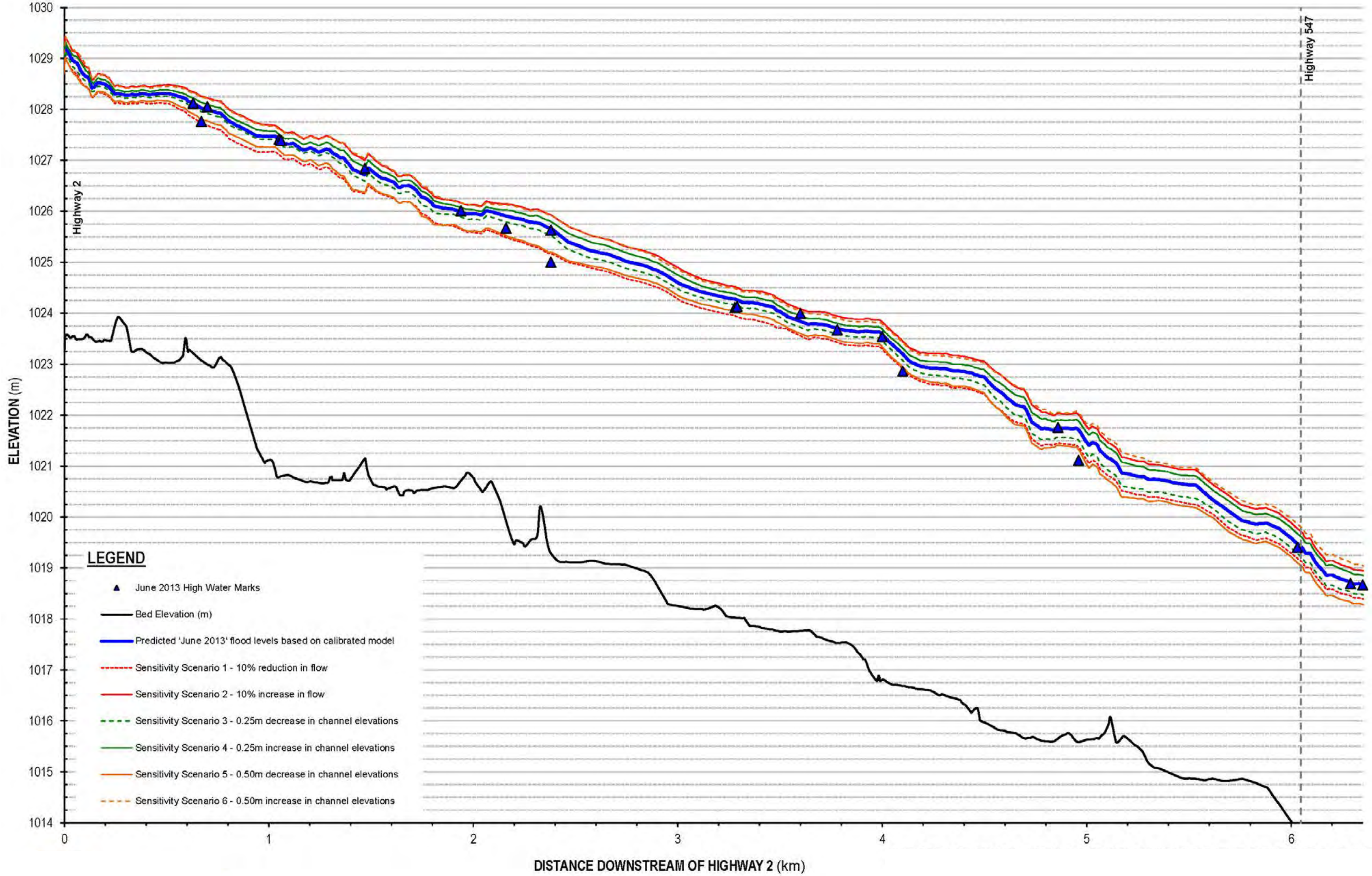


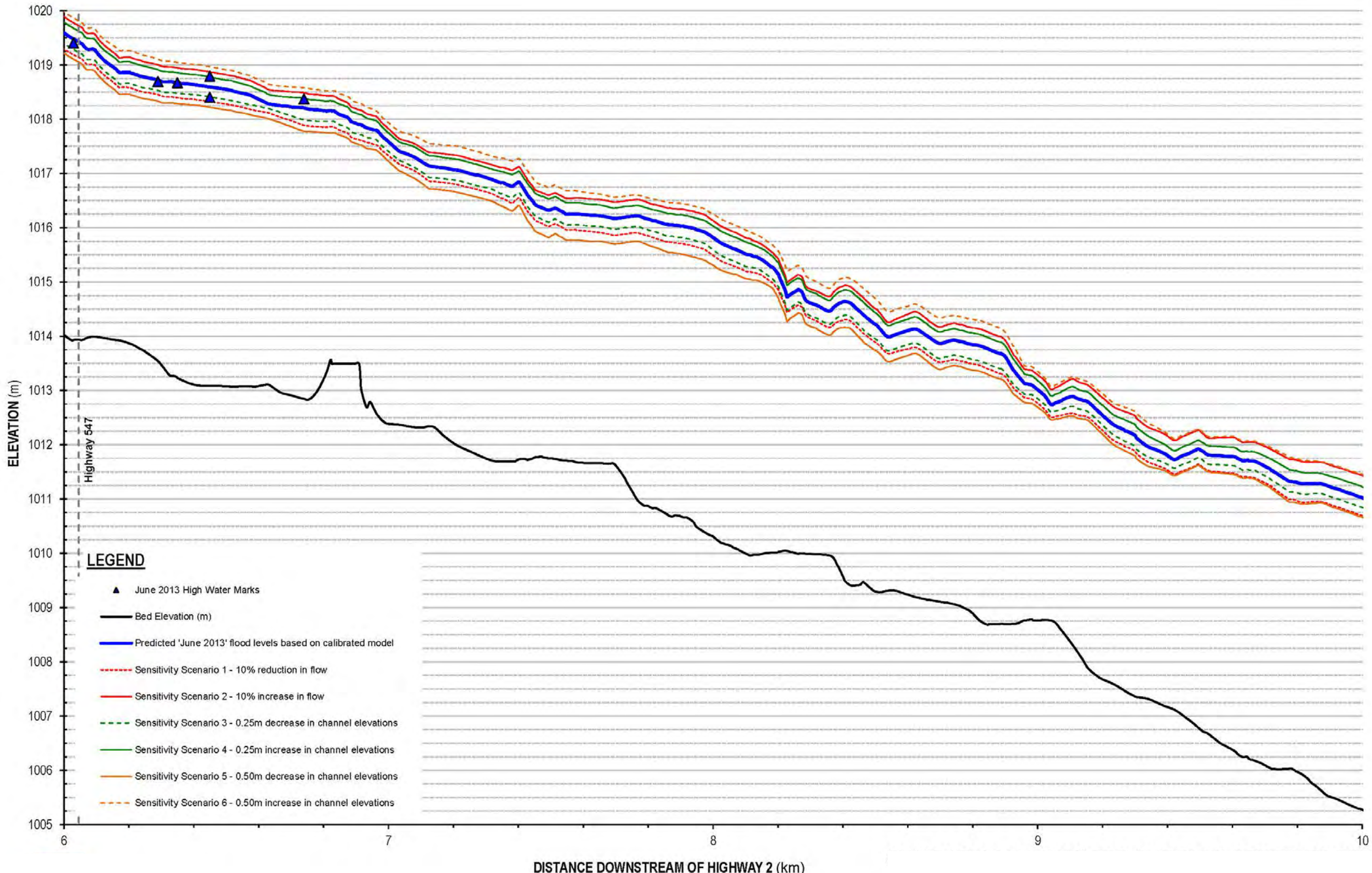
Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 [Overview]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-16	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 – Highwood River Modelling			
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 [WSP Extent 1 of 6]			
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-17	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 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6
[WSP Extent 2 of 6]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-18	Rev: 0
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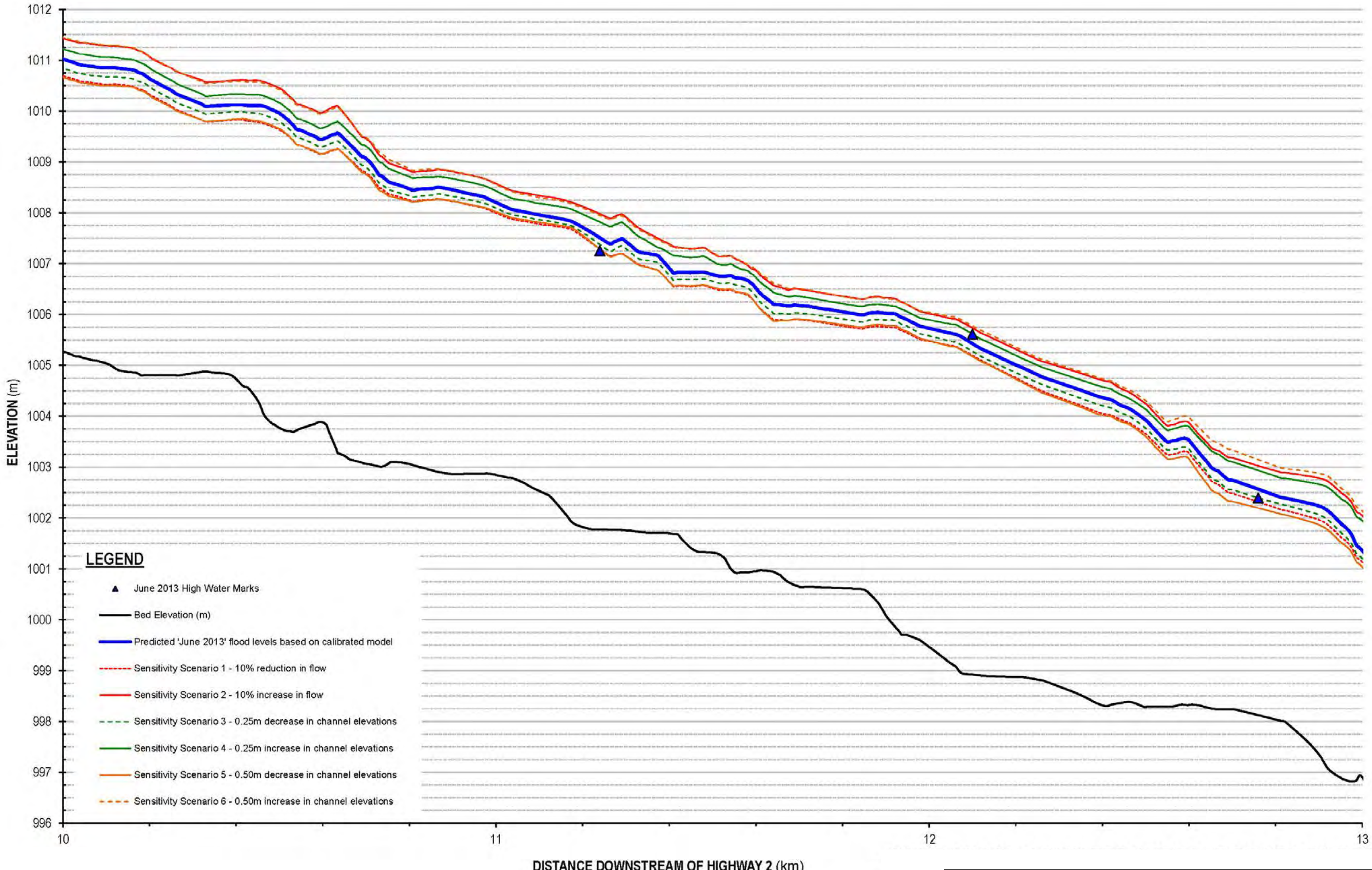
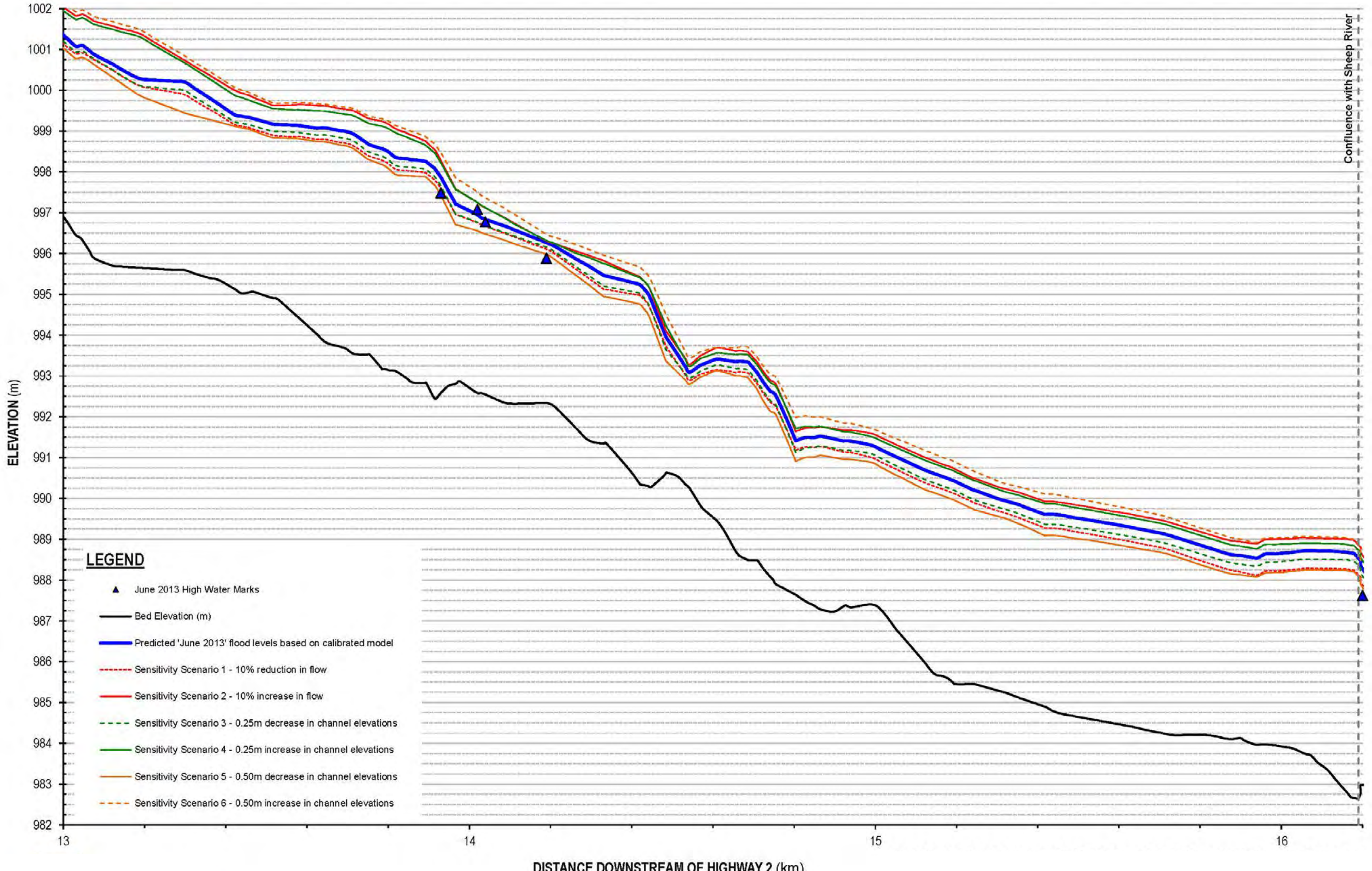
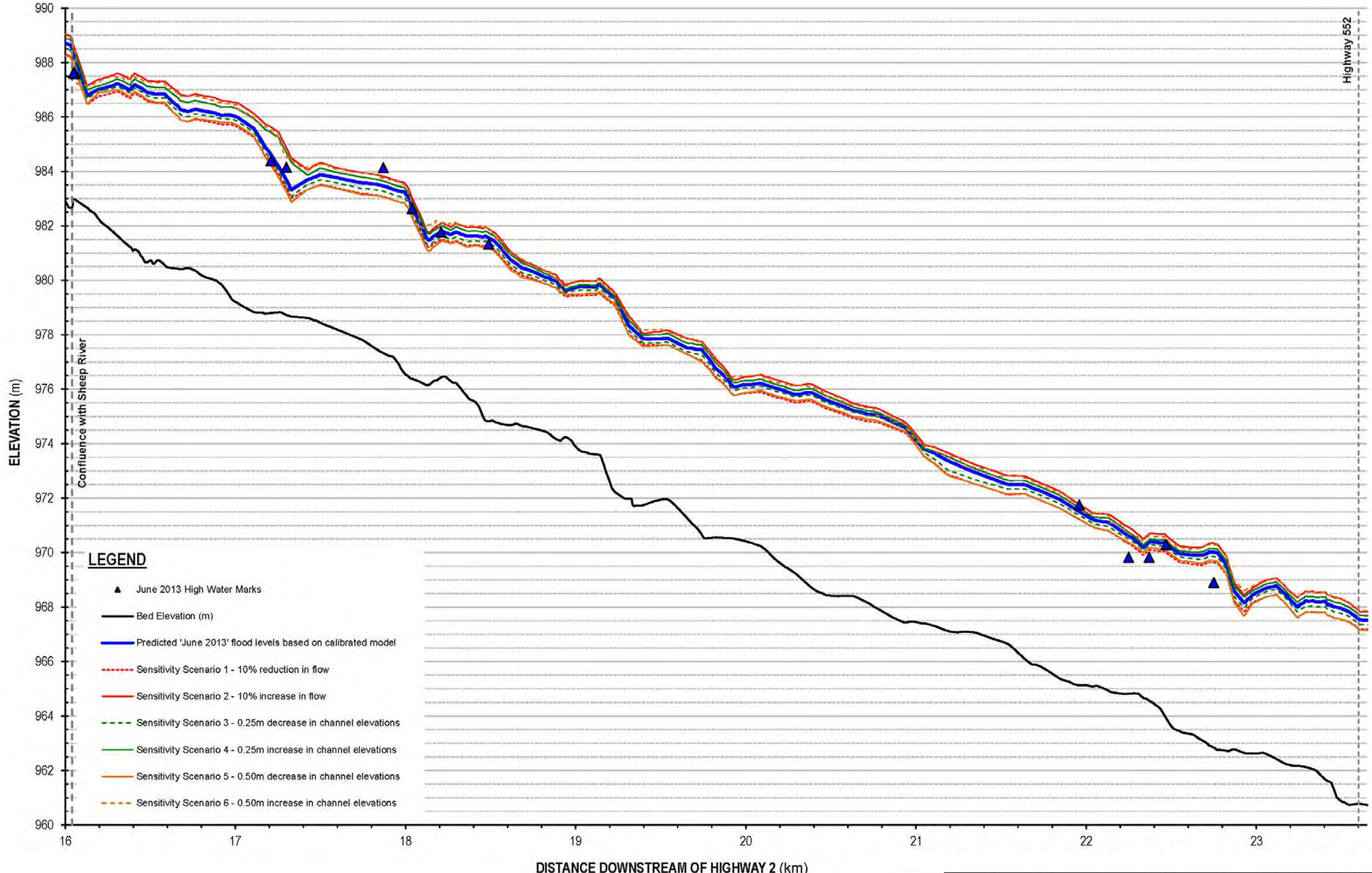


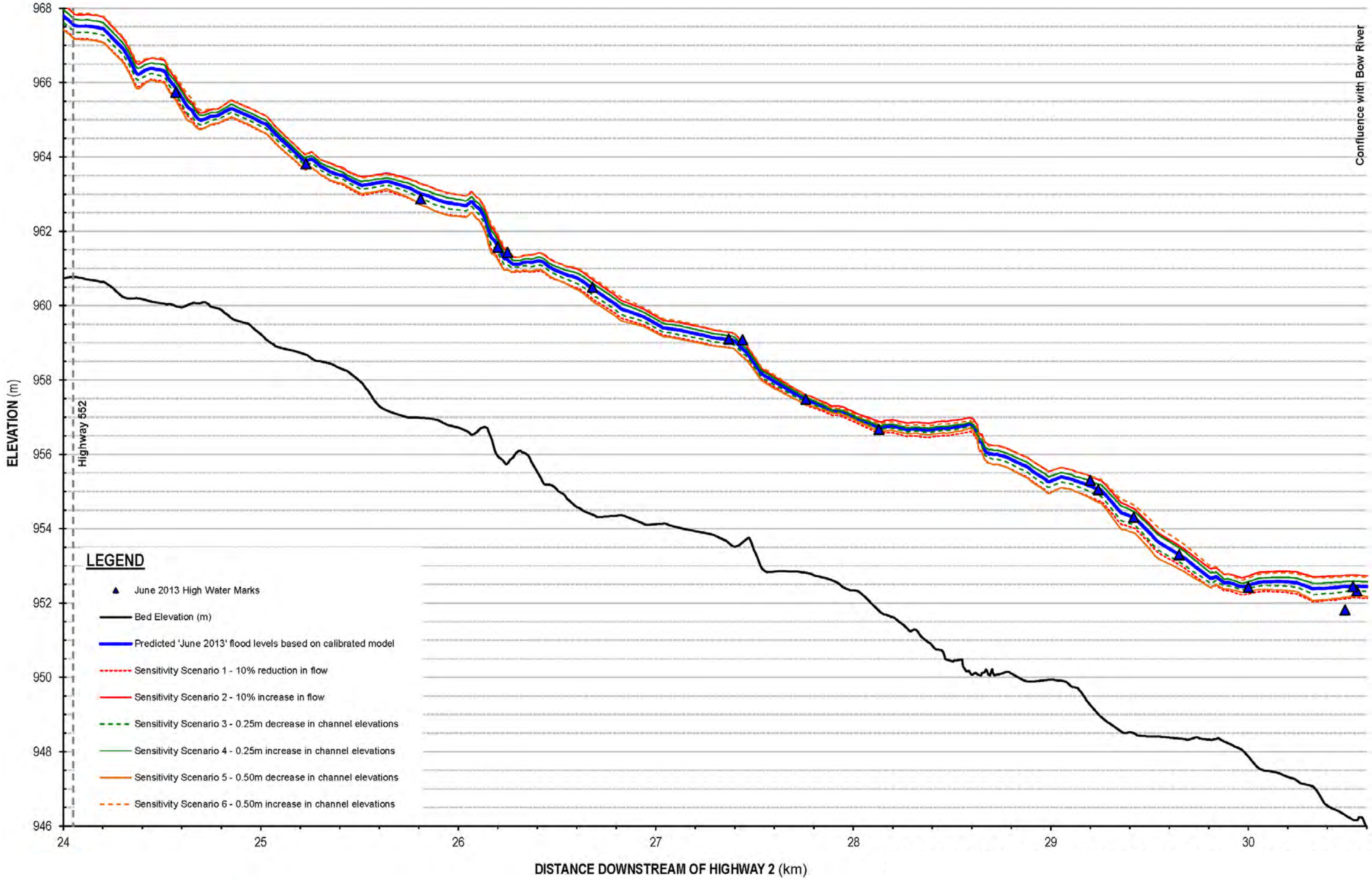
Municipal District of Foothills No. 31 – Highwood River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 [WSP Extent 3 of 6]				
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-19	Rev: 0
	Reviewed By: JB	*This figure is 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.*			



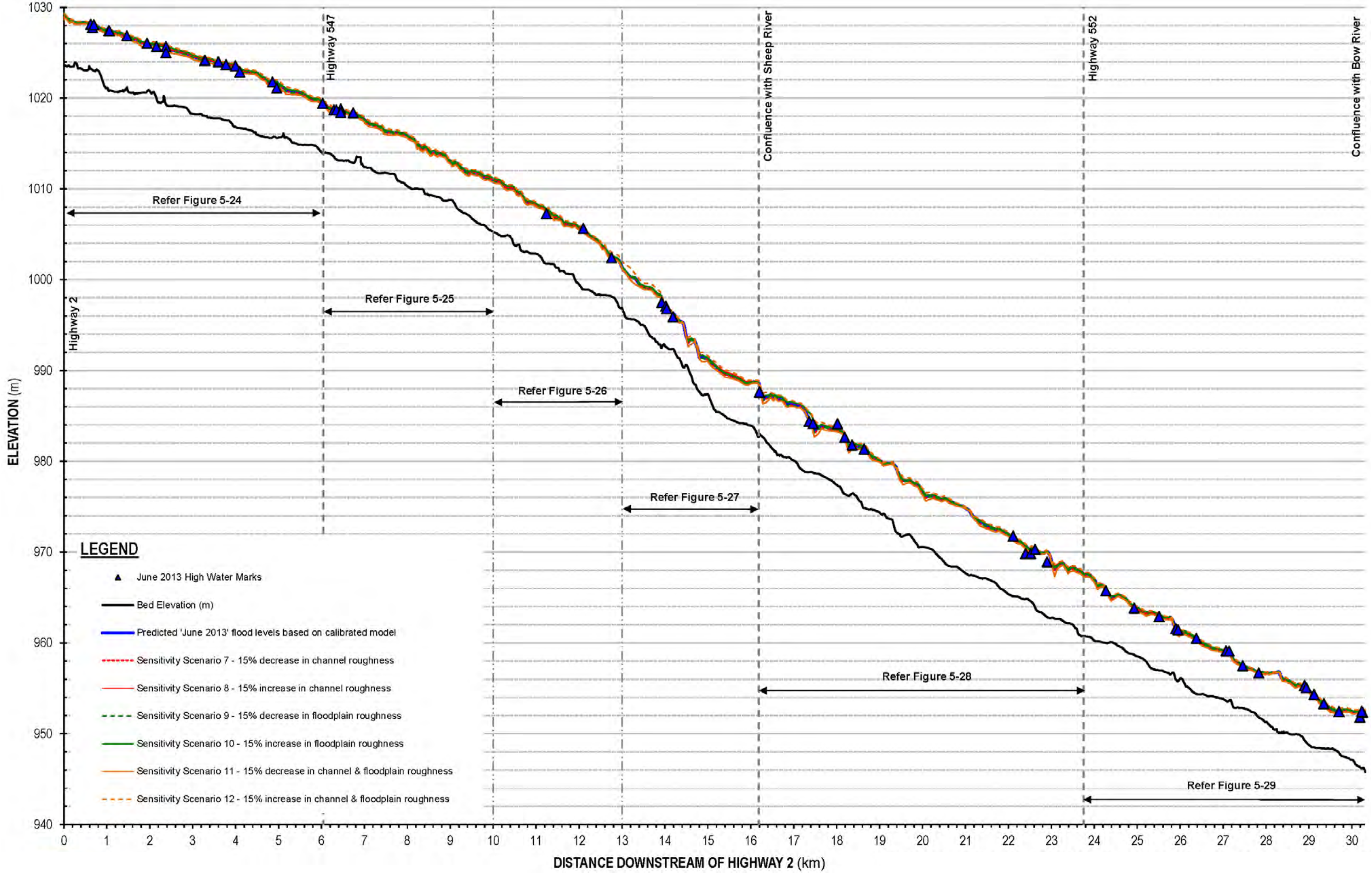
Municipal District of Foothills No. 31 – Highwood River Modelling				
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 [WSP Extent 4 of 6]				
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-20	Rev: 0
	Reviewed By: JB	*This figure is 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.*			



Advisian WorleyParsons Group	Created By: RG	**Municipal District of Foothills No. 31 – Highwood River Modelling**			
		Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 [WSP Extent 5 of 6]			
		Date: July 5, 2016	File Path:	Figure No: 5-21	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 – Highwood River Modelling		
Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 1 to 6 [WSP Extent 6 of 6]		
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016 / File Path: / Figure No: 5-22 / 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 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12
[Overview]

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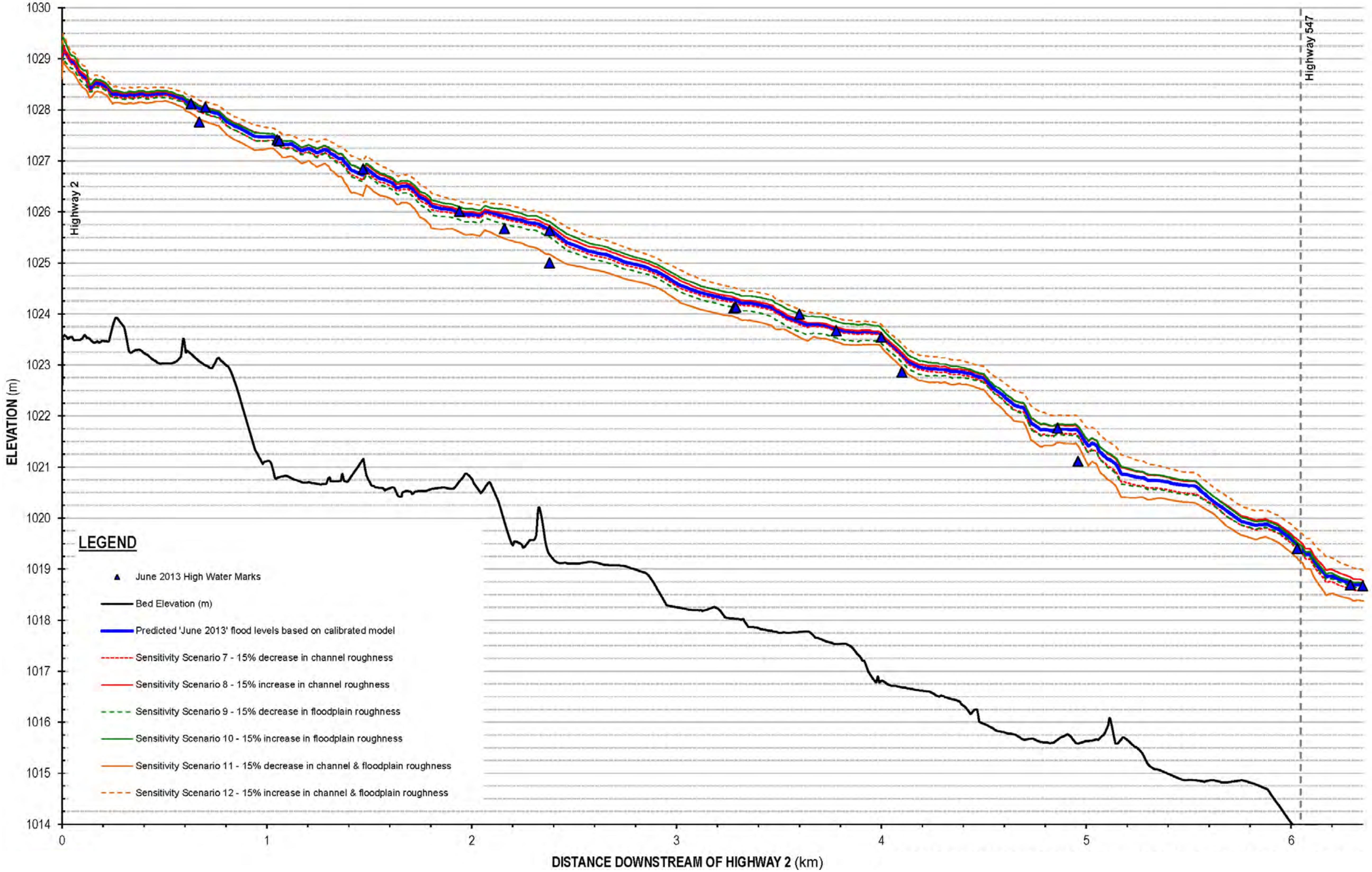
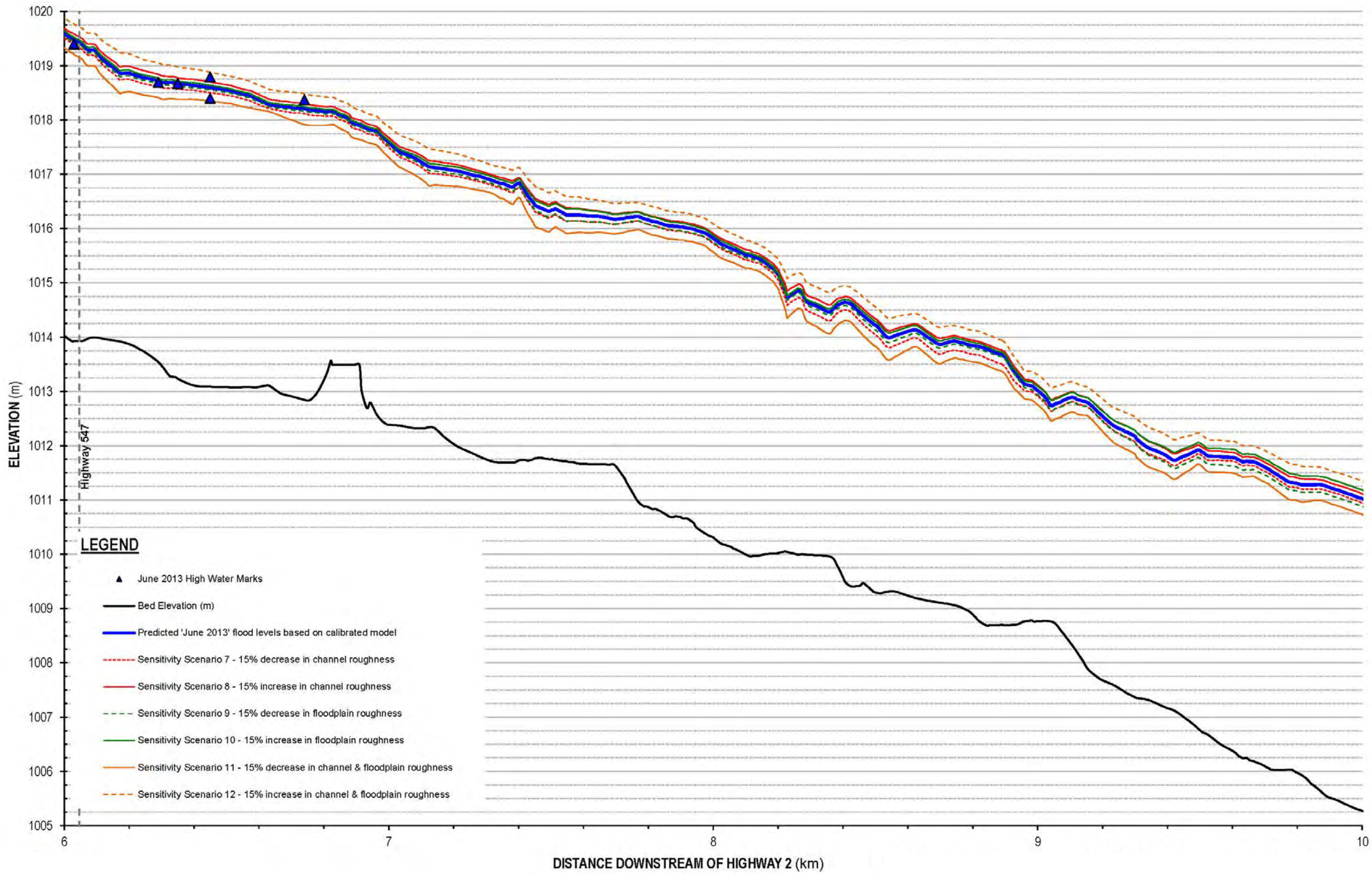


		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12 [WSP Extent 1 of 6]			
Advisian WorleyParsons Group	**Created By:** RG	**Date:** July 5, 2016	**File Path:**	**Figure No:** 5-24	**Rev:** 0
	Reviewed By: 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 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12
[WSP Extent 2 of 6]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-25	Rev: 0
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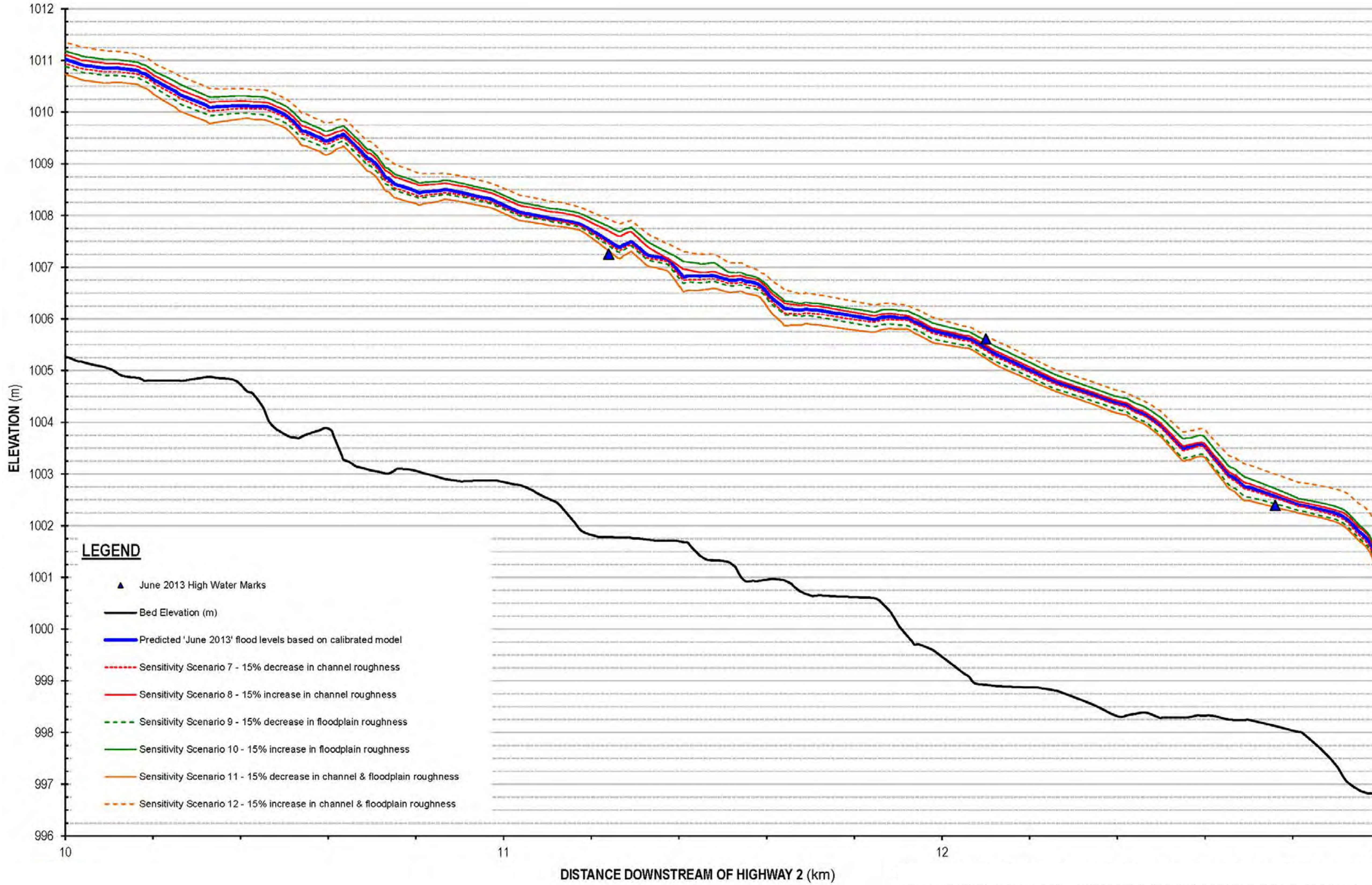

Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12
[WSP Extent 3 of 6]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-26	Rev: 0
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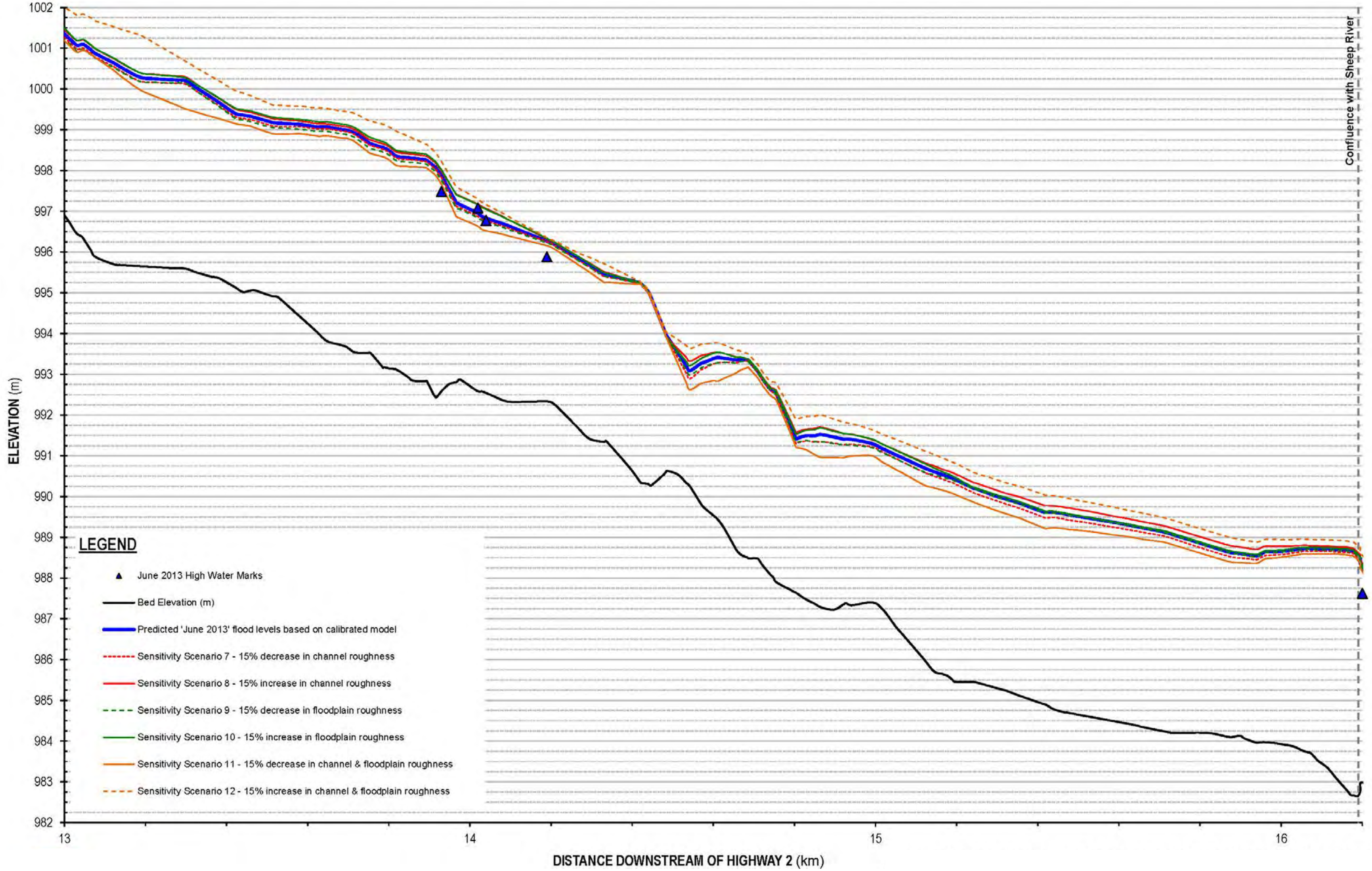

Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12
[WSP Extent 4 of 6]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-27	Rev: 0
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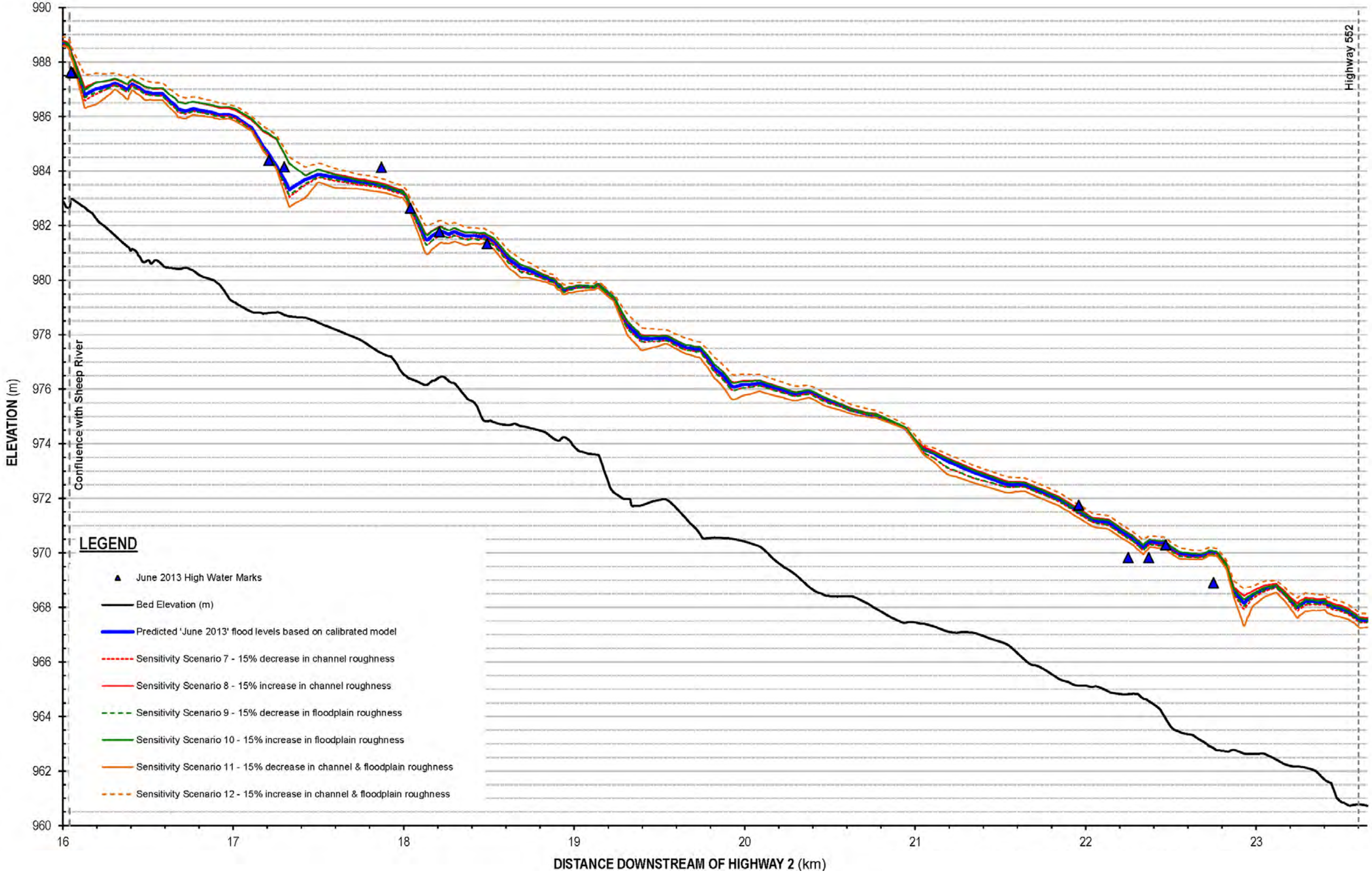

Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12
[WSP Extent 5 of 6]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-28	Rev: 0
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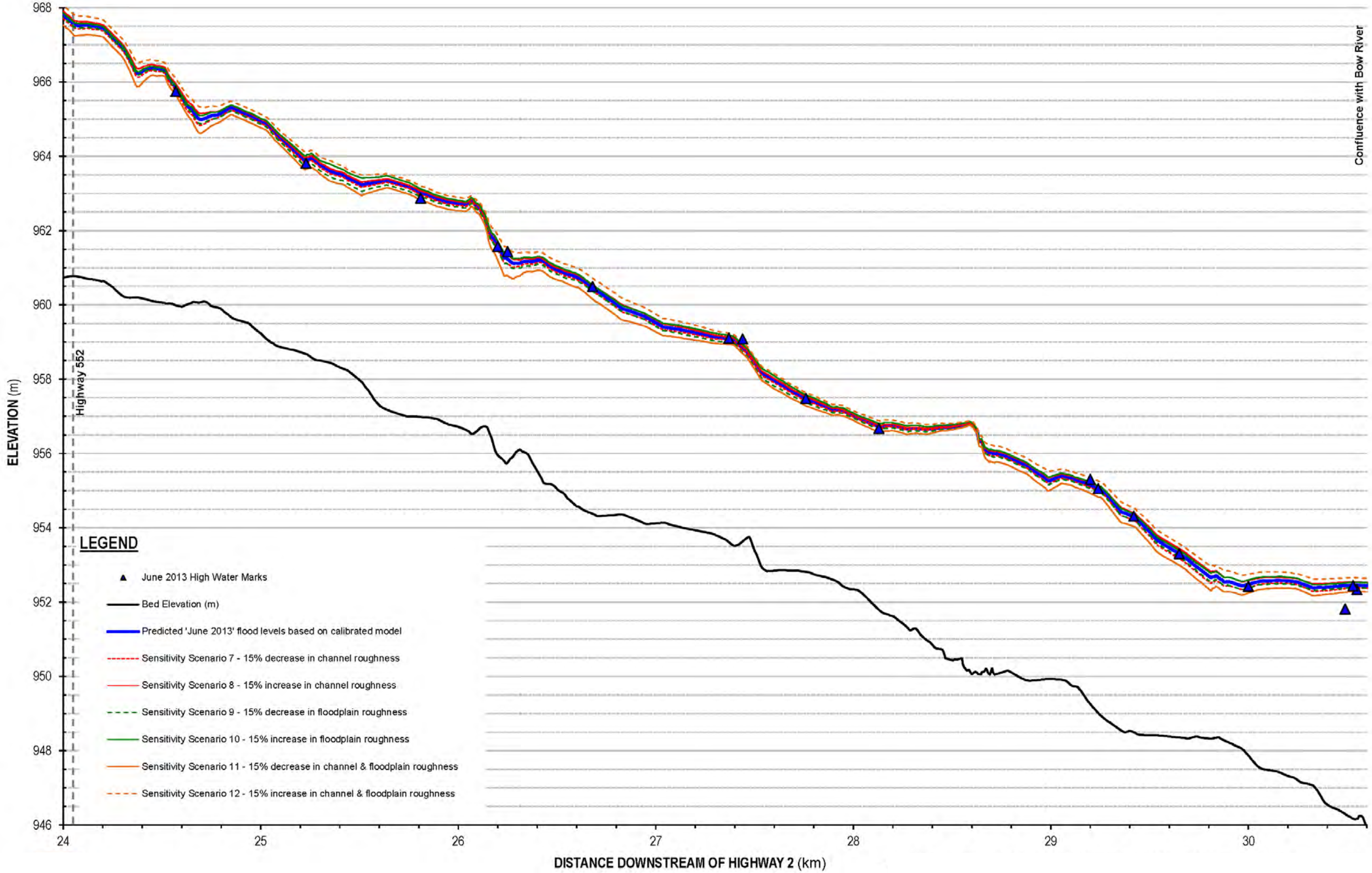

Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Water Surface Profiles for Adopted Sensitivity Scenarios 7 to 12
[WSP Extent 6 of 6]

Advisian
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Created By: RG	Date: July 5, 2016	File Path:		Figure No: 5-29	Rev: 0
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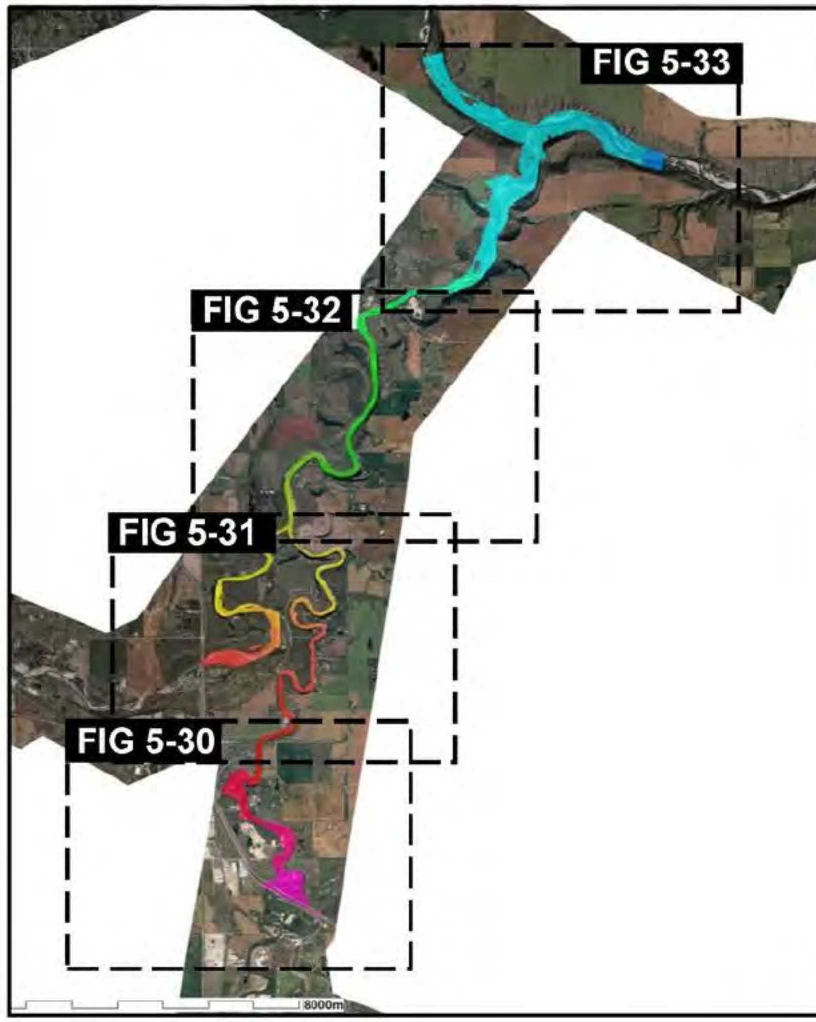
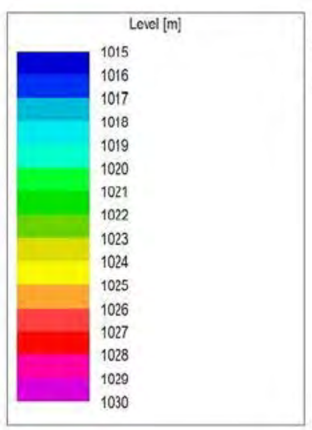
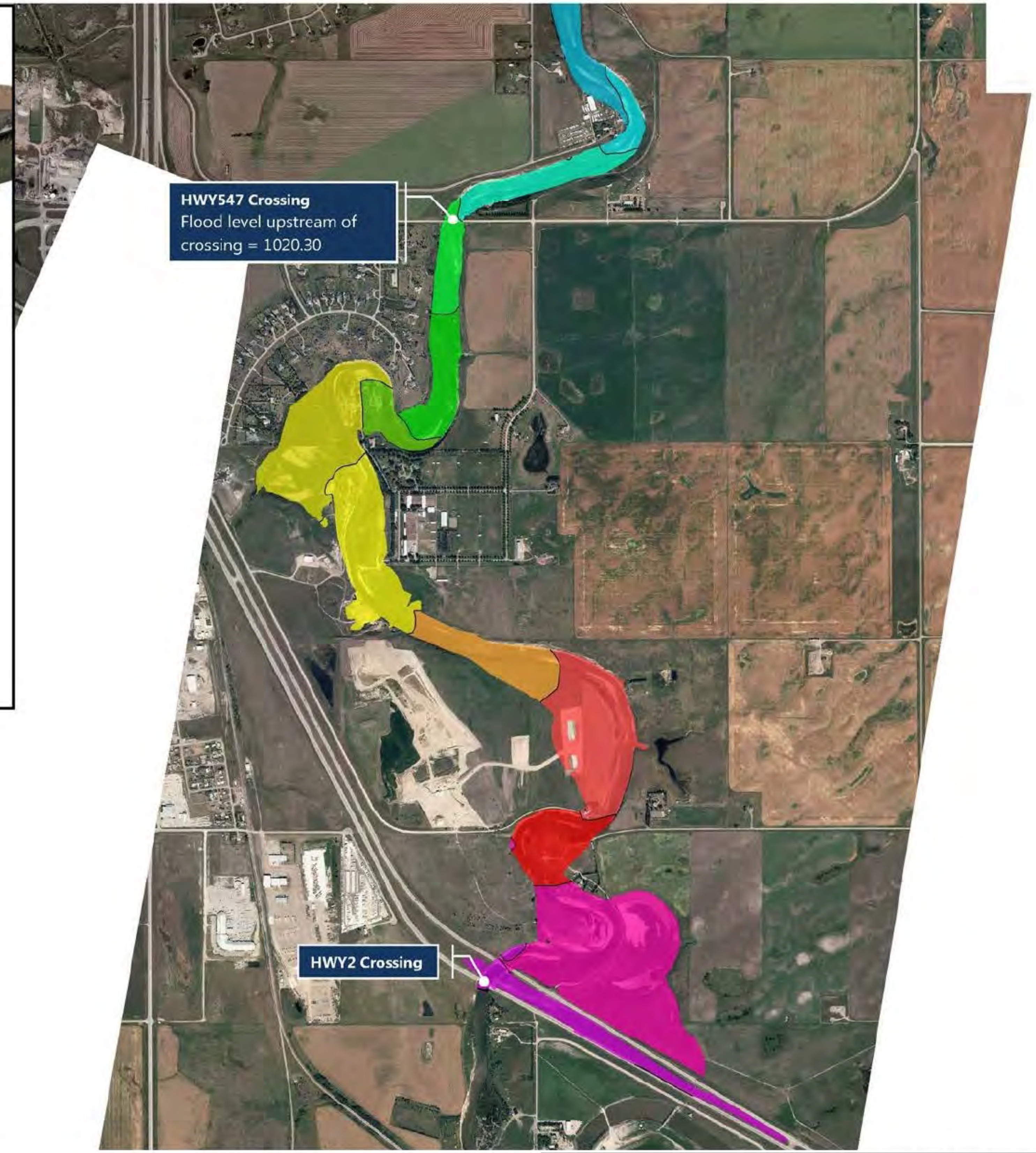




NOTE:

Flood level contours shown at 1 metre intervals



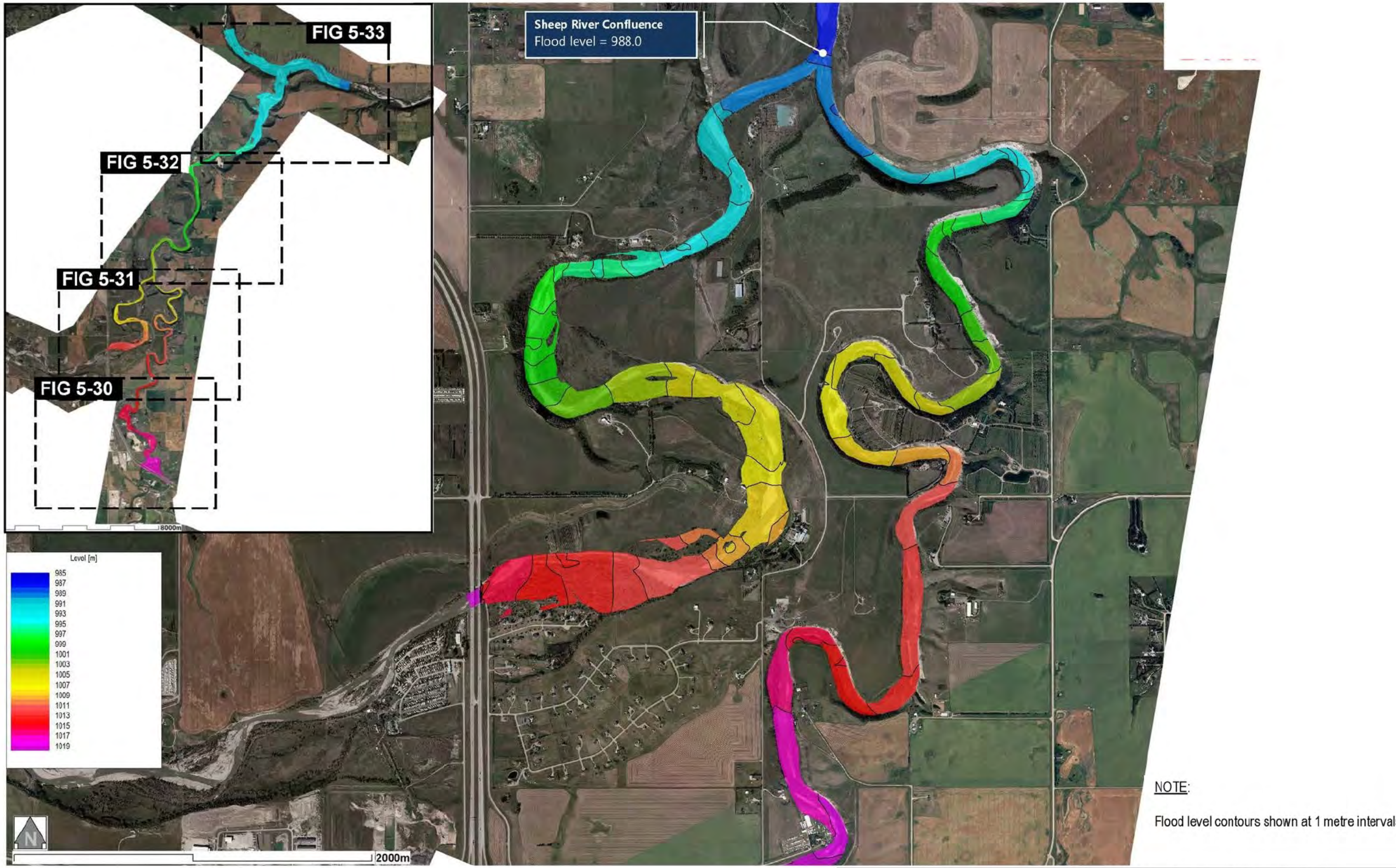
N

2000m

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Flood Levels at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 1 of 4]

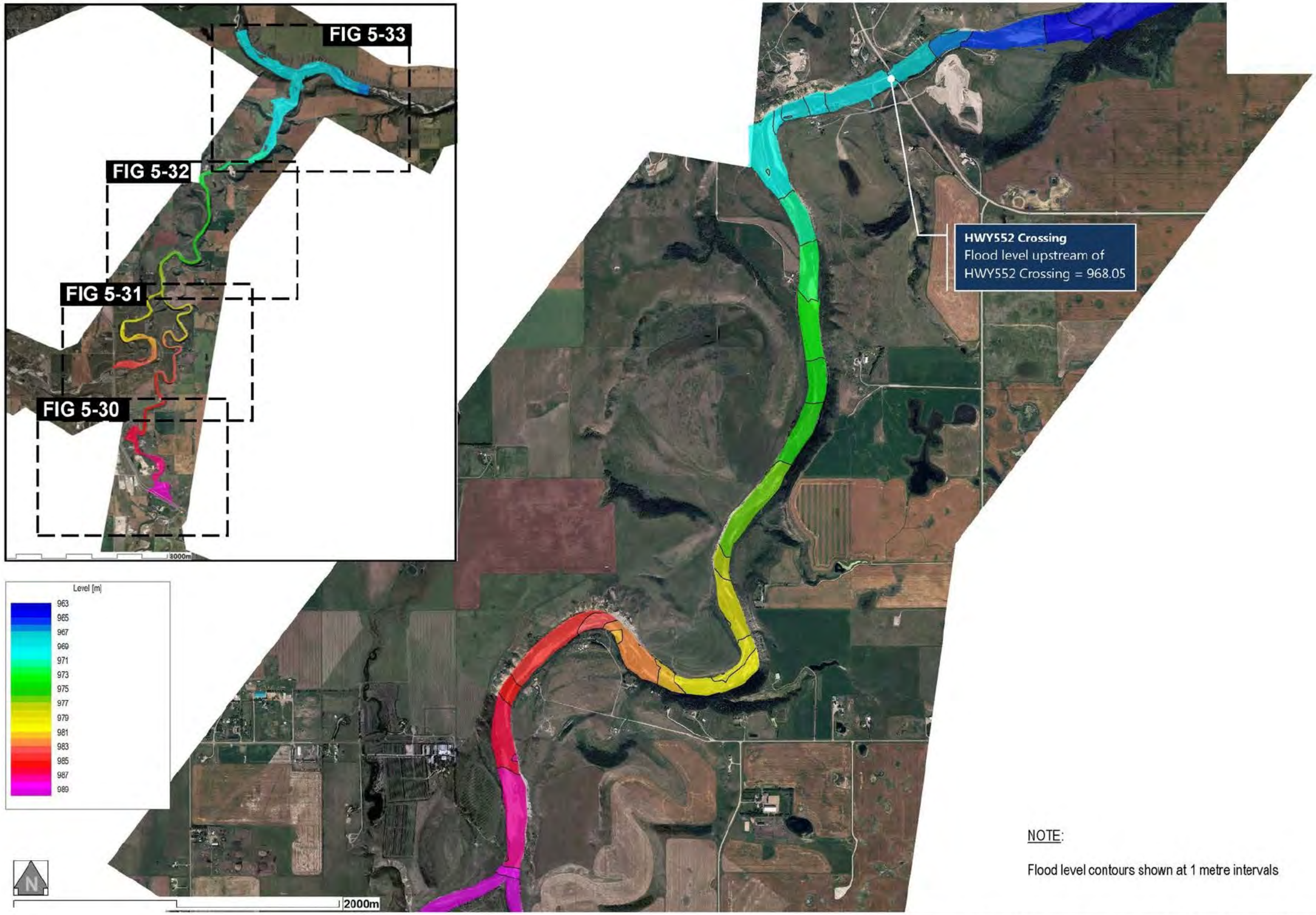
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-30	Rev: 0
	Reviewed By: JB	*This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) WorleyParsons has exercised reasonable skill, care, and diligence to 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.*			



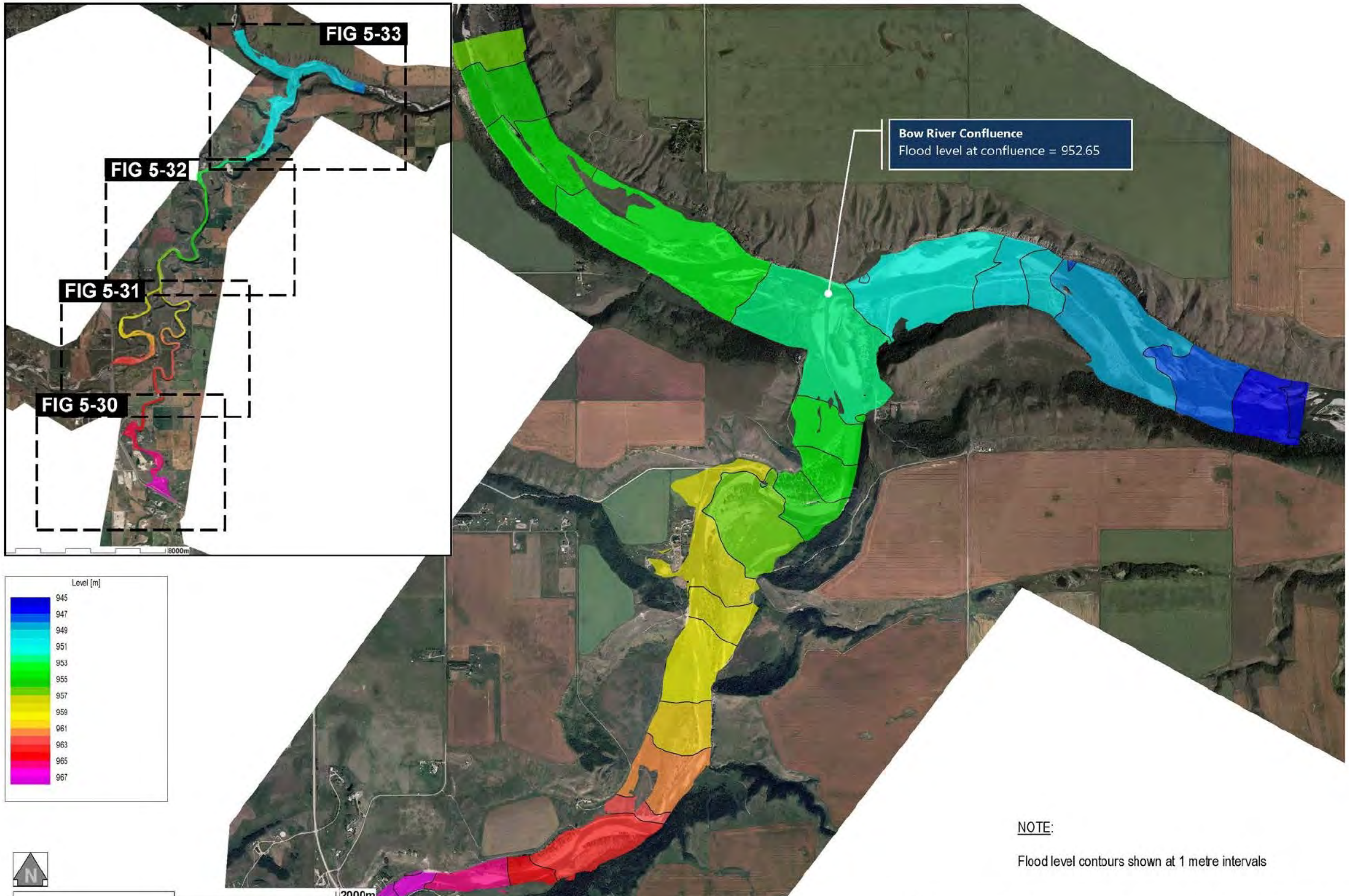
Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Flood Levels at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 2 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-31	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.*			



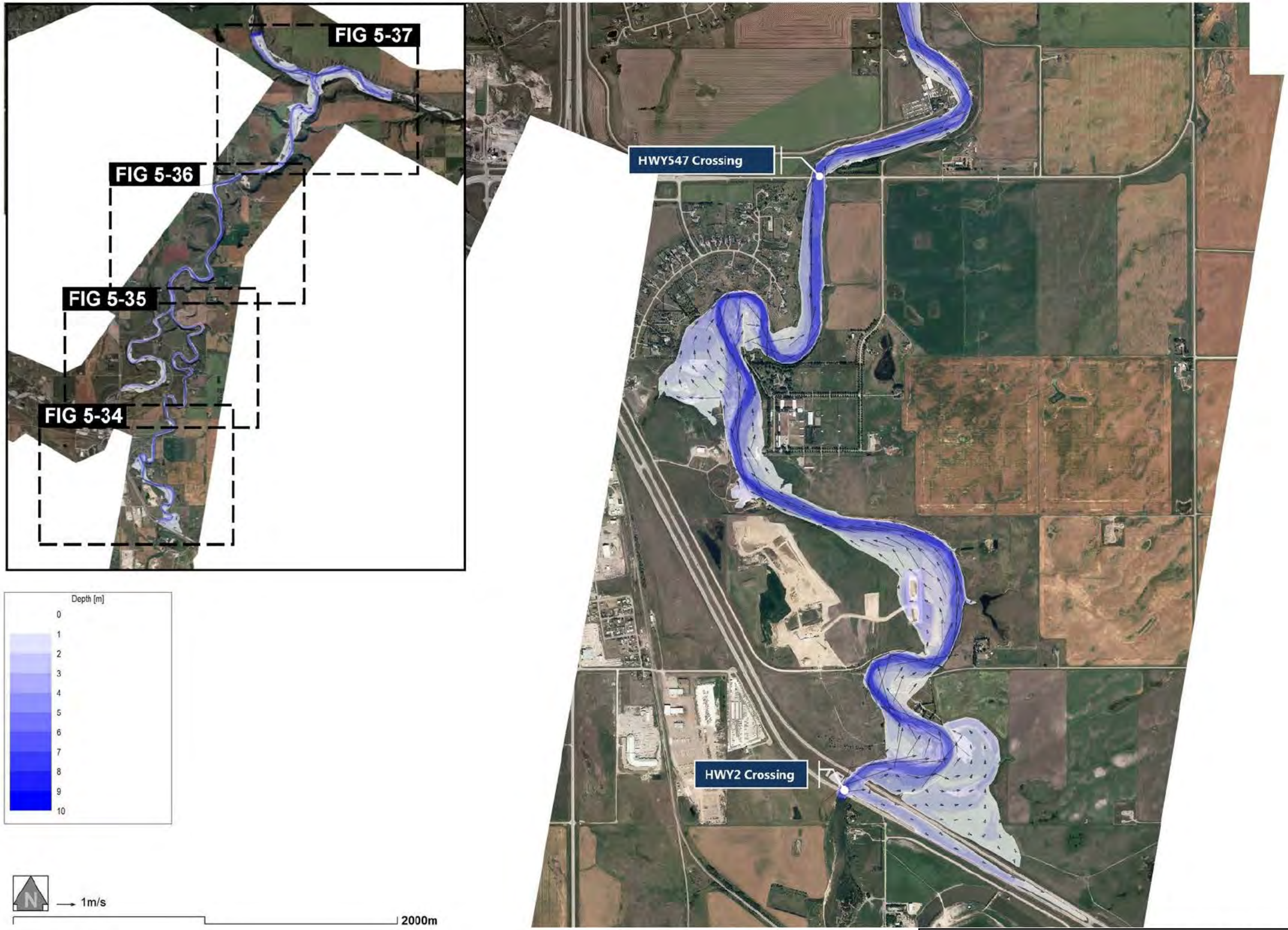
		Municipal District of Foothills No. 31 – Highwood River Modelling			
		Predicted Flood Levels at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 3 of 4]			
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-32	Rev: 0
	Reviewed 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.*			



NOTE:

Flood level contours shown at 1 metre intervals

Municipal District of Foothills No. 31 – Highwood River Modelling					
Predicted Flood Levels at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 4 of 4]					
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-33	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 – Highwood River Modelling

Predicted Depths & Velocities at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 1 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-34	Rev: 0
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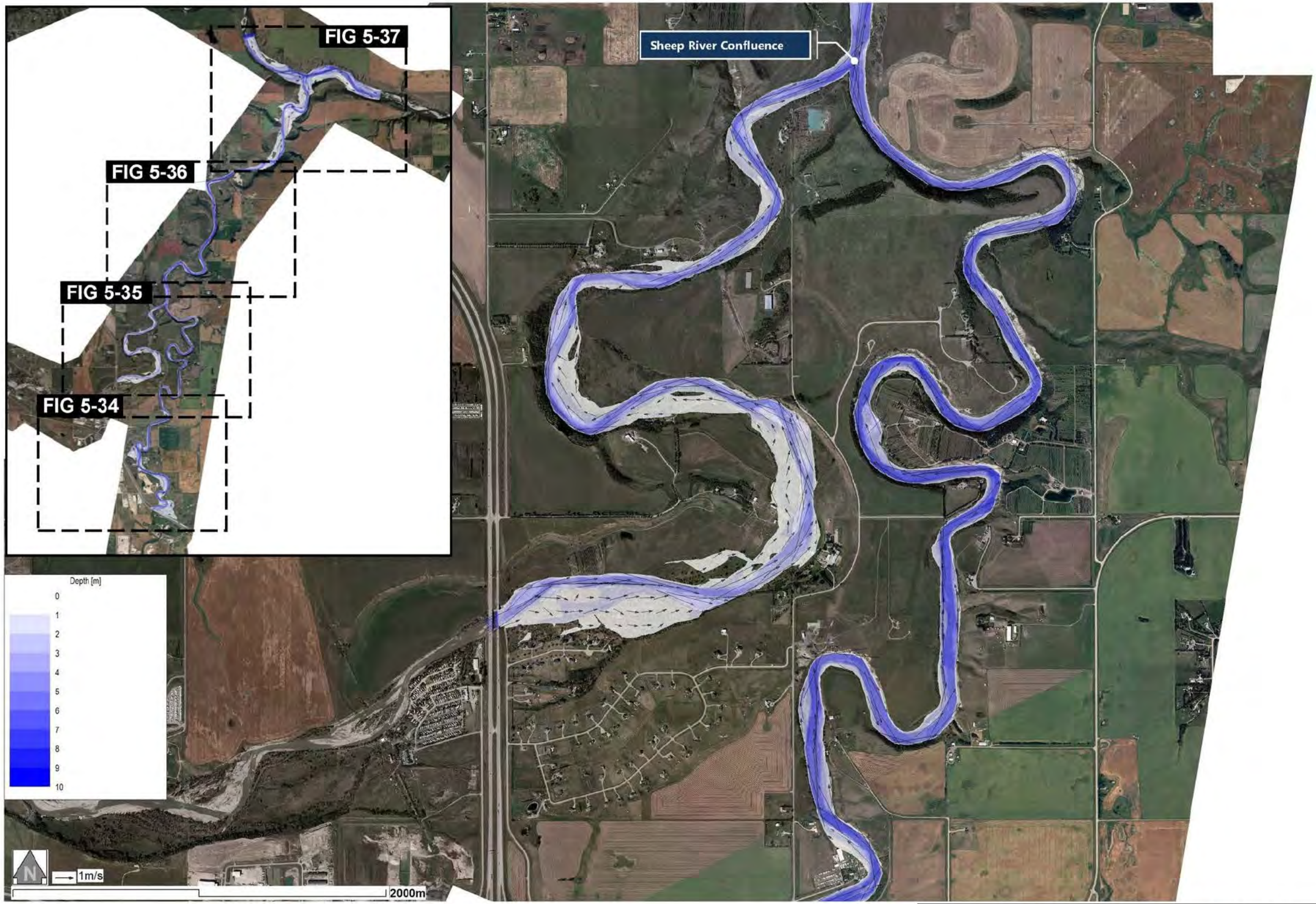
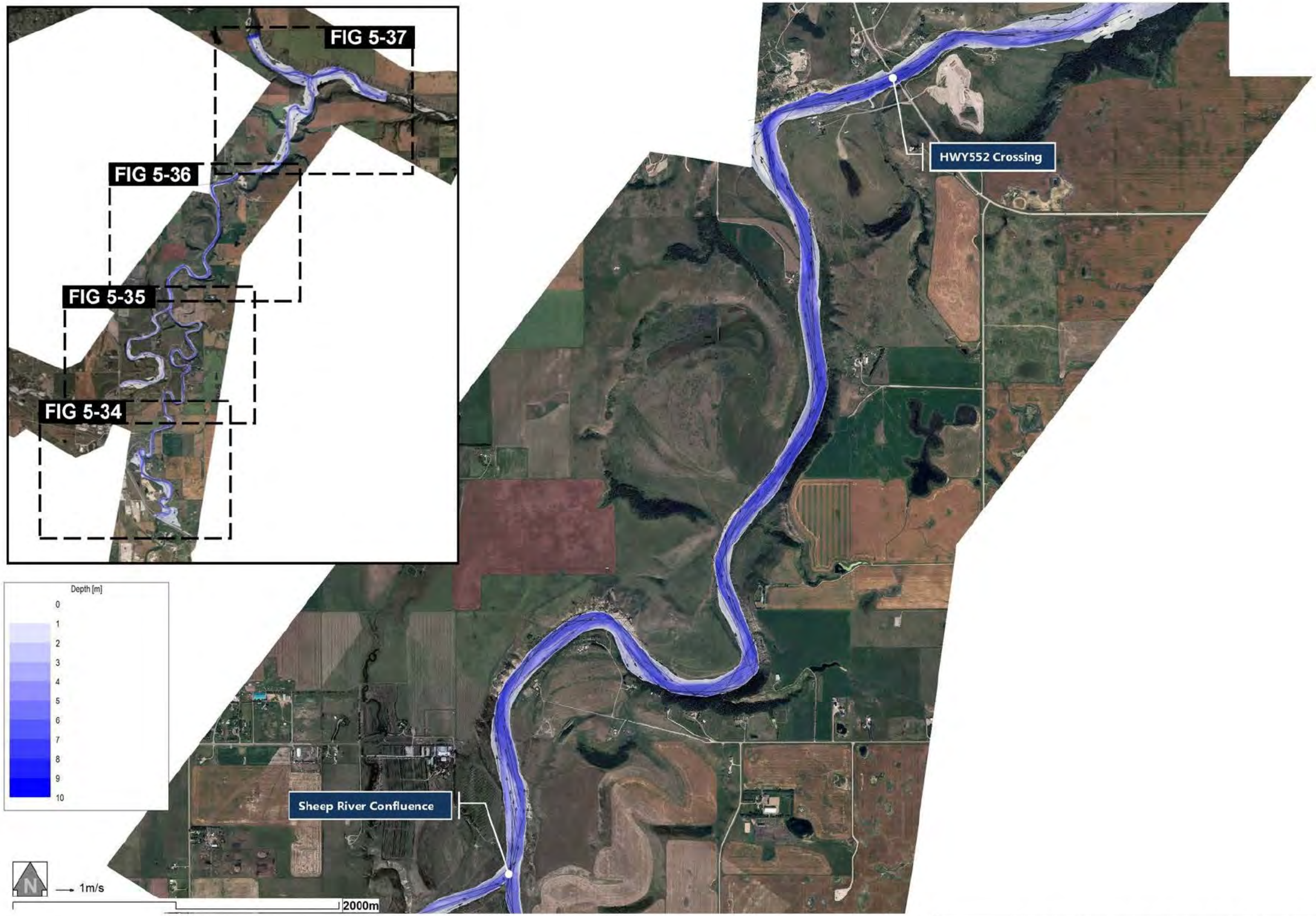


Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Depths & Velocities at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 2 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-35	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 – Highwood River Modelling

Predicted Depths & Velocities at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 3 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-36	Rev: 0
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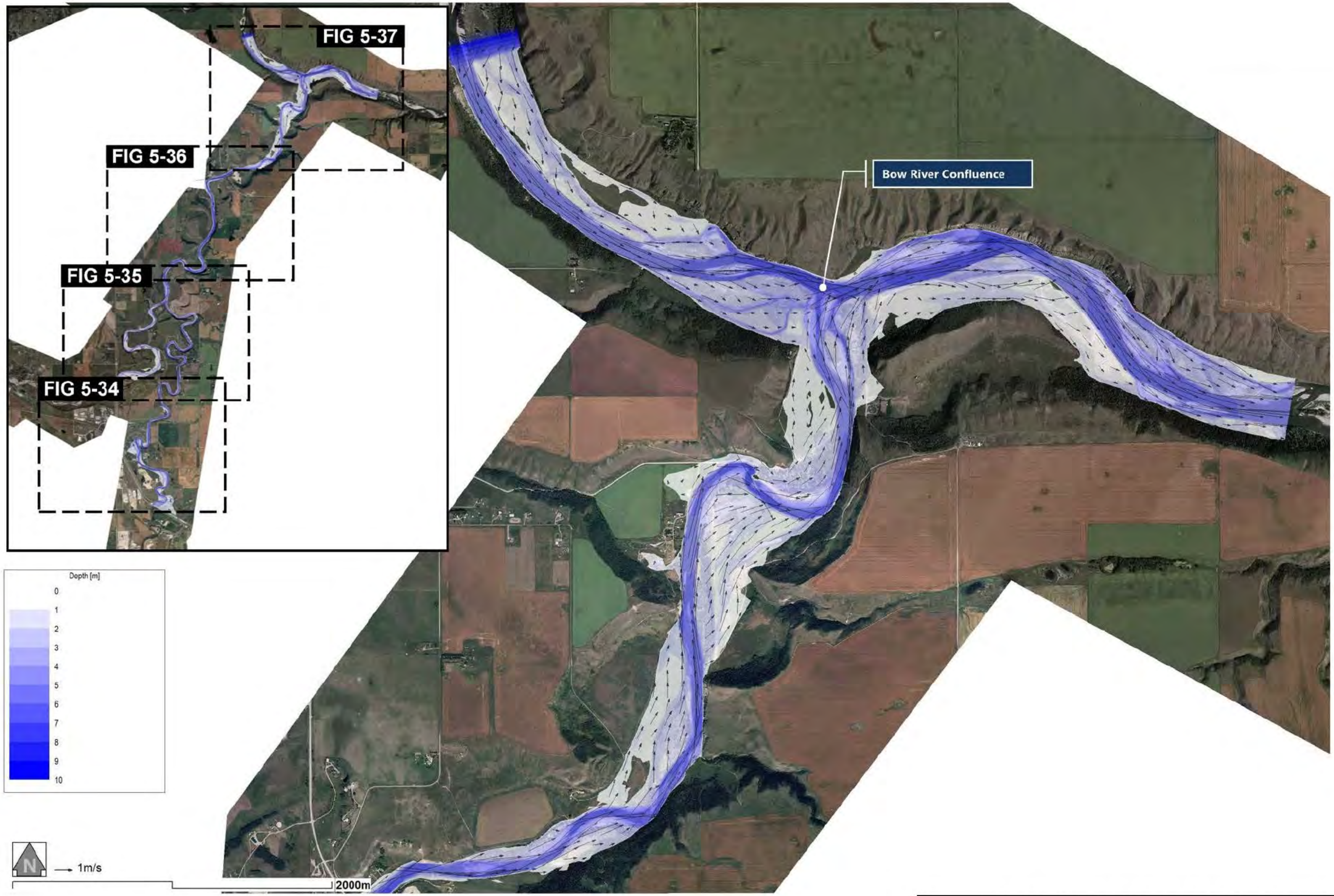

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Depths & Velocities at the Peak of a 'June 2013 – 1,820m³/s' Flood Under Post Mitigation Scenario 28A [Figure Extent 4 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-37	Rev: 0
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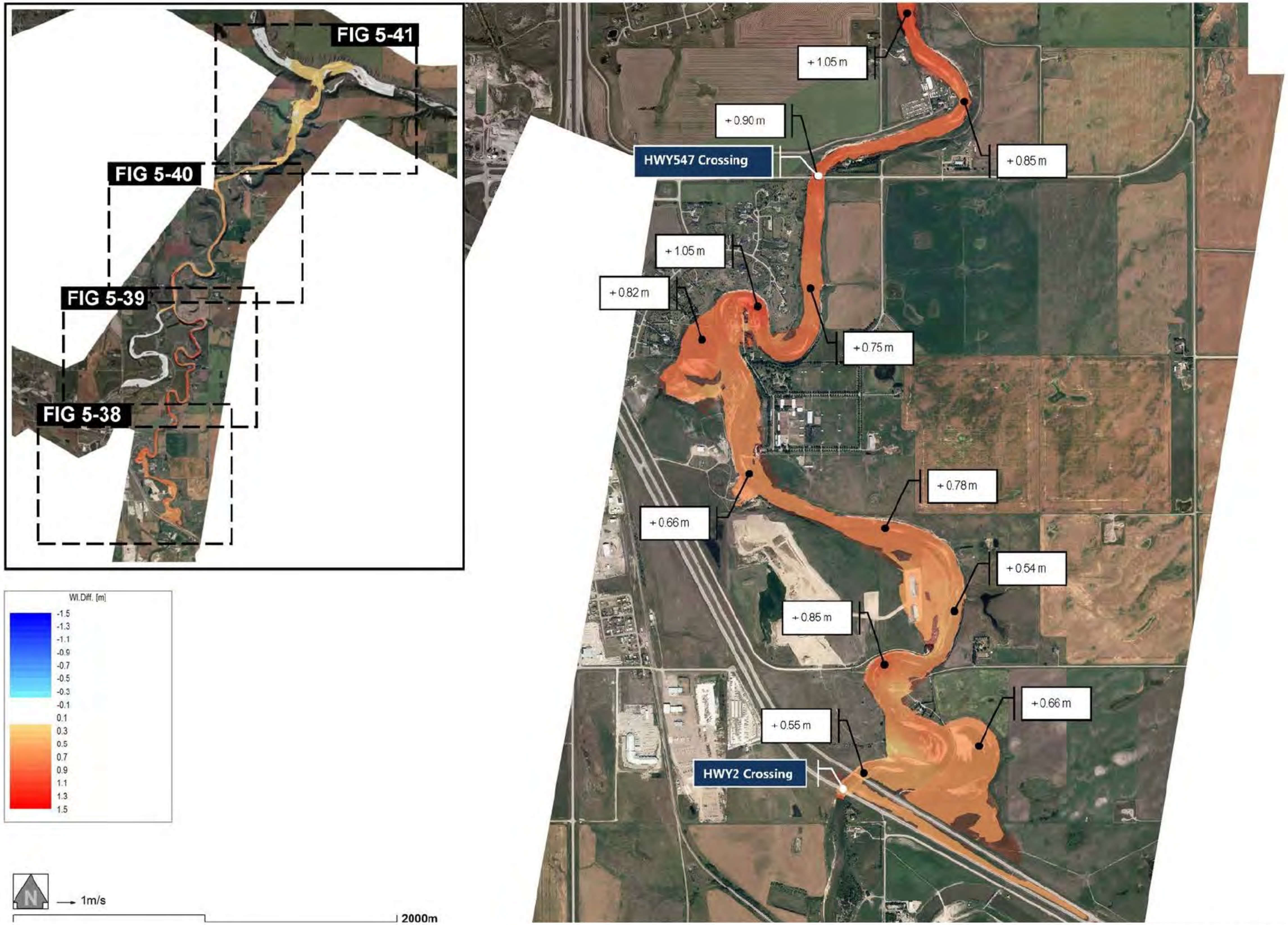
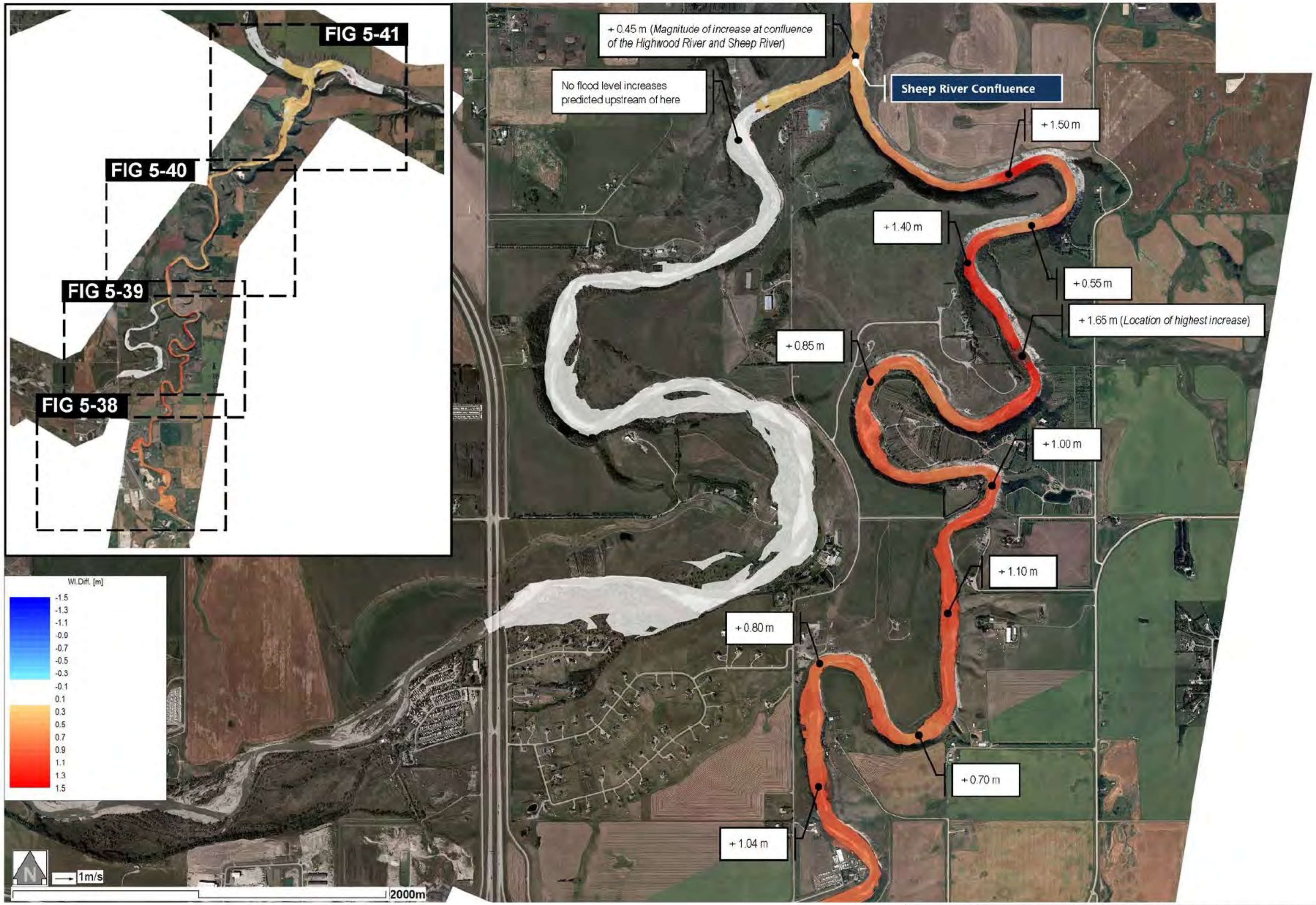


Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of Post Mitigation Scenario 28A [Figure Extent 1 of 4]

Advisian WorleyParsons Group	**Created By:** RG	**Date:** July 5, 2016	**File Path:**	**Figure No:** 5-38	**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 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of Post Mitigation Scenario 28A [Figure Extent 2 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-39	Rev: 0
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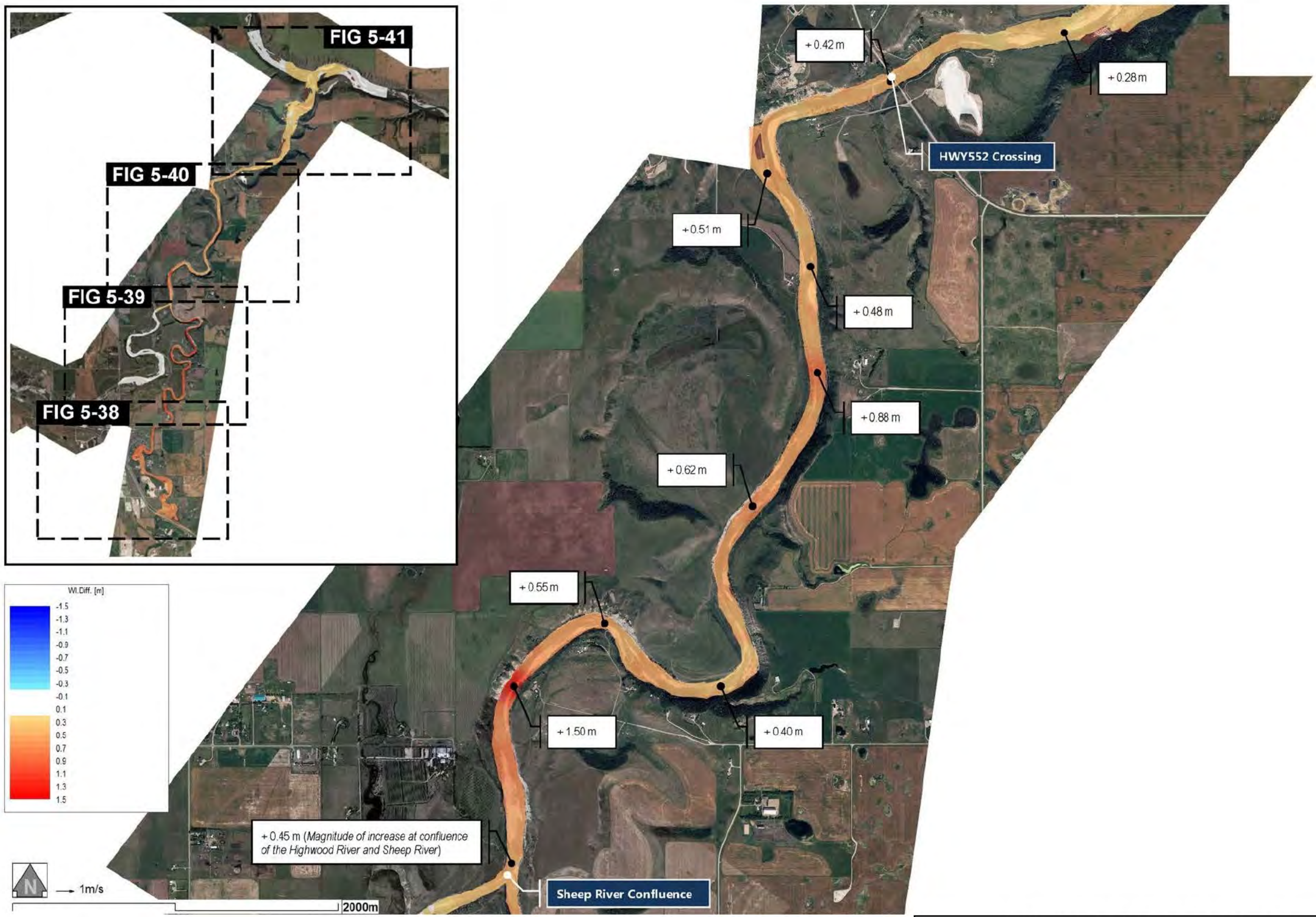
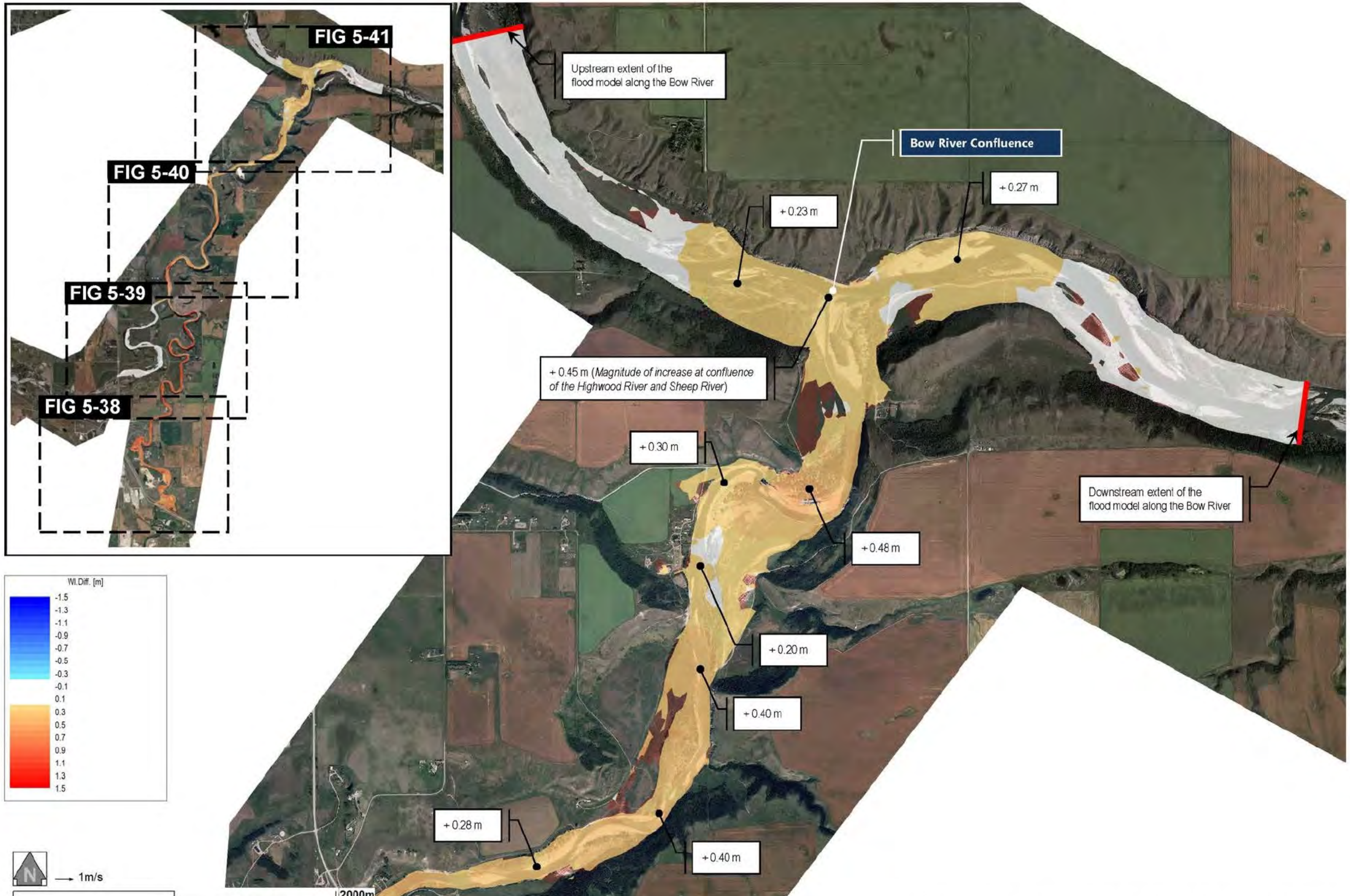
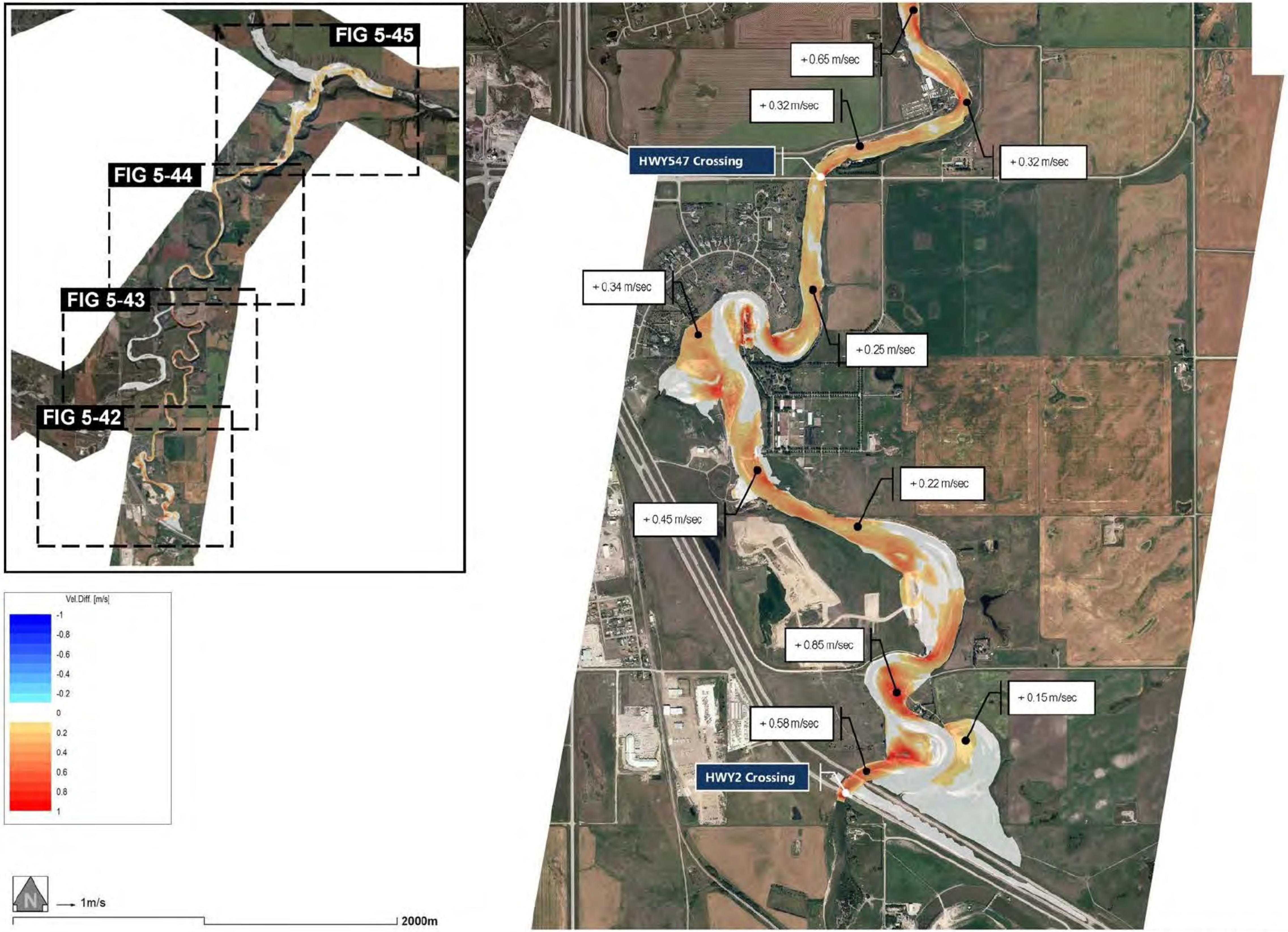


Municipal District of Foothills No. 31 – Highwood River Modelling				
Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of Post Mitigation Scenario 28A [Figure Extent 3 of 4]				
Advisian WorleyParsons Group	**Created By:** RG	**Date:** July 5, 2016	**File Path:**	**Figure No:** 5-40 **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 – Highwood River Modelling			
		Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flood Levels as a Result of Post Mitigation Scenario 28A [Figure Extent 4 of 4]			
Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-41	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.*			



Advisian WorleyParsons Group	Created By: RG Reviewed By: JB	**Municipal District of Foothills No. 31 – Highwood River Modelling** **Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flow Velocities as a Result of Post Mitigation Scenario 28A** [Figure Extent 1 of 4]

Date:	File Path:	Figure No:	Rev:
July 5, 2016		5-42	0

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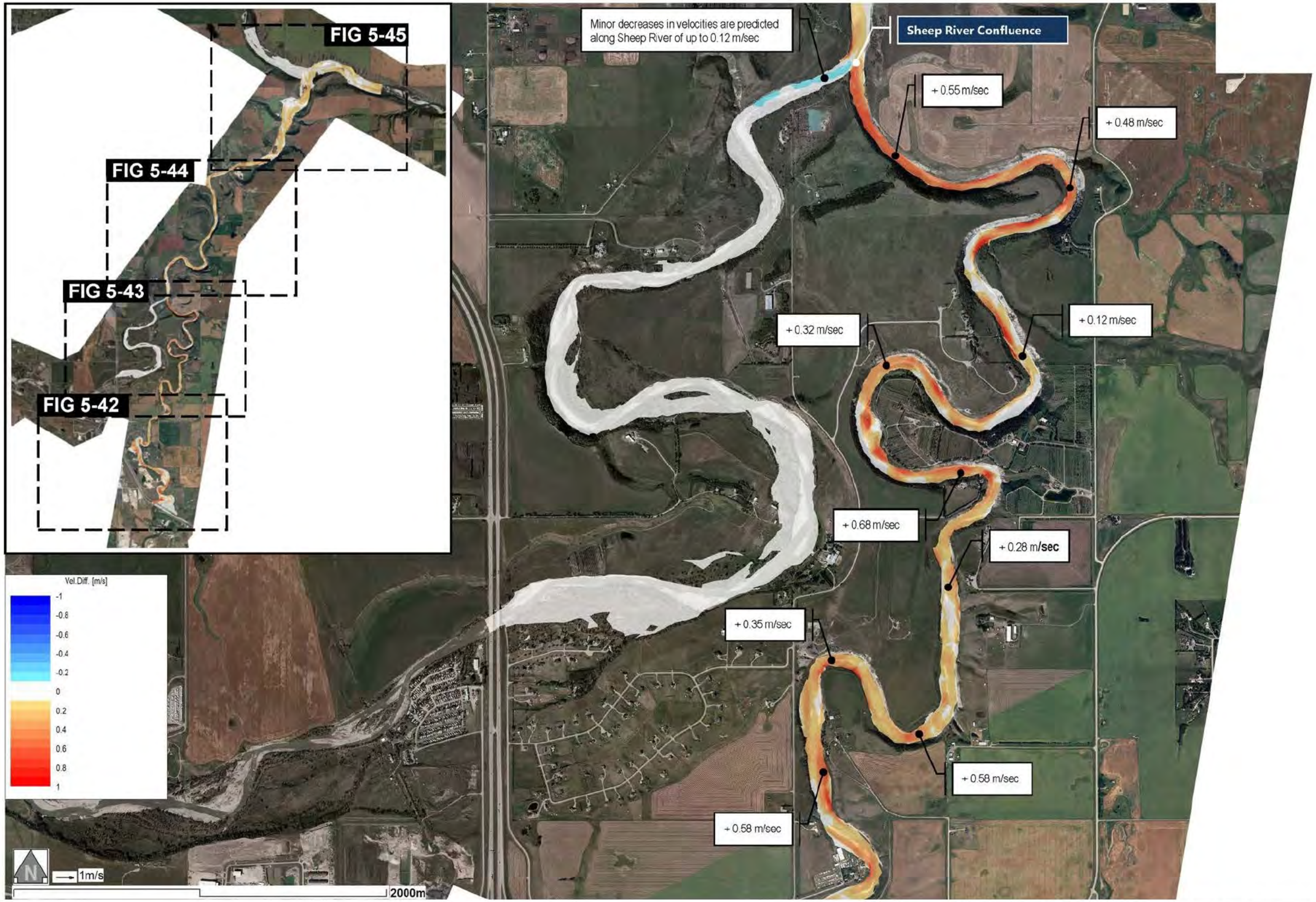

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flow Velocities as a Result of Post Mitigation Scenario 28A [Figure Extent 2 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-43	Rev: 0
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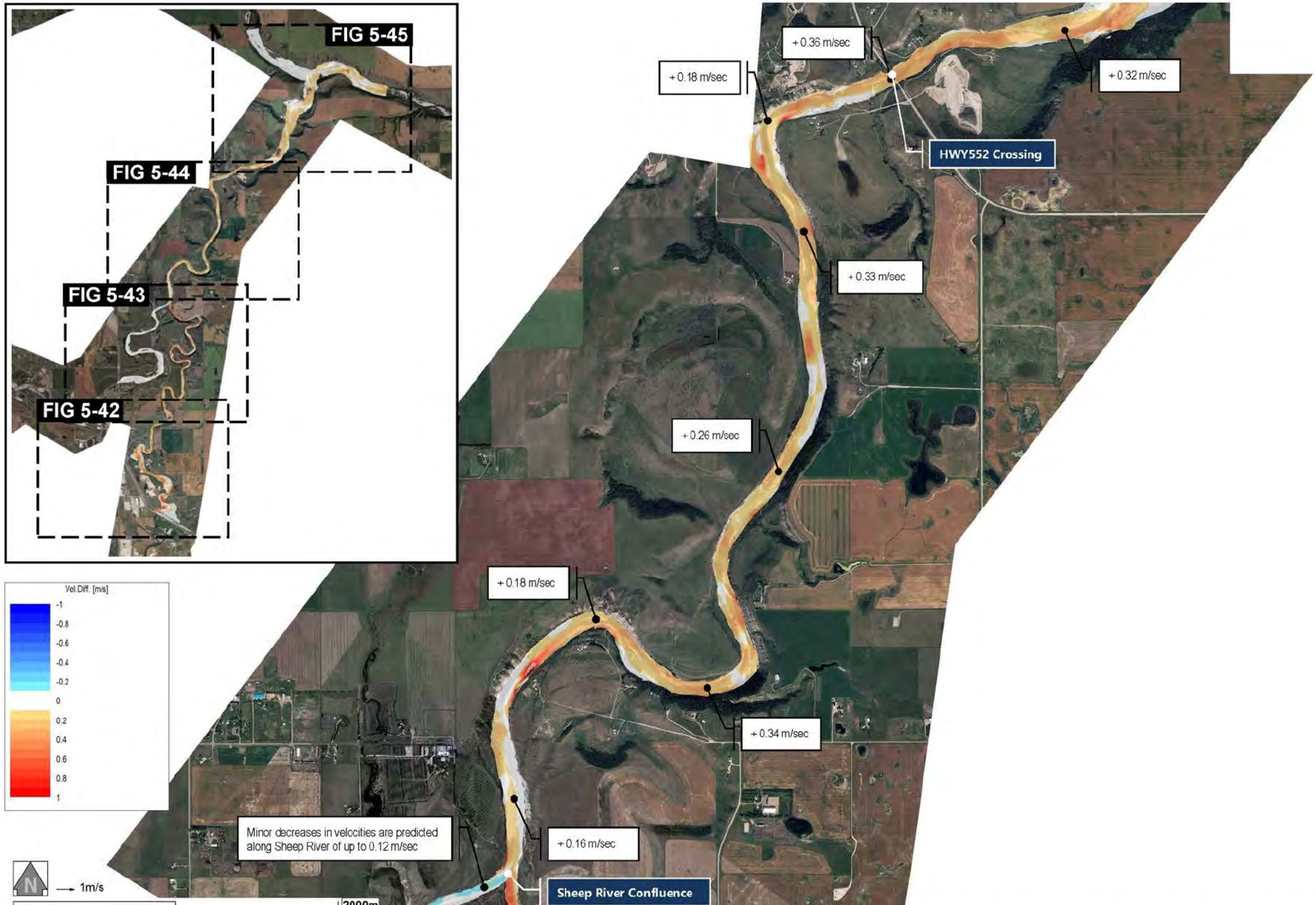

Municipal District of Foothills No. 31 – Highwood River Modelling

Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flow Velocities as a Result of Post Mitigation Scenario 28A [Figure Extent 3 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-44	Rev: 0
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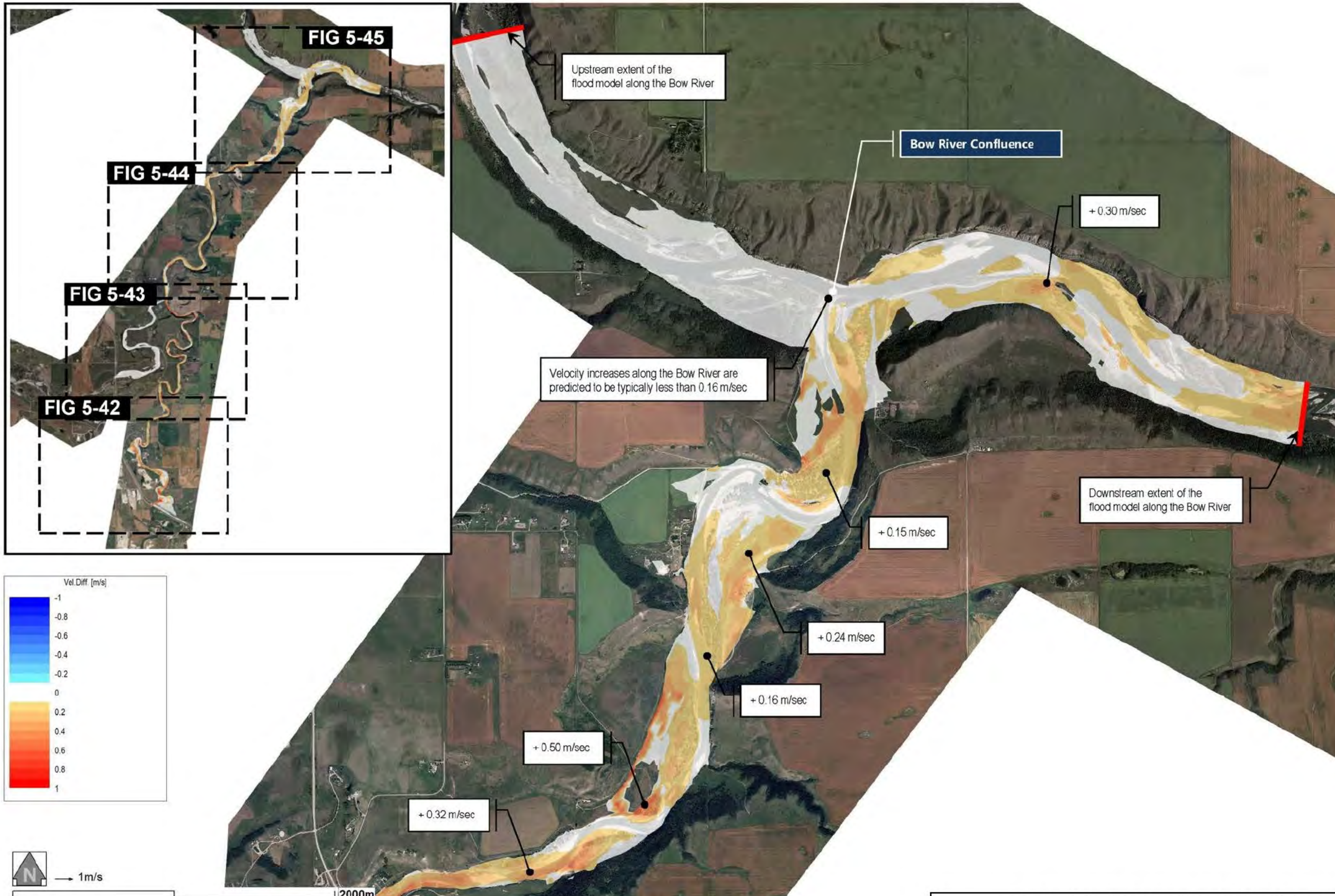
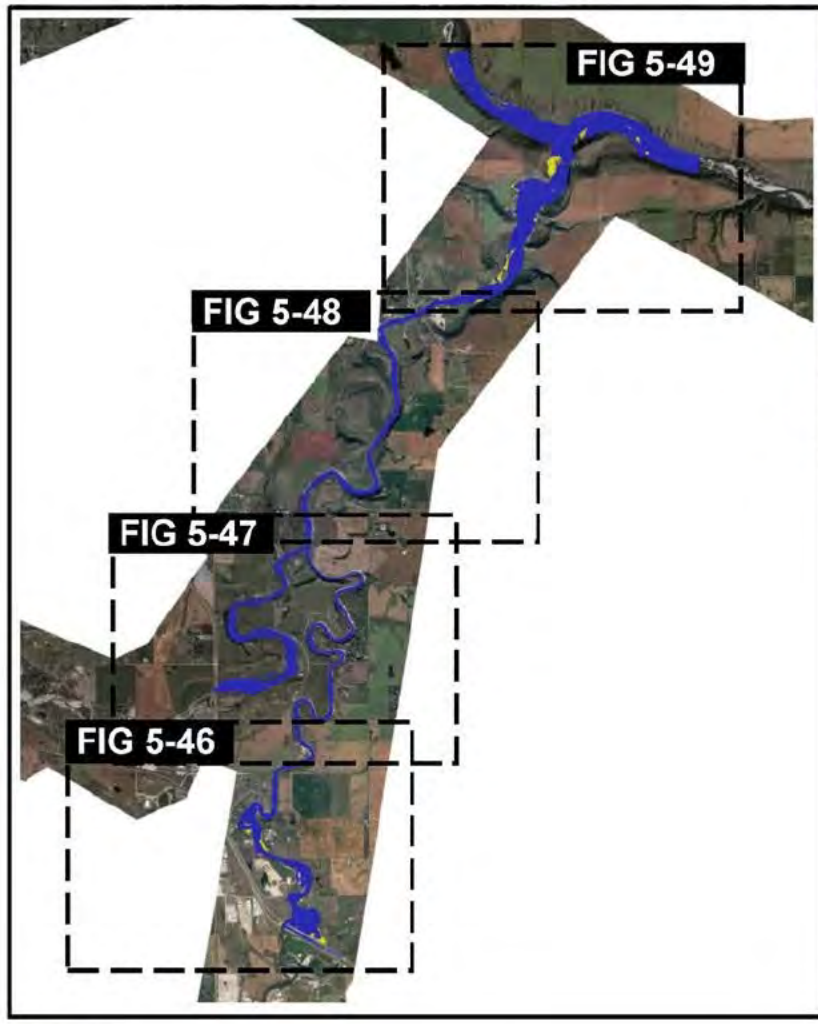


Municipal District of Foothills No. 31 – Highwood River Modelling				
Predicted Changes in Peak 'June 2013 – 1,820m³/s' Flow Velocities as a Result of Post Mitigation Scenario 28A [Figure Extent 4 of 4]				
Advisian WorleyParsons Group	**Created By:** RG	**Date:** July 5, 2016	**File Path:**	**Figure No:** 5-45 **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.*		

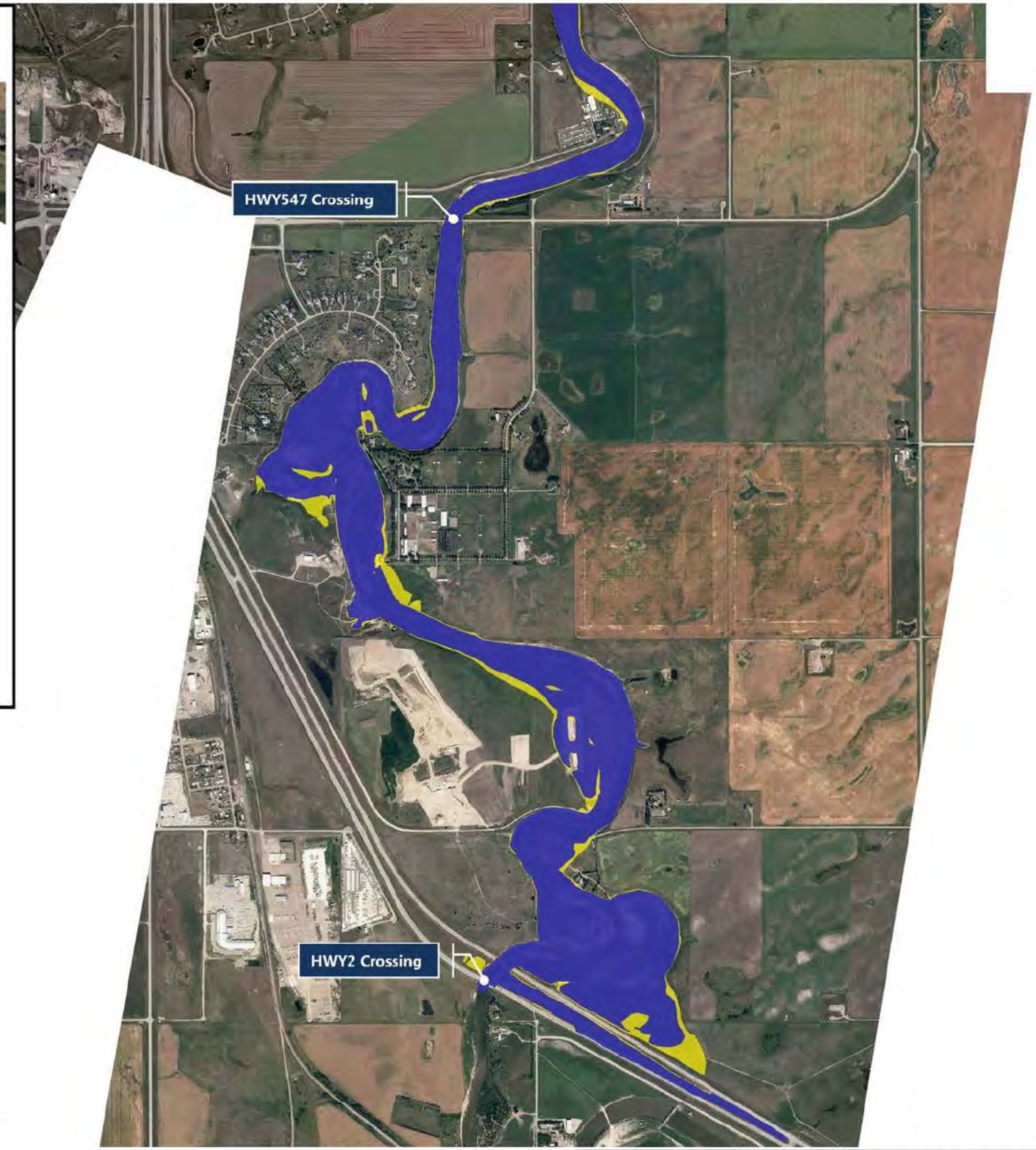


LEGEND:

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

N

2000m



Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 1,820m³/s' Flood Extents
[Figure Extent 1 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-46	Rev: 0
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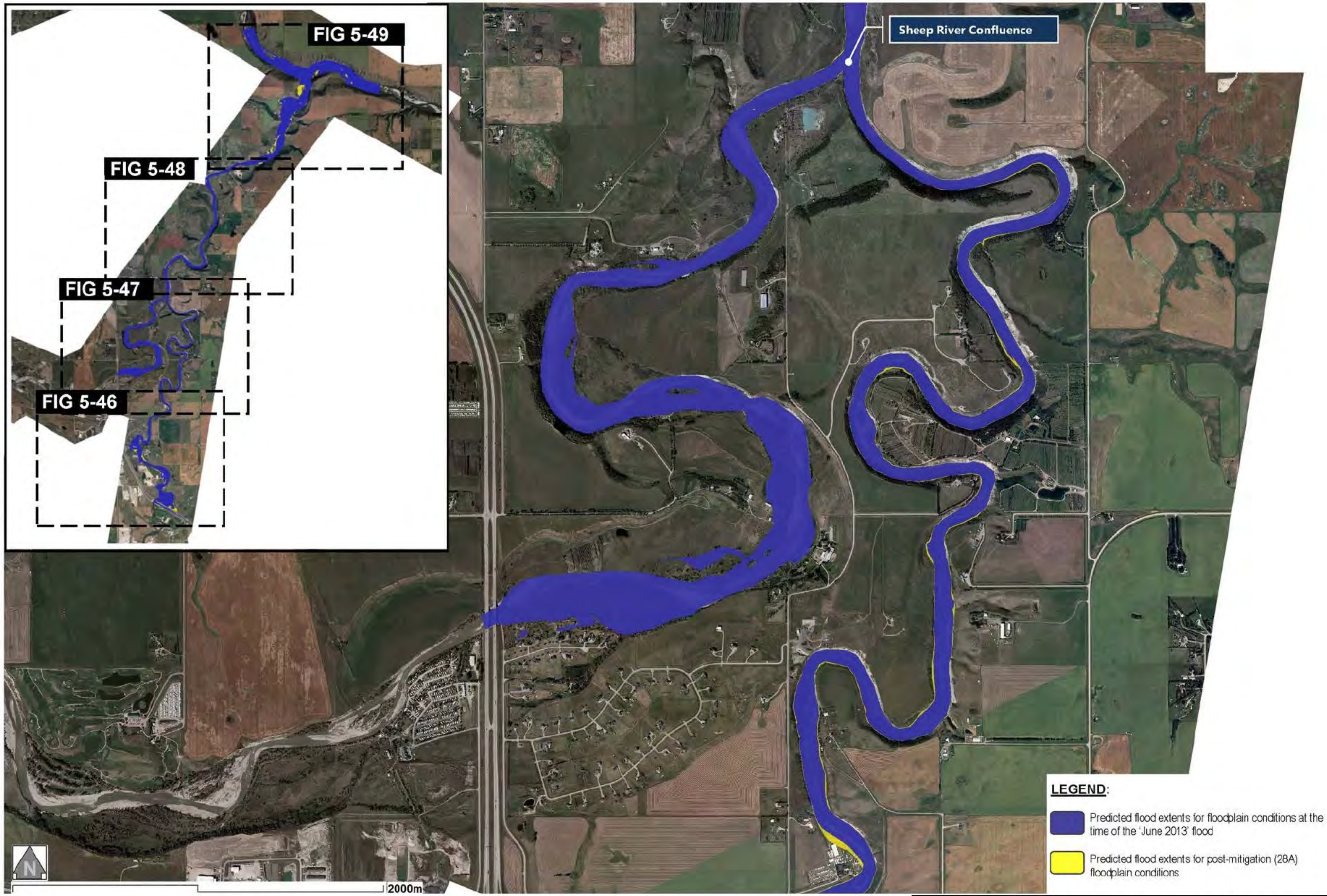

Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 1,820m³/s' Flood Extents
[Figure Extent 2 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-47	Rev: 0
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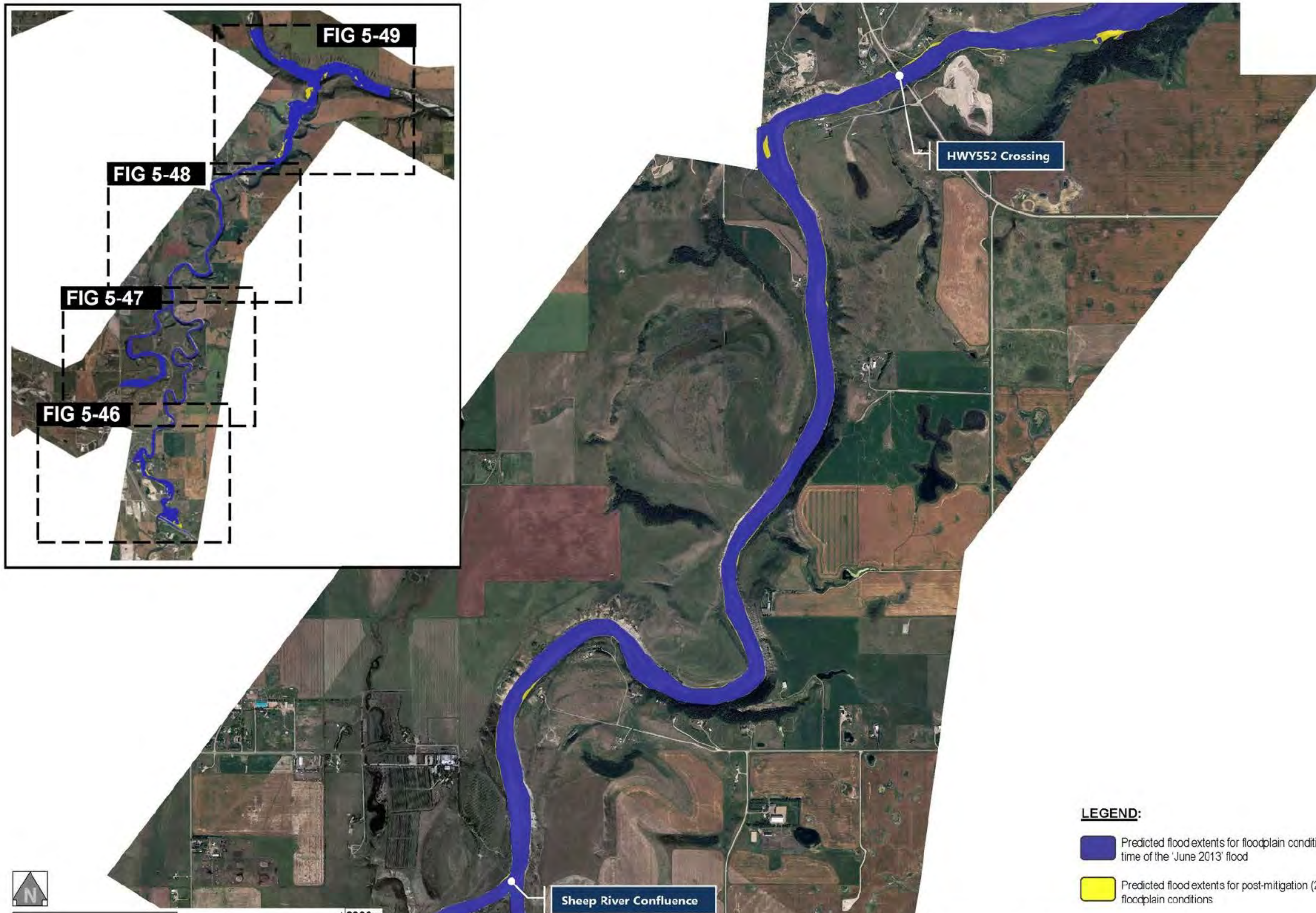
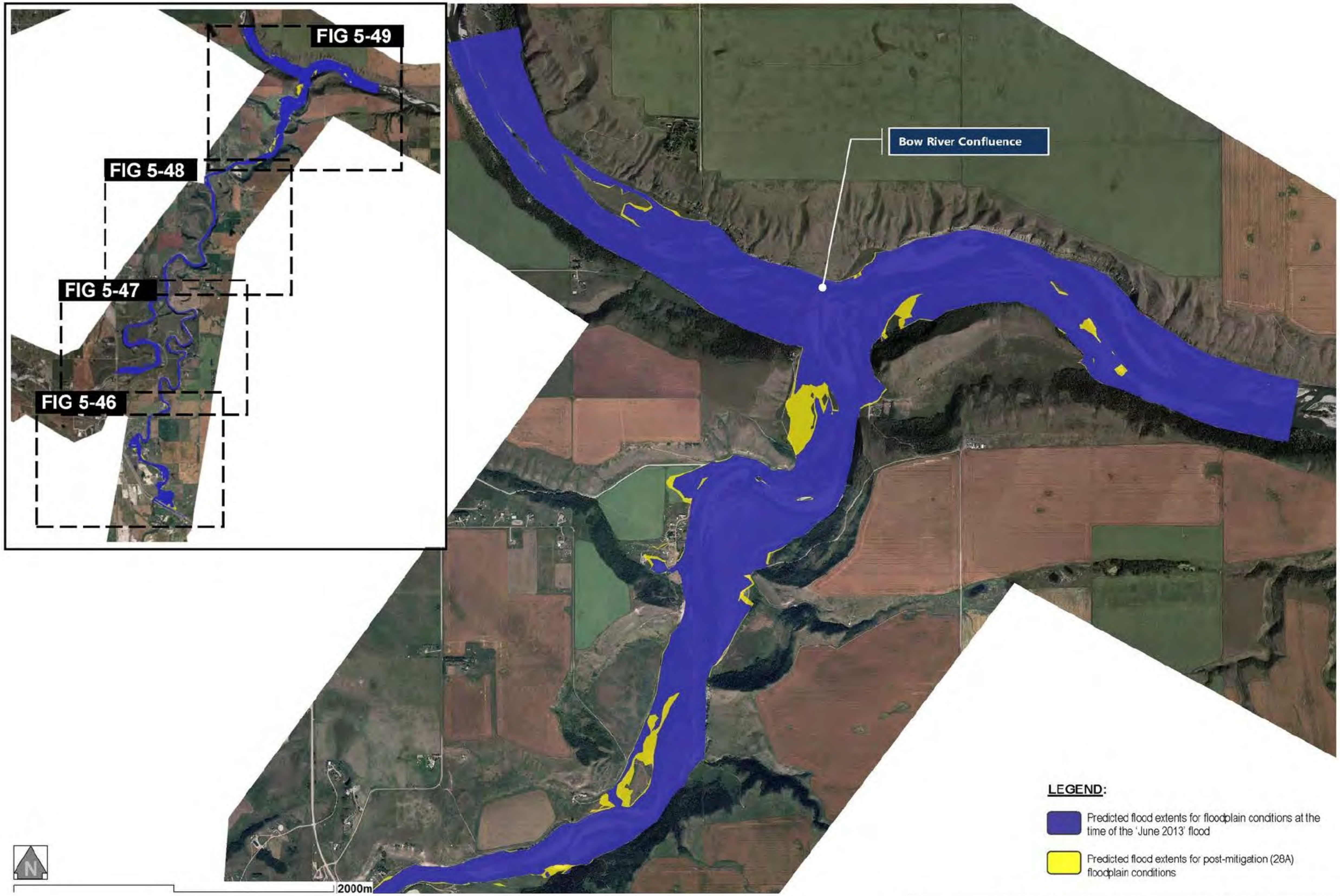


Municipal District of Foothills No. 31 – Highwood River Modelling

Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 1,820m³/s' Flood Extents
[Figure Extent 3 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-48	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 – Highwood River Modelling

Comparison of Pre and Post-Mitigation (28A) 'June 2013 – 1,820m³/s' Flood Extents
[Figure Extent 4 of 4]

Advisian WorleyParsons Group	Created By: RG	Date: July 5, 2016	File Path:	Figure No: 5-49	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.*			

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.