



**Advisian**

WorleyParsons Group



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**SCOPING STUDY OF FLOOD RELATED  
AREAS OF CONCERN ON THE HIGHWOOD RIVER  
AND LITTLE BOW RIVER WITHIN THE  
MUNICIPAL DISTRICT OF FOOTHILLS**

Submitted to:

**Municipal District of Foothills No. 31**  
High River, Alberta

Submitted by:

**Amec Foster Wheeler Environment & Infrastructure  
and  
Advisian WorleyParsons Group**  
Calgary, Alberta

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## EXECUTIVE SUMMARY

### Objective

The Scoping Study of Flood Related Areas of Concern on the Highwood River and Little Bow River within the Municipal District of Foothills (scoping study) identifies and describes flood-related risk areas in relation to the Municipal District of Foothills No. 31 (the MD) residents and infrastructure. It also provides general recommendations for further study and mitigation and presents options to protect MD residents downstream of Woman's Coulee Canal Inlet on the Highwood River and Little Bow River within the MD. Protection criterion for this assessment and concept design exercise assumes a protection level equivalent to that used by the Town of High River (the Town): that is the 2013 flood magnitude simulated for mitigated conditions plus 1 m freeboard. A significant amount of flood protection infrastructure was constructed (or is planned for construction) in the Town and the MD subsequent to the 2013 flood. The study includes an evaluation of the change in flood hazards due to the works constructed after the 2013 flood and currently planned works. The Scoping Study is the first phase of a proposed multi-phase study. The Scoping Study is intended to be a living document that will continue to evolve and be updated based on future information and analyses. A summary of the report is presented below.

### Peak Flow Hydrology and the Highwood-Little Bow Flow Split

The 2013 peak flood discharge upstream of the Town and above Woman's Coulee Canal Inlet was estimated by Water Survey of Canada (WSC) to be 1,820 m<sup>3</sup>/s. This is the inflow prior to the Highwood-Little Bow flow split and is the primary discharge scenario that was evaluated in this study. Historic observations and hydraulic model analyses (both physical and computational) indicate that before the 2013 flood, daily flood peaks above approximately 600 to 700 m<sup>3</sup>/s in the Highwood River (above Woman's Coulee Canal Inlet) result in water overflowing (or "flow-splitting") to the Little Bow River watershed from the south Highwood River floodplain downstream of the Woman's Coulee Canal Inlet. During these low probability infrequent flood events, overflow has been observed to flow east and south, flooding the Town (and areas south of the Town) before entering the Little Bow River.

The Town flood protection infrastructure constructed (or planned for construction) subsequent to the low probability 2013 flood protects the south portion of the Town (north of 12 Avenue) from flooding from the Highwood River main channel and floodplain. These structures result in significant increases to low probability infrequent flow magnitudes in the Highwood River at, and downstream of, the Town.

Preliminary estimates of the effect of the flood protection structures described above indicate an increase of approximately 180 m<sup>3</sup>/s in the Highwood River just downstream of the Town, corresponding to the upstream 2013 flood magnitude of 1,820 m<sup>3</sup>/s. Conversely, the Little Bow River is expected to experience a decrease in peak flow from approximately 560 m<sup>3</sup>/s to 405 m<sup>3</sup>/s under conditions similar to the 2013 flood.

The increase in flood flow magnitude on the Highwood River at the Highway 2 Bridge north of the Town is even greater due to the raising of 498 Avenue E (located just east of the main channel of the river) resulting in loss of floodplain storage associated with the Hamptons area (Hampton Hills, Sunshine, and Sunrise areas) located within the Town. Peak flow magnitude at the Highway 2 Bridge is estimated to be approximately 290 m<sup>3</sup>/s greater than the 2013 Flood

Landscape Scenario (which is synonymous with the existing condition at the time of the 2013 flood or the condition pre-2013/2014 flood mitigation works).

At flood peaks below approximately 1,000 m<sup>3</sup>/s (measured upstream of the flow split and Woman's Coulee Canal inlet), effects of the flood protection infrastructure appear to be low to negligible, resulting in no significant changes to flood hazards at these flows.

## Hydraulic Modelling

Portions of the Scoping Study discussion, and results presented herein, have relied on modelling results obtained from WorleyParsons' calibrated/validated two-dimensional (2D) hydraulic model of the Highwood River and upper Little Bow River in the vicinity of the Town. The two primary hydraulic modelling scenarios used for the Scoping Study include:

- ▶ 2013 Flood Landscape Scenario, which can be considered the baseline scenario used to determine subsequent changes or effects; and
- ▶ Complete Town Mitigation Scenario (Scenario 28A), which includes all as-built dike information and the proposed 12 Avenue-Centre St. Dike required to protect the southern boundary of the Town. This scenario has been used as a conservatively based design scenario (i.e., based on the Town's complete mitigation scenario).

## Flood Hazard Issues

The primary flood hazard areas of concern identified on the basis of the Scoping Study are: (1) the Highwood River from Woman's Coulee Canal Inlet (located approximately 9 km southwest of the Town) to the confluence with the Bow River; and (2) the several Little Bow River residents in the vicinity of the Town where the flood hazard will potentially increase due to works proposed by the Town. The discussion below pertains mostly to these areas.

- ▶ Woman's Coulee Canal Inlet – Woman's Coulee Canal (Mosquito Creek) Inlet and associated infrastructure are located on the south bank of the Highwood River and divert water from the Highwood River into the Little Bow River system. The inlet was damaged during the 2013 flood. The local landowners have expressed concerns that the new structure should not result in the diversion of additional floodwaters towards the south bank and floodplain (e.g., there should be no significant encroachment into the channel). In addition, the inlet should not direct water back to the Highwood River from the southern floodplain, because this would increase Hoeh Dike (discussed below) breach risk and effects downstream.
- ▶ Hoeh Dike Downstream to the Town – The Hoeh Dike parallels the Highwood River for approximately 2,000 m from approximately 7 km upstream of the Town to an area just downstream of the Woman's Coulee Canal inlet. The Hoeh Dike consists of a patchwork of various dike segments that have been constructed over the last 100 years. Baker Creek is an intermittent high-water channel of the Highwood River that originates adjacent to, and on the protected side of, the Hoeh Dike and discharges back to the river in the Town. To minimize the amount of flood flow entering Baker Creek (which feeds overflow channels to the Little Bow), Hoeh Dike construction was initiated in 1907, with upgrades occurring over the next century and repairs still being undertaken. Although only one portion of Hoeh Dike was overtopped during the 2013 flood, the area behind the dike was subject to inundation due to the dike being outflanked at the upstream end. This allowed a significant quantity of discharge to be conveyed in the floodplain behind (south of) the dike. A failure of



the Hoeh Dike could change the flood risk both locally and regionally. Due to these potential effects, a limited Hoeh Dike failure analysis was undertaken, including hydraulic modelling. Key findings based on the scenarios assessed are summarized below.

- ▶ Floodplain inundation helps equalize water levels on the river side and floodplain side of the dike, minimizing breaching risk.
- ▶ Modelling of Hoeh Dike failure scenarios indicates that dike failure appears to have significant local effects, but only minimal regional effects (e.g., effects are negligible at the Town).
- ▶ The structure is currently serving an important purpose, but should not be raised or lowered, because this will have regional flood effects. Regional impacts from lowering include increased frequency of flooding into Baker Creek which drains towards the west and south portions of the Town and overflow into the Little Bow basin.
- ▶ Town of High River – New dike infrastructure (Town Dike [TD], West Town Dike [WTD], and Little Bow Canal Dike) are designed to prevent overflow for flood magnitudes below 1,820 m<sup>3</sup>/s. The WTD, TD, and Little Bow Canal Dike have been designed and constructed to protect the south portion of the Town (north of 12 Avenue) from Baker Creek overflow and flooding from the main channel of the Highwood River. However, these structures result in retaining significant additional flood flow formerly flowing to the Little Bow River to the Highwood River at, and downstream of, the Town.
- ▶ 498 Avenue E and Hamptons – The increase in flood flow magnitude on the Highwood River at the Highway 2 Bridge north of the Town is even greater due to the raising of 498 Avenue E, which has resulted in loss of floodplain storage associated with the Hamptons area (Hampton Hills, Sunshine, and Sunrise areas) located within the Town. The raising of 498 Avenue E was undertaken to protect the east side of the Town including the Hamptons area. Peak flow magnitude at the Highway 2 bridge is estimated to be approximately 290 m<sup>3</sup>/s greater than the 2013 Flood Landscape Scenario (which is synonymous with the existing condition at the time of the 2013 flood or the condition pre-2013/2014 flood mitigation works), increasing from 955 m<sup>3</sup>/s to 1,245 m<sup>3</sup>/s for a 2013 magnitude flood equivalent.
- ▶ 498 Avenue E to Highway 2 – As discussed above, the flood peak magnitudes downstream of 498 Avenue E have been significantly altered for low probability, infrequent flood events. Flood peak magnitudes will increase due to diversion of flow by the dikes and reduction of attenuation effects due to loss of flood storage. At flood peaks below approximately 1,000 m<sup>3</sup>/s (gauged upstream of Woman's Coulee Canal inlet), effects appear to be low to negligible. However, as flows begin to increase above 1,000 m<sup>3</sup>/s, the change in flood risk level becomes more apparent. Infrastructure and landowner issues related to the increase in flood discharge are listed below.
  - ▶ Landowner flood issues include: 1) increase in flood levels (ranging from 0 to 1 m); 2) landowner erosion issues due to velocity increases (up to 0.5 m/s); and 3) landowner flood inundation (ponding) duration/frequency issues and associated agricultural damages. Mitigation options include ring dikes around the perimeter of residences, buyouts of property or residences only, installation of erosion protection, and compensation for incremental flood damages.
  - ▶ The CPR Bridge at Aldersyde is associated with an estimated increase in water levels of 0.75 m under the mitigated scenario. The bridge is subject to clogging by debris. The increase in water levels and velocities are not expected to significantly exacerbate the risks from the debris to the bridge and adjacent areas. Both the level of the bridge

and the erosion protection, however, should be reviewed in light of the new flood flow regime.

- ▶ Highway 2 to Confluence with Bow River – This segment of the Highwood River is subject to the same increase in discharge as the segment from 498 Avenue E to Highway 2. Infrastructure and landowner issues related to the increase in flood discharge are listed below.
  - ▶ Landowner flood issues include: 1) increase in flood levels (ranging from 0 to 1.65 m); 2) landowner erosion issues due to velocity increases (up to 0.85 m/s); and 3) landowner flood inundation (ponding) duration/frequency issues and associated agricultural damages. Mitigation options include ring dikes around the perimeter of residences, buyouts of property or residences, installation of erosion protection, and compensation for incremental flood damages.
  - ▶ Highway 2 Bridge Structure is subject to an estimated increase in water level of approximately 0.85 m and velocity of 0.75 m/s. Both the level of the bridge and the erosion protection should be reviewed in light of the new flood flow regime.
  - ▶ Highway 547 Bridge Structure is subject to an estimated increase in water levels of approximately 0.9 m and velocity of 0.2 m/s. Again, both the level of the bridge and the erosion protection should be reviewed in light of the new flood flow regime. Highway 552 Bridge Structure is subject to an estimated increase in water levels of approximately 0.42 m and velocity of 0.36 m/s. The bridge deck is elevated several metres above the streambed and would likely not be affected by the increased water levels. A bridge upgrade is likely not required but the erosion protection should be reviewed, if present.
- ▶ Little Bow River to the MD Boundary – The majority of Little Bow River residents and infrastructure in the MD will be subjected to significantly lower flood peak magnitudes when infrequent low probability peak floods (e.g., greater than 1,000 m<sup>3</sup>/s) occur on the Highwood River and spill over to the Little Bow. This effect is the result of diking within the Town. In general, water levels downstream of 104 Street East are expected to decrease in the range of 25 to 35 cm for a flood event similar to that which occurred in 2013, based on preliminary modelling results. It is worth noting that some areas upstream of 104 Street East but downstream of 72 Street East will experience water level increases during infrequent low probability flood events over 1,000 m<sup>3</sup>/s. The maximum water level increase during a flood event similar to the 2013 flood is estimated at 0.5 m. These residents are being approached by the Town to discuss options. A detailed analysis is proposed for the Southwest Dike (SWD) design to assess and mitigate flow increases to the Little Bow River when flood peaks on the Highwood River range from approximately 650 to 1,000 m<sup>3</sup>/s. Preliminary analysis has shown that flows to the Little Bow River from the Highwood River over this range have the potential to have a slight increase when compared to the 2013 landscape condition. Currently, the Town is proposing the SWD solution that differs in alignment from the 12 Avenue-Centre St. Dike. The SWD is being/has been designed based on the objective of having the flow-split equivalent to that of the 12 Avenue-Centre St. Dike design.
- ▶ Areas Downstream of the Study Area:
  - ▶ The Bow River Downstream of the Study Area – The increase in peak flow magnitude of a Highwood River flood flow in relation to that experienced in 2013 is approximately 290 m<sup>3</sup>/s downstream of Highway 2. The associated impacts on the Bow River downstream of the Highwood River confluence will be somewhat a function on the timing

of the peak on the Bow River during flooding. A detailed analysis would assist in better understanding these effects and the associated risk in greater detail, and should be undertaken in future studies. There is also a significant additional volume of water that will need to be managed at downstream reservoirs (such as the Bassano Dam). Estimating the total quantity of water and evaluating its impact on downstream reservoirs should also be undertaken in future studies.

- ▶ Little Bow River Downstream of the MD – The performance of the Town's flood mitigation structures during a low probability infrequent flood event, such as the design probable maximum flow (PMF) of the Twin Valley Dam (which is in the order of 3,000 m<sup>3</sup>/s) is not well understood. For example, if the diking structures in the Town undergo catastrophic failure during such an event, the effects on structures, such as the Twin Valley Dam and Travers Dam, are unknown. We understand that the overtopping of the dikes for a few hours was taken into account in the design of the dikes. However, this factor of safety will likely be insufficient to avoid a dam-breach type event. The changes to the flow split and the configuration of the Town's flood protection infrastructure should be discussed with the owners/operators of the Twin Valley Dam and the Travers Dam, which are located on the Little Bow River and are affected by the overflow from the Highwood River into the Little Bow River. An evaluation may be required by the dam operators of the performance of the Town dikes under PMF conditions, which is a design scenario evaluated for these large dam structures.

### Preliminary Level Cost Benefit Analysis

The hydraulic modelling discussed previously was the basis for the preliminary level cost benefit analysis. The analysis did not include a comparison of costs versus avoided economic damages. Rather, costs are provided for various mitigation options for areas on the Highwood River downstream of Woman's Coulee Inlet and Little Bow River to an increased flood risk.

The two hydraulic model scenarios evaluated were: a) 2013 Flood Landscape Scenario; and b) Complete Mitigation Scenario. The 2013 Flood Landscape and magnitude of the 2013 flood provides the base case to determine the incremental flood impacts due to the Town's flood mitigation measures (i.e., increased water levels and velocities). These incremental flood impacts, in conjunction with flood mitigation options such as buyouts and construction of flood and erosion protection measures, form the basis for the cost benefit analysis. The cost benefit analysis was only undertaken for areas on the Highwood River downstream of Woman's Coulee Inlet and Little Bow River. The cost benefit analysis was not undertaken for the Highwood River upstream of the Woman's Coulee Canal Inlet.

The results of the cost benefit analysis are summarized below:

- ▶ Woman's Coulee Canal Inlet to Western Town Boundary – This area is referred to as River Run and is upstream of the Town. Only a small portion of this area, adjacent to the west Town boundary, was affected by the Town's complete mitigation scenario. Only one property in the River Run area is subject to increased water levels resulting from the complete mitigation scenario. The property has an increase in water level of 0.1 m at the residence.
  - ▶ With the above noted exception, the flood risk for the remainder of the River Run area is unchanged. Thirty-four properties (including the above noted property) were identified that were subject to inundation during the 2013 flood. These properties could be

protected from future floods by buyouts or perimeter berms. The estimated total cost of these mitigation options in the River Run area is \$22,491,960.

- ▶ Additionally, a potential 50 m Hoeh Dike breach has been identified in this report and upgrading of this portion of the dike should be reviewed further. The preliminary level cost estimate for this upgrade is \$200,000.
- ▶ 498 Avenue E and Hamptons – The post-2013 flood mitigation works of raising 498 Avenue E protected the Hamptons and no further flood mitigations works were identified herein.
- ▶ 498 Avenue E to Confluence with Bow River – A total of 93 properties were identified as having increased flood risk due to the Town's complete mitigation scenario. Eighteen of these properties have residences that were affected by the increased flood risk. The remaining 75 properties have agricultural fields that were affected by the increased flood risk.
  - ▶ The 18 residences that are subject to increased flood risk could be protected from future floods by buyouts or perimeter berms. The estimated total cost of these mitigation options for these 18 properties is \$11,235,388.
  - ▶ Appropriate mitigation measures for the remaining 75 properties may include compensation for crop damage loss and should be addressed in subsequent phases of the study.
- ▶ Little Bow River from Western Town Limits to MD Boundary – A total of 74 properties were subject to flood damages in 2013. The change in flood risk for these properties due to the Town's complete mitigation scenario is summarized below:
  - ▶ Twelve properties were subject to increased water levels, consisting of:
    - ▶ Three properties with residences. The estimated total cost of these mitigation options for these three properties is \$899,638.
    - ▶ The remaining nine properties have agricultural fields that were affected by the increased flood risk. Appropriate mitigation measures for these properties may include compensation for crop damage loss and should be addressed in subsequent phases of the study.
  - ▶ A total of 62 properties were subject to a decrease in water levels, consisting of:
    - ▶ Seventeen properties where residences were subject to inundation in 2013. The residences at four of these properties are no longer subject to inundation for a 2013 magnitude event. The remaining 13 properties are still subject to inundation, albeit at a reduced level than 2013. The estimated total cost of mitigation options for these 13 properties is \$7,692,700.
  - ▶ The total cost for protecting all 16 properties with residences that are subject to flood risk (3 properties with increased flood risk and 13 properties with reduced flood risk) is \$8,592,338.

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## 1.0 INTRODUCTION

On behalf of the Municipal District of Foothills No. 31 (the MD), Amec Foster Wheeler Environment & Infrastructure (Amec Foster Wheeler) jointly with Advisian WorleyParsons Group (Advisian) undertook the Flood Related Areas of Concern on the Highwood River and Little Bow River within the Municipal District of Foothills Scoping Study (Scoping Study).

The Scoping Study is the first phase in a recommended multi-phase study approach that includes the following:

- ▶ Phase 1 Scoping Study – identify flood-related risk areas within the MD's Highwood-Little Bow watersheds;
- ▶ Phase 2 – further develop design alternatives and concepts and review feasibility to address these risks (as well as refine estimates provided in Phase 1, if necessary); and
- ▶ Phase 3 – prepare detailed designs as determined by the MD.

The phasing outlined above and the scoping nature of the Phase 1 study guides the level of detail of analysis and design contained in this report. This conceptual and high level approach is intended to inform the direction of future phases in which more detailed analysis and design will be undertaken. The Scoping Study is intended to be a living document that will continue to evolve and be updated based on future information and analyses. This may include, but is not restricted to, incorporating future hydraulic modelling, more detailed cost-benefit analysis, and review of the Little Bow River downstream of the MD boundaries.

### 1.1 Objectives and Study Area Components

The study area is defined as the Highwood-Little Bow watersheds within the MD (**Figure 1.1**). The study objectives are to:

- ▶ identify and describe flood related risk areas in relation to MD residents and infrastructure;
- ▶ undertake a high-level flood risk evaluation of the impacts resulting from existing and proposed flood control and mitigation measures (**Figure 1.3**), and natural flooding/erosion mechanisms; and
- ▶ propose mitigation options and actions to assess and/or address these risks including the development of specific actions (including high-level costing) to protect MD residents downstream of Woman's Coulee Canal Inlet on the Highwood River and Little Bow River within the MD. Protection criterion for this assessment and concept design exercise assumes a protection level equivalent to that used by the Town of High River (the Town): the 2013 flood magnitude simulated for mitigated conditions plus 1 m.

A significant amount of flood protection infrastructure was constructed (or is planned for construction) in the Town and the MD subsequent to the historic 2013 flood. The Scoping Study includes an evaluation of the change in flood hazards due to the works constructed after the 2013 flood and currently planned works.

This study is not intended to review large-scale diversion or dam projects, which have been reviewed previously in other studies (AECOM 2014 and Deltares 2014). However, this project may identify potential options and recommended further review for consideration.

The scope of the Phase 1 Scoping Study included the four components listed below:

- ▶ Component A – Desktop, field, and modelling review of flood risk and change to risk along the Highwood River from approximately Woman's Coulee Canal (Mosquito Creek) Inlet to its confluence with the Bow River (**Figure 1.2**), as well as the Little Bow River downstream to the MD boundary (**Figure 1.1**) These areas encompass the current and future extent of Advisian's two-dimensional (2D) Highwood River/Little Bow River hydraulic models. This component is discussed primarily in **Sections 2.0, 3.0, 4.0, and 5.0** of this report.
- ▶ Component B – Desktop review of flood issues on Highwood River Upstream of Woman's Coulee Canal Inlet. This component is summarized in **Sections 2.0, 4.0, and 5.0**, but discussed primarily in **Appendix A** of this report.
- ▶ Component C – Desktop review of flood issues on Pekisko Creek and Stimson Creek, which are the two major tributaries of the Highwood River with adjacent landowners. This component is summarized in **Sections 2.0, 4.0, and 5.0**, but discussed primarily in **Appendix B** of this report.
- ▶ Component D – High level cost assessment to support cost-benefit analysis and future planning. This component is discussed primarily in **Section 6.0** of this report.

## 1.2 Scope of Work

The scope of work for the Scoping Study is discussed below in relation to components A through D as described in the previous section.

The detailed tasks of the Component A scope, which focused on reviewing: 1) the Highwood River from approximately Woman's Coulee Canal (Mosquito Creek) Inlet to its confluence with the Bow River; and 2) the Little Bow River to the MD boundary, can be described as follows:

- ▶ Information Gathering, Review, and Site Visit:
  - ▶ Gather available information and 2D model simulations for review. Information review included design engineering reports for flood protection works constructed to-date, plans/reports for potential future works, and flood-related planning documents.
  - ▶ Undertake a site visit to priority areas of concern to enhance understanding of potential issues.
- ▶ High-Level Flood Risk Evaluation of the impacts on MD residents and infrastructure caused by existing and proposed flood control measures and natural flooding/erosion mechanisms. Advisian interrogated existing 2D modelling simulations and undertook new modelling to support evaluation efforts. The scope of work for flood risk evaluation included:
  - ▶ interpretation of risk based on existing information, modelling results and site visit information;
  - ▶ evaluation of increased hazard to MD residents and infrastructure, where applicable;
  - ▶ development of conceptual level designs and assessment of feasibility to mitigate flood hazard;
  - ▶ preparation of a high level cost analysis of potential local-scale mitigation options; and
  - ▶ identification scope of work requirements and recommendations for future phases of the project.

Component B (Desktop Review of Flood and Geomorphic Issues on Highwood River Upstream of Woman's Coulee Canal Inlet) and Component C (Desktop Review of Flood Issues on Pekisko Creek and Stimson Creek) were less detailed in scope than the assessment associated with Component A and Component D. The study area for Component B is the Highwood River from Woman's Coulee upstream to the western MD boundary. The study area for Component C is that portion of the Pekisko Creek and Stimson Creek subbasins that are within the MD boundary. The change in flood risk to, and quantity of MD residents and infrastructure, are considerably less in areas covered by Components B and C, compared to Component A. However, it is important from a watershed context and MD planning perspective to have an understanding of the flood and geomorphic issues in these areas, because these areas include MD residents and infrastructure and may affect downstream areas discussed in Component A. The tasks for Components B and C are listed below:

- ▶ Review of historic air photo imagery available on Google Earth and other imagery provided by the MD.
- ▶ Review of one-dimensional (1D) modelling (at Longview Highway 22) and field assessment results associated with other projects in this area.
- ▶ Undertake key informant interviews with residents of the MD including residents/operations in Longview.
- ▶ Review of previous reports documenting flood damages (including AMEC's post-2013 flood evaluations).
- ▶ Review of flood discharge data from streamflow monitoring stations.
- ▶ Review of coarse level topographic information in order to plot a profile (elevation versus distance) of the basin.
- ▶ Review of photographs available from other field studies in the project area.
- ▶ Interview MD personnel on known flood issues affecting residents or MD infrastructure.

Component D tasks focused on developing high-level costs associated with protecting and/or purchasing areas that are associated with a change in flood hazard and/or that were not offered buyouts by the Government of Alberta (GOA) following the 2013 flood. The sub-study area for Component D is the same as that for Component A (i.e., the Highwood River from approximately Woman's Coulee Canal (Mosquito Creek) Inlet to its confluence with the Bow River), as well as the Little Bow River downstream to the MD boundary. These costs estimates will also be used to determine the need to look at regional solutions in terms of cost-benefit. The tasks undertaken as part of Component D can be described as:

- ▶ Interrogate model simulations results to produce impact figures and Geographic Information System (GIS) files for water level, velocity, and inundation extents.
- ▶ Develop a costing tool that uses model and other external data to provide estimates for three scenarios: 1) buyout costs; 2) protect to 2013 landscape conditions; and 3) protect to Complete Town Mitigation Scenario (Scenario 28A), which includes all as-built and proposed flood protection structures.
- ▶ Summarize the results of the local costs for each property.
- ▶ Summarize the results of the costing exercise in terms of total estimate costs based on options evaluated.
- ▶ Outline the limitations and provide recommendations for refining cost estimates and supporting information.

### 1.3 Information Sources and Stakeholder Consultation

A considerable number of studies and flood recovery projects have been undertaken after the 2013 flood. A select listing of important information sources is listed below.

- ▶ 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 the following two reports/concepts: 1) AECOM (2014) study that investigated regional diversion options; and 2) the WorleyParsons (now Advisian; 2014) planning information, which included the proposed Little Bow Floodway Enhancement prepared for the Town.
- ▶ AECOM (2014): *Southern Alberta Flood Mitigation Feasibility Study for Sheep, Highwood River Basins and South Saskatchewan River Subbasin*; Highwood River Water Management Plan, prepared for Alberta Flood Recovery Task Force. July 2014.
- ▶ WorleyParsons (2014): *2013 Flood Mitigation Master Plan (FMMP) Draft-Living Document*, Town of High River, Alberta. March 2014.
- ▶ Amec Foster Wheeler (2014, 2013, and earlier) engineering reports for flood mitigation, diking and bank erosion projects on the Highwood River, on behalf of the MD.
- ▶ MD flood GIS information that includes residential and MD infrastructure impact summaries, flood extents estimates, and other pertinent 2013 flooding data.
- ▶ Various hydraulic model results in figure and GIS format providing flood and impact behavior estimates to support scoping. Refer to **Section 3.0** for additional information pertaining to Advisian's flood modelling.

It is envisioned that stakeholder consultation will make up significant portions of future phases of the study. For Phase 1, stakeholder consultation was limited to the following:

- ▶ numerous meetings with the MD's staff; and
- ▶ meeting with several landowners on the Highwood and Little Bow during the site assessment on 14 July 2015.

## 2.0 STUDY AREA

Having a clear understanding of study area geography and context is essential for any design scoping exercise. To this end, this section contains:

- ▶ an overview description of the watershed (and sub-watersheds) as shown in **Figure 1.1**;
- ▶ a discussion of general flood hydrology, as well as flood discharges used in modelling;
- ▶ a description of the overflow from the Highwood River into the Little Bow River;
- ▶ a discussion of the change in flood hazard level due to flood protection works constructed in the Town after the 2013 flood; and
- ▶ a discussion of river morphology with emphasis on its relationship to flood behavior.

### 2.1 Watershed Overview

A watershed can be thought of in the context of its underlying regional physiographic influences. Northwest Hydraulic Consultants (NHC 1992) describes these characteristics in the Highwood River Flood Risk Mapping Study as follows:

This [Highwood River] catchment is comprised of three basic physiographic regions. The western portion, which lies within the steep eastern slopes of the Rocky Mountains, rises to elevations above 3,200 m along the Elk Range. Lying immediately to the east of this is the comparably high Highwood and Livingstone ranges. The eastern portion of the catchment consists of the Foothills (Porcupine Hills)..., the *Southern Alberta Uplands* ...followed by a transition to the Western Alberta Plains west of the *Town of High River*. The distance from the Continental Divide to High River town along the Highwood River is in the order of 100 km.

These physiographic regions influence the characteristics of the river and its tributaries as it flows from steep mountain headwater catchments to valley bottoms and eventually to foothills and plains regions. First and second order stream channels, which are part of the upper portions of the watershed, combine to form high-order streams within mountain and foothill valleys, eventually discharging to the main Highwood River channel. Tributaries of the Highwood continue to flow into the main channel, proceeding east through the basin as the topography transitions from mountains to foothills to uplands to plains. **Table 2.1** lists Highwood River drainage areas and main stem channel stationing (measured upstream from the mouth) at key locations through the watershed, while also including physiographic region associated with each river station.

**Table 2.1 Highwood River Watershed Areas and Main Channel Stationing**

Location	Drainage Area (km <sup>2</sup> )	Approximate Channel Stationing (km)	Physiographic Region Of Station
Bow River Confluence	3,950	0	Western Alberta Plains
Upstream Of Sheep River Confluence	2,350	17	Western Alberta Plains
Highway 2 Crossing	2,315	30	Western Alberta Plains
Highway 2a Crossing (WSC Station Highwood Below Little Bow Canal)	1,950	47	Western Alberta Plains
Woman's Coulee Canal Inlet (Approx.)	1,920	61	Southern Alberta Uplands
Upstream Of Pekisko Creek Confluence	1,340	76	Southern Alberta Uplands
At Highway 22 Crossing	1,200	90	Southern Alberta Uplands
At Diebel's Ranch (Near MD Western Boundary)	774	133	Foothills
Below Picklejar Creek	132	169	Rocky Mountains

The physiographic regions outlined above also provide a framework for discussing land use within the Highwood River watershed. The Rocky Mountain portion of the watershed is associated with Provincial park lands and undeveloped areas, which are covered mainly by high-density conifer forests. Moving downstream, the Foothills area is associated with changes in both land use and cover. Private property becomes more prevalent in the Foothills area, while forest cover becomes less prevalent, being replaced by grasslands. Forest cover is still dominant in some locations but deciduous stands become much more common. The Southern Alberta Uplands region of the watershed has even less forest cover and more open grassland and private property (including small municipalities). The Western Alberta Plains portion of the watershed is associated with highest residential densities and open areas consist of mainly grasslands and agriculture. Forest cover in this area is mainly found in riparian areas adjacent to the Highwood River and tributaries.

Within the greater Highwood River watershed and the MD boundary, Pekisko Creek and Stimson Creek are two sub-watersheds of interest from a flooding perspective. Both watersheds are found mainly within the Foothills and Southern Alberta Uplands physiographic regions, although the headwaters of Pekisko Creek are located within the Rocky Mountains. Similar to the Highwood River valley, both watersheds are associated with private land ownership and related access infrastructure below their headwaters. Pekisko Creek and Stimson Creek are similar sized watersheds and both can be classified as significant tributaries to the Highwood River. On a drainage area basis, both streams combined represent approximately 30% of the Highwood River watershed (measured at the confluence with Pekisko Creek). Compared to Stimson Creek, the Pekisko Creek main stem channel length is 14 km longer (50.5 km versus 36.5 km) and headwater elevation is approximately 450 m higher.



Beyond the general physiographic regions of the Highwood River and its major sub-watersheds within the MD, a key physical characteristic of the Highwood River watershed is having a portion of its low probability, infrequent floods overflow to the Little Bow River. This overflow occurs at and upstream of the Town. NHC (1992) again provides a thorough description of this mechanism and a supporting rationale for its occurrence:

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 reestablished itself along its pre-glacial path and present-day course downstream of the High River town. During *[large]* floods, the present-day Highwood River is still able to overflow [towards the southeast] into the Little Bow River basin.

This overflow into the Little Bow River basin is discussed in greater detail in **Section 2.2.1**.

## **2.2 Hydrology and Overflow into Little Bow River Basin**

The hydrology of the Highwood River is characterized by low fall and winter base flows transitioning to significant freshet and rain-on-snow peak flow events in spring, as well as rainfall-driven flow increases and recessional cycles throughout summer. Freshet, rain-on-snow, and rainfall driven floods events can be 20 to over 100 times greater than base flows. Flow tends to stay elevated above base levels through spring and early summer before receding in late summer and fall. In dryer years, however, flows can be very low throughout summer. Local snow-melt in early spring in the uplands and plains physiographic regions result in local flow increases in the lower parts of the watershed before melting (and flow increases) begin in the foothill and mountainous portions of the watershed. Due to the objective of the Scoping Study, the remaining portion of this section focuses on low probability, infrequent flood hydrology of the Highwood River (including the Little Bow River).

Specific quantitative information pertaining to flood hydrology of the Upper Highwood River (above Woman's Coulee Canal Inlet, including Pekisko Creek and Stimson Creek tributaries) is provided in **Appendix A** and **Appendix B**. Flood hydrology of the lower segment of the Highwood River (below Woman's Coulee Canal inlet) is mainly driven by discharge from the upper catchment areas found in the Rocky Mountain and Foothill Regions, which are discussed in these appendices.

Flood hydrology at the Town can be characterized using flood peak estimates from the Town's Hogg Park Flow Monitoring station just upstream of Woman's Coulee Canal inlet and Water Survey of Canada (WSC) stations including:

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

From a low probability, infrequent flood magnitude perspective, considering error in flow estimates/measurement, timing of local runoff, and canal operating procedures, the flows from these stations can more or less be used interchangeably as long as flood storage upstream of Town, spill-over to the Little Bow River and spill-over to the east area of the Town (which has only been documented in significant quantities during the 2013 flood) are accounted for.

Further downstream below the Highway 2 bridge crossing of the Highwood River, however, flood hydrology is greatly influence by Sheep River flows. The total effective watershed area downstream of the Highwood River-Sheep River confluence is 3,950 km<sup>2</sup> measured at station 05BL024 Highwood River near the mouth, located 6.5 km upstream of the Highwood River's confluence with the Bow River.

The low-probability, high-magnitude flood hydrology of the Little Bow River is mainly governed by spill-over from the Highwood River during low probability flood events greater than approximately 600 to 700 m<sup>3</sup>/s above Woman's Coulee Canal Inlet under conditions at the time of the 2013 flood. Additional information pertaining to this mechanism is provided in **Section 2.2.1.**

**Table 2.2** below summarizes the low-probability flood instantaneous peak flows associated with the lower portion of the Highwood River and the Little Bow River.

**Table 2.2 Eight Largest Instantaneous Peak Flow and Flow Rate by WSC Station**

Highwood below Little Bow Canal 05BL004 – Area 1,950 km <sup>2</sup>			Highwood near Mouth 05BL024 – Area 3,950 km <sup>2</sup>			Little Bow River Flood Peak Estimate	
Year	Peak Flow (m <sup>3</sup> /s)	Flow Rate (m <sup>3</sup> /s/km <sup>2</sup> )	Year	Peak Flow (m <sup>3</sup> /s)	Flow Rate (m <sup>3</sup> /s/km <sup>2</sup> )	Year	Peak Flow (m <sup>3</sup> /s)
2013	1820 <sup>1</sup>	0.9333	2013	1,850 <sup>2</sup> (2,320 <sup>1</sup> )	0.4684 0.5873	2013	560 <sup>3</sup>
1995	803	0.4118	1995	1,120	0.2835	1995	---
1932	740	0.3795	1932	---	---	1932	---
1942	708 <sup>4</sup>	0.3631	1942	---	---	1942	---
2005	671	0.3441	2005	1,340	0.3392	2005	---
1923	643 <sup>4</sup>	0.3297	1923	---	---	1923	38.5 <sup>5</sup>
1929	595	0.3051	1929	---	---	1929	---
1953	536	0.2746	1953	---	---	1953	---
Notes: <sup>1</sup> Preliminary WSC estimate using slope-area methodology <sup>2</sup> Preliminary WorleyParsons estimate using model results plus WSC Sheep River at Mouth Estimate <sup>3</sup> Preliminary WorleyParsons estimate using model results <sup>4</sup> Highwood River near Aldersyde (05BL009) <sup>5</sup> Little Bow River at Carmangay (05AC003), before Twin Valley Reservoir inauguration in 2004 "---" Data not available							

The period of record for the hydrometric station of Highwood River near The Mouth (05BL024) is 1970–2016, 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 of the eight largest flow events in the area are recorded in the WSC database, as reported in **Table 2.2.** The station is still active.



A number of stations were investigated to obtain instantaneous flow peaks on the Little Bow River between High River and the MD southern limit or even further downstream. Some of them had no instantaneous peak records (05BL015: Little Bow River at High River), some had a too limited period of record (05AC928: Little Bow River at Highway No. 2 and 05AC911: Little Bow River below Frank Lake), some presented one or more instantaneous peaks inconsistent with the historical succession of peak values (05AC930: Little Bow River at Highway No. 533), and others were characterized by regulated rather than natural regime (05AC941: Little Bow River below Twin Valley Reservoir).

The station of Little Bow River at Carmangay (05AC003), used to tentatively supplement 1923 peak instantaneous flow for the Little Bow River, has a period of record that starts in 1918, and the station is still active. However, instantaneous peak flows have been not considered after the Twin Valley Dam, located upstream of Carmangay, became operative in 2004.

Among the previous largest events in **Table 2.2**, only the 1995 value was available for 05AC003, but has not been reported in the table because it is inconsistent with the historical magnitude succession expected in the watercourse.

Advisian's hydraulic models (discussed in **Section 3.0**) for the study area, which were (or will be) used to assess the 2013 flood response, the effectiveness of various mitigation options (constructed and planned), and various effects associated with these options, use specific peak inflows as upstream boundary conditions. The specific peak inflow depends on the model and its domain. The primary peak flow adopted for the upper boundary condition of the Town model (which extends from Woman's Coulee Canal Inlet to Highway 2 on both the Highwood River and Little Bow River) is 1,820 m<sup>3</sup>/s. This flow is applied at the upstream boundary of the model located just upstream of Woman's Coulee Canal Inlet. For the Town model, the peak flow was combined with a hydrograph shape similar to that recorded during the 1995 Highwood River flood for dynamic modelling purposes. However, the upper portion of this hydrograph was shortened by 30% based on sensitivity testing and validation. It is worth noting that no hydrograph estimates of the 2013 flood are available due to destruction of all monitoring stations.

### 2.2.1 The Highwood-Little Bow Flow Split

As briefly described above, historic observations and model analyses (both physical and computational) indicate that daily flood peaks above approximately 600 to 700 m<sup>3</sup>/s above Woman's Coulee Canal Inlet under conditions at the time of the 2013 flood in the Highwood River result in water overflowing (or "flow-splitting") to Little Bow River watershed from the south Highwood River floodplain in the area shown in **Figure 2.1**. Note the flow estimate of 600 to 700 m<sup>3</sup>/s is applied above the Woman's Coulee Canal inlet before flow-splitting occurs. Overflow is initiated when significant flood waters enter the southern floodplain of the Highwood River downstream of Woman's Coulee Canal inlet (**Figure 2.1**). Flood discharge from the Highwood River overflows to the Little Bow River watershed via the southern floodplain from just downstream of the canal inlet to the area just downstream of the Little Bow Canal inlet located within the Town (refer to **Figure 2.1**). During these relatively low probability flood events, 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; hence when flooding occurs within the centre of Town, this water 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 back to the river at George Lane Park in the Town (**Figure 2.1**). Anecdotal evidence suggests that in addition to floodwaters, the channel received significant quantities of groundwater in the early and mid-1900s; however, construction of the Hoeh Dike (starting in the early in the 20<sup>th</sup> 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 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 discharge point back to the main channel of the Highwood River (located in Town).

West of Town, water that overflows the RDB of Baker Creek is routed naturally to the Little Bow River along various high-water channels, the adjacent floodplain or through developed portions of Town (**Figure 2.1** and **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 channels south of the developed portion of Town, which can be described as floodway "fingers" based on the GOA's High River Flood Risk Mapping Study (NHC 1992), are shown on **Figure 2.2**.

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" channels) 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 12 Avenue and west of 72 Street East), and increasing bank heights in some areas north of 12 Avenue. 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 12 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 probability flood events protects the south side of Town and residents adjacent to the Little Bow River. These modifications, however, direct additional flow during low probability flood events back to the Highwood River's main channel, which bisects the Town.

In addition to overflow from the RDB of Baker Creek, flood waters during low probability flood events can also escape south to the Little Bow River from the main channel and floodplain of the Highwood River in the reach through Town from the mouth of Baker Creek to the downstream end of the Little Bow Canal Dike (**Figure 2.1**).

The WTD, TD, and Little Bow Canal Dike have been designed and constructed to protect the south portion of Town (north of 12 Avenue) from Baker Creek RDB overflow and flooding from the main channel of the Highwood River (**Figure 1.3**). These structures, however, can result in significant increases to low probability flood flow magnitudes in the Highwood River at and downstream of the Town. These flow additions can be summarized as follows:

- ▶ A portion of flood flow within the southern floodplain of the Highwood River/Baker Creek high-water channel that flooded the Town from the west and south, and that was eventually routed down the Little Bow River, is now diverted by the WTD down the main channel of the Highwood River resulting in significantly greater peak flows downstream of High River during low probability flood events in the Highwood River where spill-over would have occurred.
- ▶ 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 flows during low probability flood events in the Highwood River where spill-over would have occurred.

Preliminary estimates of the effect of the two flow additions described above indicate an increase of approximately 180 m<sup>3</sup>/s (from 1,225 to 1,405 m<sup>3</sup>/s), in the Highwood River just downstream of the Town, considering the 2013 flood magnitude of 1,820 m<sup>3</sup>/s above Woman's Coulee Canal inlet (**Figure 2.1**). Conversely, the Little Bow River is expected to experience a decrease in peak flow from approximately 560 m<sup>3</sup>/s to 405 m<sup>3</sup>/s under conditions similar to the 2013 flood (**Figure 2.1**). The increase in flood flow magnitude on the Highwood River at the Highway 2 Bridge north of the Town is even greater due to the raising of 498 Avenue E, and loss of floodplain storage associated with the Hamptons area located within the Town. This effect is discussed further in **Section 2.2.2**.

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 probability flood events where spill over occurs (WorleyParsons 2014). Understanding this diversion effect caused by diking, the Town and the MD committed to a design criterion to guide flood mitigation projects with a focus on:

- ▶ 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 probability floods (i.e., restoring pre-mitigation conditions);
- ▶ providing consistent downstream restoration design conditions (e.g., to ensure that new bridge and erosion protection infrastructure is not under designed due to these potential flood flow changes in the Highwood River); and
- ▶ providing an equitable solution to downstream stakeholders.

## **2.2.2 Change in Flood Risk and Hazard Level Downstream of 498 Avenue E**

The change in the flow-split between the Highwood-Little Bow rivers due to diking and the increase of flows north (downstream) of 498 Avenue E due to raising of this road (resulting in loss of floodplain storage) have significantly altered the flood peak magnitudes downstream of 498 Avenue E for low probability, infrequent flood events. The raising of 498 Avenue E was undertaken to protect the east side of the Town, including the Hampton Hills, Sunshine, and Sunrise neighbourhoods. Peak flow magnitude at the Highway 2 bridge is estimated to be approximately 290 m<sup>3</sup>/s greater than 2013 Flood Landscape Scenario (which is synonymous with the existing condition at the time of the 2013 flood or the condition pre-2013/2014 flood mitigation works), increasing from 955 m<sup>3</sup>/s to 1,245 m<sup>3</sup>/s (**Figure 2.1**). Additional information pertaining to the 2013 Landscape Scenario is provided in **Section 3.0**.

Flood peak magnitudes will increase due to diversion of flow by the dikes and loss of attenuation effects due to loss of flood storage in the Hamptons area. However, at flood peaks below approximately 1,000 m<sup>3</sup>/s (gauged upstream of Woman's Coulee Canal inlet), effects appear to be low to negligible based on review of preliminary data. Accordingly, this also produces low to negligible changes to flood hazard. The reasons that minimal effect occurs below 1,000 m<sup>3</sup>/s include:

- ▶ the proposed layout of Town diking, which causes significant flow diversion at low probability infrequent flows, does not have a major influence on the flow split at or below 1,000 m<sup>3</sup>/s; and
- ▶ the majority of flood waters downstream of the 498 Avenue E bridge do not leave the main channel of the Highwood River; hence, the effects of loss of flood plain storage associated with the raising of 498 Avenue E are negligible downstream of the Town.

However, as flows increase above 1,000 m<sup>3</sup>/s, the change in flood risk level becomes apparent. Change in flood risk in terms of flood magnitude for the 1,820 m<sup>3</sup>/s 2013 flood peak estimate are provided in **Figure 2.1**. The change in flood risk (in terms of flow magnitude), based on preliminary modelling results, between the 2013 Landscape Scenario and the complete mitigation scenario (Scenario 28A) in terms of various flow magnitudes (i.e., 750, 940, and 1,380 m<sup>3</sup>/s above Woman's Coulee Canal Inlet) is illustrated in **Figure 2.4** for the Highway 2 and 498 Avenue E bridge crossing locations. **Figure 4** indicates that the peak flow changes begin to increase between the 2013 Landscape Scenario and the complete mitigation scenario (Scenario 28) for peak flows greater than approximately 1,000 m<sup>3</sup>/s (above Woman's Coulee Canal Inlet). Note that inflow hydrographs for each peak flow magnitude were estimated using available information and that these results are preliminary. That is, these results may change with time as the model is updated and refined as information becomes available and model development progresses. The 2013 Landscape Scenario and complete mitigation scenario (Scenario 28A) are discussed further in **Section 3.0**.

## 2.3 River Morphology

Understanding channel and associated floodplain morphology in the context of the watershed and the local confining valley are important characteristics that influence flooding behavior and related risks. The following sections provide information pertaining to Highwood River and Little Bow River morphology in the study area.

### 2.3.1 Upper Highwood River (from MD Boundary to Woman's Coulee Canal Inlet)

A detailed discussion of the Highwood River morphology from the MD Boundary to Woman's Coulee Canal Inlet (Upper Highwood) is provided in **Appendix A**. Over this river segment, the river can be classed as confined with limited floodplain areas due to well defined canyons or valley confinement. The confinement somewhat dictates the irregular meandering planform of the channel through this segment. Pool-riffle channel morphology appears to dominate through this segment.

Nearly all residential development in the Upper Highwood River within the MD (outside of Pekisko and Stimson Creek sub-watersheds) is located on the upper bench above incised canyons or on elevated terraces within the greater Highwood River valley. Because of the valley and canyon morphology, there appeared to be low residential flood risk associated with this river segment during the 2013 flood.

### 2.3.2 Pekisko and Stimson Creeks

**Appendix B** includes the discussions on morphology of two key tributaries of the upper Highwood River, namely Pekisko Creek and Stimson Creek, located within the study area. The findings from this review are summarized below.

Pekisko Creek is a very mobile creek in terms of channel planform in the upper and middle portions of the watershed, whereas Stimson Creek, in comparison, is relatively stable, likely due in part to flow regulation associated with the Chain Lakes Reservoir and the lower elevation of its headwaters. A detailed on-site inspection of channel and flood plain characteristics is not available for either watershed. The majority of both watersheds are located within the MD and the primary land use is ranching, either located on deeded or crown leased land.

The infrastructure located in proximity to the stream channels is relatively restricted and consists of road and pipeline crossings and the North Chain Lakes Dam. The limited infrastructure adjacent to these watercourses in-part explains the relatively few 2013 flood issues documented in these watersheds. Following the 2013 flood, there was only one residence assessed for flood damages and six damaged bridges according to the MD's flood-related database. Other infrastructure found along the creeks includes three or more push-up dams.

### 2.3.3 Lower Highwood River from Woman's Coulee Canal Inlet to Bow River

NHC (1992) contains the following description of fluvial geomorphology of the Highwood River at High River. Additional information is provided in italics to improve clarity and expand the discussion to the mouth of the Bow River for the purpose of this report).

- ▶ It is thought that during its retreat (*during the last ice age*), the continental ice sheet for a time took up a position immediately northeast of High River town. Prior to and during this period, several meltwater channels carrying meltwater from retreating alpine glaciers to the west formed and became abandoned southwest of the present town site.
- ▶ During the two retreat positions, a broad gravelly outwash fan formed south of the town site; the apex of this fan is located about 2 km west of High River town. Ground slopes along the fan are in the range of 4 to 6 m/km.
- ▶ With diminishing amounts of alpine meltwater, Highwood River flows followed the present valley to the town and then flowed southeast across the outwash fan, into the present day Little Bow River valley. The planform of the Little Bow River channel immediately southeast of High River town closely resembles the modern day planform of the Highwood River upstream of town.
- ▶ With retreat of the continental ice sheet from the area, the Highwood River eventually returned to its pre-glacial path along its present course north of High River town, to join first with the Sheep River and eventually the Bow River. Although there are numerous swales visible across the fan surface south and southeast of High River town, there is no evidence of recent down-cutting or channelization. The scarcity of substantive silt deposition and the lack of longitudinal braided scars on the outwash fan surface suggests that periods of overflow into the Little Bow River basin south of High River town have been relatively infrequent and of short duration since the end of last glaciation.
- ▶ The present day Highwood River in the vicinity of High River Town has a rapidly changing planform (*except for areas that have been confined by diking and erosion protection within the core of Town*). From downstream to upstream *morphological characteristics of the river can be described as follows:*



- ▶ Bow River to Highway 2 – This river segment is highly confined with straight and irregular meandering reaches. Pool and riffle geomorphic structure is prevalent throughout. Sediment deposition is high just downstream of the Sheep River confluence and just upstream of the Bow River. Very little floodplain exists within this reach due to the narrow confining valley. *The gradient of this segment is approximately 0.26%.*
- ▶ Highway 2 to 498 Avenue E – The river through this segment has an irregular meandering planform through the downstream half and a straight reach on its upper half. In general, the *gradient (0.05%)* is lower through this area than both upstream and downstream river segments. The channel is slightly incised but is not confined within a river valley. The floodplain is inundated over significant areas at low probability flows above approximately 1,000 m<sup>3</sup>/s.
- ▶ 498 Avenue E to the Upstream Town boundary – *Historically, this segment of the river likely exhibited wandering to braided characteristics due to its slope, significant sediment load and loss of transport capacity due to the slope transition to the lower slope segment at its downstream end. However, river training works and the Highway 2A crossing within the Town have created a confined meandering planform through this segment. Channel translation is limited, especially at the upstream portion, due to bank protection. Floodplain access is also limited in the upper portion of this segment due to diking. The channel has shown aggradational characteristics, mainly upstream of the Highway 2A bridge, which is consistent with an undersized crossing. Average slope of this segment is 0.16%.*
- ▶ Upstream Town Boundary to Woman's Coulee Inlet – *This segment of the river is in a more natural state when compared to the segment through the Town. However, significant river training and diking works can be found in some reaches. This segment of the river can be classified as wandering. The sediment load is relatively high but transport capacity and channel form minimize braiding tendencies. The river has very low confinement within a subtle valley approximately 1 km wide at the segment's upstream end, increasing to a width of 2 km near the Town. The channel has little incision and can access its floodplain at most flows above the median (2-year) flood event where diking is not present. Slope of this segment (0.32%), consistent with channel type, is greater than the other segments discussed above.*

#### 2.3.4 Little Bow River from Town of High River to MD Boundary

The Little Bow River morphology is somewhat simpler in relation to flooding behavior than the various planform and channel characteristics of the Highwood River through the study area. As discussed in **Section 2.3.3**, the Little Bow River morphology, including channel planform and valley, were likely initially developed due to flow emanating from the Highwood River watershed. The headwater channels appear to be similar to high-water channels of the Highwood River; however, the Little Bow River headwater channels do not return flow back to the river but instead divert water south.

The main channel of the Little Bow River begins in the Town. The channel meanders south in an irregular pattern while converging with other contributing overflow channels from the Highwood River from the west. As discussed earlier in the report (**Section 2.2.1**), these channels are only active during low probability, infrequent flood events. Just upstream of Highway 2, the main channel of the Little Bow Rivers enters the Little Bow River Valley, a feature that is approximately 500 to 1,000 m wide, and approximately 25 to 35 m deep.

These characteristics indicate a glacial meltwater origin. The river valley bottom is very flat with only minor topographic diversity and terracing.

Downstream of Highway 2, the river continues its irregular meandering planform within the valley for approximately 40 km. The average channel width is approximately 15 m and a very low degree of confinement. The average thalweg depth tends to be below 1 m. The average slope is approximately 0.12% (MSA 2002). Because flood hydrology is characterized by local early season runoff from snow melt, as well as rainfall for the majority of the time, the river does not appear to be laterally active.

The river is also fed by the Little Bow Canal which diverts irrigation water from the Highwood River to the Little Bow River through the open water season. The confluence of the river and canal occurs near the southern extent of the Town. The diverted flows (maximum of 8.5 m<sup>3</sup>/s) are for the most part insignificant in relation to the low probability infrequent flood events that may be produced by overflow from the Highwood River (e.g., an estimated 560 m<sup>3</sup>/s diverted peak in 2013). The operational procedures result in closing of the intake during flooding of the Highwood River. However, these smaller consistent flows from the canal likely influence local channel morphology and capacity. The channel appeared to have a maximum capacity of approximately 3.0 m<sup>3</sup>/s in most locations (although this varies) before potential morphological changes that could have been caused by diversion rate increases initiated approximately 12 years ago and the 2013 flood (MSA 2002). Even with significant increases in channel capacity that may have occurred, the floodplain would likely be at least partially inundated for flows above the 20 m<sup>3</sup>/s.

### 3.0 MODELLING

Portions of the Scoping Study presented herein have relied on discussion of modelling results gleaned from WorleyParsons' calibrated/validated 2D RMA-2 model of the Highwood River and upper Little Bow River in the vicinity of the Town. The existing model 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. Model extension is currently in progress for both the Highwood River (to its confluence with the Bow River) and the Little Bow River (to the MD boundary).

RMA-2 is a fully 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 two-dimensional 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 overtop river banks. 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 represent the model topography and flow behaviour. The variable mesh is constructed of irregular triangles and/or quadrilaterals which are made up of either three or four corner nodes. A 2D grid is therefore used to define features such as river and/or creek channels, bank, floodplain, and breakout areas.

Creation of the High River RMA-2 model network/grid was based around the input/assessment of a number of data sources including:

- ▶ topographic data including Light Detecting and Ranging (LiDAR), surveyed spot elevations, and Work-As-Executed Survey (post-2013 flood);
- ▶ hydrographic survey of High River, Lineham Canal, and the Little Bow River (both pre- and post-2013 flood);
- ▶ bridge and culvert data; and
- ▶ aerial photography of the floodplain.

Each of the above data sources were therefore used to guide the creation of the network mesh. This process involved an incremental review of the High River floodplain to identify locations where greater network detail was necessary based on topographic features, locations of hydraulic controls, and if any significant changes in floodplain type/roughness occurred that needed to be defined. This process is particularly important in order to take advantage of a finite element model whereby there is no benefit to the model output to incorporate a small grid size where there is little change in topography. For example, there is likely to be no improvement in the model output whether a flat paddock is defined by a singular rectangle with four corner nodes or a collection of 5, 10, and 20 elements. The unnecessary use of the latter leads to excessive run times, unnecessary resource use and data limitations. The High River RMA-2 model was therefore constructed to realize the benefits of a finite element model.



The High River RMA-2 model was initially developed before the 2013 flood and then further refined, enhanced, and validated against the 2013 Flood Landscape Scenario immediately after the flood. Following 2013 Flood Landscape Scenario's original validation using a synthetic hydrograph shape (based on historic information) with a peak equivalent to WSC's estimated 1,820 m<sup>3</sup>/s 2013 flood magnitude, the model underwent additional updating and refinement based on available data to improve accuracy and performance. The model is still being updated and refined as information becomes available and model development progresses. Therefore the model results have been described as "preliminary". In addition to general model development, a multitude of new grid networks have been developed to assess numerous (over 75) flood mitigation scenarios at various peak flow magnitudes. The two most relevant scenarios used within the framework of the Scoping Study include:

- ▶ 2013 Flood Landscape Scenario (previously referred to as the Existing Condition Scenario); and
- ▶ Scenario 28A (Complete Mitigation Scenario), which includes all as-built dike information and the proposed 12 Avenue-Centre Street. Dike required to protect southern boundary of the Town (refer to **Figure 2.3**). This scenario has been used as a conservatively based design scenario (i.e., based on the Town's complete mitigation scenario) and can be considered the baseline design scenario for this Scoping Study. Currently the Town is proposing a south protection solution titled the SWD solution that differs in alignment from the 12 Avenue-Centre Street Dike. The SWD is being/has been designed based on the objective of having the flow-split equivalent to that of the 12 Avenue-Centre Street Dike design.

The previously (i.e., Advisian's previous modelling for the Town) titled *Existing Condition Scenario*, which models conditions at the time of the 2013 flood, was renamed to the *2013 Flood Landscape Scenario*, to avoid confusion. The 2013 Flood Landscape Scenario incorporates a modelling surface that was consistent with that apparent just after the 2013 flood. The floodplain and active channel topography above the low water level were defined with LiDAR collected after the flood. Cross-section survey data collected after the flood was also used to define the low water channel through Town from just upstream of George Lane Park to just downstream of the Little Bow Canal Dike. The remaining low flow channel areas were estimated using pre-2013 flood information. Updating this information has been recommended. However, this information is not expected to have significant influence (e.g., less than 30 cm based on existing model sensitivity testing with old and new channel topography) on low probability, infrequent flood water levels such as those associated with the 2013 flood.

Scenario 28A (Complete Mitigation Scenario incorporating the 12 Avenue-Centre Street Dike Scenario for south Town protection; **Figure 2.3**) incorporates all proposed and constructed mitigations measures throughout and surrounding the Town. The south portion of Town is protected by the 12 Avenue-Centre Street Dike alignment, as shown in **Figure 2.3**. This scenario is considered the baseline mitigation and design scenario, because it was used as the design scenario for the majority of the dike structures through and downstream of the Town. Advisian recommended, and the Town concurred, that any south protection solution proposed to protect the south portion of the Town not result in any additional flow being diverted north when compared to Scenario 28A. If additional water is diverted north, the constructed dike design will not meet the proposed design criteria. Currently the Town is proposing a south protection solution titled the SWD solution that differs in alignment from the 12 Avenue-Centre Street Dike.

The SWD is being designed with the objective of having the flow-split between the two rivers equivalent to that of the 12 Avenue-Centre Street Dike design. Hence, regional effects between the two options should be nearly identical. Local differences in effects (SWD versus 12 Avenue-Centre Street Dike) at flood flows below the 2013 flood magnitude are confined to the property where the SWD is located.

In addition to the 2013 flood peak flow magnitude of 1,820 m<sup>3</sup>/s, various peaks flow hydrographs have input into the model to assess various situations, which include:

- ▶ 1,390 m<sup>3</sup>/s, which is the preliminary 100-year (1% recurrence) flood of the GOA;
- ▶ 900 m<sup>3</sup>/s, which was selected as an assessment magnitude based on review of river morphology and available model results; and
- ▶ 750 m<sup>3</sup>/s, which is equivalent to the GOA design flood determined in their 1992/1993 flood study (NHC 1993).

Additional information pertaining to the flood modelling undertaken by Advisian and the flood mitigation planning framework and options for the Town are summarized in the 2013 FMMP (Advisian 2014).

Specific modelling results for these and other scenarios are discussed in **Section 4** for different reaches of the lower Highwood River and Little Bow River. Additionally, the two main scenarios discussed (i.e., 2013 Flood Landscape Scenario and the Town's Complete Mitigation Scenario [Scenario 28A]) form the basis for the conceptual level flood mitigation designs contained in **Section 5** and the high level cost-benefit analysis contained in **Section 6**.

## 4.0 FLOOD ISSUES

Flood-related issues facing the MD related to the Highwood River and Little Bow River are discussed in the following subsections. For discussion purposes, the Study Area has been divided into the following three subareas:

- ▶ the Upper Highwood River, which for the purposes of this report has been defined from the upstream MD Boundary on the Highwood downstream to Woman's Coulee Canal inlet. This area also includes major tributaries such as Pekisko and Stimson Creek;
- ▶ the Lower Highwood from Woman's Coulee Canal inlet to the Bow River. This area is associated with the most significant negative effects from flood-mitigation works in and surrounding the Town and can be considered to be at higher risk due to potential flooding scenarios and increased populations; and
- ▶ the Little Bow River within the MD boundary which begins at the Town and ends 31 km south.

The flood-related issues discussion is focused on, investigates, and summarizes changes in potential flood risks associated with manmade and/or natural changes which have or could occur. Although existing issues, such as general flooding within the Highwood River floodplain (or flood fringe) are highlighted for some areas, the focus of the discussion is on areas that could potentially see a change in flood risk. For example, diking in the Town has changed the flow-split hydrology for both the Little Bow River and Highwood River during low probability, infrequent floods as discussed in **Section 2.2.1**. The areas downstream of these changes with the potential to experience negative effects will be a focus for discussion.

### 4.1 Upper Highwood River

The Upper Highwood River is defined as the segment of the Highwood River downstream of the MD Boundary (located approximately 33 km upstream of Longview) to the Woman's Coulee Canal Inlet on the Highwood Rivers. Two reports provided in **Appendix A** and **Appendix B** discuss the main stem of the Highwood River and the major tributaries in this area (i.e., Pekisko Creek and Stimson Creek), respectively. Flood issues identified in these reports are summarized below in the following sub-sections:

- ▶ the Highwood River upstream of Pekisko Creek confluence to the MD Boundary;
- ▶ Pekisko and Stimson creek tributaries; and
- ▶ the Highwood River downstream of the Pekisko Creek confluence to Woman's Coulee Canal inlet.

#### 4.1.1 Highwood River Upstream of Pekisko Creek Confluence to MD Boundary

The reach of the Highwood River downstream of the MD western boundary and upstream of Pekisko Creek confluence is covered in **Appendix A**. Flood issues, as well as flood risk changes in this area located upstream of the proposed or realized measures of flood control following 2013 event, are limited:

- ▶ Bridge damages – The bridge on Highway 22 (01741) reported not visible flood damage or embankment erosion. No other damages were registered in the remaining four bridges in the Alberta Transportation database for this river's section. Two private bridges were destroyed within sections 6 and 7 of 18-03 W4M. Given the unchanged conditions relative to river hydraulics it is reasonable to assume that flood issues and risks will be similar in the future;
- ▶ Road damages – Two localized road washouts were reported in Eden Valley area or immediately downstream. Same considerations on unchanged river hydraulics and flood risk level apply;
- ▶ Landowner damages – Six instances of various damage typology (residential basement, land only, etc.) were reported in quarter sections between Longview and the Pekisko Creek confluence. Another twelve sites were reported between the Pekisko Creek confluence and Woman's Coulee Canal Inlet; and
- ▶ Few small barriers built by private owners in order to pond small volumes on small drainage paths for irrigation purposes (push-up dams) have been located in the agricultural areas immediately upstream of the Pekisko Creek confluence. Similar considerations apply to man-made small barriers as per following section on Pekisko and Stimson Creek.

It is worth noting that there were some damages outside the MD, in the community of Longview.

#### 4.1.2 Pekisko and Stimson Creek Tributaries

**Appendix B** contains a detailed description of flood issues for Pekisko Creek and Stimson Creek. As summarized below, no significant flood issues were identified:

- ▶ No issues or data gaps were identified on Pekisko and Stimson Creeks that would have a significant impact on the Highwood River downstream of the confluence with Pekisko Creek; and
- ▶ There are several push-up dams located within the Pekisko and Stimson watersheds. The performance of these structures during the 2013 flood is uncertain. However, it appears there were no significant issues related to push-up dams resulting from the 2013 flood. There may be some merit to further evaluate these structures to determine impacts resulting from a failure.

#### 4.1.3 Highwood River from Pekisko Creek to Woman's Coulee Canal Inlet

**Appendix A** discusses the Upper Highwood River which includes the river segment from the Pekisko Creek confluence downstream to Woman's Coulee Canal Inlet. In general, impacts associated with this area in the MD were limited to damages to the Hogg Park Campground and some basement flooding and land damage. Twelve residents reported damage between the Pekisko Creek confluence and Woman's Coulee Inlet. Although some bank erosion was present throughout, residential buildings were located mainly on elevated terraces above the 2013 flood levels.

#### 4.2 Highwood River from Woman's Coulee Canal Inlet to Bow River

Based on a review of available information and the field visits, the scoping team has identified that the majority of flood-related issues are associated with the Highwood River segment from Woman's Coulee Canal inlet to the Bow River. The increased awareness of flood related issues within this river segment can be attributed to:

- ▶ the increased quantity of infrastructure and residents adjacent to the river and the associated river-floodplain morphology; and
- ▶ the significant amount of flood mitigation work that has been performed by the Town, which has altered both floodplain morphology and flood hazard level (i.e., peak flow magnitudes and associated water levels during low probability, infrequent floods).

To aid in the discussion of flood-related issues associated with this river segment, six reaches (or areas) have been identified for discussion purposes:

- ▶ Woman's Coulee Canal inlet;
- ▶ Hoeh Dike Downstream to Town;
- ▶ the Town;
- ▶ 498 Avenue E and the Hamptons area;
- ▶ 498 Avenue E to Highway 2; and
- ▶ Highway 2 to Confluence with Bow River.

Flood-related issues for each reach or area are identified below. Local conceptual solutions to address these concerns are presented in **Section 5.0**.

#### 4.2.1 Woman's Coulee Canal Inlet

Woman's Coulee Canal (Mosquito Creek) Inlet and associated infrastructure divert water from the Highwood River into the Little Bow River system. The Woman's Coulee canal inlet is located on the south bank of the Highwood River and diverts water into a canal which drains southeast for a length of approximately 1,500 m across the south floodplain of the Highwood River and then into a pipeline. The inlet was damaged during the 2013 flood. The local landowners have expressed concerns that the new structure should not result in the diversion of additional floodwaters towards the south bank and floodplain (e.g., there should be no significant encroachment of the intake into the Highwood channel).

Approximately 2 km west (upstream) of the Woman's Coulee Canal inlet, the south floodplain opens up sufficiently to allow development consisting of agricultural use (grazing, crops) and country acreages. This type of development extends east to the Town boundaries. Similarly, the north floodplain becomes unconfined downstream of the Woman's Coulee Canal inlet allowing for similar type of development as noted for the south floodplain. Intensive feedlot operations are also located on the north floodplain.

As the floodplains become wider and the channel is less confined, the channel characteristics also change. The river is multi-channelled (i.e., braided) in this reach, with sub-channels being subject to rapid shifting and abandonment.

From a flood-issue perspective, near Woman's Coulee Canal Inlet only one rural residential property is at risk of inundation. However, the inlet repair work being performed by the GOA has the potential to change floodplain flow distribution in this area. It is essential that these repairs consider the overall effect on flooding locally and downstream from this area. At the time of reporting, a detailed repair plan/design was not available for review.

#### 4.2.2 Hoeh Dike Downstream to Town of High River

The Hoeh Dike parallels the Highwood River for approximately 2,000 m within the South 1/2 of 32-18-29 W4M and the North 1/2 of 29-18-29 W4M in the MD, approximately 7 km upstream of the Town and just downstream of the Woman's Coulee Canal inlet area. The Hoeh Dike consists of a patchwork of different segments that have been constructed over the last 100 years. **Section 2.2.1** contains a discussion of the Hoeh Dike and its role in directing floodwaters away from Baker Creek and subsequently the Town and the Little Bow River basin.

Flooding issues of the Highwood River from the Hoeh Dike to the Town of High River are summarized in **Table 4.1**.

draft



Table 4.1      Hoeh Dike to Town of High River

Issue	Assessment	Discussion	Proposed Solutions and Mitigations
1. Potential for Hoeh Dike breach during low probability infrequent flood resulting in channel avulsion and/ or increased flows downstream toward MD residents, the Town and the Little Bow River.	1. Literature review and team field visit to investigate the dike heights in relation to the downstream topography, channel morphology and general flooding and avulsion risk in the Hoeh Dike area.	- Based on literature review, the dike appears to perform satisfactorily under ~800 m³/s flows based on 1995 and 2005 flood information. Risk of breach is apparent at flows beyond 800 m³/s. However, flood water at peak magnitudes greater than 800 m³/s appears (based 2013 flood levels and effects) to short-circuit to the south of the dike and flood the fields/floodplain behind it. The flooding behind the dike appears to minimize the head difference between and front and back of the dike, reducing the breaching risk. Because of land levels and historic channel levels, an avulsion does not appear likely at the upstream dike segment due to this short-circuiting effect through the Woman’s Coulee Canal inlet area; however, this type of failure was anecdotally mentioned as a concern in previous reports.	Upgrade design level of Hoeh Dike over the downstream segment (i.e., to address failure Scenario 2) adjacent to the historic high water channel
	2. Review dike cross-sections and downstream topography behind the dike in relation to flood water levels (at 900 m³/s, 1,390 m³/s and 1,820 m³/s) to investigate breach and avulsion potential.	- To further assess the risk of avulsion and breaching flood cross-sections were analyzed at six locations along the Hoeh Dike during the floods events described in the previous column. Review of this cross-sections information indicates that flooding behind the dike begins to occur at approximately 900 m³/s. Water levels upstream and downstream of the dike tend to be relatively similar at most locations (except XS 6) over the range of flood magnitudes tested. These results do indicate that flooding through the Woman’s Coulee Canal inlet area helps equalize water levels upstream and downstream of the dike, minimizing breaching risk. Flood water behind the dike minimized hydraulic potential across the dike and therefore likely minimized the amount of breaching of the Hoeh Dike. The 2013 flood impacts on the Hoeh Dike provides a good example of how some breaching occurred, however the breaching extent was likely minimized due to water level equalization upstream and downstream of the dike.	Ensure Woman’s Coulee Inlet upgrading does not affect flood flows which could increase risk of breaching to the upper segment of the Hoeh Dike
	3. Simulate two Hoeh Dike failure scenarios using the RMA-2 flood model. Scenario 1: 150 m wide breach of the Hoeh Dike along its upper segment, down to floodplain. Scenario 2: 50 m breach of the Hoeh Dike (downstream segment) down to a historic high water channel bed	- Because of the balancing force of the flood flow coming from the Woman’s Coulee Canal inlet area, upgrading design criteria on the Hoeh Dike to avoid breaching risk may not be warranted. However, there are two or three locations where significant breaches could occur, which could in turn result in increased flow and water levels downstream. To better assess these specific areas of concern, two Hoeh Dike failure scenarios (as described in the previous column) were assessed. The results are provided in Figures 4.5-A, B and C; and Figures 4.6-A, B and C for Hoeh Dike Failure Scenario 1 and Scenario 2, respectively. From the figures it is possible to see that flow increases directly downstream of the Scenario 1 failure is fairly substantial (increasing from 180 m³/s to 205 m³/s in the south floodplain; water level increases of up to 12 cm) for 1 to 1.5 km from the point of failure. However this effect is dampened as floodwater in the south floodplain is reconnected with floodwaters from the main channel. By the time flow reaches the Town the effects on peak flow magnitude to the Little Bow are negligible. For Hoeh Dike failure Scenario 2, effects are more substantial with flows increasing from 180 to 300 m³/s in the south floodplain. Water level increases due to the flow increase are up to 70 cm adjacent to the failure, decreasing to near zero approximately 2 km downstream. For the second scenario, water level changes have become negligible near the Town, however flows down the Little Bow are estimated to increase from 410 to 430 m³/s. Based on the modelling results, a Hoeh Dike failure appears to have significant local effects with only minimal regional effects. However, the modelling did not assess potential morphological changes (bank erosion, channel avulsion) that could occur downstream of the dike breach failures. The RMA-2 flood model is a fixed-bed model that is not capable of modelling these type of failure scenarios. Additional field and analytical assessment may be required to further define risk associated with this area.	---
2. What are the pros/cons of the Hoeh Dike now that Town is completely diked? Is the Hoeh Dike still a critical piece of infrastructure?	1. See above	– The Hoeh Dike protects MD residents downstream of the dike during flooding below approximately 800 m³/s. The dike also influences flood flows that enter the southern floodplain and the Little Bow River above 800 m³/s. Any increase in dike height has the potential to route additional flow down the main Highwood River channel which is not recommended considering the significant increase in flood water that will now be routed down the main channel, through the Town, due to diking within the Town. In addition, uncertain effects of avulsion to and erosion of high water channels behind the Hoeh Dike during low probability infrequent flood events indicates that the dike is minimizing flooding risk uncertainty in this area. Therefore, the structure is currently serving an important purpose but should not be raised or lowered as this will have regional flood effects.	See above

The following description of the Hoeh Dike and the Highwood River in the vicinity of the Hoeh Dike is taken from a previous AMEC report (2008a):

- ▶ The Hoeh dike was constructed in 1917 to prevent water from entering Baker Creek Channel and flooding the Town. Much of the dike was destroyed in the 1923 flood and rebuilt in 1924. Subsequent floods caused further damage to the Hoeh dike and to other dikes developed for flood control, necessitating further repairs and reconstruction. Historical records show continuous attempts to control flooding of the Highwood River since then.
- ▶ The 2,000 m long Hoeh Dike system can be divided into six segments based on the characteristics of each segment, such as structure location with respect to the riverbank (i.e., bank dike or setback dike) and the type of dike (i.e., sheet pile or earthfill).

Discussions with local residents indicate that only one portion of the Hoeh Dike was overtopped during the 2013 flood, although the area behind the dike was subject to inundation. The dike was outflanked at the upstream end, permitting a significant quantity of discharge to be conveyed in the floodplain behind (south of) the dike. The modelling of the 2013 discharge and potential Hoeh Dike failure scenarios and their impacts is discussed in greater detail in **Section 2.2.1**. The portion of the dike that was overtopped during the 2013 flood consists of a 60 m long sheet pile section that is approximately 0.6 m lower than the adjacent sections. The sheetpile segment is in a critical location as it is at the start of the Baker Creek channel.

The following description of the Highwood River in the vicinity of the Hoeh Dike is provided in AMEC (2008a):

- ▶ In this reach, the Highwood River is multi-channelled (i.e., braided) and generally drains in a northeasterly direction.
- ▶ The sub-channels are prone to frequent overtopping and lateral shifting. There are numerous active gravel bars and bed material transport likely occurs every year during high water.
- ▶ A 50 to 200 m wide lower level floodplain is present within the study reach. This lower level floodplain is subjected to inundation on a more frequent basis than the higher level 1:100-year floodplain.
- ▶ The 1:100-year floodplain boundary varies in width from 900 m to over 1,200 m. The floodplain is widest at the downstream end of the study reach.
- ▶ Several overland flow paths and channels are evident in the study area, including:
  - ▶ several distinct flood channels on the north floodplain; and
  - ▶ Baker Creek – a historic overland flow path which has since been cut off by the Hoeh Dike.

Flooding issues associated with the Highwood River from the Hoeh Dike downstream to the Town are mainly associated with flooding and Hoeh Dike failure, which could potentially increase local and regional (e.g., at the Town and downstream on the Little Bow River) flooding effects and potential for channel migration/avulsion. However, channel migration and avulsion associated with local bank erosion are also concerns. Previous reports discussing channel migration and avulsion in this area are discussed below.



A significant meander bend cutoff adjacent to the downstream extent of the Hoeh Dike occurred in 2008 and is discussed by AMEC (2008b). Previously, the Highwood River had a sharp meander bend which curved to the right (south) and directed the flow towards the Hoeh Dike. The cutoff resulted in the flow being directed northeast, away from the downstream portion of the Hoeh Dike. The channel length within the meander bend area reduced from 1,350 m, prior to the cutoff to 890 m after the cutoff, between the start and end points of the meander bend. The post-cutoff channel alignment, at the downstream end of the avulsion, directed the attack of the river towards several residents that were located adjacent to the right (south) bank, downstream of the Hoeh Dike, at the end of 40 Street. AMEC (2008b) reviewed potential flood and erosion mitigation options that extended the Hoeh Dike downstream in order to protect these residents. However, since this area is located in the floodway, these residents were offered buyouts following the 2013 flood. Hence, this extension of the Hoeh Dike is likely not required.

AMEC (2012) reviewed the morphologic implications of meander bend cutoff in the reach downstream of the Hoeh Dike to the Town and identified several high potential erosion sites. The morphologic impacts of the 2013 flood far outweigh the 2008 meander bend cutoff and the recommendations in AMEC (2012) are superseded by those contained herein.

Repairs to the Hoeh Dike were made in March to April 2014 due to damage resulting from the 2013 flood (AMEC, October 2014). The repairs were in the vicinity of the residence on NW 29-18-24-W4M, generally upstream of the middle segment of the dike. The repairs consisted of placing riprap armoring in areas that were subject to bank erosion. The three main project components undertaken in April/June 2014 are described below.

- ▶ Class II riprap was placed at two 30 m bank revetment areas that were subject to erosion;
- ▶ The second component was a 160 m long longitudinal peak stone toe protection (LPSTP) bank reinforcement. This work consisted of a pyramid shaped berm constructed of Class II and III riprap, placed at the eroded toe of the river bank. Additionally, fish habitat structures were constructed adjacent to the LPSTP; and
- ▶ The third portion of the work was a 60 m key-in that was constructed going from the east end of the LPSTP bank reinforcement, following a natural drainage path. The key-in was excavated 3 m down, and Class II riprap was placed along the west side of the excavation. In-situ material was then used to backfill the key-in and then covered with topsoil.

A failure of the Hoeh Dike could change the flood risk both locally and regionally. Due to these potential effects, a limited Hoeh Dike failure analysis was undertaken by the scoping team. The assessment primarily consisted of two hydraulic model runs with sections of the dike removed to simulate failure, as detailed below:

- ▶ a field visit to review the condition of the dike, the lands surrounding the dike, and the channel behavior adjacent to the dike;
- ▶ a review of dike elevations at several locations in comparison to local topography behind the dike and potential flood levels surrounding the dike during various flood conditions (i.e., at flows of 900 m<sup>3</sup>/s, 1,390 m<sup>3</sup>/s, and 1,820 m<sup>3</sup>/s, as described in **Section 3.0**). This review included the assessment of six Hoeh Dike cross section locations (refer to **Figure 4.1.1**) at the three different flood peak magnitudes as shown in **Figures 4.1.2 through 4.1.7**; and

- ▶ a review of effects (i.e., changes in downstream water levels and velocities) for the two dike failure scenarios that were developed by the scoping team following review of the cross section information identified in the previous bullet. The effects were assessed through application of the RMA-2 flood model. The two scenarios that were simulated can be described as follows:
  - ▶ Hoeh Dike Failure Scenario 1 – Removing a 150 m section of the top of the Hoeh Dike down to floodplain directly north of XS3 towards XS2 (**Figure 4.1.1**); and
  - ▶ Hoeh Dike Failure Scenario 2 – The Hoeh Dike blocks water from entering a historic high water-channel at XS-6 (**Figure 4.1.1**). Because of the large head difference between the top of the dike and the historic channel bottom, the location is a prime area of concern. To assess potential effects: assume complete failure over the channel area (at XS6). The estimated failure width was 50 m, extending down to the existing bed/land level (1,061.4 m above sea level based on cross section information) associated with the historic channel as defined from the LiDAR.

It is worth noting the model simulations do not take into account potential morphological changes that will occur in the natural environment. That is, once the failure is “built” into the model domain, its geometry is fixed.

**Table 4.1** contains a discussion Hoeh Dike flood issues and modelling results. Key findings are summarized below and in **Figures 4.2.1 through 4.2.3** (Failure Scenario 1) and **Figures 4.3.1 through 4.3.3** (Failure Scenario 2).

- ▶ Flooding behind the dike begins to occur at approximately 900 m<sup>3</sup>/s. Water levels upstream and downstream of the dike tend to be relatively similar at most locations (except XS 6) over the range of flood magnitudes tested. These results do indicate that flooding through the Woman’s Coulee Canal inlet area helps equalize water levels upstream and downstream of the dike, minimizing breaching risk.
- ▶ Modelling of Hoeh Dike failure scenarios indicates that dike failure appears to have significant local effects but only minimal regional effects (e.g., at the Town of High River) based on comparison to the 2013 Flood Landscape Scenario/Scenario 28A.
- ▶ The structure is currently serving an important purpose but should not be raised or lowered as this will have regional flood effects.

#### 4.2.3 Town of High River

Construction of the Town flood mitigation works (specifically the WTD, TD, and Little Bow Canal Dike) shown in **Figure 1.3** will influence the flow-split between the Highwood River and the Little Bow River during low probability infrequent floods as described in **Section 2.2.1**. These dikes have been designed to protect against flood flows approximately equivalent to the 2013 flood event which has been estimated to have a peak flow of 1,820 m<sup>3</sup>/s. There is a risk that the Town’s dike infrastructure may breach during flood events more severe than the 2013 flood. Care should be taken during planning that both intact and failed dike scenarios are considered when assessing low probability infrequent flooding events such as failure of the Chain Lakes north dam. Dike breaching could increase flows directed downstream to Little Bow River residents and infrastructure when compared to the intact dike scenario. However, total catastrophic failure in the form of breaching is unlikely due to overflow protection on the downstream side of the dikes.

There is some concern that bar scalping performed immediately upstream of the Highway 2A Bridge to removed aggraded sediment (estimated 38,000 m<sup>3</sup> at source) and increase channel capacity in 2013 following the flood may influence downstream channel morphology and/or flooding. The aggradation observed upstream is due in part to the influence of the downstream bridge constriction, which decreases the natural sediment transport capacity of this reach. This aggradation trend has been observed in this reach since in-channel dredging was suspended in the 1980s. Aggradation observations were confirmed with the use of cross sectional data (WorleyParsons 2012). There may be long-term morphological impacts downstream of the Town, but these impacts would have been initiated when the existing bridge structure was installed and sediment transport capacity was originally affected. Loss of sediment is most often associated with channel degradation and bank destabilization. The removal of sediment upstream of the bridge during a single year would not noticeably influence downstream morphology and/or flows considering the bridge constriction effects that have been affecting sediment transport for over half a century. Moving forward, the Town was planning to maintain the 1992 cross section morphology throughout the Town using the bar scalping technique, as needed based on loss of free board capacity. However the Town has refocused their efforts on upgrading the crossing for Highway 2A due to it being severely undersized in terms of conveyance. A properly design bridge crossing will minimize the influence on sediment transport capacity and somewhat restore the sediment continuum in the Highwood River thorough the Town. This, in turn, should help to limit aggradation upstream and downstream of the Highway 2A crossing. A new bridge, however, may influence the channel further downstream as sediment transport capacity returns to a more natural condition.

In summary, beyond a significant reduction in the overflow of low probability, infrequent floods to the Little Bow River that are now diverted to the Highwood River, flood mitigation measures within the Town should have minimal regional effects.

#### 4.2.4 498 Avenue E and the Hamptons

The area east of the Little Bow Canal and north of 12 Avenue in the Town, namely the Hampton Hills, Sunshine, and Sunrise neighbourhoods, experienced significant flooding in 2013 and extended inundation due to lack of a natural surface drainage route. The majority of flood water entered this area from the north, flowing over 498 Avenue E. Peak flows entering this area are estimated at approximately 200 m<sup>3</sup>/s.

498 Avenue E was raised to protect this area, which resulted in:

- ▶ a significant loss of flood storage (preliminary estimates indicated approximately 6,100,000 m<sup>3</sup>) south of 498 Avenue E;
- ▶ increased storage of flood waters and water levels north of the road due to backwater effects as shown in **Figure 4.7** (A through I); and
- ▶ an increase in flow downstream in the Highwood River, which is already affected by flow increases caused by diking within the Town.

Local residents directly north of 498 Avenue E affected by increased water levels were also protected by raising 112 Street E north of 498 Avenue E. However, residents downstream will experience increased flow accompanied by increased water levels and velocities (refer to **Figure 4.4.1 through 4.4.3** and **Figures 4.5.1 through 4.5.3**).

In addition to loss of flood plain storage capacity, this area also includes the 498 Avenue E Bridge crossing. Water levels at this bridge are expected to increase. This may affect bridge integrity and debris passage efficient. It is recommended that an assessment be performed to determine risk and potential upgrades required.

#### **4.2.5 498 Avenue E to Highway 2**

As previously noted, this area will experience increased flow accompanied by increased water levels and velocities. **Table 4.2** lists flood issues, assessments, discussion of results, and potential solutions and mitigations for this section.

The effects of increased low probability infrequent flood magnitudes are presented in **Figure 4.4.1 through 4.4.3** and **Figures 4.5.1 through 4.5.3**.

#### **4.2.6 Highway 2 to Confluence with Bow River**

As previously noted, this area will experience increased flow accompanied by increased water levels and velocities. **Table 4.3** lists flood issues, assessments, discussion of results, and potential solutions and mitigations for this section.

**Table 4.2 Flood Issue Identification for Section from 498 Avenue to Highway 2**

Issue	Assessment	Discussion	Proposed Solutions and Mitigations
498 Avenue E	2D modelling of Scenario 28A indicates an increase in water levels and velocities in the order of 0.7 m and 0.4 m/s at 1,820 m <sup>3</sup> /s.	The design level of the bridge and erosion protection should be reviewed considering the new flood flow regime.	
Aldersyde CPR bridge constriction impacts on flood levels and debris clogging	2D modelling of Scenario 28A indicates an increase in water levels in the order of 0 to 1 m at a flow rate of 1,820 m <sup>3</sup> /s.	The bridge is subject to clogging by debris. The increases in water levels and velocities are not expected to significantly exacerbate the risks from the debris to the bridge and adjacent areas. However, the design level of the bridge and erosion protection should be reviewed considering the new flood flow regime.	
Landowner flood level issues	2D modelling of Scenario 28A at 1,820 m <sup>3</sup> /s indicates an increase in velocities in the order of 0.1 to 0.5 m/s on the outside of meander bends.	These properties will be subject to higher water levels during low probability floods and mitigation works are required to offset these adverse impacts.	Ring dikes, located on the floodplain, around the perimeter of residences. Other options include compensation for damages or buyout of entire property or buyout of just the residence (allowing agricultural use to continue on the remainder of the property).
Landowner erosion issues	2D modelling of Scenario 28A at 1,820 m <sup>3</sup> /s indicates an increase in water levels and velocities in the order of 0 to 1 m and 0 to 0.5 m/s.	The increase in velocities is small in relatively straight sections of the river and on the inside of meander bends and no mitigation works are required at these locations. However, the increase in velocities at outside of meander bends is in the order of 0.2 m/s. Some mitigation works may be required in these areas that are subject to the greatest erosive forces.	Installation of erosion protection where infrastructure or land is at greater risk of erosion (e.g., on bends or where increased erosional forces are expected to cause a concern) other options include compensation for damages or buyout of entire property or buyout of just the residence (allowing agricultural use to continue on the remainder of the property).
Landowner flood inundation (ponding) duration/frequency issues and associated agricultural damages	2D modelling of Scenario 28A indicates minimal increase in water levels and velocities in the order of 0.2 m and 0.1 m/s at 1,820 m <sup>3</sup> /s.	These properties will be subject to higher water levels during low probability floods and mitigation works are required to offset these adverse impacts.	Compensation for damages to agricultural lands due to increased levels and duration of inundation.

**Table 4.3 Flood Issue Identification for Section from Highway 2 to Bow River Confluence**

Issue	Assessment	Discussion	Proposed Solutions and Mitigations
Review impacts of increased flow on Highway 2 Structure	2D modelling of Scenario 28A at 1,820 m <sup>3</sup> /s indicates an increase in water levels and velocities in the order of 0.85 m and 0.75 m/s, as shown in Figures 4.7A and 4.7B.	The design level of the bridge and erosion protection should be reviewed considering the new flood flow regime.	
Review impacts of increased flow on Highway 547 Structure	2D modelling of Scenario 28A indicates an increase in water levels in the order of 0 to 0.8 m at a flow rate of 1,820 m <sup>3</sup> /s.	Since the impact of increased water levels with respect to the bridge low chord and the increase in water velocities with respect to the bridge abutments is unknown, it may be best to assume that some bridge upgrade is required. In particular, because this is secondary highway structure, the current design standard will likely not accommodate the increased discharge.	Raise height of bridge deck and associated structure in the order of 0.5 m to accommodate increased water levels. Additional erosion protection of abutments to account for increased velocity.
Review impacts of increased flow on Highway 552 Structure	2D modelling of Scenario 28A at 1,820 m <sup>3</sup> /s indicates an increase in velocities, in the order of 0 to 0.7 m/s on the outside of meander bends.	The bridge deck is elevated several metres above the streambed and would likely not be affected by the increased water levels. The bridge abutments consist of sloping earth embankment that is protected at the lower levels by a concrete apron and at the higher levels is well vegetated. The three span bridge has two sets of concrete piers. The bridge can likely handle increased flow with minimal or no improvements required.	None required
Landowner flood level issues	2D modelling of Scenario 28A at 1,820 m <sup>3</sup> /s indicates an increase in water levels in the order of 0 to 0.8 m.	These properties will be subject to higher water levels during low probability floods and mitigation works are required to offset these adverse impacts.	Ring dikes, located on the floodplain, around the perimeter of residences. Other options include compensation for damages or buyout of entire property or buyout of just the residence (allowing agricultural use to continue on the remainder of the property).
Landowner erosion issues	2D modelling of Scenario 28A at 1,820 m <sup>3</sup> /s indicates an increase in water levels and velocities in the order of 0.85 m and 0.75 m/s.	The increase in velocities is small in relatively straight sections of the river and on the inside of meander bends and no mitigation works are required at these locations. However, the increase in velocities at outside of meander bends is in the order of 0.2 m/s. Some mitigation works may be required in these areas that are subject to the greatest erosive forces.	Installation of erosion protection where infrastructure or land is at greater risk of erosion (e.g., on bends or where increased erosional forces are expected to cause a concern). Other options include compensation for damages or buyout of entire property or buyout of just the residence (allowing agricultural use to continue on the remainder of the property).
Landowner flood inundation (ponding) duration/frequency issues and associated agricultural damages	2D modelling of Scenario 28A indicates an increase in water levels in the order of 0 to 0.8 m at a flow rate of 1,820 m <sup>3</sup> /s.	These properties will be subject to higher water levels during low probability floods and mitigation works are required to offset these adverse impacts	Reimbursement for damages to agricultural lands due to increased levels and duration of inundation.



### 4.3 Little Bow River to the MD Boundary

The Little Bow River residents and infrastructure in the MD will be subjected to significantly lower flood peak magnitudes when low probability infrequent peak events (e.g., greater than 1,000 m<sup>3</sup>/s) occur on the Highwood River and spill over. This effect is the result of diking within the Town as discussed in **Section 2.2.1**. In general, water levels downstream of 104 Street E are expected to decrease in the range of 25 to 35 cm for a flood event similar to that which occurred in 2013 based on preliminary modelling results (refer to **Figures 4.6.1 through 4.6.3** and **Figures 4.7.1 through 4.7.3**). More detailed analysis extending over the entire Little Bow River watershed within the MD boundary will be available once the next stage of modelling is completed by the MD.

It is worth noting that some areas between 104 Street E and 72 Street E will experience water level increases during low probability, infrequent floods that spill over to the Little Bow River from the Highwood River. The maximum water level increase during a flood event similar to the 2013 flood is estimated at 50 cm. These water level increases are the result of diking on the south side of the Town (with the 12 Avenue-Centre Street Dike or an alternative, such as the SWD) which confines and redirects flow in the southern floodplain when compared to 2013 flood conditions.

A detailed analysis is proposed for the southern dike protection option which will assess and mitigate flow increases to the Little Bow River when flood peaks on the Highwood River range from approximately 600 to 1,000 m<sup>3</sup>/s (measured upstream of Woman's Coulee Canal inlet). Preliminary analysis has shown that flows to the Little Bow River from the Highwood River over this range have the potential to increase when compared to the 2013 landscape condition.

#### 4.3.1 Baker Creek Dike

The Baker Creek Dike, likely constructed to protect the railway and/or south portion of the Town, is located on private land east of 72 Street E and south of 12 Avenue (**Figure 2.3**). This dike consists of an approximately 125 m long earthen berm elevated approximately 0.5 to 1.0 m above the natural upstream and downstream bank levels (pers. comm. E. Rocher). Our understanding is that the Town, the MD, and the GOA have no plans to remove this feature. The MD, however, was interested in determining the effects of its removal. A simulation was therefore undertaken which involved (i.e., removing) lowering the berm/dike to match upstream and downstream bank topography (i.e., removing approximately 0.5 to 1.0 m of earth along its length). The flood level difference results are provided as **Figure 4.8**. The results indicate that impacts will be localized and relatively minor. The water level is estimated to increase approximately 16 cm downstream of the dike with increases becoming negligible downstream at 72 Street E). The flow directed toward the Little Bow River increases approximately 5 m<sup>3</sup>/s (based on an upstream flow of 1,820 m<sup>3</sup>/s) under Scenario 28A (i.e., an increase from 402 m<sup>3</sup>/s to 407 m<sup>3</sup>/s).

#### 4.4 Areas Downstream of the Study Area or Outside MD Jurisdiction

The main purpose of this study is to provide a list of issues facing MD residents and infrastructure considering natural and man-made changes to the Highwood River that could possible influence flood risk on the Highwood River and Little Bow River. However, as flood planning should be a watershed or basin planning exercise, the downstream risks that should be considered by downstream planning authorities or the Province of Alberta have been summarized below considering natural and man-made changes to the Highwood River and Little Bow River upstream.

##### 4.4.1 The Highwood River

The Railway Bridge, Highway 2 Bridge, Highway 547 Bridge, and Highway 552E Bridge on the Highwood River downstream of 498 Avenue E all have the potential to be impacted under the modified low probability flood hydrology. Review of the design is outside of the MD's jurisdiction. However, parties responsible for their operation and maintenance should be notified so appropriate design checks can be undertaken. Note that the former Railway Bridge just upstream of Highway 2 and the Highway 2 Bridge are discussed in **Section 4.2.5**.

##### 4.4.2 The Bow River Downstream of the Study Area

The increase in peak magnitude of a Highwood River flood flow similar to that experienced in 2013 is approximately 300 m<sup>3</sup>/s downstream of Highway 2. The associated impacts on the Bow River downstream of the Highwood River confluence will be somewhat a function of the timing of the peak on the Bow River during Highwood floods. The peaks from the Bow River and the Highwood River may not arrive at their confluence simultaneously. Hence, the cumulative effect and risk may be somewhat reduced. However, a detailed analysis would assist in better understanding these effects and the associated risk in greater detail and should be undertaken in future studies.

In general, peak flow magnitude governs water level and flood planning risk in eastern fluvial systems. However, when in-reservoir flood storage becomes a management option, both the incoming flood peak magnitude, as well as the flood volume (duration), need to be considered. With the loss of approximately 6,100,000 m<sup>3</sup> plus of storage at the Town, plus the recapturing of a 180 m<sup>3</sup>/s flow (based on an upstream flow of 1,820 m<sup>3</sup>/s) that originally was routed to the Little Bow River system, there is a significant additional volume of water that will need to be managed at downstream reservoirs, such as the one associated with Bassano Dam. Estimating the total quantity of water should also be undertaken in future studies.

##### 4.4.3 The Little Bow River Downstream of the MD

Flood mitigation works that have been constructed in the Town post-2013 flood have resulted in decreased peak floods flows spilling to the Little Bow River watershed from the Highwood River at flows greater than approximately 1,000 m<sup>3</sup>/s. Because of this reduction of flow to the Little Bow River from the Highwood River during these low probability infrequent flood events, the flood risk has somewhat decreased for residents and infrastructure downstream of the MD on the Little Bow. The performance of the Town's flood mitigation structures during an low probability, infrequent flood event, such as the design PMF of the Twin Valley Dam (which is in the order of 3,000 m<sup>3</sup>/s), is not well understood. For example, if the diking structures in the Town undergo catastrophic failure during such a low probability infrequent event, the effects on structures such as the Twin Valley Dam and Travers Dam are unknown.

The overtopping of the dikes for a few hours was taken into account in the design of the dikes. However, this safety feature will likely be insufficient to avoid large-scale breaching for a PMF type event. The changes to the flow split and the configuration of the Town's flood protection infrastructure should be discussed with the owners/operators of the Twin Valley Dam and the Travers Dam, which are located on the Little Bow River and are affected by the overflow from the Highwood River into the Little Bow River. An evaluation may be required by the dam operators of the performance of the Town dikes under PMF conditions, which is a typical design scenario evaluated for these large dam structures.

*Draft*

## **5.0 CONCEPTUAL LEVEL DESIGNS AND ACTIONS TO MITIGATE CHANGE IN FLOOD HAZARD AND/OR GENERAL RISKS**

Flood mitigation concepts and mitigative measures are summarized below for the river segments of concern within the MD. A summary of the mitigation measures is provided, as well as costing (or cost-benefit when land purchase is an option), in the following section when the design option is straight forward. Larger more complex issues and associated options have been identified for later study as discussed. The flood mitigation designs are discussed in terms of the Highwood River and the Little Bow River.

### **5.1 The Upper Highwood and Tributaries within the MD**

There are no recommendations for the upper Highwood River above Woman's Coulee Canal inlet or the major tributaries at this time. However, the scoping team has identified concerns with the safety and potential risk of "push-up" dams within the upper reaches of the watershed. These dams have the potential to increase flood risk if a failure occurs during a flood event. Currently the licensing, integrity, design level, and safety of these dams are poorly understood. Further review is recommended including site visits and an assessment of licensing, design level, integrity, and overall safety.

### **5.2 Highwood River at Woman's Coulee Canal Inlet to Bow River**

The Highwood River from Woman's Coulee canal inlet to the Bow River was identified as the area of greatest concern in terms of flood risk (and changes to flood risk) in the MD and hence is the primary focus of this study. Mitigation measures and conceptual designs for this area are discussed below based on the previously defined river segments.

#### **5.2.1 Woman's Coulee Canal Inlet**

No mitigation work for the Woman's Coulee Canal inlet area was identified. The channel is subject to ongoing erosion of the RDB (south bank). However, the potential for an avulsion into the south floodplain area has been deemed relatively low by the scoping team based on preliminary assessment. Additionally, the channel-floodplain cross-sectional area and channel width(s) were reviewed to assess blockage risk. Due to the broad floodplain in relation to the channel and the width of the channels in relation to natural large-size wood sources, overall risk of blockage is thought to be low.

The Woman's Coulee Canal Inlet was subject to damage during the 2013 flood and is currently being repaired and upgraded by the GOA. It is important that this work not adversely affect the main channel and floodplain flow paths and flow distribution, because this would have an impact on downstream infrastructure such as the Hoeh Dike and residential properties. For example, future works at the inlet should not confine flow to the Highwood River main channel and north floodplain. Such confinement could increase the risk of breaching and subsequent channel avulsion at the Hoeh Dike. In addition, this action could influence the flow-split between the Highwood River–Little Bow River by sending additional low probability infrequent flood flow north, through High River. Hence, any upgrading or modifications that are undertaken at Woman's Coulee Canal inlet needs to be thoroughly assessed in terms of regional effects and risk.

### 5.2.2 Hoeh Dike Downstream to Town of High River

Risk associated with the Highwood River segment from the Hoeh Dike downstream to the Town mainly deals with Hoeh Dike breaching (which will increase avulsion risk, local flooding risk and the downstream flow split) and local flooding of landowners. The main mitigation that has been proposed for this river segment is upgrading the design criteria of the riprap at the Scenario 2 Failure Assessment location on the downstream segment of the Hoeh Dike. The dike should not be raised or lowered during this upgrade; erosion protection at this location should be upgraded to withstand a more severe event and to withstand overtopping flows. Design criteria and extent of the upgrade are to be determined.

As previously noted in **Section 4.2.2**, some repairs to the Hoeh Dike were undertaken in 2014 to address damages resulting from the 2013 flood. Also, as previously noted in that section, the structure is currently serving an important purpose but should not be raised or lowered, because this will have regional flood effects. Hence, raising of the Hoeh Dike is not recommended. However, as with any critical piece of flood infrastructure it is important to have an ongoing monitoring and maintenance plan as recommended in AMEC (2008a).

Additional large scale diking works (over and above those that are part of the Town's flood protection plans) are not recommended in the reach from Hoeh Dike to the Town, because the works would likely have adverse regional impacts. Other than flooding which is fairly well understood and characterized, the other main risk in this area is channel migration which is the result of bank erosion and potentially a large scale channel avulsion. A large scale avulsion has the potential to influence the regional flow-split between the Highwood and Little Bow Rivers. As described in AMEC (2012b) and assessed in this report (**Section 4.2.2**), one high risk area is an abandoned high water channel on the south floodplain, which is bounded to the west by 40 Street, to the east by 56 Street and south by 2538 Drive E. The abandoned main channel drains through this area and was active as recently as 1949. A channel avulsion that reactivates this abandoned channel would have severe local consequences for the residences north of 2538 Drive E.

In high risk areas that were subject to bank erosion and inundation, property buyouts are the preferred alternative recommended by the scoping team. Given the dynamic and highly mobile nature of the river, armouring should be used selectively in areas where it is economical and used to protect key pieces of infrastructure. This reach should be monitored in the future, particularly after floods and in areas where a large scale channel avulsion may threaten residences and infrastructure.

### 5.2.3 Town of High River

The Town of High River Highwood River segment has been heavily altered as discussed in **Section 2.2.1** and **Section 4.2.3**. However, there is no direct risk to adjacent MD residents or infrastructure. Hence, no conceptual mitigation designs were provided for this area.

### 5.2.4 498 Avenue E and the Hamptons Area

As discussed in **Section 4.2.4**, the height of 498 Avenue E was increased by the MD to provide flood protection for the northeast part of the Town (including the Hamptons). There are also MD residents south of 498 Avenue E that are protected by the road raising. Additionally, there are MD residents north of 498 Avenue E that were protected by the raising of 112 Street E.

The flood storage volume lost with this action, based on the 2013 flood, is approximately 6,100,000 m<sup>3</sup>. This loss of storage equates to an increase in peak flow of approximately 110 m<sup>3</sup>/s downstream. To minimize this loss of storage while still protecting residents, 498 Avenue E could be lowered to pre-flood heights and a dike could be constructed to the south in a horse-shoe planform. This dike layout would decrease the loss of storage nearly 50%, to approximately 3,000,000 m<sup>3</sup>. The decrease in the peak flow increase would likely be relatively similar (e.g., 50%). This option has been brought forward for discussion purposes only and has not been costed or assessed in detail.

It is worth noting that the area south of 498 Avenue E is subject to extended duration flood inundation and greater risk than other areas adjacent to the Highwood River, because this area does not drain following the recession of flood waters. Before any additional future development occurs in this area, it is strongly recommended that a flood risk assessment and drainage plan be undertaken to understand the cost-benefits of such an action under more extreme flood conditions and under either the existing or any future diking scenarios.

### 5.2.5 498 Avenue E to Highway 2 and Highway 2 to Confluence with Bow River

The MD flood issues downstream of 498 Avenue E–Highway 2 to the Bow River along the Highwood River are mainly associated with residential flooding, agricultural flooding, and risk to infrastructure due to bank erosion, as discussed in **Sections 4.2.6 and 4.2.7**. As shown in **Figures 4.4.1 through 4.4.3** and **Figures 4.5.1 through 4.5.3**, these impacts become greater at discharges exceeding 1,000 m<sup>3</sup>/s (as measured above Woman's Coulee Canal inlet), due to increased flow in the Highwood River. As discussed earlier, the increased flow is caused by the Town's flood mitigation works. For example, a flow of 1,820 m<sup>3</sup>/s above Woman's Coulee Canal inlet resulted in a peak of approximately 955 m<sup>3</sup>/s at the Highway 2 Bridge before flood mitigation works. Following mitigation works, the peak flow is estimated to increase to 1,245 m<sup>3</sup>/s (or an increase of approximately 290 m<sup>3</sup>/s or 30%). This significant increase will create further risk to residences, lands and river-side infrastructure.

To address these concerns three general solutions were identified:

- ▶ ring dikes, located on the floodplain, around the perimeter of residences (and nearby infrastructure as routing permits);
- ▶ reimbursement for damages to agricultural lands due to increased levels and duration of inundation; and
- ▶ installation of erosion protection where infrastructure or land is at greater risk of erosion (e.g., on bends or where increased erosional forces are expected to cause a concern).

The goal of these measures is to reduce the incremental impacts for each property to 2013 conditions and/or compensate the land owner accordingly. The cost of these solutions have been assessed and are summarized in **Section 6**. Flood mitigation costs associated with these proposed works are also compared to estimate (tax-based) land value plus demolition and reclamation as a general cost-benefit exercise to better understand the potential options.

## 5.3 Little Bow River to MD Boundary

In general, the Little Bow River residents downstream of 104 Street E are now somewhat protected by the same dikes that protect the south side of the Town. In general, these residences will likely be subject to no effects or slight increases at Highwood River flood flows



from initial spill-over up to approximately 1000 m<sup>3</sup>/s (at Woman's Coulee Canal inlet). In general, residences will be subject to significantly improved conditions in terms of water levels at flows above approximately 1000 m<sup>3</sup>/s.

There are, however, approximately 16 residences that are still at risk in the MD along the Little Bow River under a 1,820 m<sup>3</sup>/s flow in the Highwood River (above Woman's Coulee Canal inlet). To minimize risk under this design flow, the scoping team has proposed a mitigation measure consisting of ring dikes around the perimeter of residences. No other compensation (loss of agricultural capability or land) was considered for these residents since flood magnitudes in the Little Bow River have been reduced. A discussion of the cost-benefit of these dikes versus the taxable value of the lands are provided in **Section 6.2** to guide the MD in determining future assessment and action.

As mentioned previously, the current flood mitigation solution planned for the south part of the Town is the SWD. The SWD differs in alignment from the 12 Avenue–Centre Street Dike. The SWD is, however, is being/has been designed based on the objective of having the flow-split equivalent to that of the 12 Avenue–Centre Street Dike design. The final alignment has not been determined. However, any alignment and redirection of flow in this area will likely result in effects on some MD residential properties located between the abandoned railway line (on the west) and the west side of the Little Bow River, upstream from 104 Street E. These landowners will be approached on a case-by-case basis once final dike alignment and associated impacts have been determined.

In addition to the general flood mitigation protection for Little Bow River residences, it is also worth mentioning the Little Bow Enhanced Natural Floodway that was proposed jointly by the MD and the Town. This conceptual project focused on enhancing (through shallow excavation) the natural flood channels found south of the Town to reestablish flood flow to the Little Bow River that was experienced during the 2013 flood (and decrease flows diverted north by the Town diking). This option was not supported by the GOA. The GOA's lack of support led the Town to pursue the southern diking option (e.g., the 12 Avenue–Centre Street Dike or the SWD). The southern diking option, however, does not reestablish low probability infrequent flood flow between the Highwood–Little Bow Rivers, leaving residents downstream on the Highwood River subject to significant potential effects during low probability infrequent flooding (refer to **Sections 4.2.4, 4.2.5, and 4.2.6**).

## 6.0 PRELIMINARY LEVEL COST-BENEFIT ANALYSIS

### 6.1 Cost Benefit Analysis Approach

As noted in the report introduction, this Scoping Study is at a conceptual and high level with more detailed analysis and design recommended to be undertaken in futures phases. The scoping nature of this Phase 1 Study guides the level of detail for the cost benefit analysis contained herein. Limitations of the cost analysis approach are noted below:

- ▶ The analysis contained herein is not a detailed cost-benefit analysis since it does not include a comparison of costs versus avoided economic damages. Rather, costs are provided for various mitigation options for areas subject to an increased flood risk; and
- ▶ The flood damage compensation option was not evaluated in this analysis due to complexities and uncertainties such as estimating incremental bank erosion rates, crop damage losses, and evaluation period.

The assumptions and approach for this preliminary level cost benefit analysis are discussed below.

#### 6.1.1 Primary Flood Scenarios Evaluated

The hydraulic modelling described in **Section 3** was the basis for the preliminary level cost analysis. The two hydraulic model scenarios evaluated were:

- ▶ 2013 Flood Landscape Scenario, which is also referred to as '2013 Conditions' in this section; and
- ▶ Complete Mitigation Scenario (Scenario 28A), which is based on all of the Town's flood protection structures constructed to-date plus the 12 Avenue–Centre Street Dike.

The 2013 Flood Landscape and magnitude of the 2013 flood provides the base case to determine the incremental flood impacts due to the Town's flood mitigation measures (i.e., increased water levels and velocities) represented as Scenario 28A. These incremental flood impacts in conjunction with flood mitigation options, such as buyouts and construction of flood protection measures, form the basis for the cost analysis. The cost analysis was undertaken for the three areas described below. **Figures 6.1.1 to 6.3.15** show information such as the 2103 flood extent, the incremental flood inundation zone due to the complete mitigation scenario, the location of potential flood protection works, and zones of heightened erosion vulnerability for the three areas.

The following list describes the physical location of the three areas in more detail:

- ▶ **Figures 6.1.1 to 6.1.5** show the Highwood River from the Woman's Coulee Canal Inlet to the western limits of the Town. This area is referred to as River Run and is upstream of the Town. Only one property, which is south of 12 Avenue SW and directly east of 72 Street E was affected by the flood protection works constructed/planned by the Town under Scenario 28A.
- ▶ **Figures 6.2.1 to 6.2.12** show the Highwood River downstream of the Town. This area extends from the 498 Avenue E Bridge downstream to the confluence with the Bow River. This area contains the majority of properties that were affected by the Complete Mitigation Scenario (Scenario 28A).
- ▶ **Figures 6.3.1 to 6.3.15** show the Little Bow River south of the Town boundary (and east of 88 Street E) to the MD boundary. 72 Street E forms the boundary between the River Run area and the Little Bow River area (as shown in **Figure 6.1.5**).

### 6.1.2 Site-Specific Property Information and Structural Flood Protection Costs

The 2014 tax assessed valuations obtained from the MD were the basis for the residence and property valuations as well as obtaining the square footage of individual buildings. It is important to note that appraised property values are often greater than assessed valuations. Appraised property values should be considered in future study phases.

Structural flood protection costs were estimated based on ring berms, which are earthfill structures around the perimeter of residences and their yards. The engineering and construction costs are based on typical costs for similar work that was done recently as part of the Flood Recovery and Erosion Control (FREC) program.

### 6.1.3 Mitigation Options Evaluated

Mitigation options, as discussed in **Section 5**, were assessed for each property on the Highwood River from the Woman's Coulee Canal Inlet downstream to the Bow River confluence. For the Little Bow River, the mitigation measures consist of protecting those properties located from the southern Town boundary downstream to the MD boundary, which were subject to flooding in 2013.

The four flood mitigation options that were evaluated are listed below. These options were compared against each other to determine preferred course of action.

Areas subject to a greater risk of erosion due to increased velocities resulting from the complete Town mitigation scenario (Scenario 28A) were identified on the following basis:

- ▶ pre- and post-2013 flood imagery was reviewed to determine areas that were subject to erosion during the 2013 flood; and
- ▶ areas that were subject to a significant increase in velocity (in the order of 20%) based on the modelling.

Areas that met the above criteria are identified as zones of heightened erosion vulnerability on **Figures 6.1.1 to 6.3.15**. The costs associated with the installation of erosion protection works in these zones was not estimated herein, because these costs are prohibitive and significantly greater than other options.

#### Option 1 – Property Buyout

Buyout of the entire property was based on the 2014 tax assessed values plus a 20% provision for administrative and reclamation costs.

#### Option 2 – Residence and Ancillary Buildings Buyout

Buyout of the residence and yard area and associated ancillary buildings. This option allows agricultural use to continue on the remainder of the property. The residence and ancillary building buyout option eliminates flood risks associated with residential activities; however, additional monetary compensation for unprotected land due to more frequent inundation and infrastructure may be required. This option may be viable when the value of the property is weighed heavily on the land rather than the residence. Legal provisions would be required to prevent future residential development on flood-prone land, in order to make this option feasible.

The residence and ancillary building buyout option is based on tax-assessed valuation of the residential and other infrastructure on the property. The residence building and yard area would be purchased from the property owner while the land remained under existing ownership. Other less costly options may fall under this category to address residential flooding impacts such as relocating a home on a non-flood affected area of the property. These options should likely be considered on a site-specific basis with further stakeholder consultation during subsequent study phases.

### **Option 3 – Residential and Ancillary Buildings Flood Protection to 2013 Landscape Scenario Flood Levels**

The residential and ancillary buildings flood protection option ensures residential and yard area infrastructure is protected from future flood events by constructing a berm structure around the perimeter to the 2013 flood level under 2013 Landscape Scenario plus 1 m freeboard, which is consistent with level of protection provided by the Town. This option reduces flood damages for the residence; however, several risks are still present during a low probability, infrequent flood, such as that presented to residents and emergency services during evacuation of residents in an extreme event.

The constructed berm component consists of an earthfill structure to protect residential and ancillary buildings. The dimensions of the proposed berm structures were based on the modelling results and a preliminary air photo review of infrastructure deemed suitable for flood protection (e.g., residential infrastructure). The alignment of these structures is shown on **Figures 6.1.1 to 6.3.15** (for the Highwood River and the Little Bow River) and accounts for other nearby infrastructure and site characteristics. For example, nearby out-buildings were included within the perimeter of the berm structure. In these cases, it may be more costly to ensure the residence is protected without protecting the out-buildings as structures would have to be relocated to allow sufficient unoccupied land for a berm. Further refinement of the berm dimensions and alignment may be required upon stakeholder consultation in subsequent study phases.

### **Option 4 – Residential and Ancillary Buildings Flood Protection to Existing Conditions (Scenario 28A) Flood Levels**

Option 4 provides protection is to a higher elevation for properties on the Highwood River downstream of the Town and to a lower elevation for properties on the Little Bow than Option 3, but in other respects is similar. Protection upstream of the Town is the same for Option 3 and Option 4. The Option 4 berm heights are 1 m higher than the complete mitigation modelling scenario (Scenario 28A). The alignment of these structures is shown on **Figures 6.1.1 through 6.3.15** (for the Highwood River and the Little Bow River). Further refinement of the berm dimensions and alignment may be required upon stakeholder consultation in subsequent study phases.

#### **6.1.4 Format for Presenting Cost-Benefit Analysis**

This high-level cost-benefit analysis does not account for site-specific considerations that may arise through subsequent stakeholder consultation and may impact the mitigation option selected. The cost-benefit assessments are presented separately for the previously defined areas. **Tables 6.1, 6.2, and 6.4** contain the cost associated with each mitigation option for each of the three areas. Additionally, **Tables 6.3, and 6.5** show the changes in water level, inundation area, and velocities between the Town's complete mitigation scenario and 2013 conditions for each of the three areas.

It is difficult to judge at this time whether Option 2 will gain widespread acceptance with landowners. Landowners may prefer either buyout of the entire property (Option 1) or flood protection (Options 3 and 4). Given these uncertainties, Option 2 was not included in the total summation of the most cost effective options that is provided in **Tables 6.1, 6.2, and 6.4**. These summations consider only the most cost effective of either property buyout (Option 1) or flood protection (Options 3 or 4).

## **6.2 Highwood River from Woman's Coulee Canal Inlet to Bow River**

### **6.2.1 Women's Coulee Canal Inlet to Western Town Boundary**

The River Run area is upstream of the Town, as shown in **Figures 6.1.1 through 6.1.5**. Only a small portion of this area, adjacent to the west Town boundary, was affected by the Town's complete mitigation scenario. **Table 6.1** contains the estimated costs for Option 1 (property buyout), Option 2 (residence and ancillary buildings buyout), and Option 3 (flood protection to 2013 conditions). **Table 6.1** does not contain a cost estimate for Option 4 (flood protection for the complete mitigation scenario), since the 0.1 m increase in water level at the residence is well within the 1 m freeboard for Option 3.

The flood risk for the River Run area is unchanged between modelling scenarios. Thirty four properties were identified that were subject to inundation during the 2013 flood. These properties could be protected from future floods by buyouts or perimeter berms. The estimated total cost of these mitigation options in the River Run area is \$22,491,960, as shown in **Table 6.1**.

Additionally, as noted in **Section 5.2.2**, an approximately 50 m section of the Hoeh Dike, if breached, has been identified in this report as a potential significant flood risk. Upgrading of this portion of the dike should be reviewed further. The preliminary level cost estimate for this upgrade is \$200,000.

Table 6.1

**Women's Coulee Inlet to Western Limits of Town (72 St) - Estimated Costs for Highwood River Remedial Measures and Buyouts**

Roll Number	Legal Land	Option 1	Option 2	Option 3	Most Cost Effective of Options 1 & 3 <sup>3</sup>	Price of Most Cost Effective Option
		Property Buyout Cost <sup>1</sup>	Residence and Ancillary Buildings Buyout Cost <sup>1</sup>	2013 Conditions Berm Cost <sup>2</sup>		
1829295000	NW-29-18-29-4	\$732,552	\$320,208	\$1,018,000	Option 1	\$732,552
1829297500	NE-29-18-29-4	\$639,492	\$192,924	\$424,000	Option 3	\$424,000
1829305000	NW-30-18-29-4	\$102,756	\$24,984	\$373,000	Option 1	\$102,756
1829307500	NE-30-18-29-4	\$925,740	\$7,812	\$449,000	Option 3	\$449,000
1829320000	SE-32-18-29-4	\$1,403,988	\$493,152	\$474,000	Option 3	\$474,000
1829327550	NE-32-18-29-4	\$840,432	\$413,160	\$516,000	Option 3	\$516,000
1829330020	SE-33-18-29-4	\$920,676	\$500,712	\$503,000	Option 3	\$503,000
1829330030	SE-33-18-29-4	\$720,660	\$276,552	\$519,000	Option 3	\$519,000
1829330050	SE-33-18-29-4	\$623,844	\$216,876	\$452,000	Option 3	\$452,000
1829330060	SE-33-18-29-4	\$744,060	\$683,448	\$429,000	Option 3	\$429,000
1829330070	SE-33-18-29-4	\$709,260	\$459,960	\$440,000	Option 3	\$440,000
1829330080	SE-33-18-29-4	\$1,109,520	\$703,296	\$880,000	Option 3	\$880,000
1829332500	SW-33-18-29-4	\$1,297,788	\$829,212	\$826,000	Option 3	\$826,000
1829332510	SW-33-18-29-4	\$923,436	\$443,760	\$618,000	Option 3	\$618,000
1829332530	SW-33-18-29-4	\$671,232	\$212,424	\$641,000	Option 3	\$641,000
1829332540	SW-33-18-29-4	\$926,916	\$464,460	\$849,000	Option 3	\$849,000
1829332550	SW-33-18-29-4	\$820,068	\$434,040	\$584,000	Option 3	\$584,000
1829337510	NE-33-18-29-4	\$932,952	\$471,336	\$1,205,000	Option 1	\$932,952
1829337530	NE-33-18-29-4	\$803,880	\$198,876	\$776,000	Option 3	\$776,000
1829337540	NE 33-18-29-4	\$538,824	\$15,792	\$532,000	Option 3	\$532,000
1829337610	NE-33-18-29-4	\$1,201,608	\$749,508	\$842,000	Option 3	\$842,000
1829340010	SE-34-18-29-4	\$668,268	\$267,816	\$427,000	Option 3	\$427,000
1829345000	NW-34-18-29-4	\$1,648,092	\$1,139,112	\$1,342,000	Option 3	\$1,342,000
1829345010	NW-34-18-29-4	\$649,236	\$230,520	\$2,024,000	Option 1	\$649,236
1829345030	NW-34-18-29-4	\$807,432	\$212,520	\$1,634,000	Option 1	\$807,432
1829345040	NW-34-18-29-4	\$1,342,044	\$594,215	\$1,308,000	Option 3	\$1,308,000
1829345060	NW-34-18-29-4	\$709,776	\$289,932	\$452,000	Option 3	\$452,000
1829345100	NW-34-18-29-4	\$1,060,260	\$587,412	\$576,000	Option 3	\$576,000
1829347500	NE-34-18-29-4	\$969,624	\$527,136	\$914,000	Option 3	\$914,000
1829347510	NE-34-18-29-4	\$834,384	\$340,956	\$604,000	Option 3	\$604,000
1829355010	NW-35-18-29-4	\$778,908	\$375,516	\$485,000	Option 3	\$485,000
1830257500	NE-25-18-30-4	\$814,572	\$474,192	\$1,230,000	Option 1	\$814,572
1929020000	SE-2-19-29-4	\$1,178,100	\$525,408	\$946,000	Option 3	\$946,000
1929022500	SW-2-19-29-4	\$644,460	\$61,056	\$797,000	Option 1	\$644,460
<b>Total For Most Cost Effective of Options 1 &amp; 3</b>						<b>\$22,491,960</b>

## Notes

- 1 Buyout cost based on tax-assessed value plus 20% for admin and reclamation costs. May not include cost of all infrastructure on property.
- 2 Berm cost based on dimensions estimated from air photo review and flood depth calculated from modeling plus 1m freeboard. Subject to revision based on detailed site investigations.
- 3 Changes to water levels between 2013 and complete mitigation conditions are minor and well within the 1 m freeboard and so an estimate of additional cost for increased berm height was not required.

Similarly highlighted berm costs reflect properties that share a berm. Sum of values equals the total cost of the berm.



## 6.2.2 Town of High River

The post-2013 flood mitigation works constructed by the Town protected this area, and no further flood mitigation works were identified.

## 6.2.3 498 Avenue E and the Hamptons

The post-2013 flood mitigation works of raising 498 Avenue E protected the Hamptons, and no further flood mitigations works were identified. However, additional assessment of the 498 Avenue E Bridge should be undertaken, based on the mitigated modelling scenario.

## 6.2.4 Highwood River from 498 Avenue E to Confluence with Bow River

This area is shown in **Figures 6.2.1 through 6.2.12. Table 6.2** summarizes the cost analysis for the Highwood River from 498 Avenue E to the confluence with the Bow River. **Table 6.2** contains the tax-assessed property values and the values flood mitigation options. The methodology for estimating values is discussed below. Two examples are provided to illustrate how mitigation options are assessed.

### Example #1:

Roll Number: 1928325030

Legal Land Description: NW-32-19-28-W4M

- ▶ This property has an estimated buyout cost (Option 1) of \$735,144 which includes reclamation and administration costs.
- ▶ The residence and ancillary building buyout cost (Option 2) is valued at \$343,860.
- ▶ The berm required to protect the residence and ancillary buildings (Option 3) to 2013 conditions costs \$1,167,000.
- ▶ The berm required to protect the residence and ancillary buildings to existing conditions (Option 4) costs \$1,435,000.

### Example #2:

Roll Number: 1928207510

Legal Land Description: E-20-19-28-W4M

- ▶ This property has an estimated buyout cost (Option 1) of \$1,784,004 which includes reclamation and administration costs.
- ▶ The residential and ancillary building buyout cost (Option 2) is \$1,254,672.
- ▶ The berm protection cost to 2013 conditions (Option 3) is \$1,180,000.
- ▶ The berm protection cost to existing conditions is \$1,300,000.

A total of 93 properties (as shown in **Table 6.3**) were identified as having increased flood risk due to the Town's complete mitigation scenario. Eighteen of these properties have residences that were affected by the increased flood risk. The remaining 75 properties have agricultural fields that were affected by the increased flood risk.

The 18 residences that are subject to increased flood risk could be protected from future floods by buyouts or perimeter berms. The estimated total cost of these mitigation options for these 18 properties is \$11,235,388, as shown in **Table 6.2**. Appropriate mitigation measures for the remaining 75 properties may include compensation for crop damage loss and should be addressed in subsequent phases of the study.

Table 6.2

## Downstream of 498 Ave to Confluence with Bow River - Estimated Costs for Highwood River Remedial Measures and Buyouts

		Option 1	Option 2	Option 3				Option 4			
Roll Number	Legal Land	Property Buyout Cost <sup>1</sup>	Residence and Ancillary Buildings Buyout Cost <sup>1</sup>	2013 Conditions Berm Cost <sup>2</sup>	Most Cost Effective of Options 1 & 3	Price of Most Cost Effective Option	Complete Mitigation Conditions Additional Berm Height (m) <sup>3</sup>	Complete Mitigation Conditions Berm Cost <sup>2</sup>	Most Cost Effective of Options 1 & 4	Price of Most Cost Effective Option	
1928207510	NE-20-19-28-4	\$1,731,372	\$1,254,672	\$1,180,000	Option 3	\$1,180,000	0.25	\$1,300,000	Option 4	\$1,300,000	
1928292500	SW-29-19-28-4	\$3,197,736	\$38,304	\$535,000	Option 3	\$535,000	0.25	\$595,000	Option 4	\$595,000	
1928295000	NW-29-19-28-4	\$526,116	\$157,164	\$660,000	Option 1	\$526,116	0.1	\$685,000	Option 1	\$526,116	
1928300000	SE-30-19-28-4	\$96,168	\$67,800	\$528,000	Option 1	\$96,168	0.35	\$616,000	Option 1	\$96,168	
1928302510	SW-30-19-28-4	\$751,236	\$49,872	\$277,000	Option 3	\$277,000	0.35	\$323,000	Option 4	\$323,000	
1928305010	NW-30-19-28-4	\$879,984	\$511,608	\$872,000	Option 3	\$872,000	0.25	\$964,000	Option 1	\$879,984	
1928307500	NE-30-19-28-4	\$661,404	\$333,516	\$508,000	Option 3	\$508,000	0.1	\$527,000	Option 4	\$527,000	
1928317520	NE 31-19-28-4	\$119,208	\$36,144	\$329,000	Option 1	\$119,208	0.5	\$407,000	Option 1	\$119,208	
1928325010	NW-32-19-28-4	\$2,013,636	\$1,443,420	\$1,894,000	Option 3	\$1,894,000	0.35	\$2,206,000	Option 1	\$2,013,636	
1928325030	NW-32-19-28-4	\$735,144	\$343,860	\$1,167,000	Option 1	\$735,144	0.5	\$1,435,000	Option 1	\$735,144	
2028052500	SW-5-20-28-4	\$922,908	\$396,576	\$1,358,000	Option 1	\$922,908	0.6	\$1,739,000	Option 1	\$922,908	
2028052510	SW-5-20-28-4	\$1,442,520	\$1,068,876	\$915,000	Option 3	\$915,000	1	\$1,371,000	Option 4	\$1,371,000	
2028055000	NW-5-20-28-4	\$841,428	\$5,964	\$361,000	Option 3	\$361,000	0.05	\$368,000	Option 4	\$368,000	
2028060010	SE-6-20-28-4	\$606,276	\$25,692	\$470,000	Option 3	\$470,000	0.75	\$645,000	Option 1	\$606,276	
2028060020	SE-6-20-28-4	\$349,932	\$0	\$641,000	Do Nothing	\$0	0.85	\$903,000	Do Nothing	\$0	
2028067500	NE-6-20-28-4	\$386,136	\$38,508	\$354,000	Option 3	\$354,000	0.85	\$492,000	Option 1	\$386,136	
2028077520	NE-7-20-28-4	\$2,770,176	\$98,772	\$577,000	Option 3	\$577,000	0.7	\$759,000	Option 4	\$759,000	
2028187510	NE-18-20-28-4	\$970,200	\$510,384	\$806,000	Option 3	\$806,000	0.25	\$884,000	Option 4	\$884,000	
2128262520	SW-26-21-28-4	\$836,448	\$128,616	\$1,608,000	Option 1	\$836,448	0.85	\$2,204,000	Option 1	\$836,448	
		Total For Most Cost Effective of Options 1 & 3				\$11,984,992		Total For Most Cost Effective of Options 1 & 4			\$13,249,024
							Additional Remedial and Buyout Costs Associated with Complete Mitigation Conditions			\$1,264,032	

## Notes

- 1 Buyout cost based on tax-assessed value plus 20% for admin and reclamation costs. May not include cost of all infrastructure on property.
  - 2 Berm cost based on dimensions estimated from air photo review and flood depth calculated from modeling plus 1m freeboard. Subject to revision based on detailed site investigations.
  - 3 Additional height of berm needed to incorporate change in water level from 2013 to complete mitigation conditions.
- Similarly highlighted berm costs reflect properties that share a berm. Sum of values equals the total cost of the berm.
- Property currently not included in the Highwood River Flood Model (2013 Landscape and Scenario 28A) due to the regional nature of the model. Model-estimated water levels adjacent to and upstream of this property where used to provide a conservative estimate to support design and flood planning for the highlighted property.

Table 6.3

Downstream of 498 Ave to Confluence with Bow River - Highwood River Water Level, Velocity Changes, and Rick of Additional Erosion

Roll Number	Legal Land	Change <sup>1</sup> in Property Inundation (Ac)	Change <sup>1</sup> in Property Inundation (Ha)	Change <sup>1</sup> in Residential Water Level (m)	Change <sup>1</sup> in Property Water Level (m)	Change <sup>1</sup> in Velocity at River Bank (m/s)	Projected Length of Increased Velocity (m) <sup>2</sup>	Risk of Additional Erosion
1928162520	SW-16-19-28-4	-4.79	-1.94	0	-1	N/A	0	No
1928170000	SE-17-19-28-4	10.00	4.05	0	0.95	-0.2	0	No
1928172500	SW-17-19-28-4	14.94	6.05	0	0.2	0.1	0	No
1928172510	SW-17-19-28-4	0	0	0	0.15	0	0	No
1928175000	NW-17-19-28-4	9.36	3.79	0	0.4	0.05	0	No
1928175010	NW-17-19-28-4	0	0	0	0.15	0	0	No
1928177500	NE-17-19-28-4	16.00	6.47	0	0.75	0	0	No
1928180000	SE-18-19-28-4	0	0	0	0.15	0.05	0	No
1928182510	SW-18-19-28-4	11.20	4.53	0	0.15	0	0	No
1928185010	NW-18-19-28-4	1.69	0.68	0	0.15	0	0	No
1928187500	NE-18-19-28-4	5.37	2.17	0	0.15	0.05	0	No
1928190000	SE-19-19-28-4	2.17	0.88	0	0.25	N/A	0	No
1928190010	SE-19-19-28-4	12.74	5.16	0	0.25	N/A	0	No
1928197500	NE-19-19-28-4	8.07	3.27	0	0.25	0.4	0	No
1928200000	SE-20-19-28-4	21.8	8.8	0	0.6	0.1	0	No
1928202500	SW-20-19-28-4	0.97	0.39	0	0.45	0	0	No
1928202510	SW-20-19-28-4	0	0	0	0.25	0.1	0	No
1928205000	NW-20-19-28-4	0	0	0	0.35	0.25	0	No
1928205010	NW-20-19-28-4	3.63	1.47	0	0.25	0.2	378	Yes
1928207500	NE-20-19-28-4	0	0	0	0.25	0.2	66	Yes
1928207510	NE-20-19-28-4	14.50	5.87	0.25	0.45	0.25	0	No
1928290000	SE-29-19-28-4	9.1	3.7	0	0.35	0.4	366	Yes
1928292500	SW-29-19-28-4	6.76	2.74	0.25	0.25	0.2	213	Yes
1928295000	NW-29-19-28-4	15.90	6.43	0.10	0.4	0.4	585	Yes
1928297500	NE-29-19-28-4	7.87	3.18	0	0.45	0.2	0	No
1928300000	SE-30-19-28-4	4.86	1.97	0.35	0.30	0.35	0	No
1928302510	SW-30-19-28-4	0.3	0.1	0.35	0.35	N/A	303	Yes
1928305010	NW-30-19-28-4	2.54	1.03	0.25	0.4	0.2	229	Yes
1928305020	NW-30-19-28-4	1.45	0.59	0	0	0.1	0	No
1928305030	NW-30-19-28-4	9.49	3.84	0	0.4	0	0	No
1928307500	NE-30-19-28-4	18.89	7.64	0.1	0.25	0.3	0	No
1928310000	SE-31-19-28-4	3.7	1.5	0	0.5	0.4	0	No
1928310010	31-19-28-4	18.00	7.28	0	0.6	0.2	103	Yes
1928317510	NE-31-19-28-4	8.43	3.41	0	0.75	0.2	60	Yes
1928317520	NE 31-19-28-4	0.17	0.07	0.5	0.5	0.5	0	No
1928320010	SE-32-19-28-4	3.15	1.27	0	0.35	N/A	0	No
1928322500	SW-32-19-28-4	26.77	10.83	0	0.35	0.20	0	No
1928325000	NW-32-19-28-4	3.91	1.58	0	0.35	N/A	0	No
1928325010	NW-32-19-28-4	4	1.62	0.35	0.35	N/A	0	No
1928325030	NW-32-19-28-4	0.97	0.39	0.5	0.5	0.4	176	Yes
1928327500	NE-32-19-28-4	11.77	4.76	0	0.55	N/A	0	No
2028050020	SE-5-20-28-4	1.0	0.4	0	0.55	N/A	0	No
2028052500	SW-5-20-28-4	0	0	0.6	0.6	0.4	0	No
2028052510	SW-5-20-28-4	0.20	0.08	1	1	0.1	0	No
2028052530	SW-5-20-28-4	2.19	0.89	0	0.55	0.4	55	Yes
2028055000	NW-5-20-28-4	3.5	1.4	0.05	0.5	0.6	401	Yes
2028060000	SE-6-20-28-4	0.64	0.26	0	0.65	0	0	No
2028060010	SE-6-20-28-4	0	0	0.75	0.75	0.1	0	No
2028060020	SE-6-20-28-4	0	0	0.85	0.85	0.3	0	No
2028060040	S -6-20-28-4	0.29	0.12	0	0.85	0.4	0	No
2028067500	NE-6-20-28-4	0	0	0.85	0.85	0.5	0	No
2028067540	NE-6-20-28-4	0	0	0	0	0.6	93	Yes
2028067570	NE-6-20-28-4	0.60	0.24	0	0.85	0.4	0	No
2028075010	NW-7-20-28-4	2.86	1.16	0	0.75	0.2	497	Yes
2028077520	NE-7-20-28-4	3.66	1.48	0.7	0.7	0.2	0	No
2028082510	SW-8-20-28-4	0	0	0	0	0.4	484	Yes
2028082520	SW-8-20-28-4	5.00	2.02	0	0.55	0.6	288	Yes
2028175010	NW-17-20-28-4	1.94	0.79	0	0.85	0.4	500	Yes
2028180010	SE-18-20-28-4	0.99	0.40	0	0.75	1	212	Yes
2028180050	SE-18-20-28-4	0.47	0.19	0	0.75	1	77	Yes
2028187500	NE-18-20-28-4	0	0	0	0	0.4	444	Yes
2028187510	NE-18-20-28-4	0.76	0.31	0.25	0.8	0.3	0	No
2028200000	SE-20-20-28-4	0	0	0	0	0.4	182	Yes
2028202500	SW-20-20-28-4	0	0	0	0.8	0.4	975	Yes
2028205010	NW-20-20-28-4	0.5	0.2	0	1.1	0.6	343	Yes
2028207500	NE-20-20-28-4	0	0	0	0	0.6	570	Yes
2028207510	NE-20-20-28-4	0	0	0	0	0.6	245	Yes
2028290000	SE-29-20-28-4	0.51	0.21	0	0.85	0.2	624	Yes
2028290020	SE-29-20-28-4	0	0	0	1	0.6	120	Yes
2028292500	SW-29-20-28-4	0	0	0	0	0.4	385	Yes
2028297500	NE-29-20-28-4	0	0	0	0	0.6	94	Yes
2028325010	NW-32-20-28-4	0	0	0	0	0.6	530	Yes
2128042500	SW-4-21-28-4	0	0	0	0	0.4	150	Yes
2128045000	NW-4-21-28-4	0	0	0	0	0.6	583	Yes

Roll Number	Legal Land	Change <sup>1</sup> in Property Inundation (Ac)	Change <sup>1</sup> in Property Inundation (Ha)	Change <sup>1</sup> in Residential Water Level (m)	Change <sup>1</sup> in Property Water Level (m)	Change <sup>1</sup> in Velocity at River Bank (m/s)	Projected Length of Increased Velocity (m) <sup>2</sup>	Risk of Additional Erosion
2128045010	NW-4-21-28-4	0	0	0	0	0.3	532	Yes
2128050010	SE-5-21-28-4	0	0	0	0	0.4	553	Yes
2128052510	SW-5-21-28-4	0	0	0	0	0.2	142	Yes
2128057500	NE-5-21-28-4	0	0	0	0	0.3	249	Yes
2128092510	SW-9-21-28-4	0	0	0	0	0.3	608	Yes
2128155000	NW-15-21-28-4	2.16	0.87	0	0.28	0.6	782	Yes
2128157510	NE-15-21-28-4	4.59	1.86	0	0.4	0.6	420	Yes
2128162510	SW-16-21-28-4	0.92	0.37	0	0.51	0.3	1222	Yes
2128167500	NE-16-21-28-4	0	0	0	0.4	0.5	417	Yes
2128167550	NE-16-21-28-4	0	0	0	0.4	0.5	218	Yes
2128220000	SE-22-21-28-4	9.20	3.72	0	0.4	0.2	0	No
2128227500	NE-22-21-28-4	3.27	1.32	0	0.4	0.2	595	Yes
2128232500	SW-23-21-28-4	0	0	0	0.4	0.2	336	Yes
2128235000	NW-23-21-28-4	2.00	0.81	0	0.4	0.4	0	No
2128260000	SE-26-21-28-4	0.57	0.23	0	0.5	0.2	135	Yes
2128262500	SW-26-21-28-4	15.84	6.41	0	0.5	0.2	0	No
2128262510	SW-26-21-28-4	0	0	0	0.75	0	0	No
2128262520	SW-26-21-28-4	0	0	0.85	0.85	0.15	0	No
2128265000	NW-26-21-28-4	3.73	1.51	0	0.5	0.1	0	No
2128267500	NE-26-21-28-4	3.43	1.39	0	0.5	0.4	432	Yes
9000000010	CPR	0	0	0	0	0.2	55	Yes

Notes

1 Change refers to the difference between 2013 conditions and complete mitigation conditions given the same flow seen in 2013.

2  
 Projected length of increased velocity pertains to erosion protection length based on vulnerable stream banks identified through a historical air photo review. 2013 flood aerial photographs show the highlighted property as inundated during the 2013 flood. The inundated area was at least partially the result of the routing of water to this area via local drainage features (e.g. small culverts and minor driveways) that are currently not included in the Highwood River Flood Model (2013 Landscape and Scenario 28A) due to the regional nature of the model. Model-estimated water levels adjacent to and upstream of these inundated areas, however, do provide conservative estimates to support design and flood planning for the highlighted property. Design and planning will also need to take into account local drainage features to ensure all flood concerns are addressed. Future model runs will attempt to include these minor features, where feasible, to more accurately represent the behavior of flooding in this area.

### 6.3 Little Bow River from Southern Town Limits to MD Boundary

This area is shown in **Figures 6.3.1 through 6.3.15**. With the exception of water level increases for several MD residents adjacent to the southern limit of the Town and east of 72 Street E, the complete mitigation modelling scenario indicates a reduced water level for the majority of properties and infrastructure adjacent to the Little Bow River during a future 2013-magnitude event. None of the properties are subject to an increase in river bank velocity. Several properties are subject increase in water level as shown in **Table 6.5**. Additionally, all properties are still subject to flood risks and flood protection costs have been estimated for all properties. The primary flood mitigation option is the construction of a perimeter berm around the residence and ancillary buildings. **Table 6.4** summarizes the costs associated with buyouts and constructing berms around the affected residential buildings, as identified on **Figures 6.3.1 through 6.3.15**.

A total of 74 properties (total properties listed in **Table 6.5**) were subject to flood damages in 2013. The change in flood risk for these properties (based on the *change in property water level* column in **Table 6.5**) due to the Town's complete mitigation scenario is summarized below:

- ▶ 12 properties were subject to increased water levels, consisting of:
  - ▶ Three properties that have residences. The estimated total cost of these mitigation options for these three properties is \$899,638, as shown in **Table 6.4**.
  - ▶ The remaining nine properties have agricultural fields that were affected by the increased flood risk. Appropriate mitigation measures for these properties may include compensation for crop damage loss and should be addressed in subsequent phases of the study.
- ▶ A total of 62 properties were subject to a decrease in water levels, consisting of:
  - ▶ 17 properties where residences were subject to inundation in 2013. The residences at four of these properties residences are no longer subject to inundation for a 2013 magnitude event.
  - ▶ The remaining 13 properties are still subject to inundation, albeit at a reduced level than 2013. The estimated total cost of mitigation options for these 13 properties is \$7,692,700, as shown in **Table 6.4**.

The total cost for protecting all 16 properties with residences that are subject to flood risk (3 properties with increased flood risk and 13 properties with reduced flood risk) is \$8,592,338, as shown in **Table 6.4**.

Additionally, a conservative estimate of infrastructure damages and miscellaneous costs due to the 2013 flood are presented in **Table 6.6**. As previously noted, the future flood risks for these structures has been reduced due to the works constructed by the Town.

Table 6.4

## Southern Limit of Town (72 St) to MD Boundary - Estimated Costs for Little Bow River Remedial Measures and Buyouts

Roll Number	Legal Land	Option 1	Option 2	Option 3	Most Cost Effective of Options 1 & 3	Price of Most Cost Effective Option	Complete Mitigation Conditions Additional Berm Height (m) <sup>3</sup>	Option 4	Most Cost Effective of Options 1 & 4	Price of Most Cost Effective Option
		Property Buyout Cost <sup>1</sup>	Residence and Ancillary Buildings Buyout Cost <sup>1</sup>	2013 Conditions Berm Cost <sup>2</sup>				Complete Mitigation Conditions Berm Cost <sup>2</sup>		
1727262500	SW-26-17-27-4	\$735,960	\$425,148	\$1,826,000	Option 1	\$735,960	-0.25	\$1,649,000	Option 1	\$735,960
1727277500	NE-27-17-27-4	\$2,622,396	\$257,448	\$919,000	Option 3	\$919,000	-0.25	\$832,000	Option 4	\$832,000
1727332500	SW-33-17-27-4	\$201,936	\$148,812	\$1,096,000	Option 1	\$201,936	-0.35	\$940,000	Option 1	\$201,936
1727335000	NW-33-17-27-4	\$10,230,336	\$74,064	\$969,000	Option 3	\$969,000	-0.35	\$835,000	Option 4	\$835,000
1728367500	NE-36-17-28-4	\$1,079,364	\$135,120	\$1,010,000	Option 3	\$1,010,000	-0.25	\$905,000	Option 4	\$905,000
1828015000	NW-1-18-28-4	\$58,008	\$19,524	\$677,000	Option 1	\$58,008	-0.25	\$609,000	Option 1	\$58,008
1828020010	SE-2-18-28-4	\$1,031,892	\$723,672	\$533,000	Option 3	\$533,000	-0.25	\$1,345,000	Option 1	\$1,031,892
1828030000	SE-3-18-28-4	\$571,020	\$346,800	\$1,354,000	Option 1	\$571,020	-0.25	\$1,221,000	Option 1	\$571,020
1828212500	SW-21-18-28-4	\$32,592	\$0	\$214,000	Do Nothing	\$0	0	\$0	Do Nothing	\$0
1828195000	NW-19-18-28-4	\$987,456	\$246,984	\$1,015,000	Option 1	\$987,456	-0.25	\$924,000	Option 4	\$924,000
1828215000	NW-21-18-28-4	\$639,564	\$72,348	\$767,000	Option 1	\$639,564	-0.25	\$690,000	Option 1	\$639,564
1828302500	SW-30-18-28-4	\$438,840	\$28,728	\$1,500,000	Option 1	\$438,840	-0.25	\$1,350,000	Option 1	\$438,840
1829247500	NE-24-18-29-4	\$519,480	\$190,968	\$912,000	Option 1	\$519,480	-0.11	\$870,000	Option 1	\$519,480
1829250010	SE-25-18-29-4	\$897,660	\$634,560	\$1,023,000	Option 1	\$897,660	-0.5	\$0	Do Nothing	\$0
1829255010	NW-25-18-29-4	\$690,180	\$295,896	\$0	Do Nothing	\$0	0.1	\$519,000	Option 4	\$519,000
1829267510	NE-26-18-29-4	\$75,588	\$65,832	\$463,000	Option 1	\$75,588	0.35	\$539,000	Option 1	\$75,588
1829350000	SE-35-18-29-4	\$305,050	\$366,060	\$625,000	Option 1	\$305,050	0.5	\$775,000	Option 1	\$305,050
1829350020	SE-35-18-29-4	\$553,416	\$249,696	\$674,000	Option 1	\$553,416	-0.75	\$0	Do Nothing	\$0
1829350050	SE-35-18-29-4	\$699,000	\$358,848	\$533,000	Option 3	\$533,000	-0.75	\$0	Do Nothing	\$0
1829360000	SE-36-18-29-4	\$1,114,872	\$79,512	\$974,000	Option 3	\$974,000	-0.1	\$0	Do Nothing	\$0
Total For Most Cost Effective of Options 1 & 3						\$10,921,978	Total For Most Cost Effective of Options 1 & 4 <sup>4</sup>			\$8,592,338
							Additional Remedial and Buyout Costs Associated with Complete Mitigation Conditions			-\$2,329,640

## Notes

- 1 Buyout cost based on tax-assessed value plus 20% for admin and reclamation costs. May not include cost of all infrastructure on property.
  - 2 Berm cost based on dimensions estimated from air photo review and flood depth calculated from modeling plus 1m freeboard. Subject to revision based on detailed site investigations.
  - 3 Additional height of berm needed to incorporate change in water level from 2013 to complete mitigation conditions.
  - 4 Value is the sum of 3 properties that experienced an increased level of inundation (\$899,638) and 13 properties that experienced a decreased level of inundation (\$7,962,700).
- Similarly highlighted berm costs reflect properties that share a berm. Sum of values equals the total cost of the berm.
- Properties experienced an increased level of inundation with a total mitigation price of \$899,638



Table 6.5

Southern Limit of Town (72 St) to MD Boundary - Little Bow River Water Level, Velocity Changes, and Risk of Additional Erosion

Roll Number	Legal Land	Change <sup>1</sup> in Property Inundation (Ac)	Change <sup>1</sup> in Property Inundation (Ha)	Change <sup>1</sup> in Residential Water Level (m)	Change <sup>1</sup> in Property Water Level (m)	Change <sup>1</sup> in Velocity (m/s)	Additional Erosion Risk
1726070000	SE-7-17-26-4	0	0	0	-0.05	-0.1	No
1726072500	SW-7-17-26-4	0	0	0	-0.05	-0.1	No
1726075000	NW-7-17-26-4	0	0	0	-0.25	-0.2	No
1726182500	SW-18-17-26-4	-0.90	-0.36	0	-0.55	-0.2	No
1727130000	SE-13-17-27-4	-0.82	-0.33	0	-0.45	-0.2	No
1727137500	NE-13-17-27-4	-0.40	-0.16	0	-0.5	-0.2	No
1727237510	NE-23-17-27-4	-0.86	-0.35	0	-0.35	-0.1	No
1727240000	SE-24-17-27-4	-1.68	-0.68	0	-0.45	-0.2	No
1727242500	SW-24-17-27-4	-0.13	-0.05	0	-0.35	-0.15	No
1727245000	NW-24-17-27-4	-0.2	-0.1	0	-0.35	-0.2	No
1727262500	SW-26-17-27-4	-7.03	-2.84	-0.25	-0.25	-0.15	No
1727265000	NW-26-17-27-4	-3.80	-1.54	0	-0.3	-0.2	No
1727270000	SE-27-17-27-4	-1.14	-0.46	0	-0.45	-0.05	No
1727272500	SW-27-17-27-4	-17.10	-6.92	0	-0.5	-0.05	No
1727275000	NW-27-17-27-4	-4.39	-1.78	0	-0.35	-0.2	No
1727277500	NE-27-17-27-4	-20	-8	-0.25	-0.35	-0.2	No
1727310000	SE-31-17-27-4	-0.81	-0.33	0	-0.35	-0.1	No
1727312500	SW-31-17-27-4	-1.29	-0.52	0	-0.3	-0.2	No
1727320000	SE-32-17-27-4	0	0	0	-0.55	-0.1	No
1727322500	SW-32-17-27-4	-0.68	-0.28	0	-0.45	-0.15	No
1727327500	NE-32-17-27-4	0	0	0	-0.55	-0.1	No
1727330000	SE-33-17-27-4	-5.32	-2.15	0	-0.35	-0.2	No
1727332500	SW-33-17-27-4	-1.04	-0.42	-0.35	-0.4	-0.15	No
1727335000	NW-33-17-27-4	0	0	-0.35	-0.4	-0.2	No
1727342500	SW-34-17-27-4	0	0	0	-0.25	-0.2	No
1728360000	SE-36-17-28-4	-6.45	-2.61	0	-0.35	-0.15	No
1728367500	NE-36-17-28-4	-3.2	-1.3	-0.25	-0.3	-0.1	No
1828010000	SE-1-18-28-4	-3.43	-1.39	0	-0.25	-0.15	No
1828012500	SW-1-18-28-4	-1.51	-0.61	0	-0.2	-0.2	No
1828015000	NW-1-18-28-4	-0.5	-0.2	-0.25	-0.25	-0.1	No
1828020010	SE-2-18-28-4	-23.50	-9.51	-0.25	-0.25	-0.25	No
1828022500	SW-2-18-28-4	-0.37	-0.15	0	-0.25	-0.3	No
1828030000	SE-3-18-28-4	0	0	-0.25	-0.25	-0.05	No
1828030010	SE-3-18-28-4	0	0	0	-0.45	-0.1	No
1828035000	NW-3-18-28-4	-2.88	-1.17	0	-0.3	-0.1	No
1828037500	NE-3-18-28-4	-12.16	-4.92	0	-0.25	-0.15	No
1828090000	SE-9-18-28-4	-0.70	-0.28	0	-0.2	-0.15	No
1828095000	NW-9-18-28-4	-0.38	-0.15	0	-0.2	-0.15	No
1828097500	NE-9-18-28-4	-1.72	-0.70	0	-0.2	-0.15	No
1828102500	SW 10-18-28 W4	-0.79	-0.32	0	-0.25	-0.1	No
1828160000	SE-16-18-28-4	-1.59	-0.64	0	-0.25	-0.15	No
1828162500	SW-16-18-28-4	-0.76	-0.31	0	-0.25	-0.15	No
1828165000	NW-16-18-28-4	-4.08	-1.65	0	-0.25	-0.15	No
1828195000	NW-19-18-28-4	-4.56	-1.85	-0.25	-0.25	-0.15	No
1828197500	NE-19-18-28-4	0	0	0	-0.25	-0.15	No
1828200000	SE-20-18-28-4	-2.11	-0.85	0	-0.25	-0.15	No
1828207500	NE-20-18-28-4	-21.61	-8.75	0	-0.3	-0.2	No
1828212500	SW-21-18-28-4	-3.59	-1.45	0	-0.25	-0.15	No
1828215000	NW-21-18-28-4	0	0	-0.25	-0.25	-0.15	No
1828290000	SE-29-18-28-4	-1.53	-0.62	0	-0.3	-0.1	No
1828292500	SW-29-18-28-4	-4.62	-1.87	0	-0.3	-0.2	No
1828300000	SE-30-18-28-4	0	0	0	-0.25	-0.15	No
1828302500	SW-30-18-28-4	-4.61	-1.87	-0.25	-0.25	-0.15	No
1829247500	NE-24-18-29-4	0	0	-0.11	-0.11	-0.11	No
1829250000	SE-25-18-29-4	4.67	1.89	0	-0.1	-1.2	No
1829250010	SE-25-18-29-4	-2.18	-0.88	-0.5	-0.75	-1.2	No
1829250020	SE-25-18-29-4	2.0	0.8	0	0.2	-1.2	No
1829252510	SW-25-18-29-4	2.56	1.04	0	0.35	0.5	No
1829252530	SW-25-18-29-4	12.20	4.94	0	0.35	0.5	No
1829255000	NW-25-18-29-4	22	9	0	0.3	0.5	No
1829255010	NW-25-18-29-4	11.52	4.66	0.1	0	-1.2	No
1829255030	NW-25-18-29-4	3.5	1.4	0	0	-1.2	No
1829257500	NE-25-18-29-4	-8.70	-3.52	-0.1	0	-1.2	No
1829257510	NE-25-18-29-4	-34.70	-14.04	-0.25	0	-1.2	No
1829350040	SE-35-18-29-4	8	3	0	0	0	No
1829267500	NE-26-18-29-4	8.22	3.33	0	0.25	0	No
1829267510	NE-26-18-29-4	0.2	0.1	0.35	0.35	0.25	No
1829350000	SE-35-18-29-4	0.93	0.38	0.5	0.5	0.25	No
1829350010	SE-35-18-29-4	0	0	0.25	0.25	0.1	No
1829350020	SE-35-18-29-4	-2.10	-0.85	-0.75	-0.75	0	No
1829350030	SE-35-18-29-4	0.57	0.23	0.25	0.25	0.1	No
1829350050	SE-35-18-29-4	-3.26	-1.32	-0.75	-0.75	0	No
1829360000	SE-36-18-29-4	-85.0	-34.4	-0.1	0	-1.2	No
1829362500	SW-36-18-29-4	-47.55	-19.24	0	0	-1.2	No

Notes

1 Change refers to the difference between 2013 conditions and complete mitigation conditions given the same flow seen in 2013.

**Table 6.6**  
**Little Bow River Cost Estimate of 2013 Flood Infrastructure Damage**

Structure	Location	Description	Design Flow (m <sup>3</sup> /s)	Estimated Flood Damage Level	Estimated Flood Damage Cost	Indirect Flood Damage Cost (20%)	Total Flood Damage Cost
Bridge	232 St	BF00957	120	2013	\$1,267,739	\$253,548	\$1,521,287
Bridge	168 St	BF2009	120	2013	\$1,357,279	\$271,456	\$1,628,734
Bridge	104 St	BF13546	100	2013	\$1,377,373	\$275,475	\$1,652,848
Bridge	658 Ave E	BF6548	155	2013	\$394,525	\$78,905	\$473,430
Road	554 Ave E (103 St - 98 St)	750m of MD road washed out	N/A	2013	\$45,232	\$9,046	\$54,278
Various	Along Entire Little Bow	Debris Clean Up	N/A	2013	\$413,459	\$82,692	\$496,151
<b>Totals</b>					<b>\$4,855,606</b>	<b>\$971,121</b>	<b>\$5,826,727</b>

## 7.0 SUMMARY OF FLOOD ISSUES

Presented below is a summary of the flood issue findings for the Scoping Study. In the discussion below, and consistent with previous report information, the overall study area was divided into several subareas in order to present the associated local flood issues.

The Scoping Study findings are based in large part on modelling results gleaned from WorleyParsons' calibrated/validated 2D hydraulic model of the Highwood River and upper Little Bow River in the vicinity of the Town. The model was run for the 2013 flood peak (1,820 m<sup>3</sup>/s measured just upstream of Woman's Coulee Canal, prior to the Little Bow River flow-split) for the following scenarios:

- ▶ 2013 Flood Landscape Scenario (previously referred to as the Existing Condition Scenario); and
- ▶ Scenario 28A (Complete Mitigation Scenario), which includes all as-built dike information and the proposed 12 Avenue–Centre Street Dike required to protect southern boundary of the Town (refer to **Figure 2.3**). This scenario has been used as a conservatively-based design scenario (i.e., based on the Town's complete mitigation scenario) and can be considered the baseline design scenario for this Scoping Study. Currently the Town is proposing a south protection solution titled the SWD solution that differs in alignment from the 12 Avenue–Centre Street Dike. The SWD is being/has been designed based on the objective of having the flow-split equivalent to that of the 12 Avenue–Centre Street Dike design.

### 7.1 Upper Highwood

A desktop review was conducted of flood and geomorphic issues on the Upper Highwood River (defined as upstream of Woman's Coulee Canal Inlet) and Pekisko Creek and Stimson Creek. The findings are summarized below.

#### 7.1.1 Highwood River Upstream of Pekisko Creek Confluence to MD Boundary

The stretch of the Highwood River downstream of the MD western boundary and upstream of Pekisko Creek confluence is covered in **Appendix A**. Flood issues, as well as flood risk changes in this area located upstream of the proposed or realized measures of flood control following 2013 event, are limited to bridge damages, road damages, and landowner damages (six instances of residential basement, land only damages) between Longview and Pekisko Creek confluence. Another 12 resident issues were reported between Pekisko Creek confluence and Woman's Coulee Canal Inlet. In addition to these issues, a few small barriers built by private owners in order to pond small volumes on small drainage paths for irrigation purposes (push-up dams) were identified as flood risks.

#### 7.1.2 Pekisko Creek and Stimson Creek

Pekisko Creek and Stimson Creek are similar sized watersheds and both can be classified as significant tributaries to the Highwood River. On a drainage area basis, both streams combined represent approximately 30% of the Highwood River watershed (measured at the confluence with Pekisko Creek). As summarized below, no significant flood issues were identified:

- ▶ No issues or data gaps were identified on Peksiko and Stimson Creeks that would have a significant impact on the Highwood River downstream of the confluence with Pekisko Creek; and
- ▶ There are several push-up dams located within the Pekisko and Stimson watersheds. The performance of these structures during the 2013 flood is uncertain. However, it appears there were no significant issues related to push-up dams resulting from the 2013 flood. There may be some merit to further evaluate these structures to determine impacts resulting from a failure.

### 7.1.3 Upper Highwood River from Pekisko Creek to Woman's Coulee Canal Inlet

Flood issues were minimal through this river segment. Although some bank erosion occurred throughout, residential buildings were located mainly on elevated terraces above the 2013 flood levels. Twelve residents reported damage between the Pekisko Creek confluence and Woman's Coulee Canal Inlet. Although some bank erosion was present throughout, residential buildings were located mainly on elevated terraces above the 2013 flood levels. It is worth noting that there were some damages outside the MD, in the town of Longview, Alberta.

## 7.2 Highwood River from Woman's Coulee Canal Inlet to Bow River

Issues for the Highwood River from Woman's Coulee Canal inlet to the Bow River are discussed below in terms of seven reaches/areas.

A major characteristic of flow over this river segment is the diversion of flow from the Highwood River to the Little Bow River (refer to **Section 2.2.1**). Flood peaks above approximately 550 to 650 m<sup>3</sup>/s in the Highwood River result in water overflowing (flow-splitting) to the Little Bow River watershed from the south Highwood River floodplain. Note the flow estimate of 550 to 650 m<sup>3</sup>/s is gauged above the Woman's Coulee Canal inlet before flow-splitting occurs. Overflow is initiated when significant flood waters enter the southern floodplain of the Highwood River downstream of Woman's Coulee Canal inlet. Flood discharge from the Highwood River overflows to the Little Bow River watershed via the southern floodplain from just downstream of the inlet to the Little Bow Canal inlet located within the Town.

### 7.2.1 Woman's Coulee Canal Inlet

Woman's Coulee Canal (Mosquito Creek) Inlet and associated infrastructure are located on the south bank of the Highwood River and divert water from the Highwood River into the Little Bow River system. The inlet was damaged during the 2013 flood. The local landowners have expressed concerns that the new structure should not result in the diversion of additional floodwaters towards the south bank and floodplain (e.g., there should be no significant encroachment into the channel). In addition, the inlet should not direct water back to the Highwood River, because this would increase the Hoeh Dike breach risk and effects downstream. It is essential that these repairs consider the greater overall effect on flooding locally and downstream from this area. At the time of reporting, a detailed repair plan/design was not available for review.

### 7.2.2 Hoeh Dike Downstream to Town of High River

The Hoeh Dike parallels the Highwood River for approximately 2,000 m, approximately 7 km upstream of the Town and just downstream of the Woman's Coulee Canal inlet area. The Hoeh Dike consists of a patchwork of different segments that have been constructed over the last 100 years. Baker Creek is an intermittent high-water channel of the Highwood River that originates adjacent to the Hoeh Dike and discharges back to the river at George Lane Park in the Town. To minimize the amount of flood flow entering Baker Creek (which feeds these "overflow" channels) through diking (e.g., Hoeh Dike construction was initiated in 1907, with upgrades occurring over the next century and repairs still being undertaken today).

Discussions with local residents indicate that two portion of the Hoeh Dike were overtopped during the 2013 flood, although the area behind the dike was subject to inundation. The dike was overtopped with water flowing out of the river and overtopped in a second area just downstream with water flowing back into the river. The dike was also outflanked at the upstream end, permitting a significant quantity of discharge to be conveyed in the floodplain behind (south of) the dike.

A failure of the Hoeh Dike could change the flood risk both locally and regionally. Due to these potential effects, a Hoeh Dike failure analysis was undertaken, including hydraulic modelling. Key findings are summarized below.

- ▶ Floodplain inundation helps equalize water levels upstream and downstream of the dike, minimizing breaching risk.
- ▶ Modelling of Hoeh Dike failure scenarios indicates that dike failure appears to have significant local effects but only minimal regional effects (e.g., at the Town of High River).
- ▶ The structure is currently serving an important purpose but should not be raised or lowered, because this will have regional flood effects.

### 7.2.3 Town of High River

New dike infrastructure (TD, WTD, and Little Bow Canal Dike) are designed to prevent overflow for flood magnitudes below 1,820 m<sup>3</sup>/s. The WTD, TD, and Little Bow Canal Dike have been designed and constructed to protect the south portion of Town (north of 12 Avenue) from Baker Creek overflow and flooding from the main channel of the Highwood River. These structures, however, result in recapturing of significant diversion to the Little Bow River which increases the flood flow in the Highwood River at, and downstream of the Town. These flow additions can be summarized as follows:

- ▶ A portion of flood flow within the southern floodplain of the Highwood River/Baker Creek high-water channel that flooded the Town from the west and south, and that was eventually routed down the Little Bow River, is now diverted by the WTD down the main channel of the Highwood River resulting in significantly greater peak flows during low probability flood events in the Highwood River.
- ▶ Water from the main channel of the Highwood River that flooded the Town's centre from the north, and that was eventually flowed into 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 flows during low probability 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<sup>3</sup>/s (from 1,225 to 1,405 m<sup>3</sup>/s), in the Highwood River just downstream of the Town, considering the 2013 flood magnitude of 1,820 m<sup>3</sup>/s above Woman's Coulee Canal inlet. Conversely, the Little Bow River is expected to experience a decrease in peak flow from approximately 560 m<sup>3</sup>/s to 410 m<sup>3</sup>/s under conditions similar to the 2013 flood.

#### **7.2.4 498 Avenue E and the Hamptons**

The increase in flood flow magnitude on the Highwood River at the Highway 2 Bridge north of the Town is even greater due to the raising of 498 Avenue E and loss of floodplain storage associated with the Hamptons area located within the Town. The raising of 498 Avenue E was undertaken to protect the east side of the Town, including the Hamptons. Peak flow magnitude at the Highway 2 bridge is estimated to be approximately 290 m<sup>3</sup>/s greater than 2013 Flood Landscape Scenario (which is synonymous with the existing condition at the time of the 2013 flood or the condition pre-2013/2014 flood mitigation works), increasing from 955 m<sup>3</sup>/s to 1,245 m<sup>3</sup>/s for a 2013 magnitude flood equivalent.

In addition to loss of flood plain storage capacity, this area also includes the 498 Avenue E Bridge crossing. Water levels at this bridge are estimated to increase approximately 0.2 m due to the increases. This may affect bridge integrity and debris passage efficient. It is recommended that an assessment be performed to determine risk and potential upgrades required.

#### **7.2.5 498 Avenue E to Highway 2**

The change in the flow-split between the Highwood-Little Bow rivers (due to diking) and the increase of flows north (downstream) of 498 Avenue E (due to raising of this highway resulting in loss of floodplain storage) have significantly altered the flood peak magnitudes downstream of 498 Avenue E for low probability, low occurrence flood events. Flood peak magnitudes will increase due to diversion of flow by the dikes and loss of flow attenuation effects due to loss of flood storage. At flood peaks below approximately 1,000 m<sup>3</sup>/s (gauged upstream of Woman's Coulee Canal inlet), effects appear to be low to negligible. However, as flows being to increase above 1,000 m<sup>3</sup>/s, the change in flood risk level becomes more pronounced.

Infrastructure and landowner issues related to the increase in flood discharge are listed below.

- ▶ Landowner flood issues include: 1) increase in flood levels (ranging from 0 to 1 m); 2) landowner erosion issues due to velocity increases (up to 0.5 m/s); and 3) landowner flood inundation (ponding) duration/frequency issues and associated agricultural damages. Mitigation options include ring dikes around the perimeter of residences, buyouts of property or residences, installation of erosion protection, and compensation for incremental flood damages.
- ▶ The CPR Bridge at Aldersyde has an increase in water levels of 0.75 m. The bridge is subject to clogging by debris. The increase in water levels and velocities are not expected to significantly exacerbate the risks from the debris to the bridge and adjacent areas. However, the design level of the bridge and erosion protection should be reviewed considering the new flood flow regime.



### 7.2.6 Highway 2 to Confluence with Bow River

This segment of the Highwood River is subject to the same increase in discharge as the segment from 498 Avenue E to Highway 2. Infrastructure and landowner issues related to the increase in flood discharge are listed below.

- ▶ Landowner flood issues include: 1) increase in flood levels (ranging from 0 m to 1.65 m); 2) landowner erosion issues due to velocity increases (up to 0.85 m/s); and 3) landowner flood inundation (ponding) duration/frequency issues and associated agricultural damages. Mitigation options include ring dikes around the perimeter of residences, buyouts of property or residences, installation of erosion protection, and compensation for incremental flood damages.
- ▶ Highway 2 Bridge Structure is subject to an increase in water levels of 0.85 m and velocity of 0.75 m/s. Both the level of the bridge and the erosion protection should be reviewed in light of the new flood flow regime.
- ▶ Highway 547 Bridge Structure is subject to an increase in water levels of 0.9 m and velocity of 0.2 m/s. Bridge upgrade is likely required.
- ▶ Highway 552 Bridge Structure is subject to an increase in water levels of 0.42 m and velocity of 0.36 m/s. The bridge deck is elevated several metres above the streambed and would likely not be affected by the increased water levels. A bridge upgrade is likely not required.

### 7.3 Little Bow River to the MD Boundary

The low probability infrequent flood hydrology of the Little Bow River is mainly governed by spill-over from the Highwood River during low probability, infrequent flood events greater than approximately 500 to 600 m<sup>3</sup>/s. The headwaters of the Little Bow River are located within the Town and, hence when flooding occurs within the centre of Town, this water feeds these headwater channels. West of the Town, water that overflows the Baker Creek is routed naturally to the Little Bow River along various high-water channels, the adjacent floodplain, or through developed portions of the Town. Natural high-water channels within the developed portion of the Town have been largely infilled to accommodate development and are no longer apparent.

The Little Bow River residents and infrastructure in the MD will be subjected to significantly lower flood peak magnitudes when low probability infrequent peak events (e.g., greater than 1,000 m<sup>3</sup>/s) occur on the Highwood River and spill-over. This effect is the result of diking within the Town, as discussed in **Section 2.2.1**. In general, water levels downstream of 104 Street E are expected to decrease in the range of 25 to 35 cm for a flood event similar to that which occurred in 2013, based on preliminary modelling results (refer to **Figures 4.6.1 through 4.6.3** and **Figures 4.7.1 through 4.7.3**).

It is worth noting that some areas north of 104 Street E, but south of 72 Street E, will experience water level increases during low probability infrequent flood events over 1,000 m<sup>3</sup>/s. The maximum water level increase during a flood event similar to the 2013 flood is estimated at 50 cm. These residents will be approached by the Town to discuss mitigation options.

A detailed analysis is proposed for the southern diking option (i.e., currently the SWD) to assess and mitigate flow increases to the Little Bow River when flood peaks on the Highwood River range from approximately 600 to 1,000 m<sup>3</sup>/s (just upstream of Woman's Coulee Inlet). Preliminary analysis has shown that flows to the Little Bow River from the Highwood River over this range have the potential to increase when compared to the 2013 landscape condition.

## 7.4 Areas Downstream of the Study Area or Outside the MD Jurisdiction

This section provides a list of issues downstream of the study area or outside the MD's jurisdiction.

### 7.4.1 Highwood River

The Railway Bridge upstream of Highway 2, Highway 2 Bridge, Highway 547 Bridge, and the Highway 552E Bridge on the Highwood River downstream of 498 Avenue E all have the potential to be impacted under the modified low probability flood hydrology. Review of the bridge designs is outside of the MD's jurisdiction. However, responsible operation and maintenance parties should be notified so appropriate design checks can be undertaken.

### 7.4.2 Bow River Downstream of the Study Area

The increase in peak flow magnitude of a Highwood River flood flow similar to that experienced in 2013 is approximately 300 m<sup>3</sup>/s downstream of Highway 2. The associated impacts on the Bow River downstream of the Highwood River confluence will be somewhat a function on the timing of the peak on the Bow River during flooding. A detailed analysis would assist in better understanding these effects and the associated risk and should be undertaken in future studies.

There is also a significant additional volume of water that will need to be managed at downstream reservoirs (such as the Bassano Dam). Estimating the total quantity of water and evaluating its impact on downstream reservoirs should also be undertaken in future studies.

### 7.4.3 Little Bow River Downstream of the MD

The flood issues for the area downstream of the MD will be similar to those within the MD, summarized in **Section 7.3**. The performance of the Town's flood mitigation structures during an low probability, infrequent flood event, such as the design PMF of the Twin Valley Dam (which is in the order of 3,000 m<sup>3</sup>/s), is not well understood. For example, if the diking structures in the Town undergo catastrophic failure during such a low probability infrequent event, the effects on structures (such as the Twin Valley Dam and Travers Dam) are unknown. We understand that the overtopping of the dikes for a few hours was taken into account in the design of the dikes. However, this factor of safety will likely be insufficient to avoid large-scale breaching for a PMF type event. The changes to the flow split and the configuration of the Town's flood protection infrastructure should be discussed with the owners/operators of the Twin Valley Dam and the Travers Dam, which are located on the Little Bow River and are affected by the overflow from the Highwood River into the Little Bow River. An evaluation may be required by the dam operators of the performance of the Town dikes under PMF conditions, which is a typical design scenario evaluated for these large dam structures.

## 8.0 SUMMARY OF DESIGN CONCEPTS AND PRELIMINARY LEVEL COST BENEFIT ANALYSIS

The hydraulic modelling discussed previously was the basis for the comparison of costs for the various mitigation options evaluated. The two scenarios that were modeled were: a) 2013 Flood Landscape Scenario; and b) Scenario 28A (Complete Mitigation Scenario). The 2013 Flood Landscape and magnitude of the 2013 flood provides the base case to determine the incremental flood damage costs due to the Town's flood mitigation measures. This incremental flood damage cost was compared to flood mitigation options, such as buyouts and construction of flood protection measures.

The scoping nature of this Phase 1 Study guides the level of detail for the cost benefit analysis. The cost benefit analysis was only undertaken for those areas affected by the flood protection works constructed by the Town, including the River Run area upstream of the Town, the Highwood River downstream of the Town, and the Little Bow River.

More detailed cost benefit analyses undertaken in a future phase of the study may consider a comparison of costs versus avoided economic damages and the compensation option.

### 8.1 Woman's Coulee Canal Inlet to Western Town Boundary

The flood risk for the River Run area is unchanged. Thirty-four properties were identified that were subject to inundation during the 2013 flood. These properties could be protected from future floods by buyouts or perimeter berms. The estimated total cost of these mitigation options in the River Run area is \$22,491,960, as shown in **Table 6.1**.

### 8.2 498 Avenue E and the Hamptons

The post-2013 flood mitigation works of raising 498 Avenue E protected the Hamptons and neighbouring MD residents. Hence, no further residential flood mitigations works were identified herein.

### 8.3 498 Avenue E to Confluence with Bow River

A total of 93 properties (as shown in **Table 6.3**) were identified as having increased flood risk due to the Town's complete mitigation scenario. Eighteen of these properties have residences that were affected by the increased flood risk. The remaining 75 properties have agricultural fields that were affected by the increased flood risk.

The 18 residences that are subject to increased flood risk could be protected from future floods by buyouts or perimeter berms. The estimated total cost of these mitigation options for these 18 properties is \$11,235,388, as shown in **Table 6.2**. Appropriate mitigation measures for the remaining 75 properties may include compensation for crop damage loss and should be addressed in subsequent phases of the study.

### 8.4 Little Bow River

A total of 74 properties (total properties listed in **Table 6.5**) were subject to flood damages in 2013. The change in flood risk for these properties (based on the *change in property water level* column in **Table 6.5**) due to the Town's complete mitigation scenario is summarized below:

- 12 properties were subject to increased water levels, consisting of:

- ▶ Three properties that have residences. The estimated total cost of these mitigation options for these three properties is \$899,638, as shown in **Table 6.4**; and
- ▶ The remaining nine properties have agricultural fields that were affected by the increased flood risk. Appropriate mitigation measures for these properties may include compensation for crop damage loss and should be addressed in subsequent phases of the study
- ▶ A total of 62 properties were subject to a decrease in water levels, consisting of:
  - ▶ 17 properties where residences were subject to inundation in 2013. The residences at four of these properties residences are no longer subject to inundation for a 2013 magnitude event. The remaining 13 properties are still subject to inundation, albeit at a reduced level than 2013. The estimated total cost of mitigation options for these 13 properties is \$7,692,700, as shown in **Table 6.4**.

The total cost for protecting all 16 properties with residences that are subject to flood risk (three properties with increased flood risk and 13 properties with reduced flood risk) is \$8,592,338, as shown in **Table 6.4**.

## **9.0 RECOMMENDATIONS AND SCOPE OF WORK FOR FUTURE PHASES**

Presented below are recommendations and recommended scope of work for future phases of the study.

### **9.1 Upper Highwood**

There are several push-up dams located within the Pekisko and Stimson watersheds, as well as a few in the Upper Highwood area outside these sub-watersheds. The performance of these structures during the 2013 flood is uncertain. However, it appears there were no significant issues related to push-up dams resulting from the 2013 flood. There may be some merit to further evaluate these structures to determine risk and impacts resulting from a failure.

### **9.2 Highwood River from Woman's Coulee Canal Inlet to Bow River and Little Bow River within the MD's Boundary**

Recommendations and scope of work for future phases are discussed below for the remaining portions of the Highwood River and Little Bow River within the MD's boundary.

#### **9.2.1 Woman's Coulee Canal Inlet**

Woman's Coulee Canal inlet was damaged during the 2013 flood. The local landowners have expressed concerns that the new structure should not result in the diversion of additional floodwaters towards the south bank and floodplain (e.g., there should be no significant encroachment into the channel). In addition, the scoping team recommends that the new structure/layout should also not divert more flood water down the main channel of the Highwood River, because this could increase Hoeh Dike breach risk and increase impacts downstream. It is essential that these repairs consider the greater overall effect on flooding locally and downstream from this area. At the time of reporting, a detailed repair plan/design was not available for review.

#### **9.2.2 Hoeh Dike Downstream to Town of High River**

The main mitigation that has been proposed for this river segment is upgrading the design criteria of the riprap at the Scenario 2 Failure Assessment location on the downstream segment of the Hoeh Dike based on a limited failure assessment undertaken as part of the Scoping Study. The scoping team recommends that the dike will not be raised or lowered for this mitigation work; erosion protection at this location should be upgraded to withstand a more severe event and to withstand overtopping forces. Design criteria and upgrade length are to be determined. This may include a site visit by the scoping team and additional modelling scenarios to ensure the entire risk area is included in the detailed design.

#### **9.2.3 Town of High River**

At this point in time, there are no recommendations within this reach of the Highwood River.

#### **9.2.4 498 Avenue E and the Hamptons**

It is worth noting that the area south of 498 Avenue E is subject to longer duration flood inundation and greater risk than other areas adjacent to the Highwood River, because this area does not drain following the recession of flood waters. Before any additional future development occurs in this area, it is strongly recommended that a risk assessment (including cost-benefits) and drainage plan be undertaken to assess risk under failure and either the existing or any future diking scenarios.

In addition, part of the area south of 498 Avenue E could be investigated for flood storage. This would require construction of a horse-shoe dike structure to replace the Highway 543 embankment.

An additional assessment of the 498 Avenue E Bridge should also be undertaken, based on the mitigated modelling scenario.

#### **9.2.5 Areas Downstream of 498 Avenue E with Increased (or Change in) Flood Risk**

It is the MD's desire to have residents downstream of 498 Avenue E protected to the equivalent level of the Town (i.e., 2013 flood level determined under mitigated conditions plus 1 m freeboard). The following recommendations apply to these areas with increased flood risk including: (1) Highwood River from 498 Avenue E to Highway 2; (2) Highwood River from Highway 2 to Confluence with Bow River; and (3) Little Bow River to MD Boundary.

- ▶ Undertake a more detailed design of the flood mitigative measures on the basis of finalized flood modelling (including additional runs at various flow rates and scales), topographic ground surveys, geotechnical/hyrotechnical/environmental investigations, landowner feedback (as detailed below), and further detailed analysis.
- ▶ Undertake a more detailed cost benefit analysis that includes a comparison of costs versus avoided economic damage, incorporates Net Present Value, and is based on damages estimated for several flood events. Additionally, it may be beneficial to evaluate the compensation option.
- ▶ Appraised property values should be considered in future study phases. The 2014 tax assessed valuations obtained from the MD were the basis for the residence and property valuations. It is important to note that appraised property values are often greater than assessed valuations.
- ▶ Prepare site-specific option packages and undertake meetings with stakeholders (including landowners) to discuss the findings of this report, including the recommended mitigative flood measures. In addition, these meetings would be of an exploratory nature to identify items and issues that were potentially missed in the Scoping Study.

### **9.3 Areas Outside the MD's Jurisdiction**

#### **9.3.1 Highway Bridge Crossings**

Further investigation is required of the highway bridge crossings on the Highwood River that are affected by the increased discharge resulting from the construction of the Town's flood protection works. This includes the railway bridge (just upstream of Highway 2), Highway 2, Highway 547, and Highway 552. At a minimum, owners of these bridges should be formally notified of the potential impacts.



### 9.3.2 Bow River Downstream of Highwood River Confluence

A detailed analysis of increased peak flood discharges on the Bow River downstream of the Highwood River confluence would assist in better understanding the effects and the associated risk in greater detail and should be undertaken in future studies.

There is also a significant additional volume of water that will need to be managed at downstream reservoirs (such as the Bassano Dam). Estimating the total quantity of water and evaluating its impact on downstream reservoirs should also be undertaken in future studies

### 9.3.3 Little Bow River Downstream of MD Boundary

The performance of the Town's flood mitigation structures during an low probability, frequent flood event, such as the design PMF of the Twin Valley Dam (which is in the order of 3,000 m<sup>3</sup>/s), is not well understood. For example, if the diking structures in the Town undergo catastrophic failure during such a large event, the effects on structures such as the Twin Valley Dam and Travers Dam are unknown. We understand that the overtopping of the dikes for a few hours was taken into account in the design of the dikes. However, this factor of safety will likely be insufficient to avoid large-scale breaching for a dam-breach type event. The changes to the flow split and the configuration of the Town's flood protection infrastructure should be discussed with the owners/operators of the Twin Valley Dam and the Travers Dam, which are located on the Little Bow River and are affected by the overflow from the Highwood River into the Little Bow River. An evaluation may be required by the dam operators of the performance of the Town dikes under PMF conditions, which is a primary design scenario evaluated for these large dam structures.

Although the Little Bow River has seen a significant reduction in 2013 flow from approximately 560 m<sup>3</sup>/s to 405 m<sup>3</sup>/s, these flows are still far greater than the design flows of the four MD bridges that cross the river. These design flows range from 100 m<sup>3</sup>/s to 155 m<sup>3</sup>/s as seen in **Table 6.6**.

## 10.0 CLOSURE AND LIMITATIONS

This report has been prepared for the exclusive use of Municipal District of Foothills No. 31. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, expressed or implied, is made.

Yours truly,

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

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Attach.

**Permit to Practice No. P-4546**

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- Figure 4.6.3 Little Bow River – Predicted Velocity Changes North of 498 Avenue E (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,390 m<sup>3</sup>/s
- Figure 4.7.1 Little Bow River – Predicted Inundation Extent Changes North of 498 Avenue E (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,820 m<sup>3</sup>/s
- Figure 4.7.2 Little Bow River – Predicted Level Changes North of 498 Avenue E (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,820 m<sup>3</sup>/s
- Figure 4.7.3 Little Bow River – Predicted Velocity Changes North of 498 Avenue E (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,820 m<sup>3</sup>/s
- Figure 4.8 Southwest Dike – Predicted Level Changes (Comparing 2013 Landscape Conditions to Scenario 38Ax [Removing Baker Creek Dike]) – 1,820 m<sup>3</sup>/s
- Figure 6.1.1 Incremental Flood Damages and Mitigation Options – Highwood River – River Run (1 of 5)
- Figure 6.1.2 Incremental Flood Damages and Mitigation Options – Highwood River – River Run (2 of 5)
- Figure 6.1.3 Incremental Flood Damages and Mitigation Options – Highwood River – River Run (3 of 5)
- Figure 6.1.4 Incremental Flood Damages and Mitigation Options – Highwood River – River Run 2 (4 of 5)
- Figure 6.1.5 Incremental Flood Damages and Mitigation Options – Highwood River – River Run (5 of 5)
- Figure 6.2.1 Incremental Flood Damages and Mitigation Options – Highwood River – 498 Avenue E to Confluence (1 of 17)
- Figure 6.2.2 Incremental Flood Damages and Mitigation Options – Highwood River – 498 Avenue E to Confluence (2 of 17)
- Figure 6.2.3 Incremental Flood Damages and Mitigation Options – Highwood River – 498 Avenue E to Confluence (3 of 17)



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- Figure 6.2.4 Incremental Flood Damages and Mitigation Options – Highwood River – 498 Avenue E to Confluence (4 of 17)
- Figure 6.2.5 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (5 of 17)
- Figure 6.2.6 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (6 of 17)
- Figure 6.2.7 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (7 of 17)
- Figure 6.2.8 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (8 of 17)
- Figure 6.2.9 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (9 of 17)
- Figure 6.2.10 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (10 of 17)
- Figure 6.2.11 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (11 of 17)
- Figure 6.2.12 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (12 of 17)
- Figure 6.2.13 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (13 of 17)
- Figure 6.2.14 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (14 of 17)
- Figure 6.2.15 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (15 of 17)
- Figure 6.2.16 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (16 of 17)
- Figure 6.2.17 Incremental Flood Damages and Mitigation Options –Highwood River – 498 Avenue E to Confluence (17 of 17)
- Figure 6.3.1 Incremental Flood Damages and Mitigation Options – Little Bow River (1 of 15)
- Figure 6.3.2 Incremental Flood Damages and Mitigation Options – Little Bow River (2 of 15)
- Figure 6.3.3 Incremental Flood Damages and Mitigation Options – Little Bow River (3 of 15)
- Figure 6.3.4 Incremental Flood Damages and Mitigation Options – Little Bow River (4 of 15)
- Figure 6.3.5 Incremental Flood Damages and Mitigation Options – Little Bow River (5 of 15)
- Figure 6.3.6 Incremental Flood Damages and Mitigation Options – Little Bow River (6 of 15)



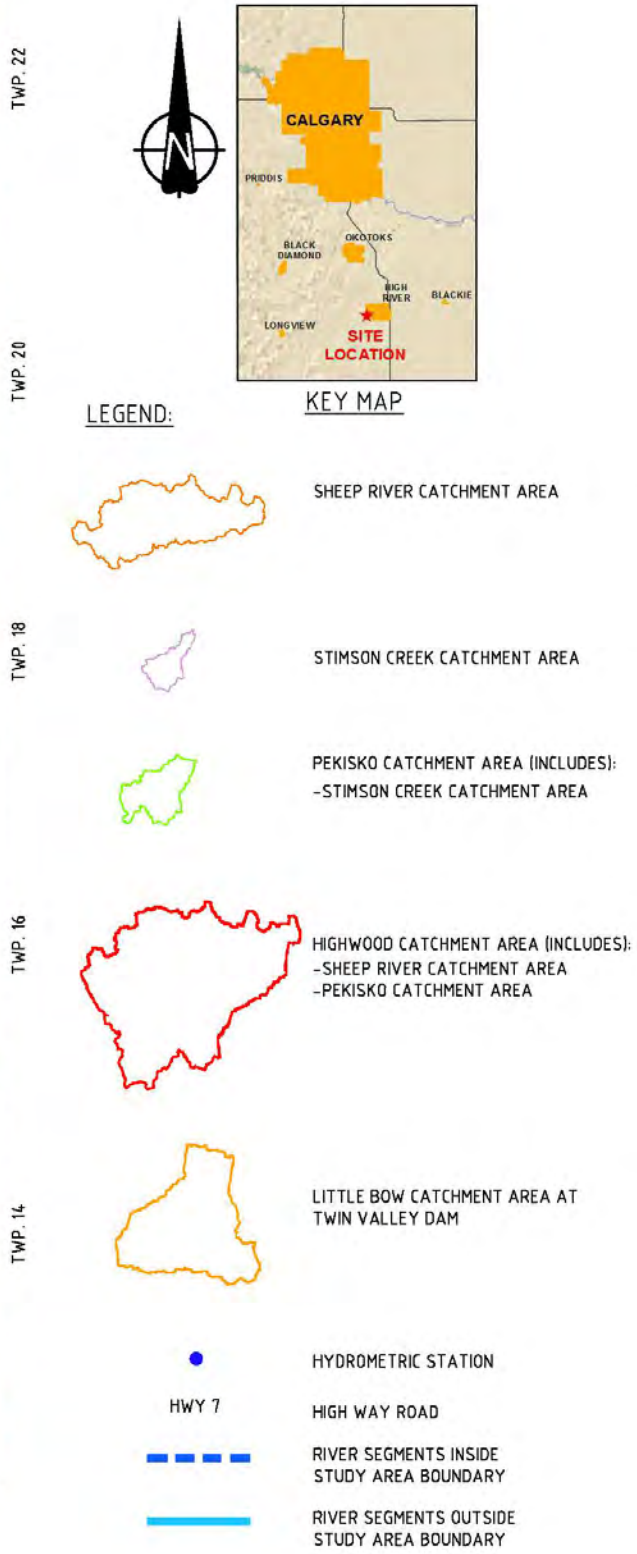
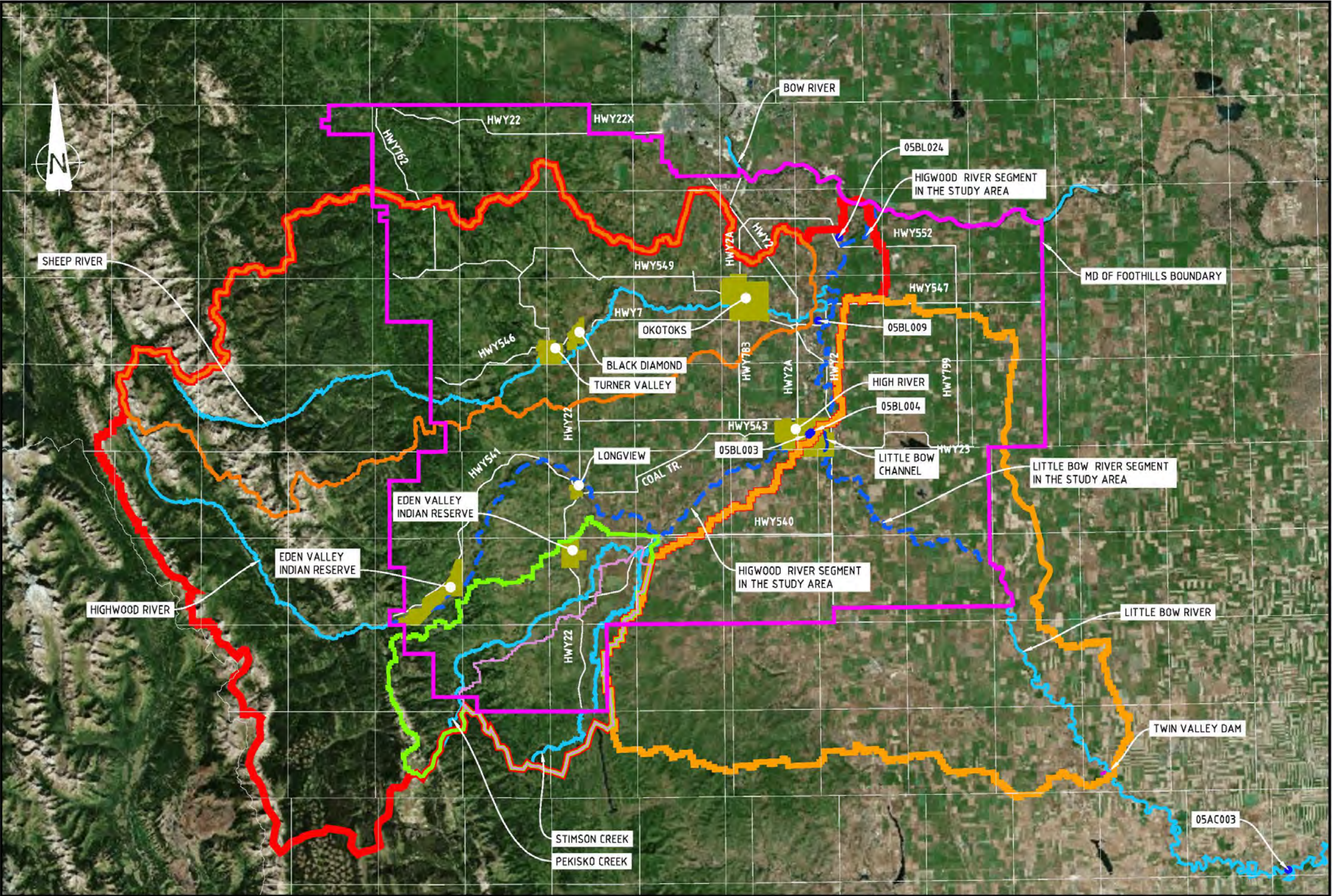


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- Figure 6.3.7 Incremental Flood Damages and Mitigation Options – Little Bow River  
(7 of 15)
- Figure 6.3.8 Incremental Flood Damages and Mitigation Options – Little Bow River  
(8 of 15)
- Figure 6.3.9 Incremental Flood Damages and Mitigation Options – Little Bow River  
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- Figure 6.3.10 Incremental Flood Damages and Mitigation Options – Little Bow River  
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- Figure 6.3.11 Incremental Flood Damages and Mitigation Options – Little Bow River  
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- Figure 6.3.12 Incremental Flood Damages and Mitigation Options – Little Bow River  
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- Figure 6.3.13 Incremental Flood Damages and Mitigation Options – Little Bow River  
(13 of 15)
- Figure 6.3.14 Incremental Flood Damages and Mitigation Options – Little Bow River  
(14 of 15)
- Figure 6.3.15 Incremental Flood Damages and Mitigation Options – Little Bow River  
(15 of 15)







DATE SOURCE:  
1. MD BOUNDARY, ROAD LAYOUT AND TOWN AREA ARE REFERENCE FROM M.D. OF FOOTHILLS NO. 31, LAND USE MAP.  
2. IMAGE REFERENCE FROM GLOBAL MAPPER.

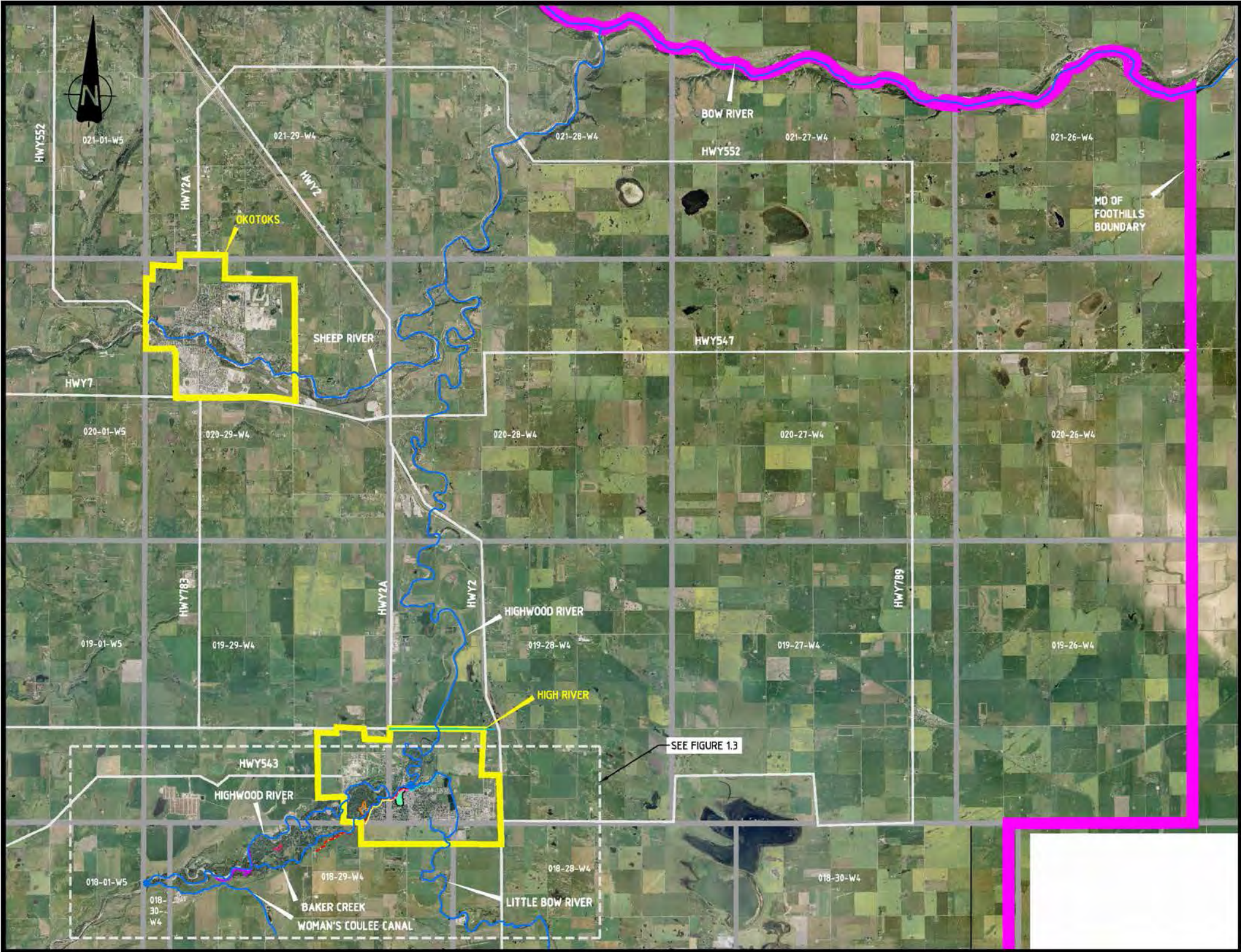
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<b>Municipal District of Foothills No. 31</b>				
<b>Study Area and River Segments</b>				
 <b>Advisian</b> WorleyParsons Group	Created By: <b>TDG</b>			
	Reviewed By: <b>JB</b>	Date: <b>April 15, 2016</b>	File Path: 307074-02030\12.0_Reports\12.2_Final\Scoping Study\Figures	Figure No: <b>1.1</b> Rev: <b>0</b>
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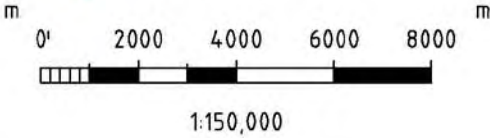


**DATA SOURCE:**

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

**LEGEND:**

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



**Municipal District of Foothills No. 31**

**Lower Highwood Study Area and Key Features**



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Created By: TDG

Reviewed By: JB



Date: April 15, 2016

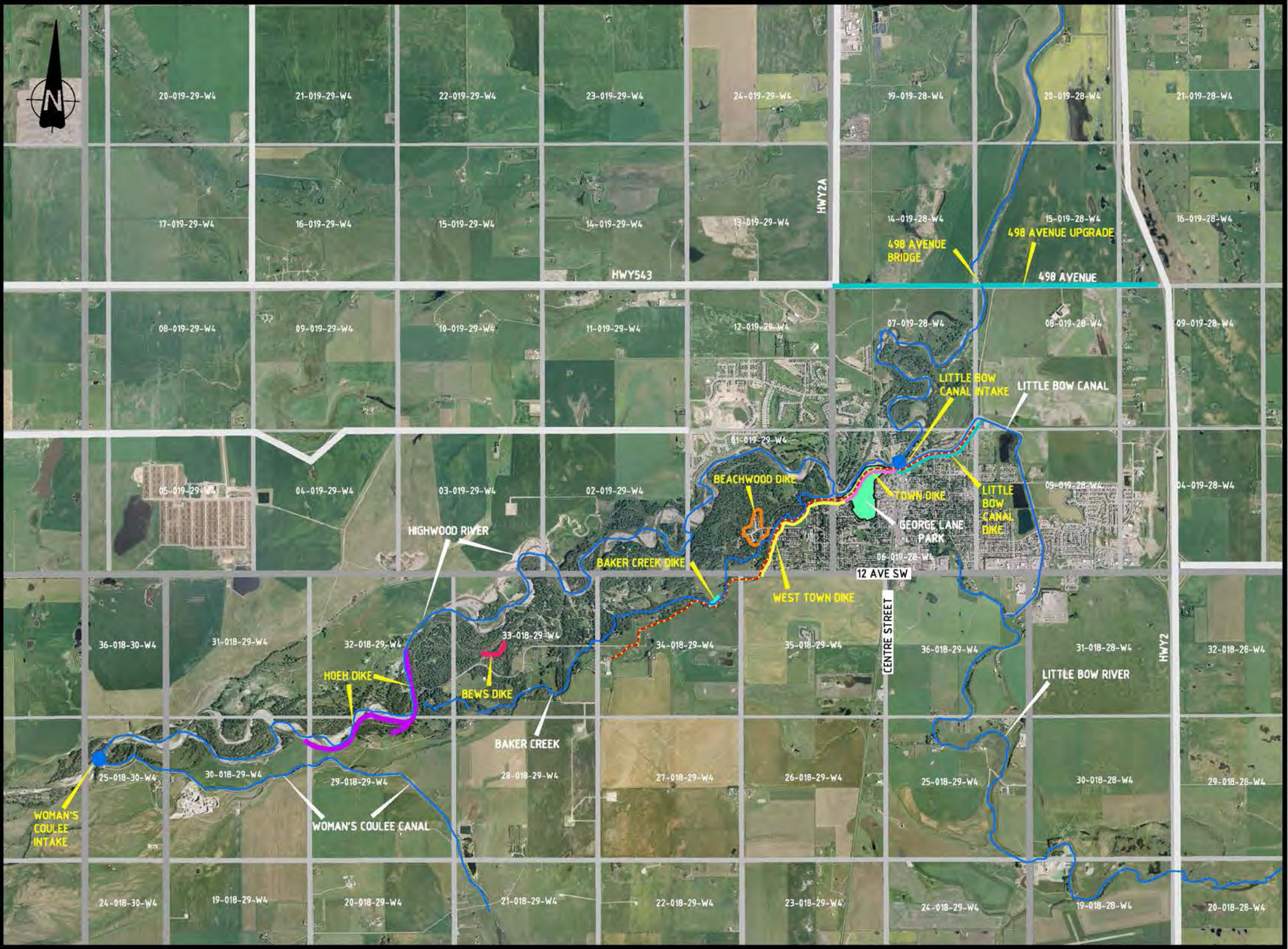
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Figure No: 1.2

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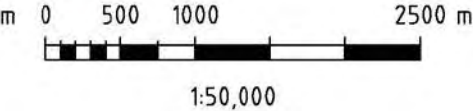


**DATA SOURCE:**

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



**LEGEND:**

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



**Municipal District of Foothills No. 31**

**Highwood River Features Between Woman's Coulee Canal Inlet and Town of High River**

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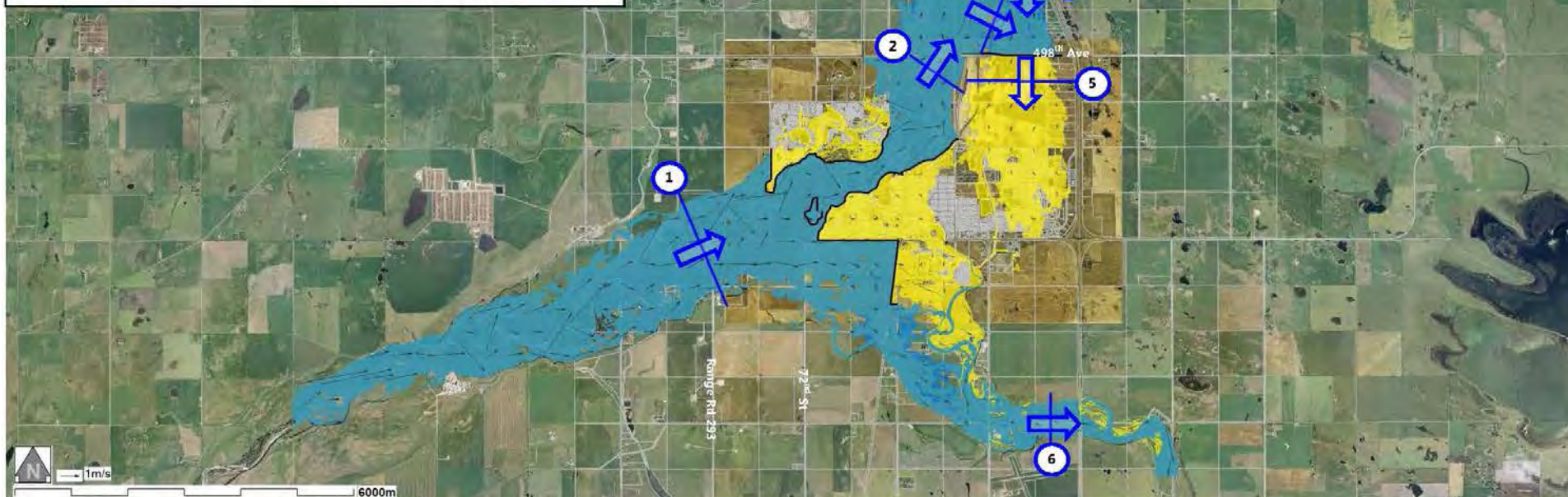
**TABLE 1 Summary of Peak Flow Differences for Existing and Post Mitigation Scenario 28A**

Location	Predicted Peak Flow (m <sup>3</sup> /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 489 AVE)	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 – Little Bow River Estimated Flow Split Scenarios**

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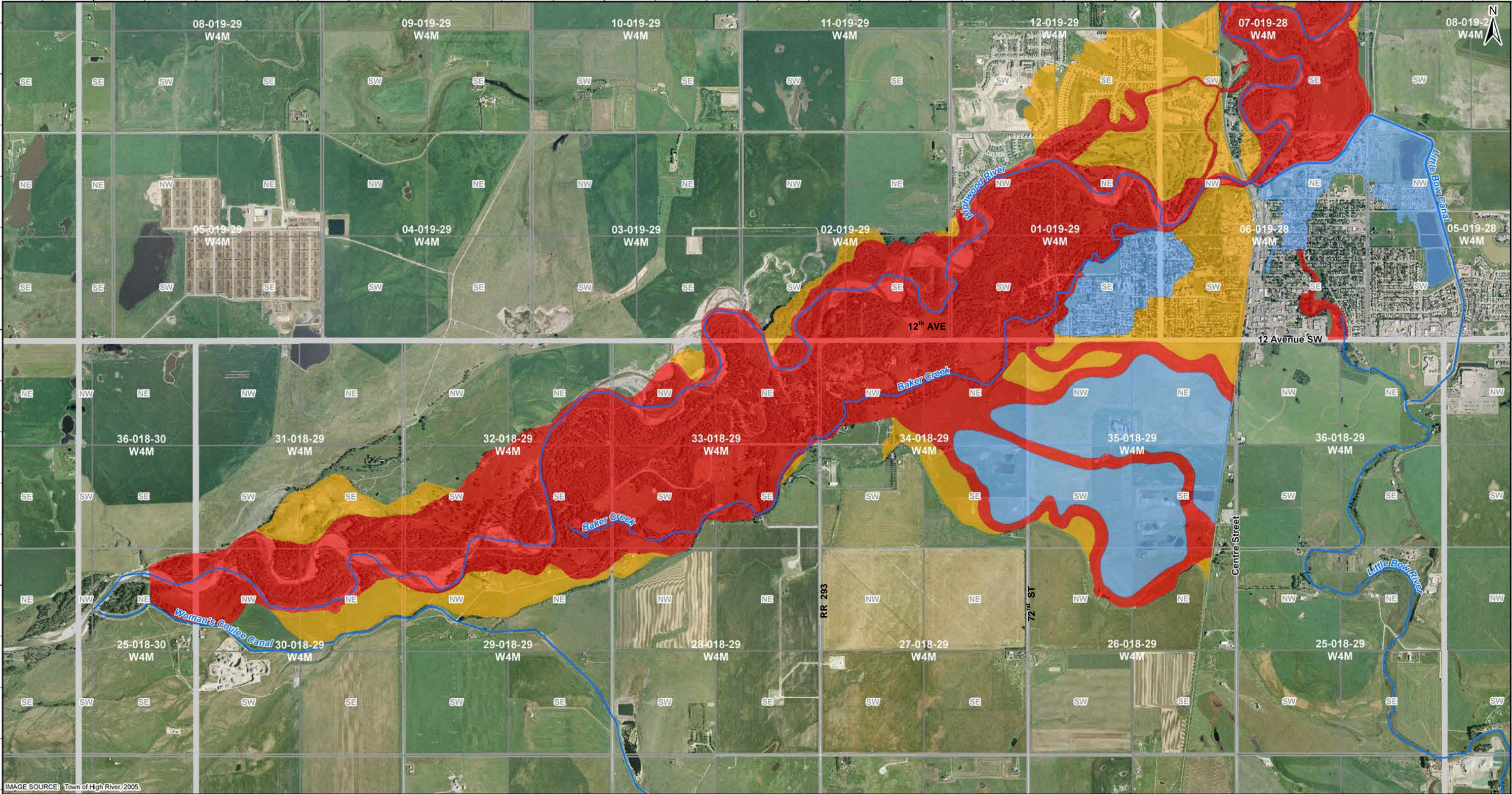
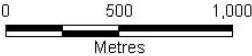


IMAGE SOURCE: Town of High River, 2005.

LEGEND

- Floodway
- Flood Fringe
- Areas affected by overland flow
- Watercourse / Canal

Flood Zones Source:  
River Forecast Section, Alberta Environment and Sustainable Resource Development,  
Government of Alberta  
July 10, 2013  
<http://www.envinfo.gov.ab.ca/FloodHazard/>  
Original Source: 1992 Alberta Environment High River Flood Study





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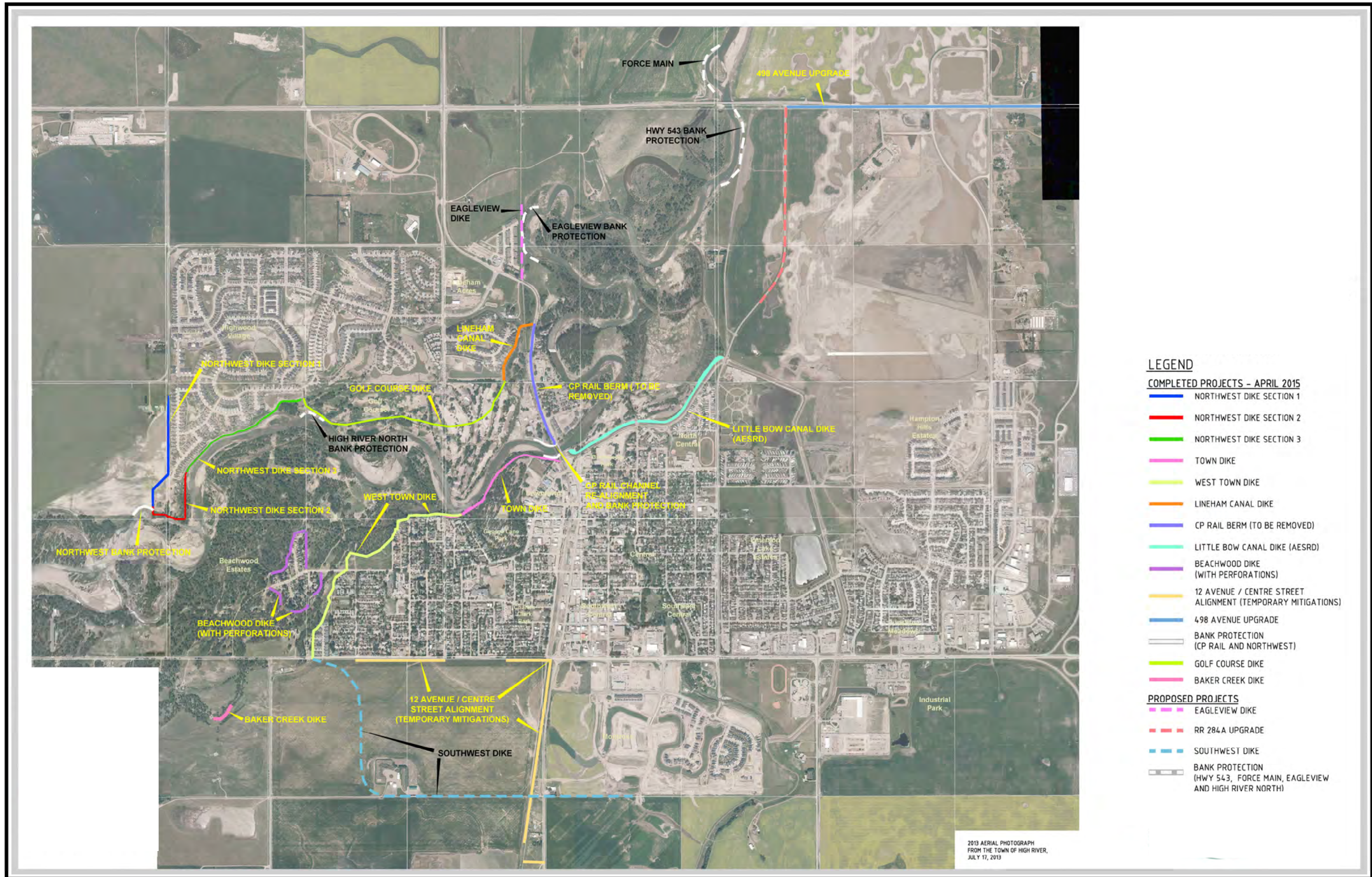
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Municipal District of Foothills No. 31				
1992 Flood Inundation Area and Floodway Channels Upstream and South of Town				
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Rev:	0	This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have 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 and AMEC assume no liability to any other party for any representations contained within.		





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Figure No: 2.3

Rev: 0

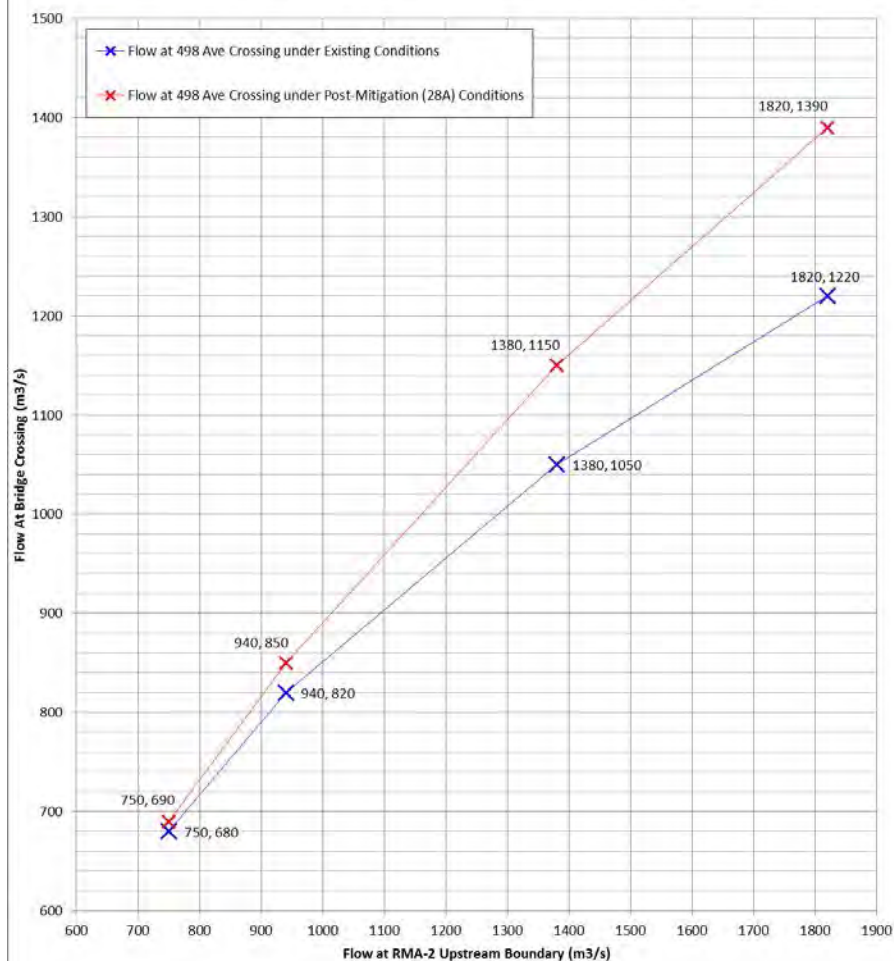
Municipal District of Foothills No. 31

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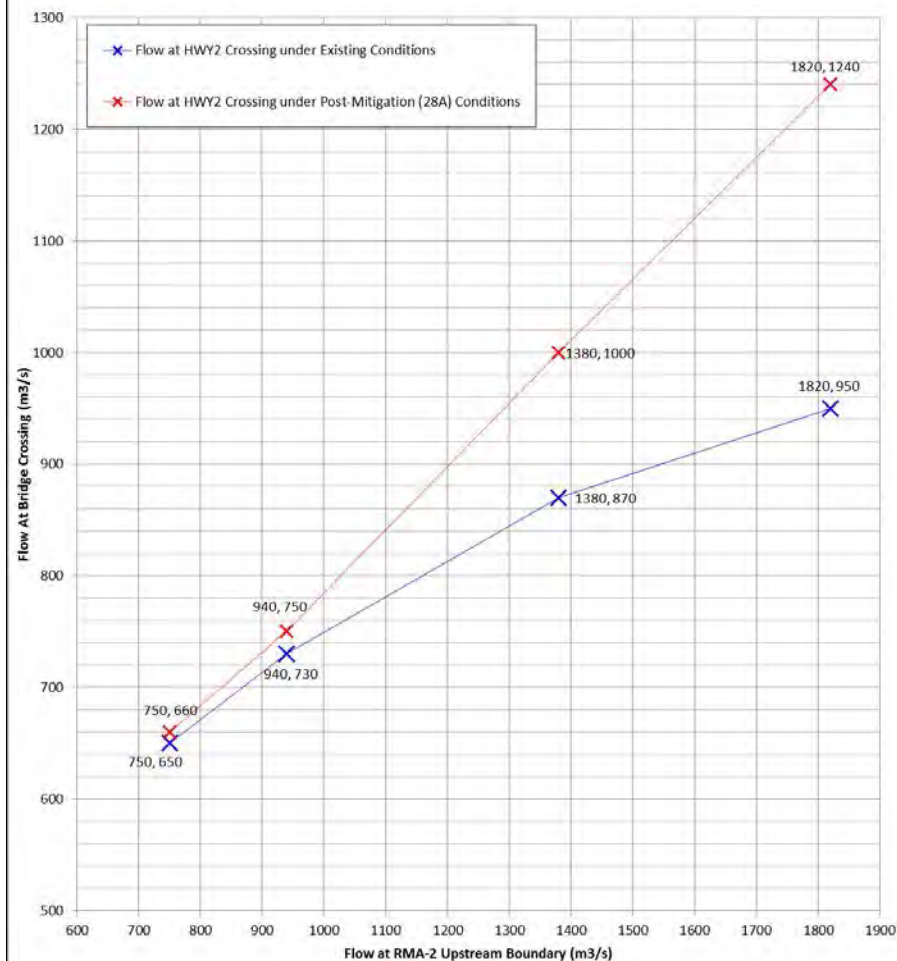
**Town of High River Flood Mitigation Infrastructure (Existing and Proposed)**



### Flow & Level Analysis at 498 Ave Crossing of High River



### Flow & Level Analysis at HWY2 Crossing of High River



## Municipal District of Foothills No. 31

### Flow Relationship; Highwood River Above Woman's Coulee Inlet vs Highwood River At Crossing Downstream of Town of High River



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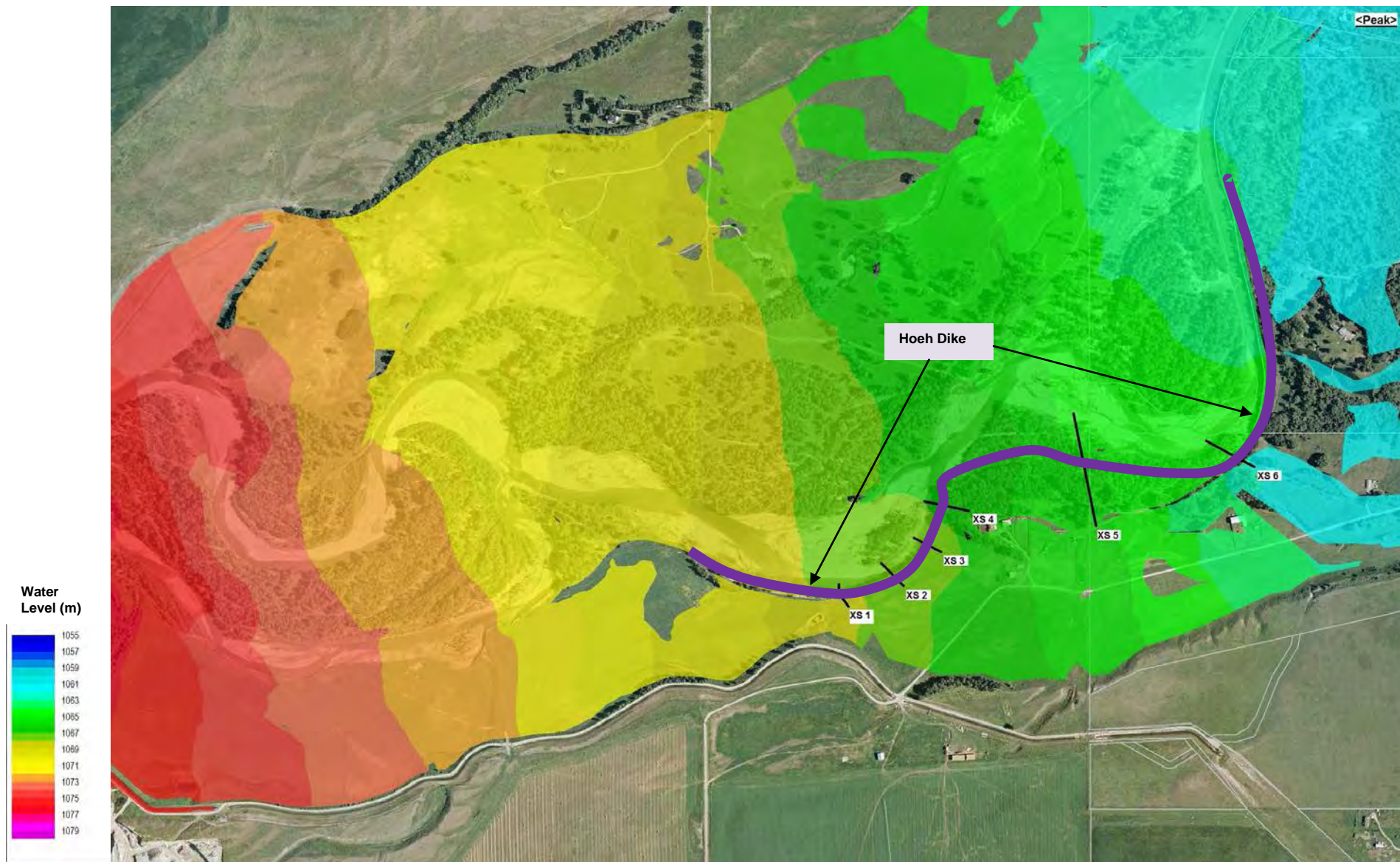
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Figure No: 2.4

Rev: 1

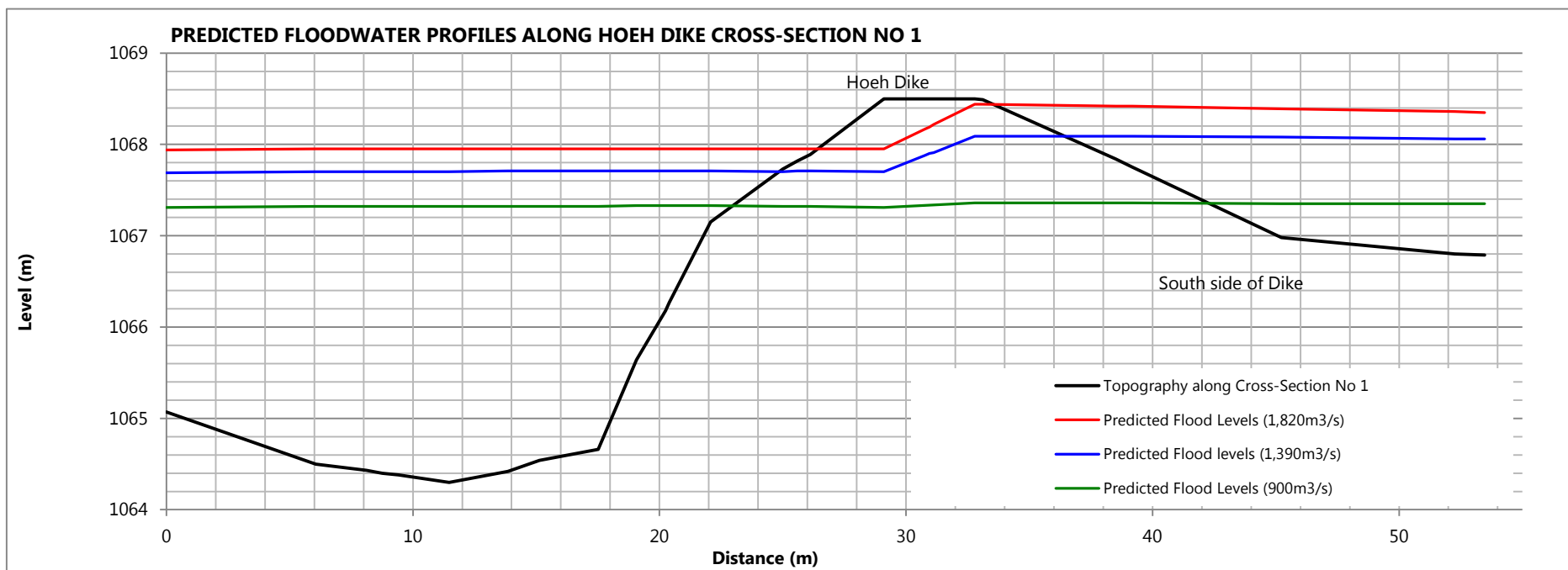
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See Figure 1.3 for location of Hoeh Dike in relation to study area.



Municipal District of Foothills No. 31				
Hoeh Dike Cross Section Locations with 1820 m <sup>3</sup> /s Water Level				
Date: May 18, 2016	File Path: 307074-02030\12.0_Reports\12.2_Final\Scoping Study\Figures	Figure No: 4.1.1	Rev: 1	
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	Reviewed By: JB	

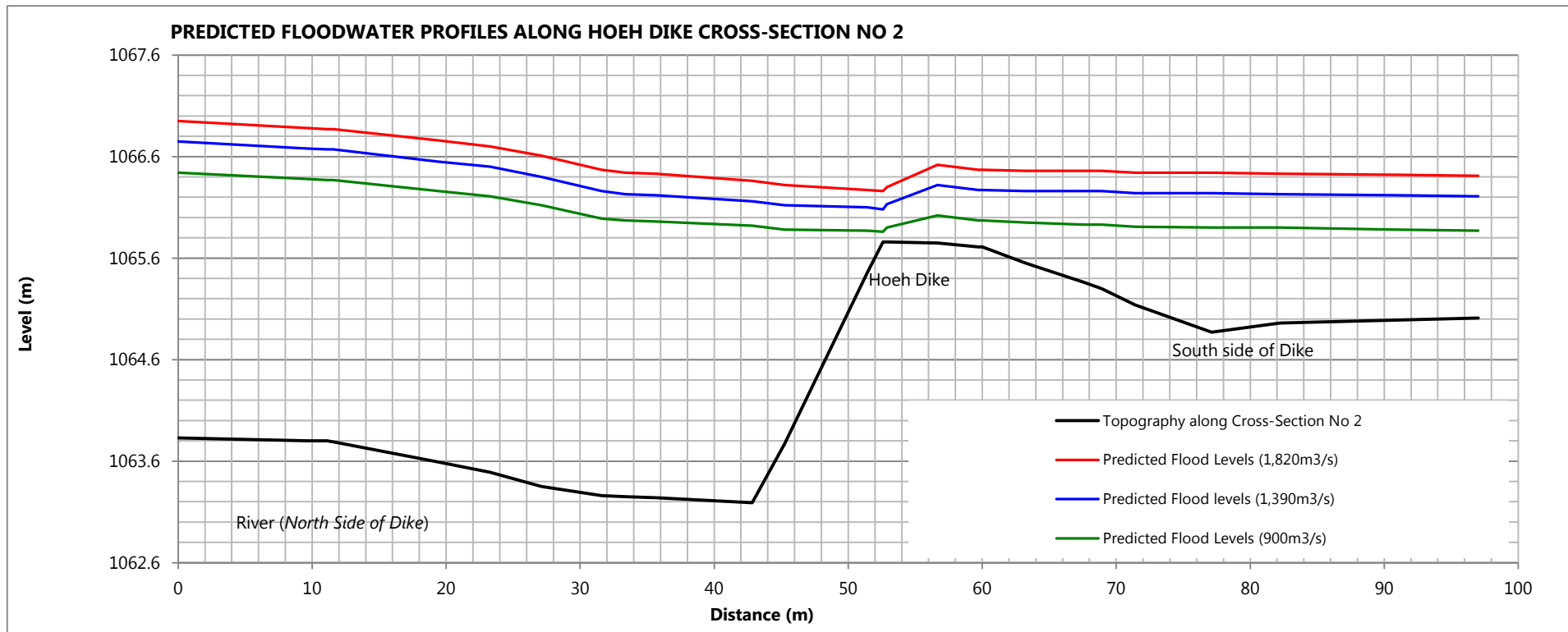




**Municipal District of Foothills No. 31**

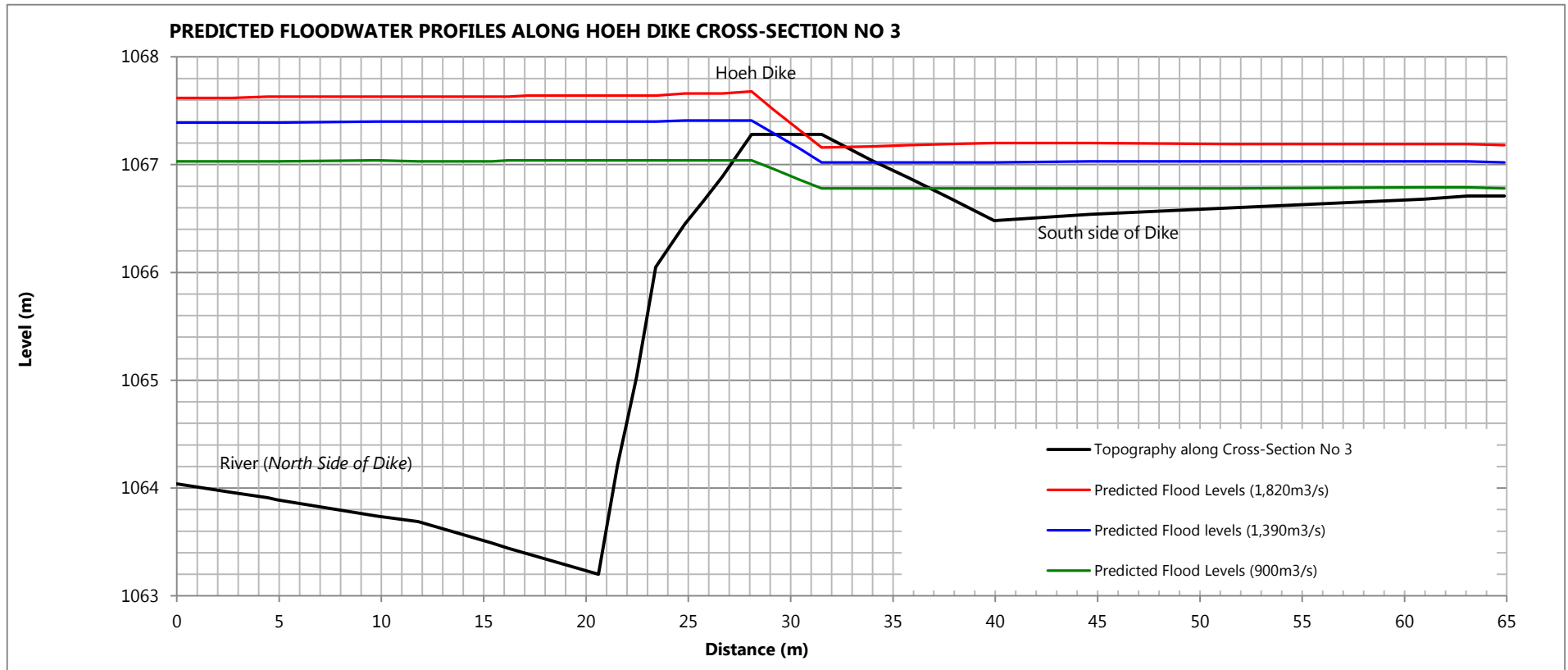
**HoeH Dike Cross Section 1**

 <p><b>Advisian</b> WorleyParsons Group</p>	Created By: <b>TDG</b>	 <p>amec foster wheeler</p>	Date: <b>April 15, 2016</b>	File Path: 307074-02030\12.0_Reports\ 12.2_Final\Scoping Study\Figures	Figure No: <b>4.1.2</b>	Rev: <b>0</b>
	Reviewed By: <b>JB</b>		<p><i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have 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 and AMEC assume no liability to any other party for any representations contained within.</i></p>			





			Municipal District of Foothills No. 31			
			Hoehe Dike Cross Section 2			
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	Reviewed By: JB		This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have 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 and AMEC assume no liability to any other party for any representations contained within.			



**Municipal District of Foothills No. 31**

**Hoeh Dike Cross Section 3**

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**Figure No:** 4.1.4

**Rev:** 0



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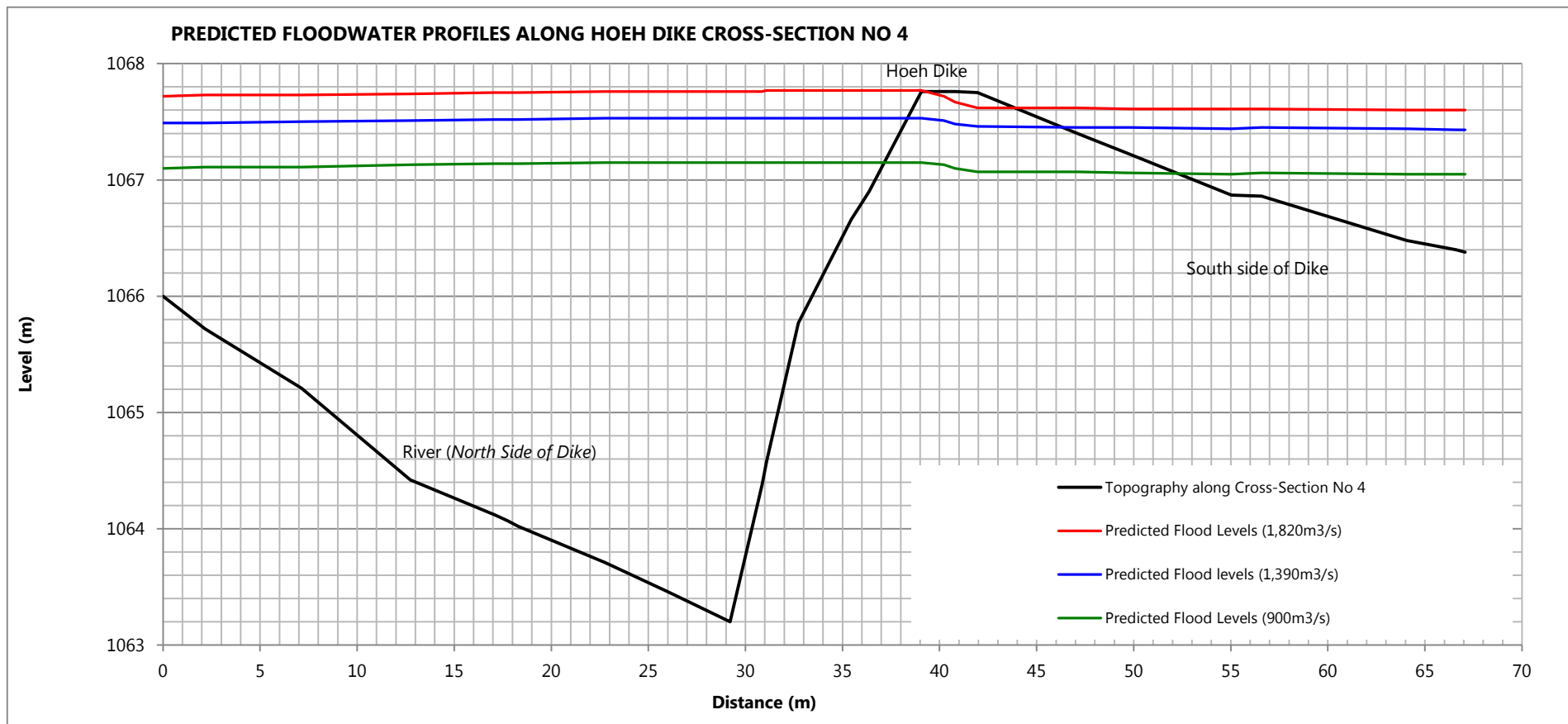
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**Reviewed By:** JB

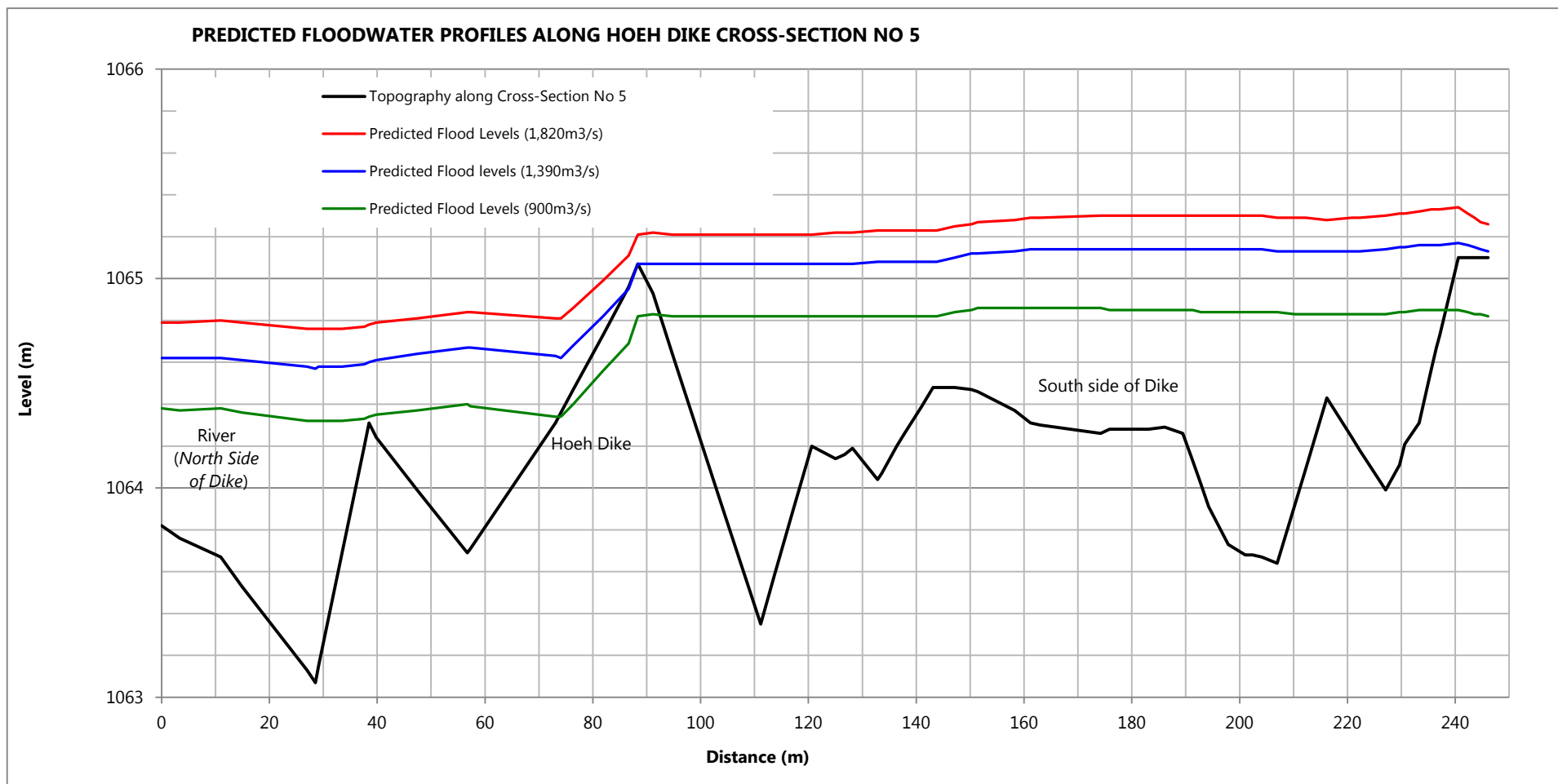


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			Municipal District of Foothills No. 31			
			Hoeh Dike Cross Section 4			
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**Municipal District of Foothills No. 31**

**Hoehe Dike Cross Section 5**

**Date:** April 15, 2016

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**Figure No:** 4.1.6

**Rev:** 0



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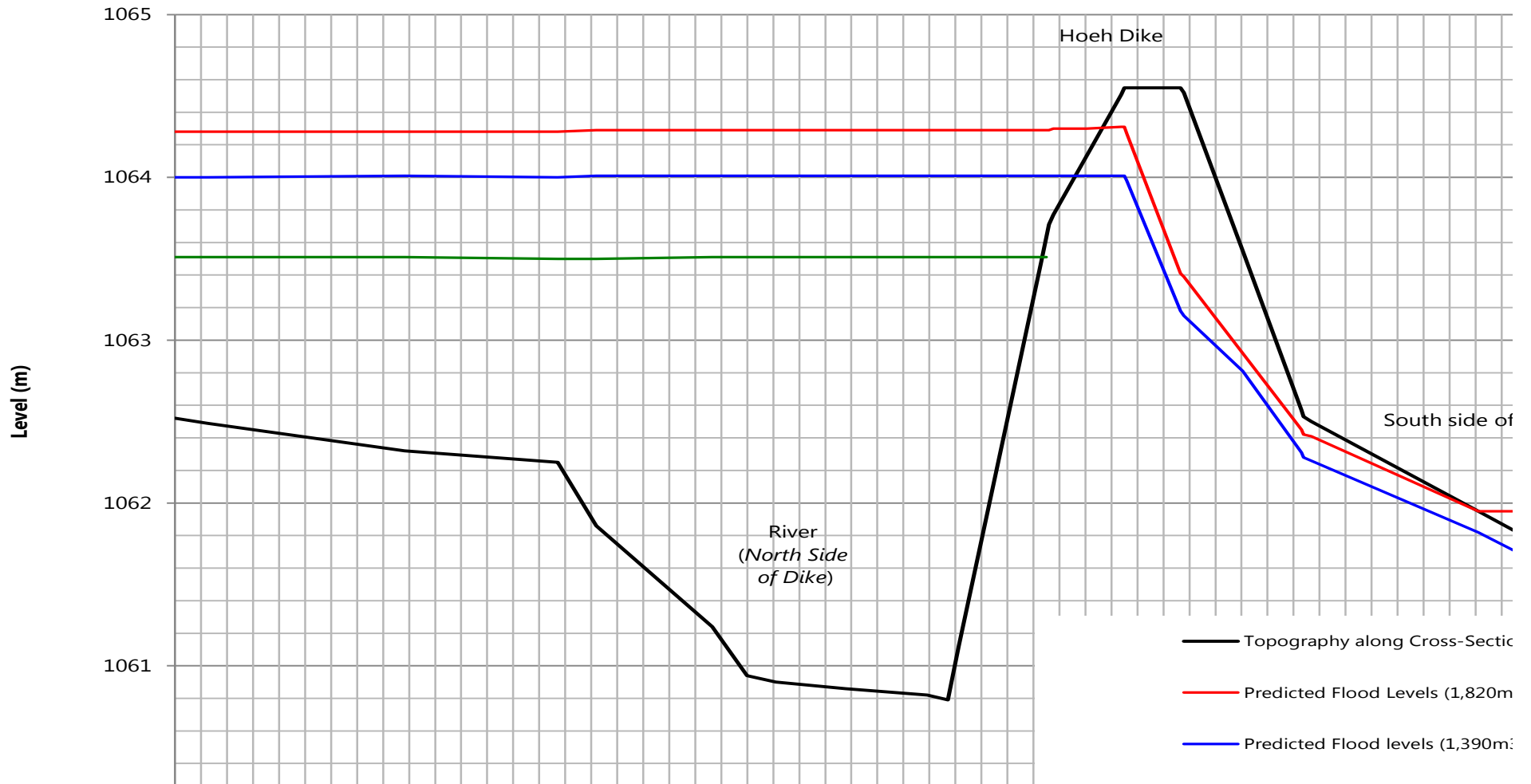
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# PREDICTED FLOODWATER PROFILES ALONG HOEH DIKE CROSS-SECTION NO 6



Municipal District of Foothills No. 31

Hoeh Dike Cross Section 6

Date: April 15, 2016

File Path: 307074-02030\12.0\_Reports\  
12.2 Final\Scoping Study\Figures

Figure No: 4.1.7

Rev: 0



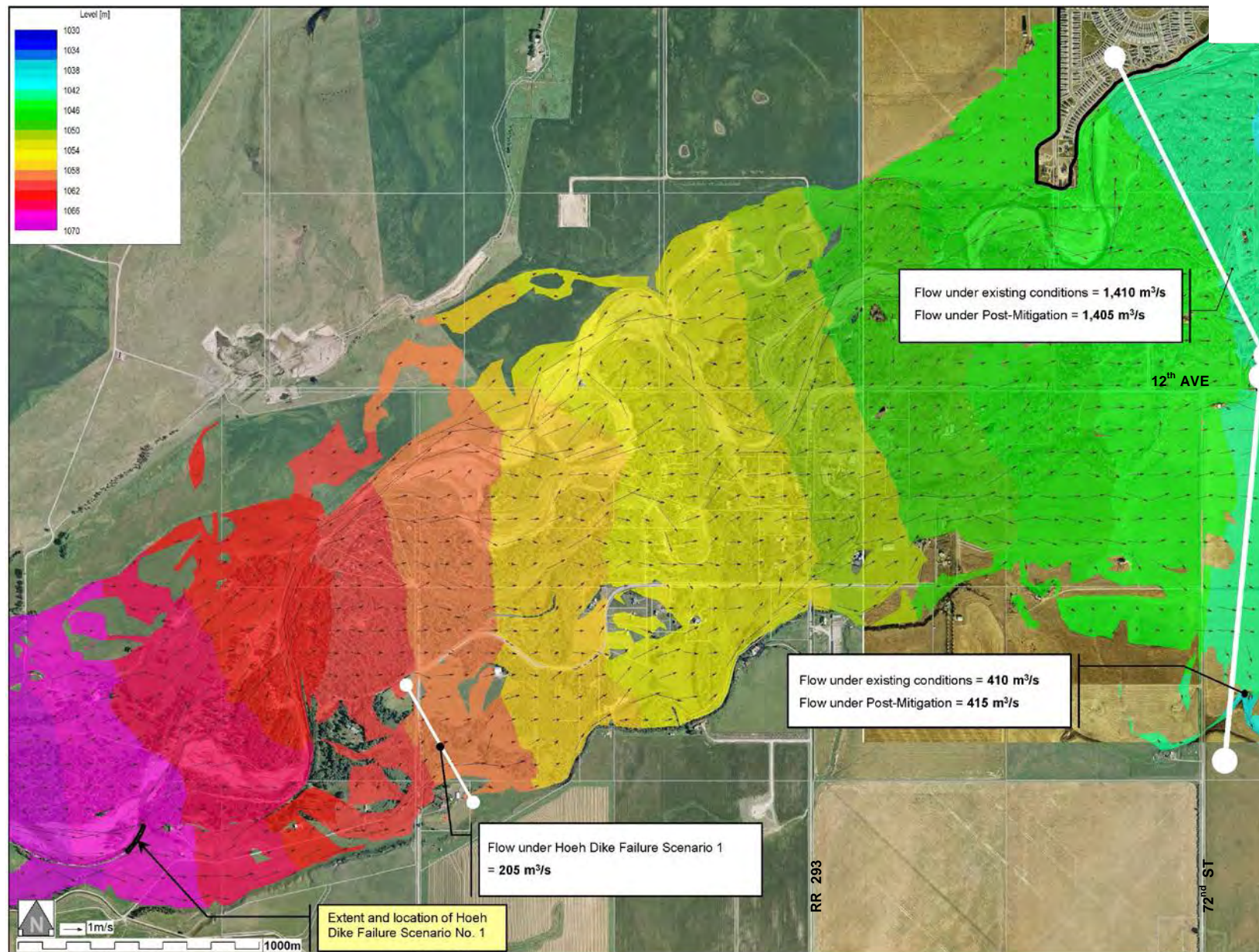
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## Municipal District of Foothills No. 31

### Hoeh Dike Failure Scenario 1 (150 m breach of upstream segment) – Peak Flow Summary (Scenario 28A) - 1,820 m<sup>3</sup>/s



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Reviewed By: JB



Date: April 15, 2016

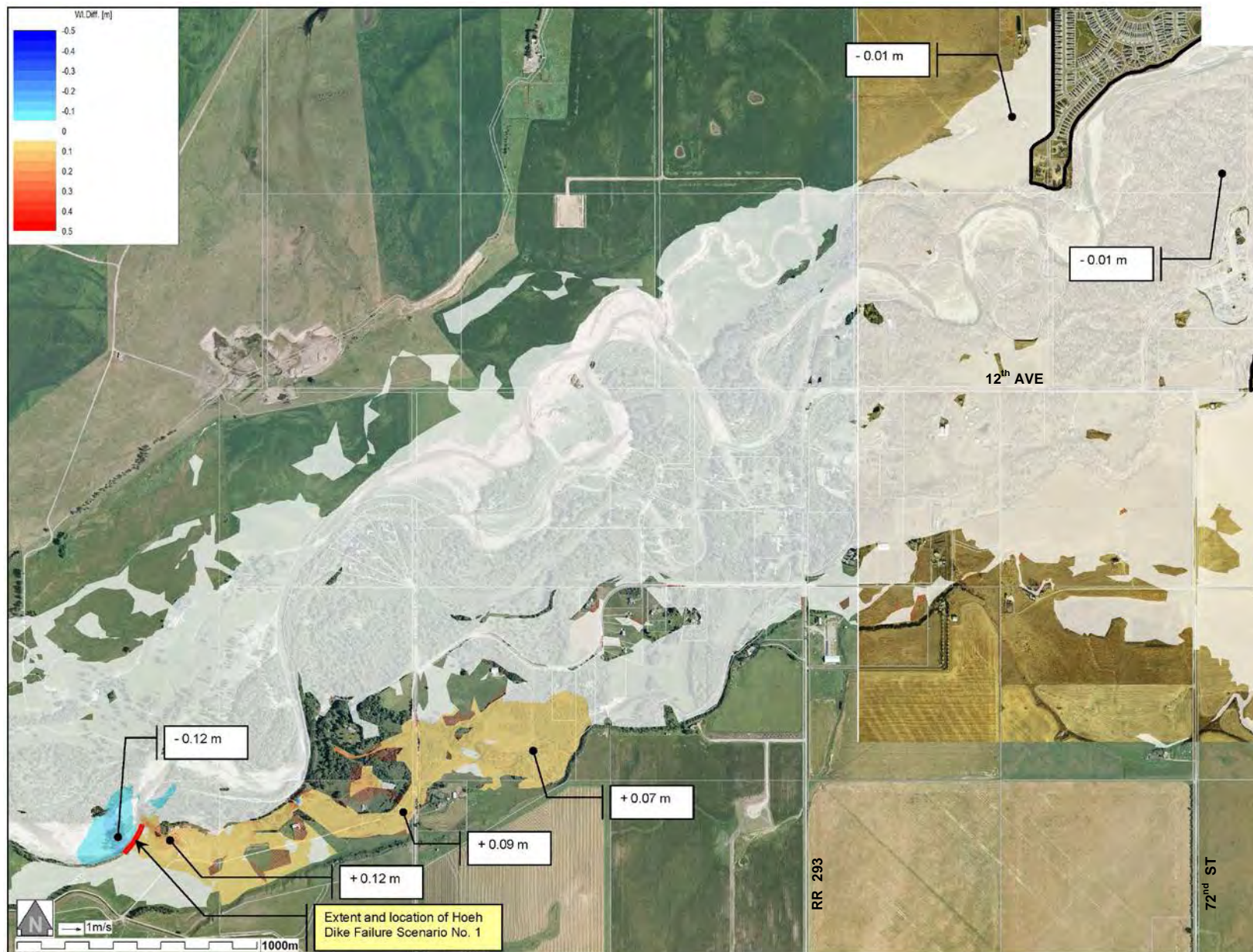
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### Municipal District of Foothills No. 31

#### Hoeh Dike Failure Scenario 1 (150 m breach of upstream segment) – Water Level Increases (Scenario 28 A – 1,820 m<sup>3</sup>/s)



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Date: April 15, 2016

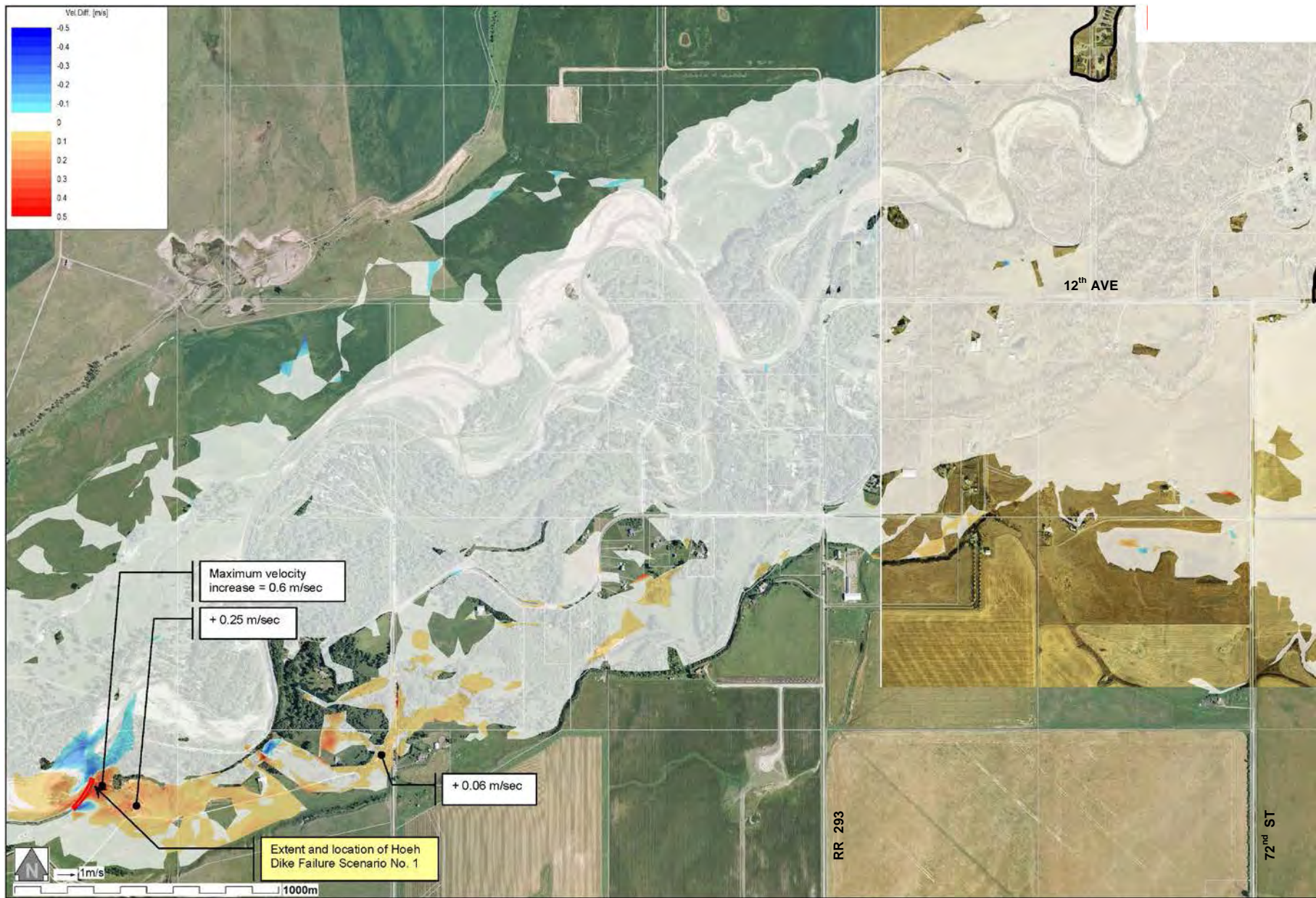
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### Municipal District of Foothills No. 31

#### Hoeh Dike Failure Scenario 1 (150 m breach of upstream segment) – Velocity Increases (Scenario 28A) - 1,820 m<sup>3</sup>/s



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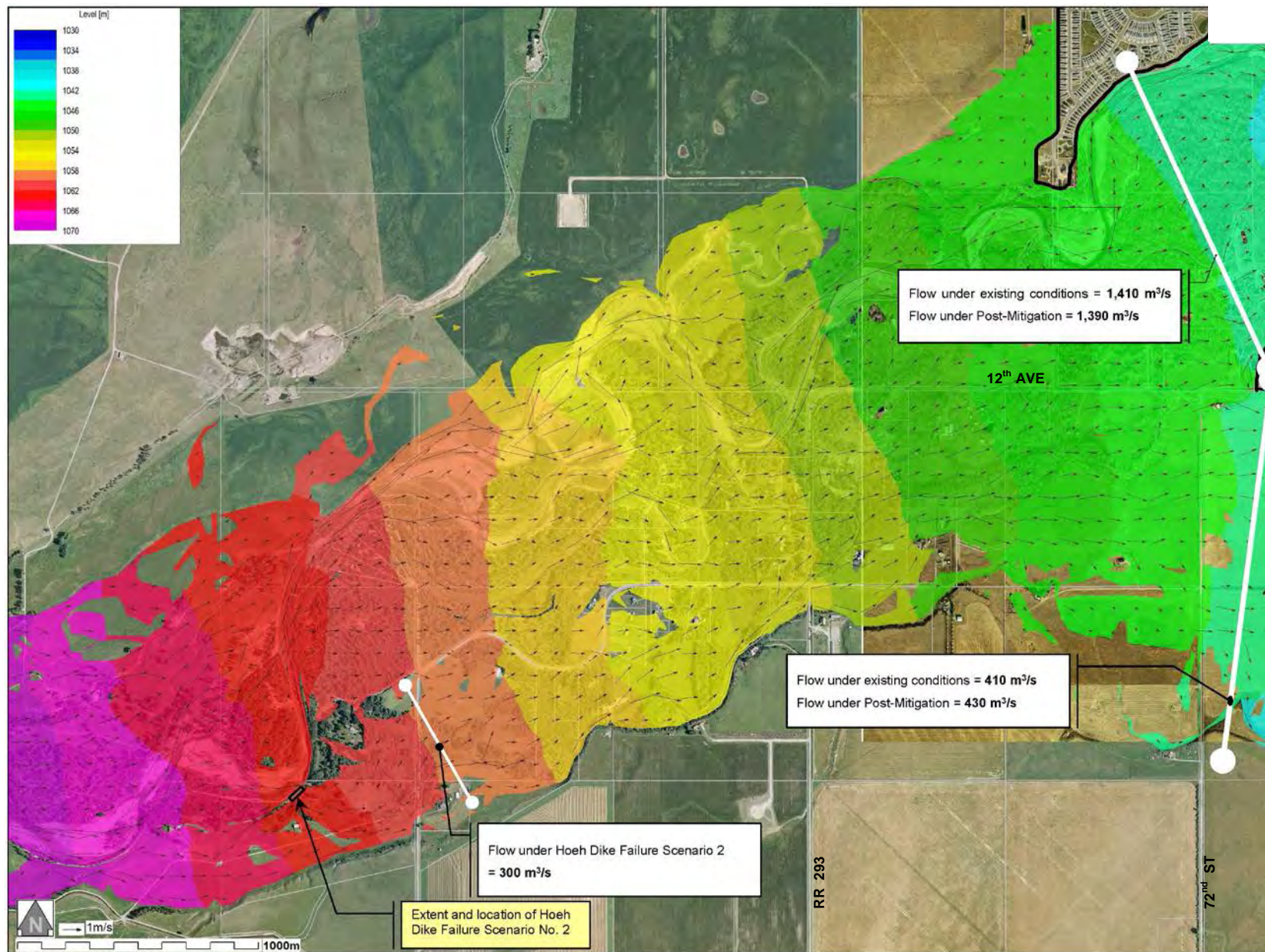
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Figure No: 4.2.3

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## Municipal District of Foothills No. 31

### Hoeh Dike Failure Scenario 2 (50 m breach of downstream segment) – Peak Flow Summary (Scenario 28A) - 1,820 m³/s

Created By: TDG

Reviewed By: JB



Date: April 15, 2016

File Path: 307074-02030\12.0\_Reports\  
12.2\_Final\Scoping Study\Figures

Figure No: 4.3.1

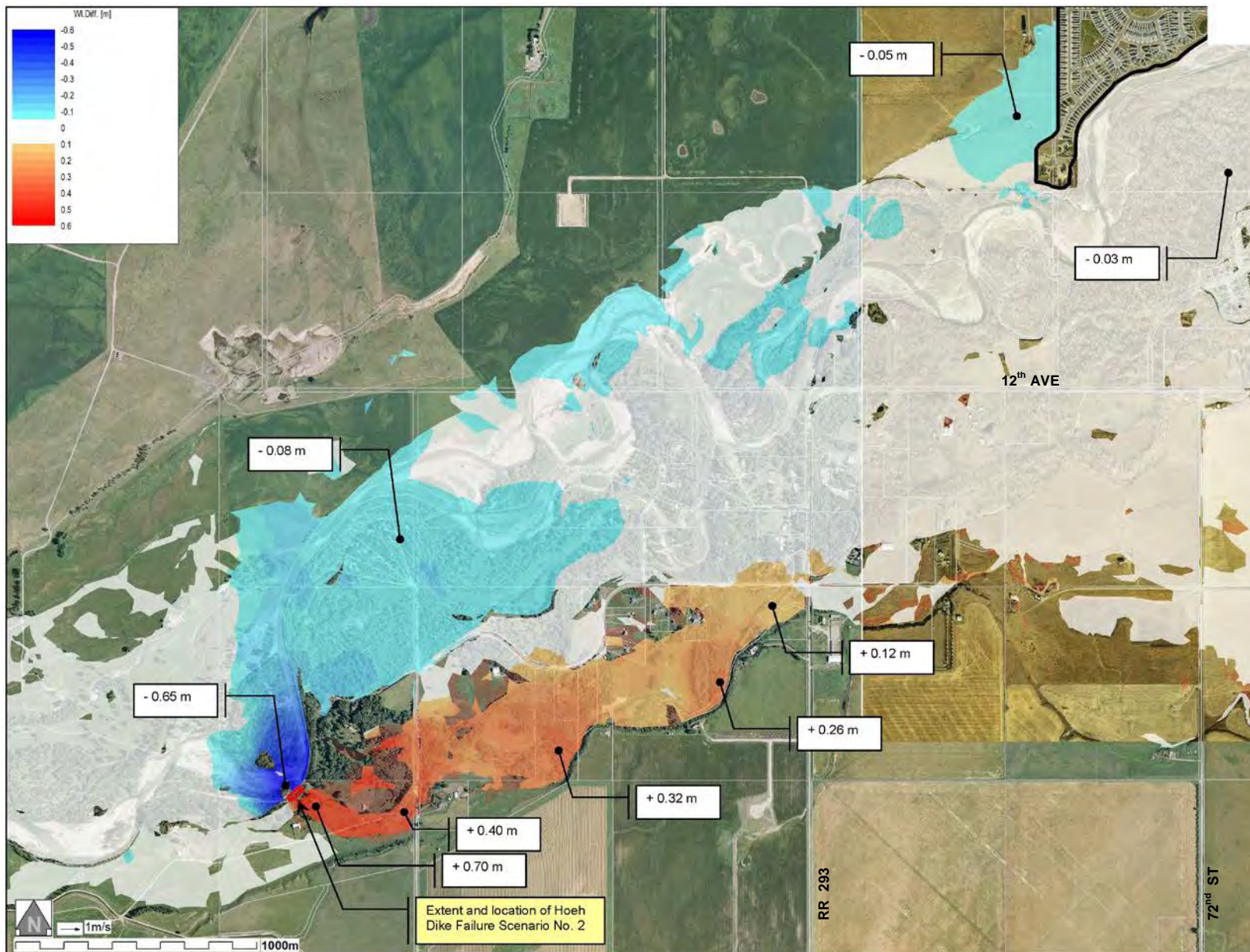
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### Municipal District of Foothills No. 31

Hoeh Dike Failure Scenario 2 (50 m breach of downstream segment) – Water Level Increases (Scenario 28A) - 1,820 m<sup>3</sup>/s



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Created By: TDG

Reviewed By: JB



Date: April 15, 2016

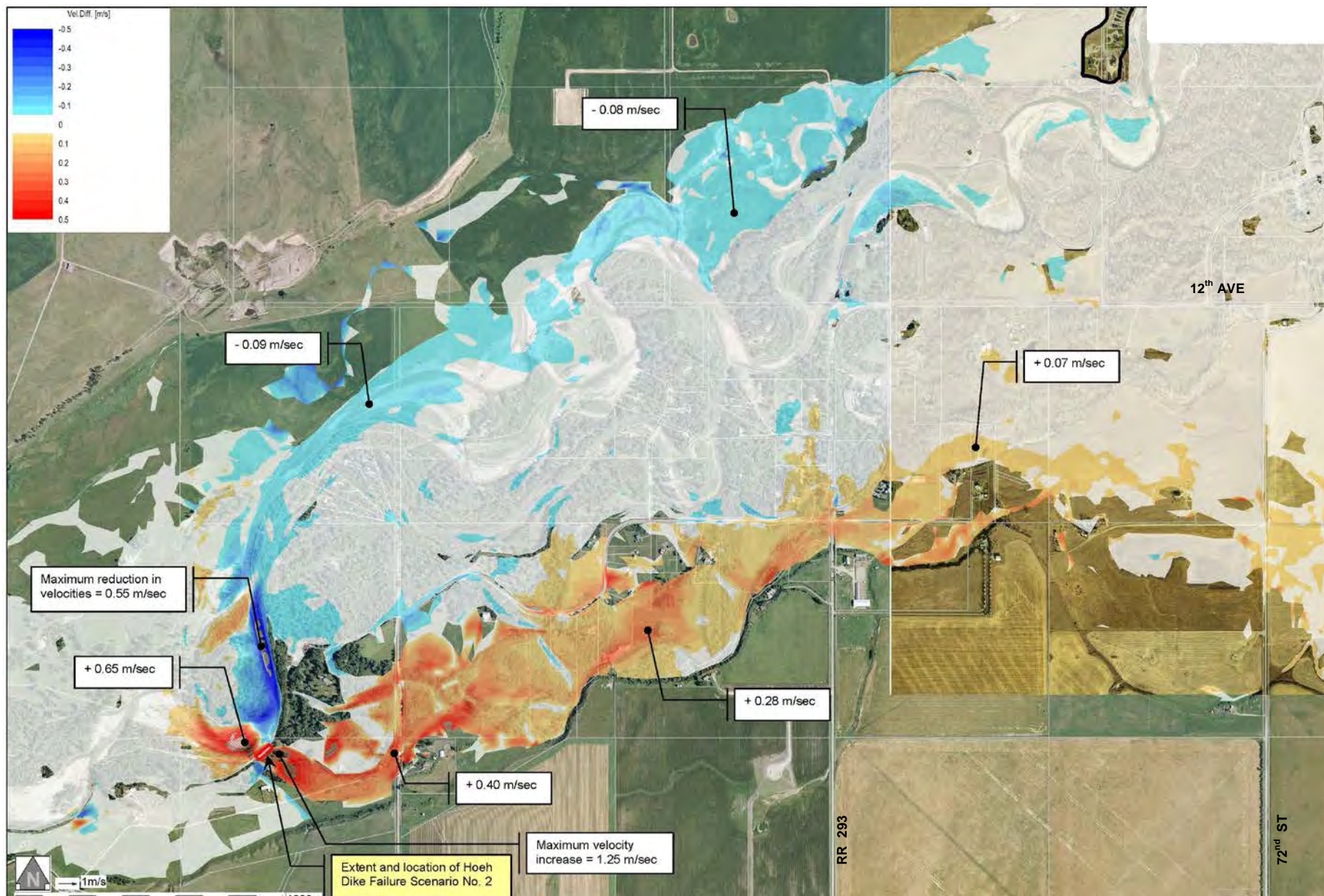
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Figure No: 4.3.2

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### Municipal District of Foothills No. 31

#### Hoeh Dike Failure Scenario 2 (50 m breach of downstream segment) – Velocity Increases (Scenario 28A) - 1,820 m<sup>3</sup>/s

Created By: TDG

Reviewed By: JB



Date: April 15, 2016

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Figure No: 4.3.3

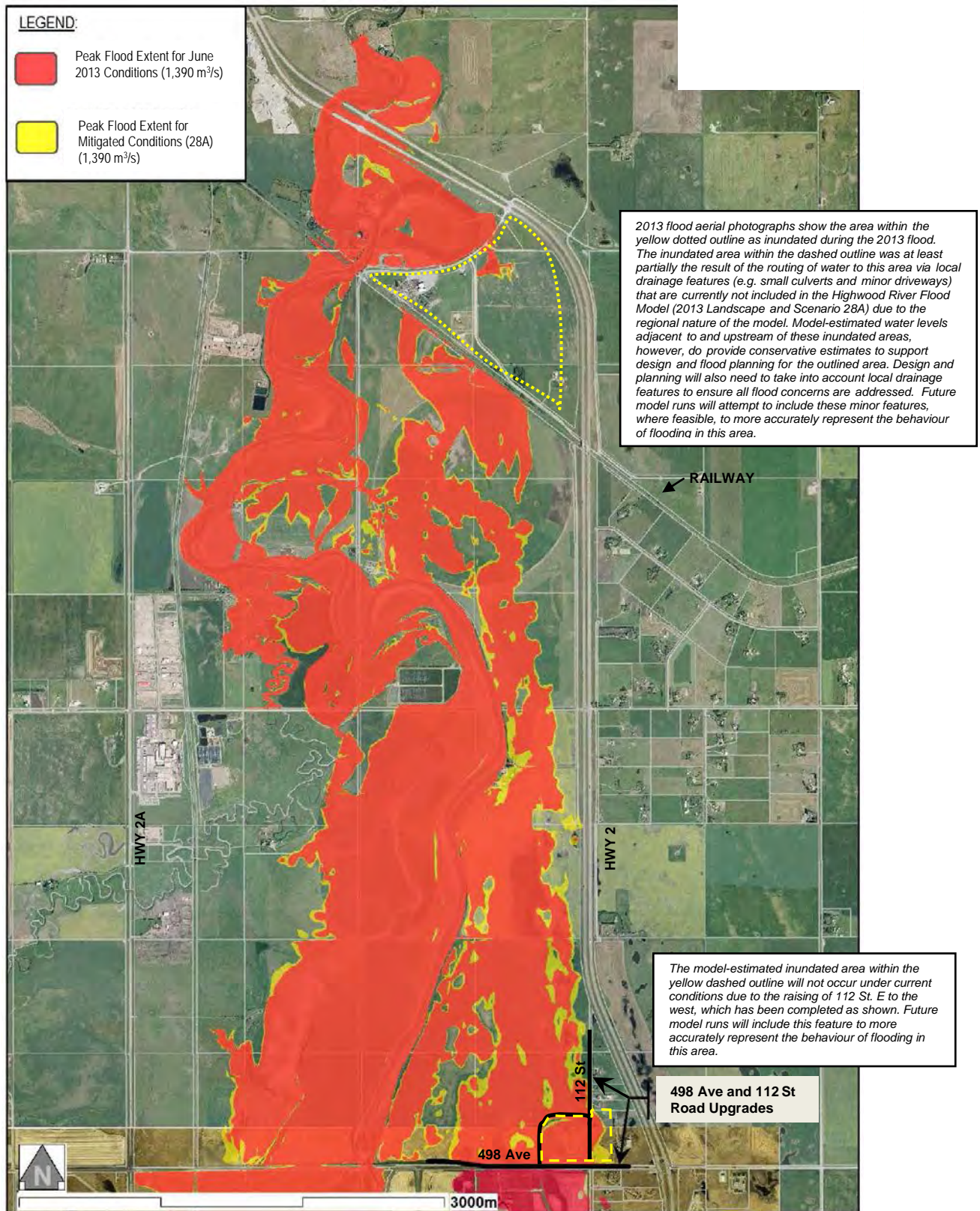
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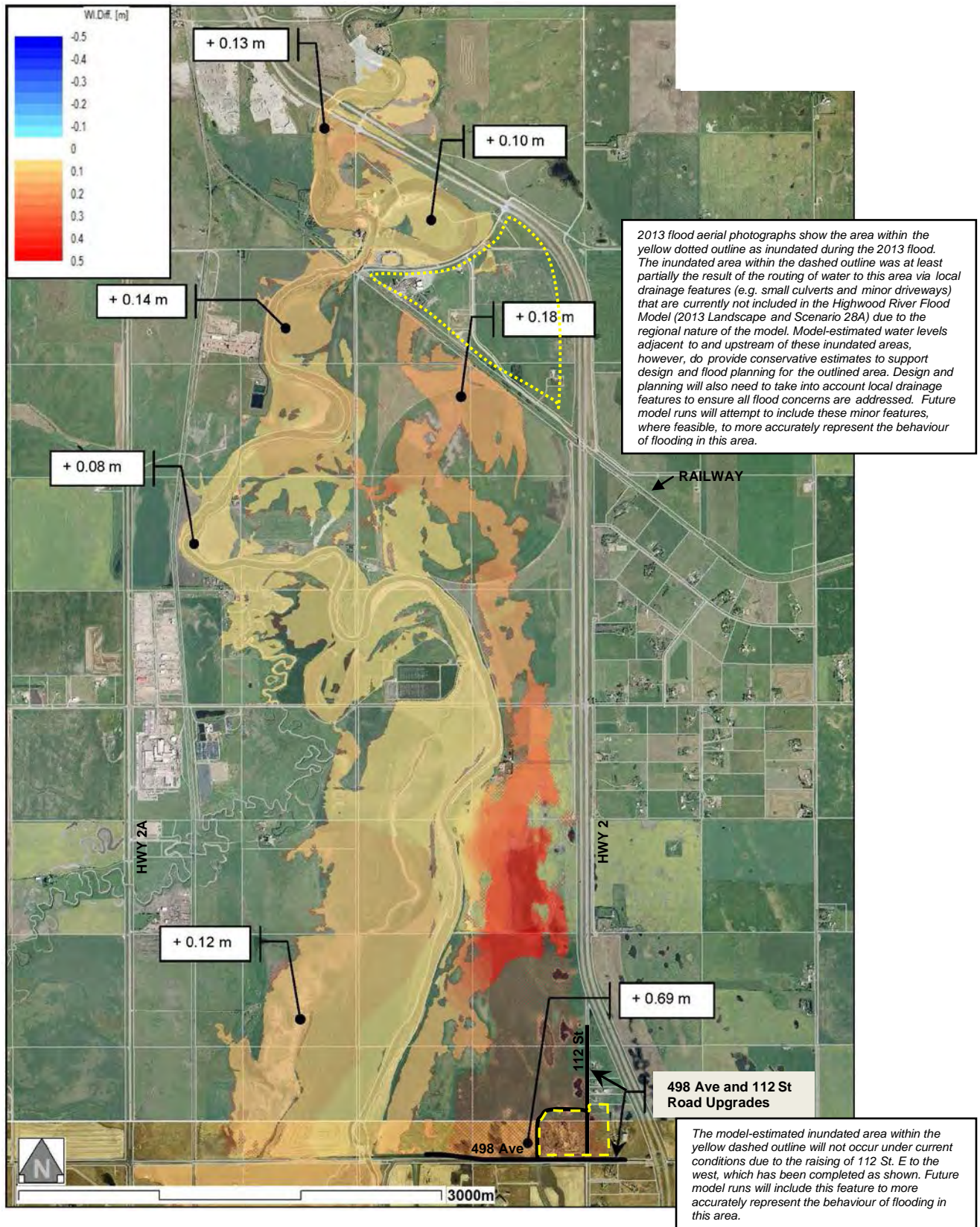
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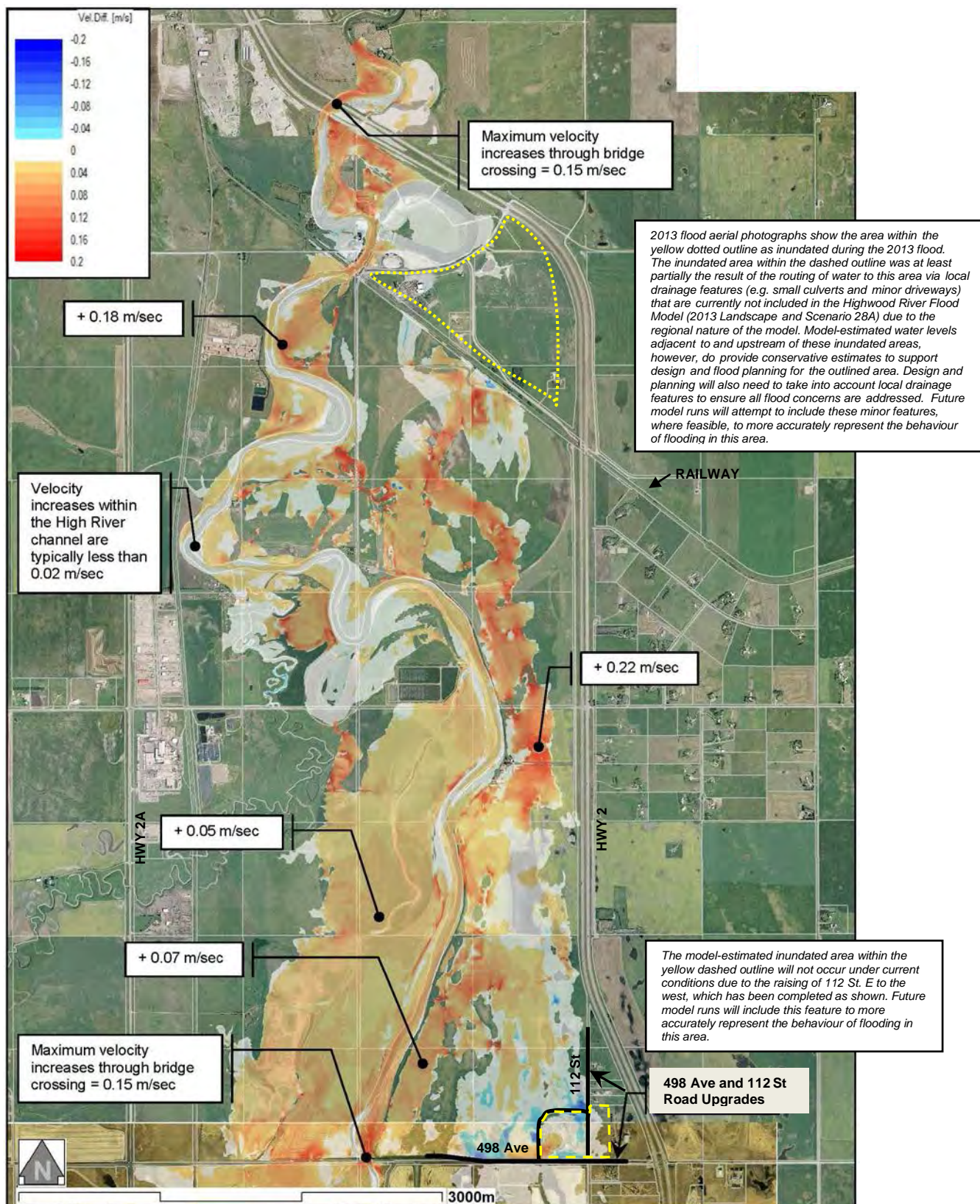
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		Highwood River – Predicted Inundation Extent Changes North of 498 <sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1390 m <sup>3</sup> /s			
Created By: TDG		Date: May 18, 2016	File Path: 307074-02030\12.0_Reports\12.2_Final\Scoping Study\Figures	Figure No: 4.4.1	Rev: 1
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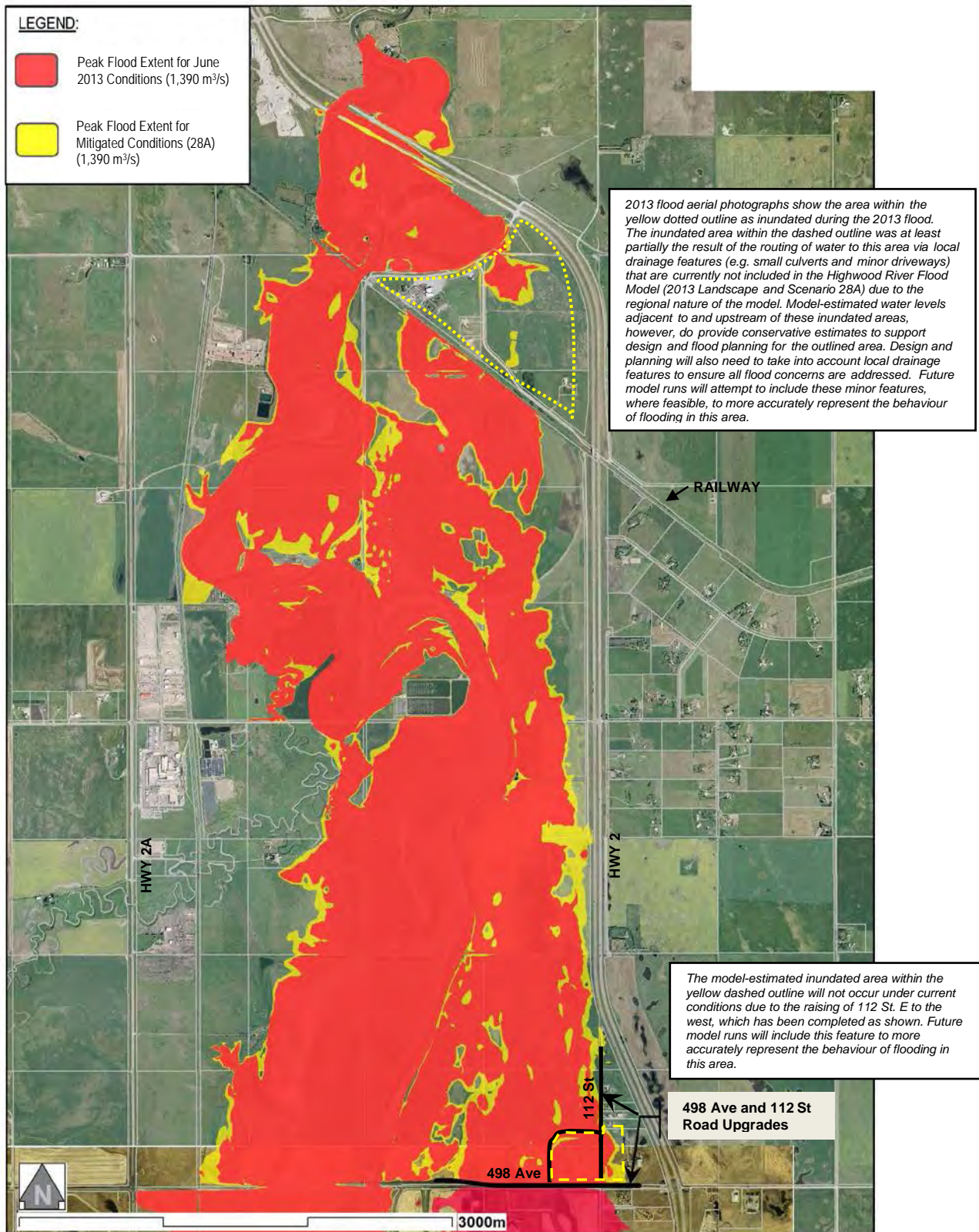
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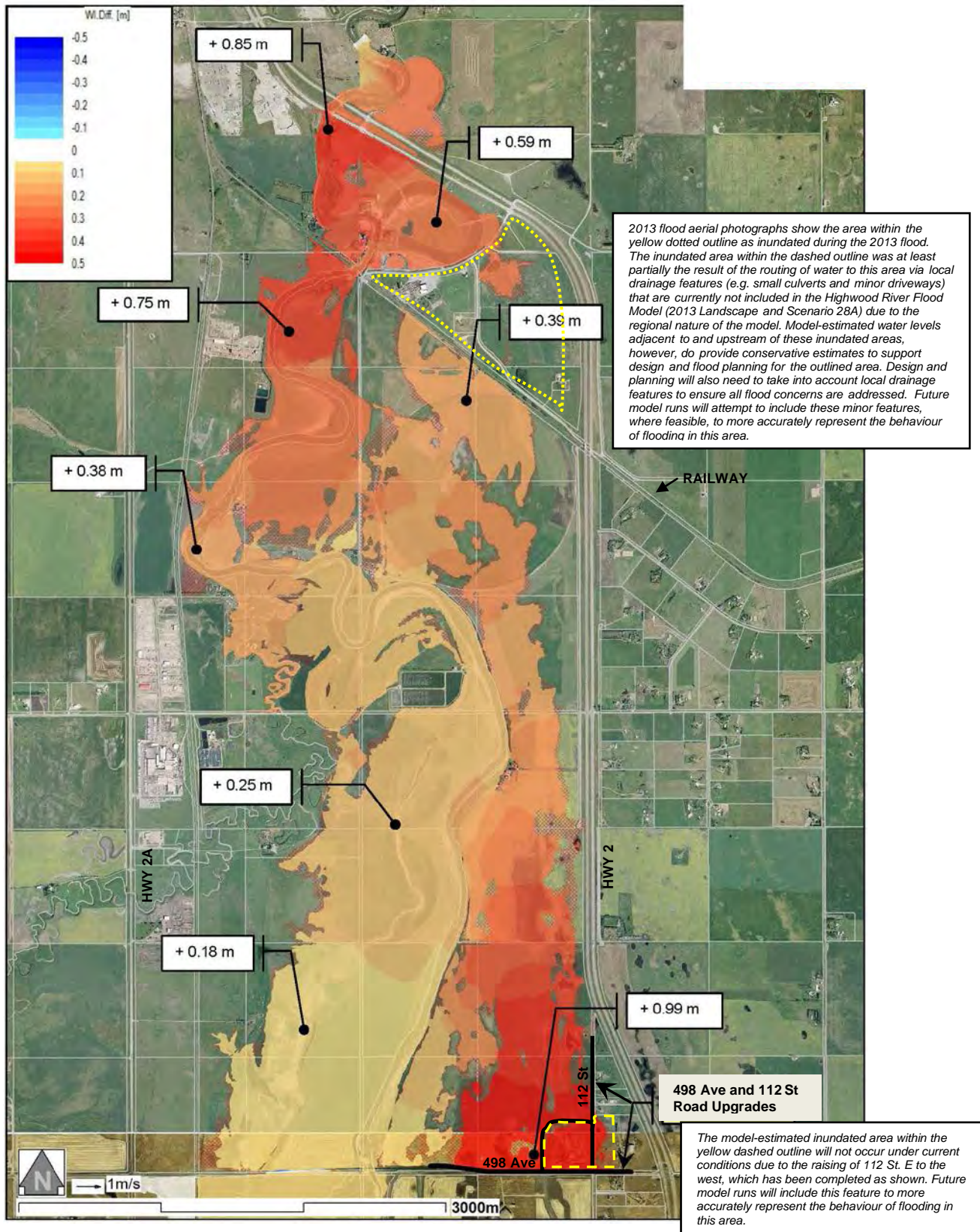
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Reviewed By: <b>JB</b>		This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable 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 and AMEC assume no liability to any other party for any representations contained within.			







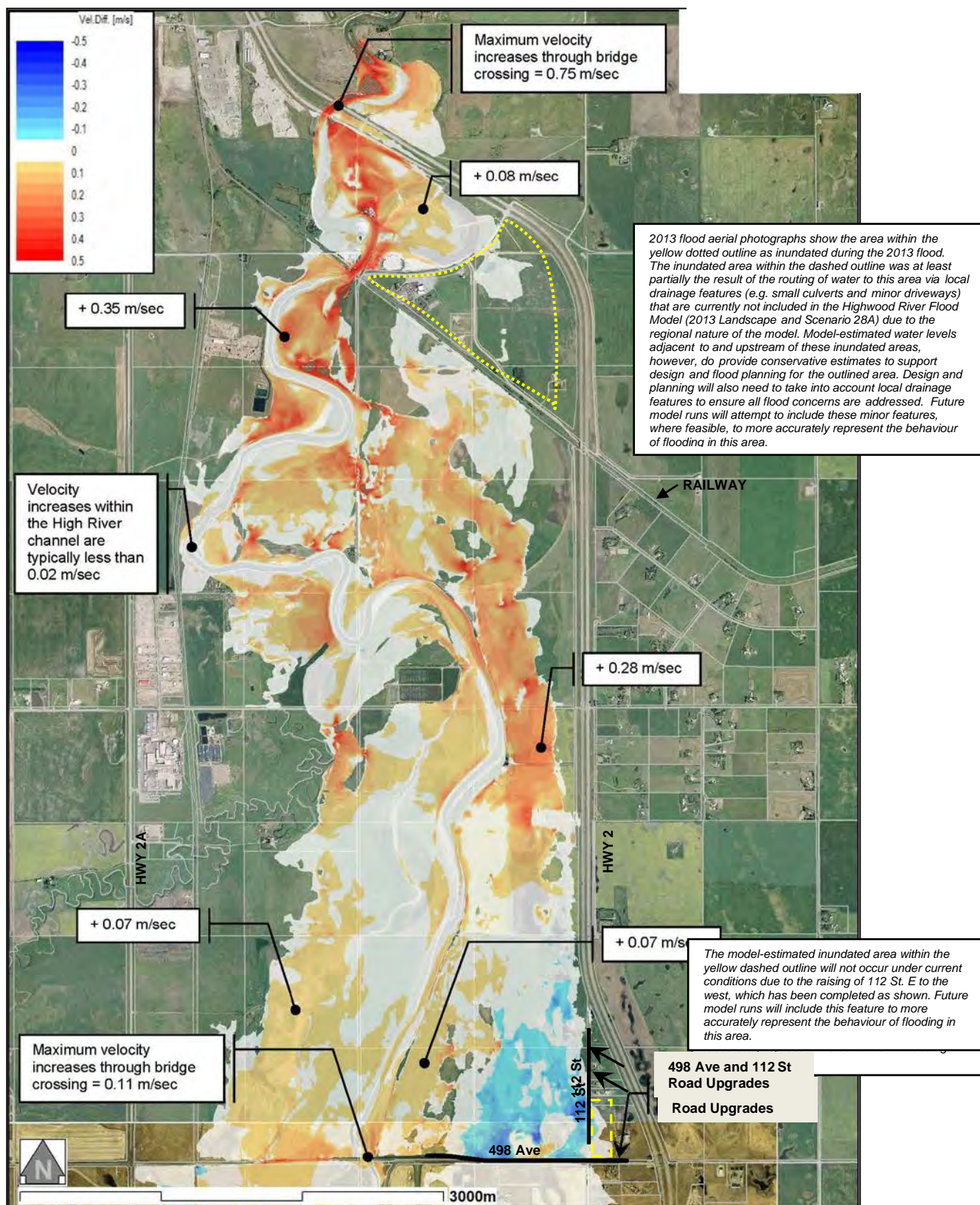
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		<b>Highwood River – Predicted Inundation Extent Changes North of 498<sup>th</sup> Ave  (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,820 m<sup>3</sup>/s</b>			
Created By: TDG	 <b>amec  foster  wheeler</b>	Date: May 18, 2016	File Path: 307074-02030\12.0_Reports\12.2_Final\Scoping Study\Figures	Figure No: 4.5.1	Rev: 1
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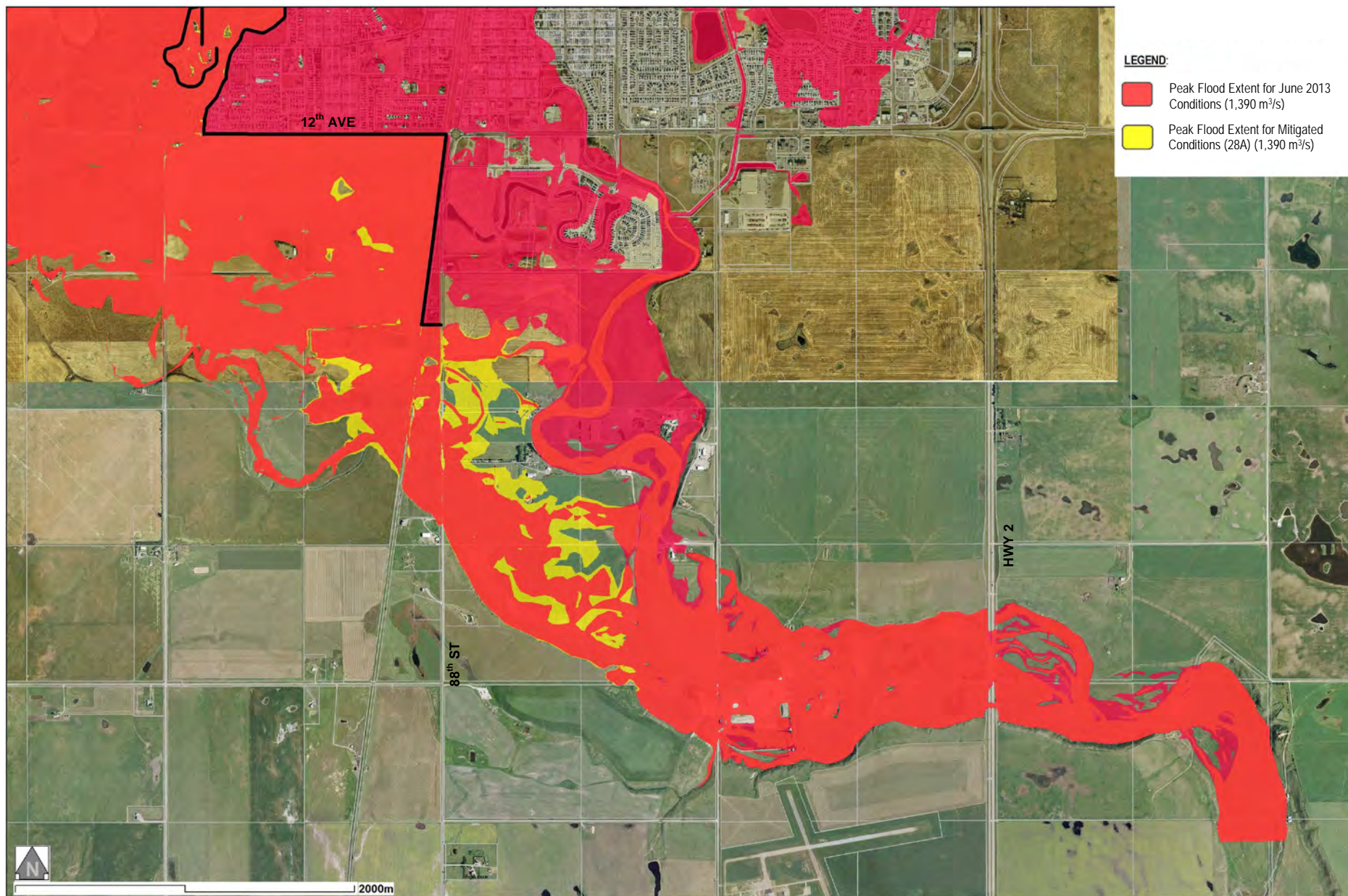
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		Highwood River – Predicted Level Changes North of 498 <sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,820 m <sup>3</sup> /s			
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 <b>Advisian</b> WorleyParsons Group		Municipal District of Foothills No. 31			
		Highwood River – Predicted Velocity Changes North of 498 <sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1,820 m <sup>3</sup> /s			
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### Municipal District of Foothills No. 31

#### Little Bow River – Predicted Inundation Extent Changes South of 12<sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1390 m³/s



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Reviewed By: JB



Date: April 15, 2016

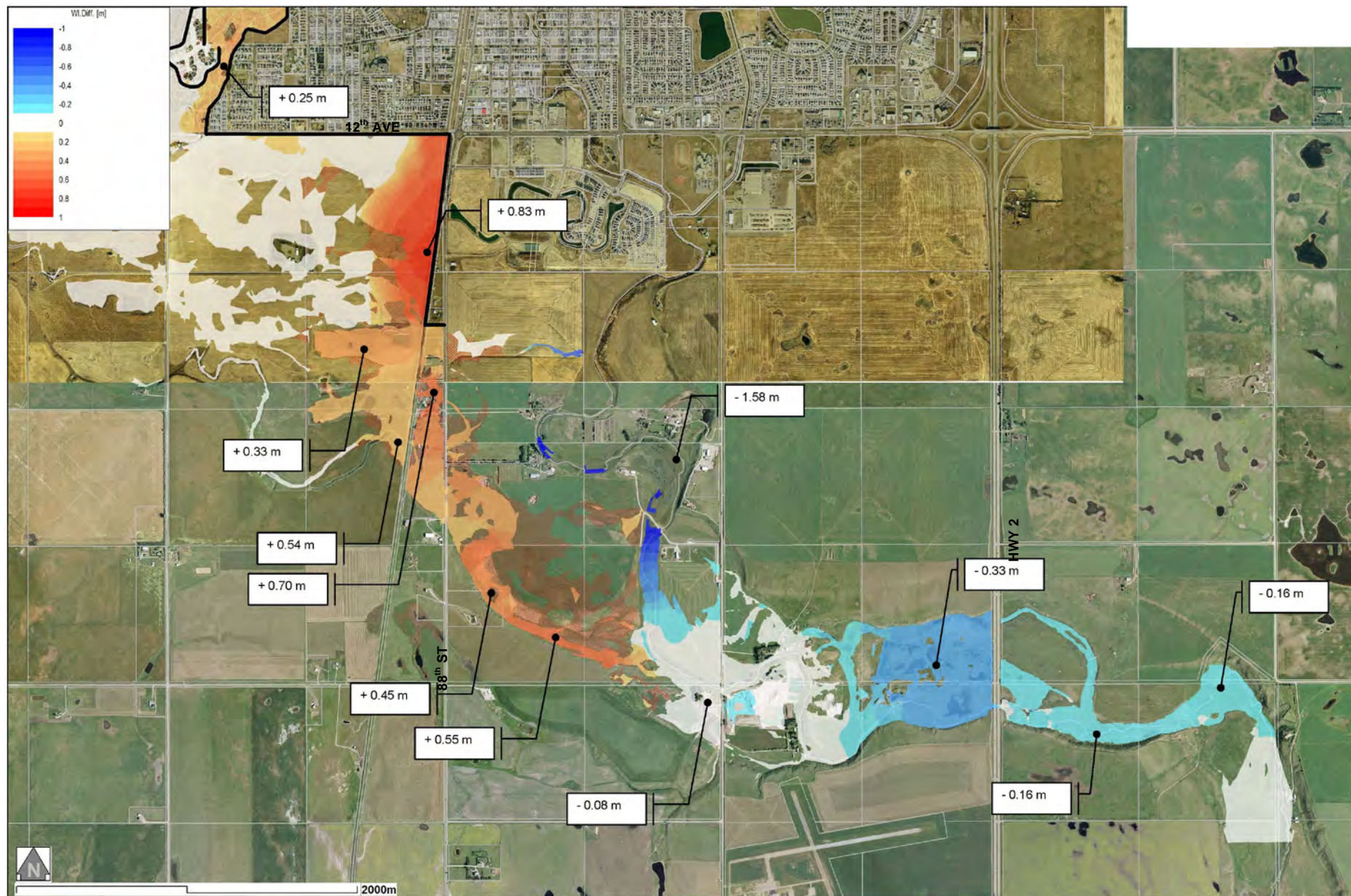
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### Municipal District of Foothills No. 31

### Little Bow River – Predicted Level Changes South of 12<sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1390 m<sup>3</sup>/s



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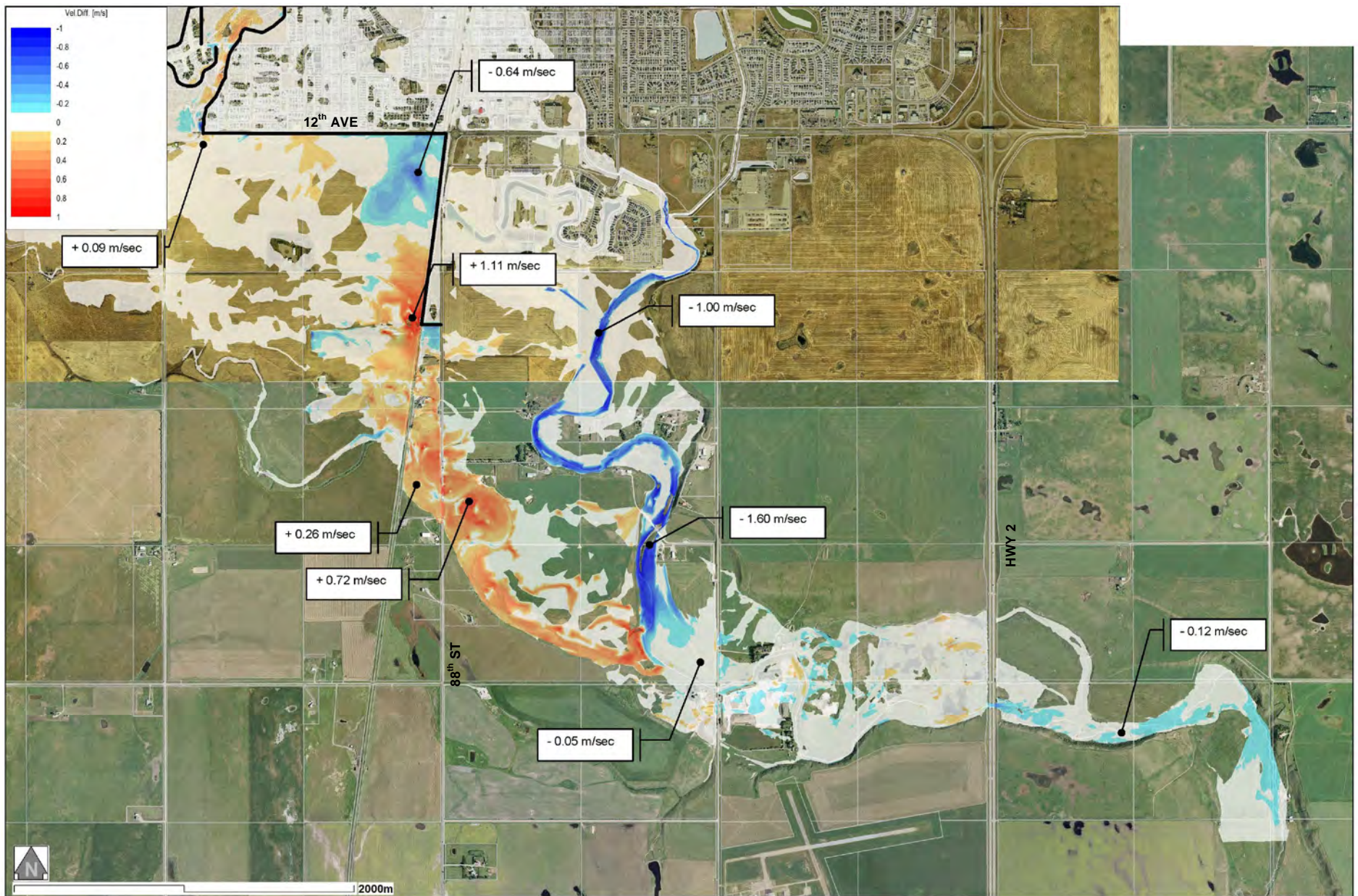
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### Municipal District of Foothills No. 31

#### Little Bow River – Predicted Velocity Changes South of 12<sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1390 m<sup>3</sup>/s



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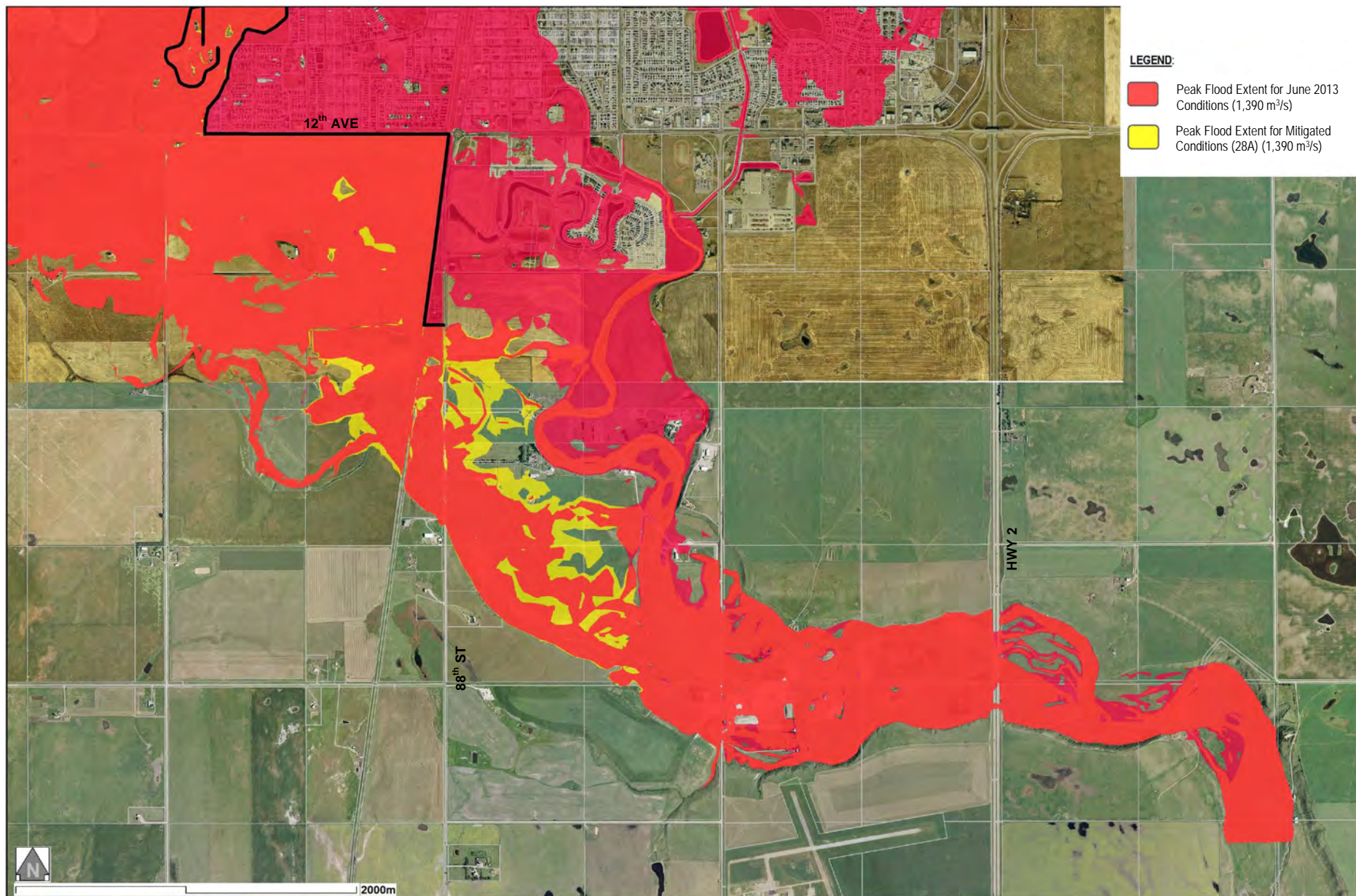
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### Municipal District of Foothills No. 31

### Little Bow River – Predicted Inundation Extent Changes South of 12<sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1820 m³/s



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Created By: TDG

Reviewed By: JB



Date: April 15, 2016

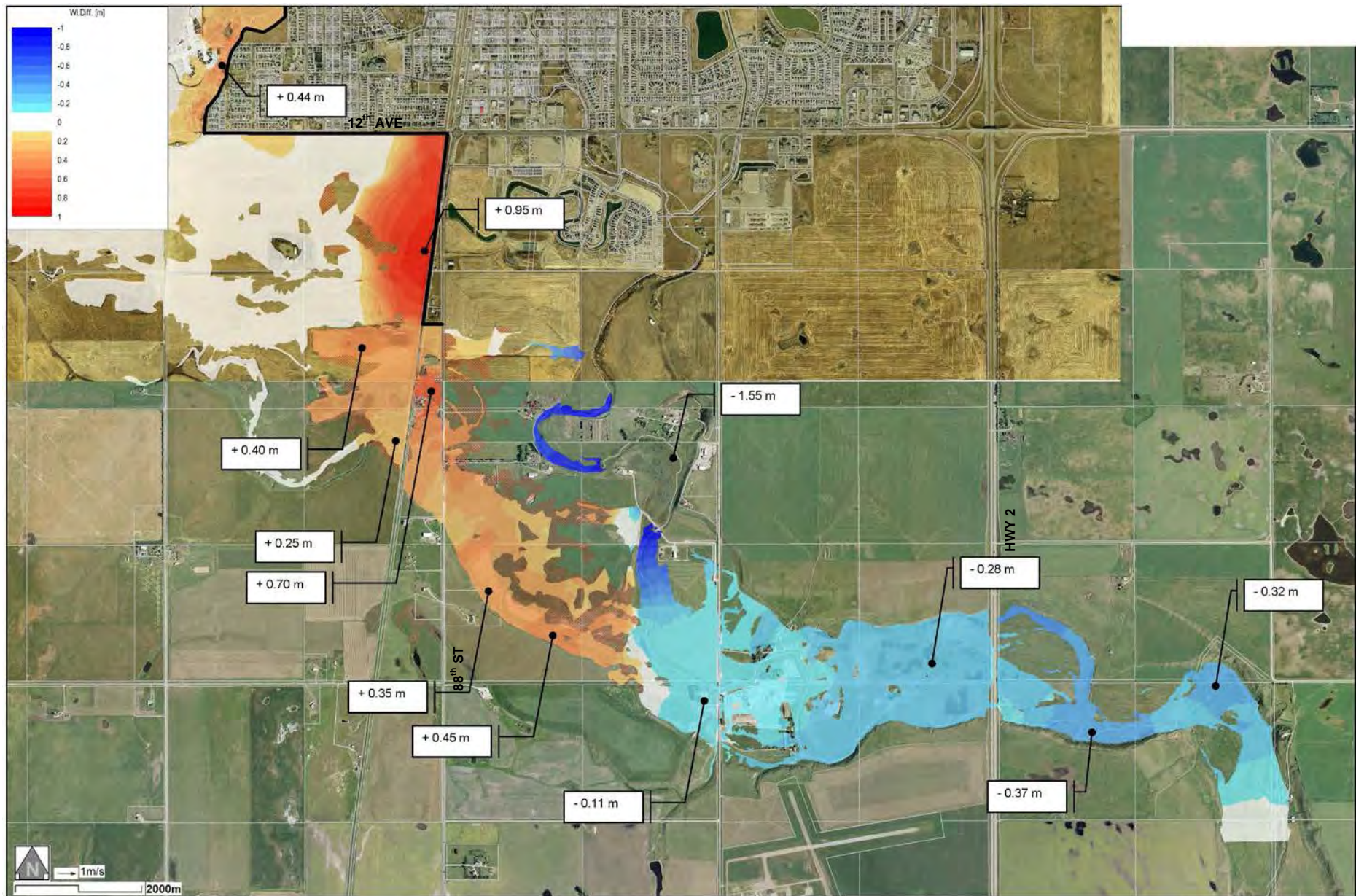
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### Municipal District of Foothills No. 31

### Little Bow River – Predicted Level Changes South of 12<sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1820 m<sup>3</sup>/s



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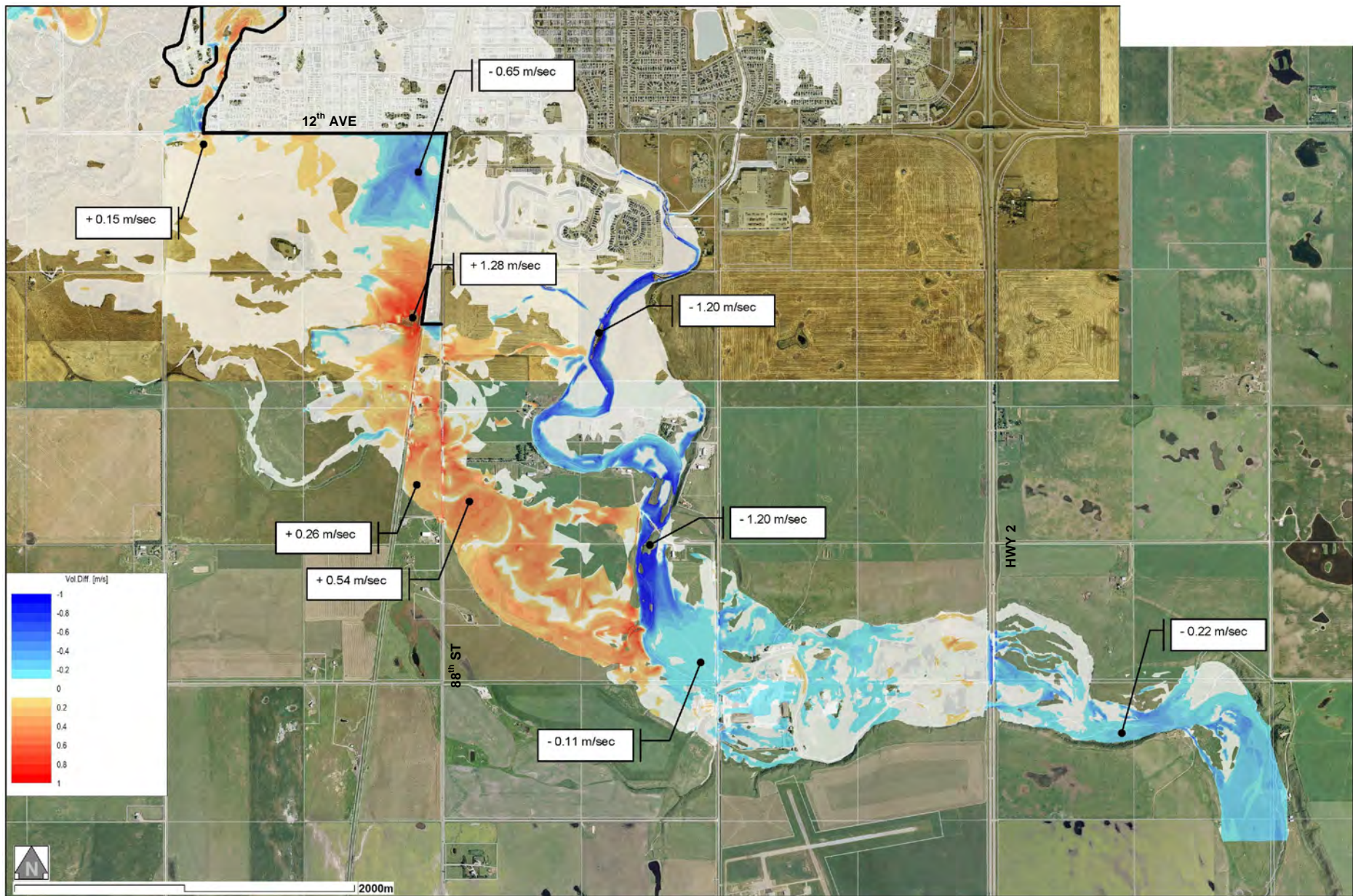
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Figure No: 4.7.2

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### Municipal District of Foothills No. 31

#### Little Bow River – Predicted Velocity Changes South of 12<sup>th</sup> Ave (Comparing 2013 Landscape Conditions to Scenario 28A) – 1820 m<sup>3</sup>/s



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Date: April 15, 2016

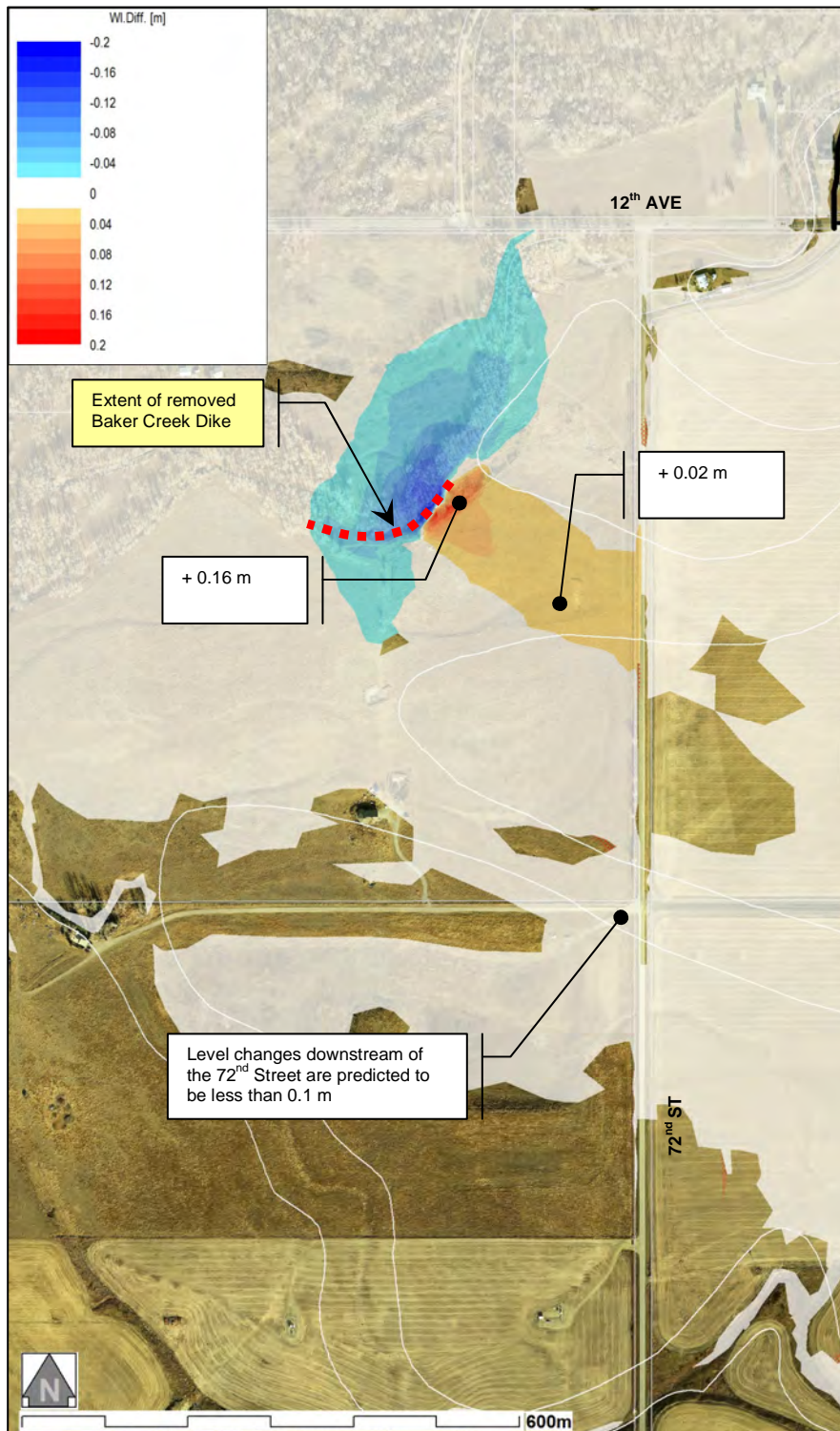
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LOCATION	PREDICTED FLOW (m <sup>3</sup> /s) ^		
	EXISTING [2013 FLOOD LANDSCAPE]	28A [MITIGATED]	28Ax [28A + BAKER CREEK DIKE REMOVED]
HIGHWOOD RIVER –UPSTREAM TOWN	1,820	1,820	1,820
HIGHWOOD RIVER – DOWNSTREAM TOWN	1,222	1,398 (+176)	1,393 (+181)
LITTLE BOW RIVER	550	402 (-148)	407 (-153)
ATTENUATED FLOW	48	20	20

See Figure 1.3 for location of Baker Creek Dike in relation to study area.

### Municipal District of Foothills No. 31

#### Southwest Dike - Predicted Level Changes [Comparing 2013 Landscape Conditions to Scenario 28Ax (Removing Baker Creek Dike)] - 1,820 m<sup>3</sup>/s

Date: May 18, 2016

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Figure No: 4.8

Rev: 1



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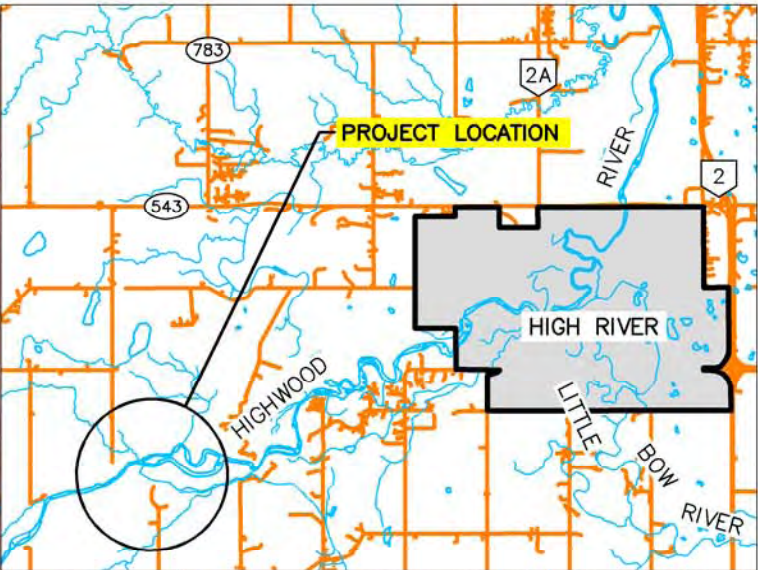
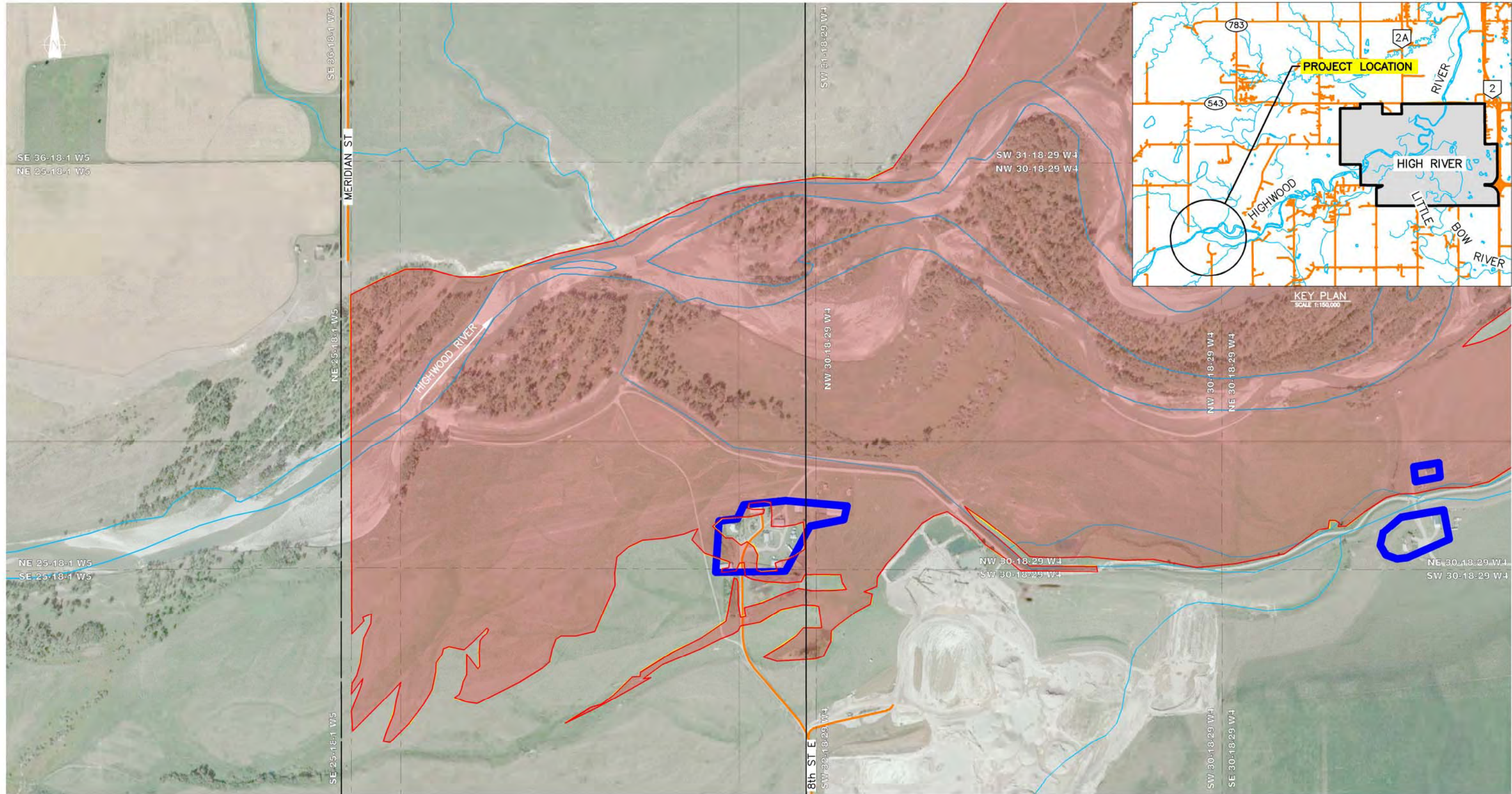
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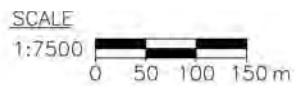
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KEY PLAN  
SCALE 1:150,000

- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



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

**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - RIVER RUN (1 OF 5)**

Date: APRIL 2016

File Path: 216703-F611.dwg

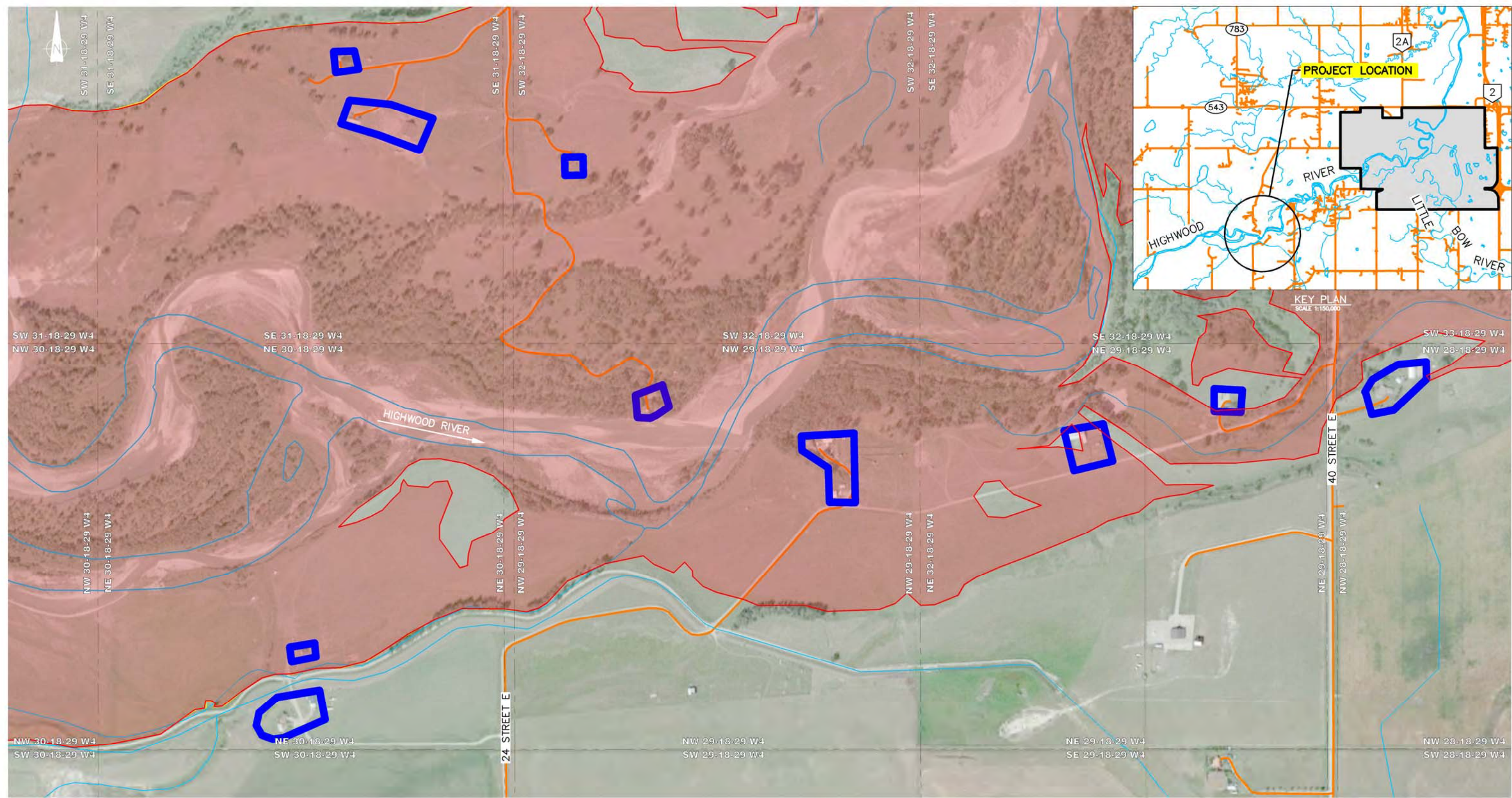
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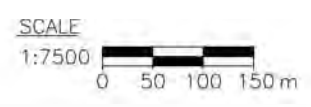
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- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



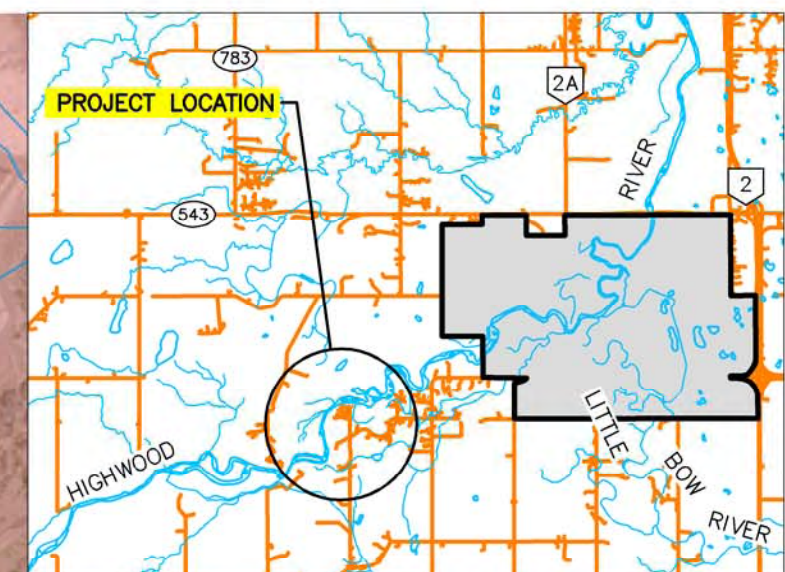
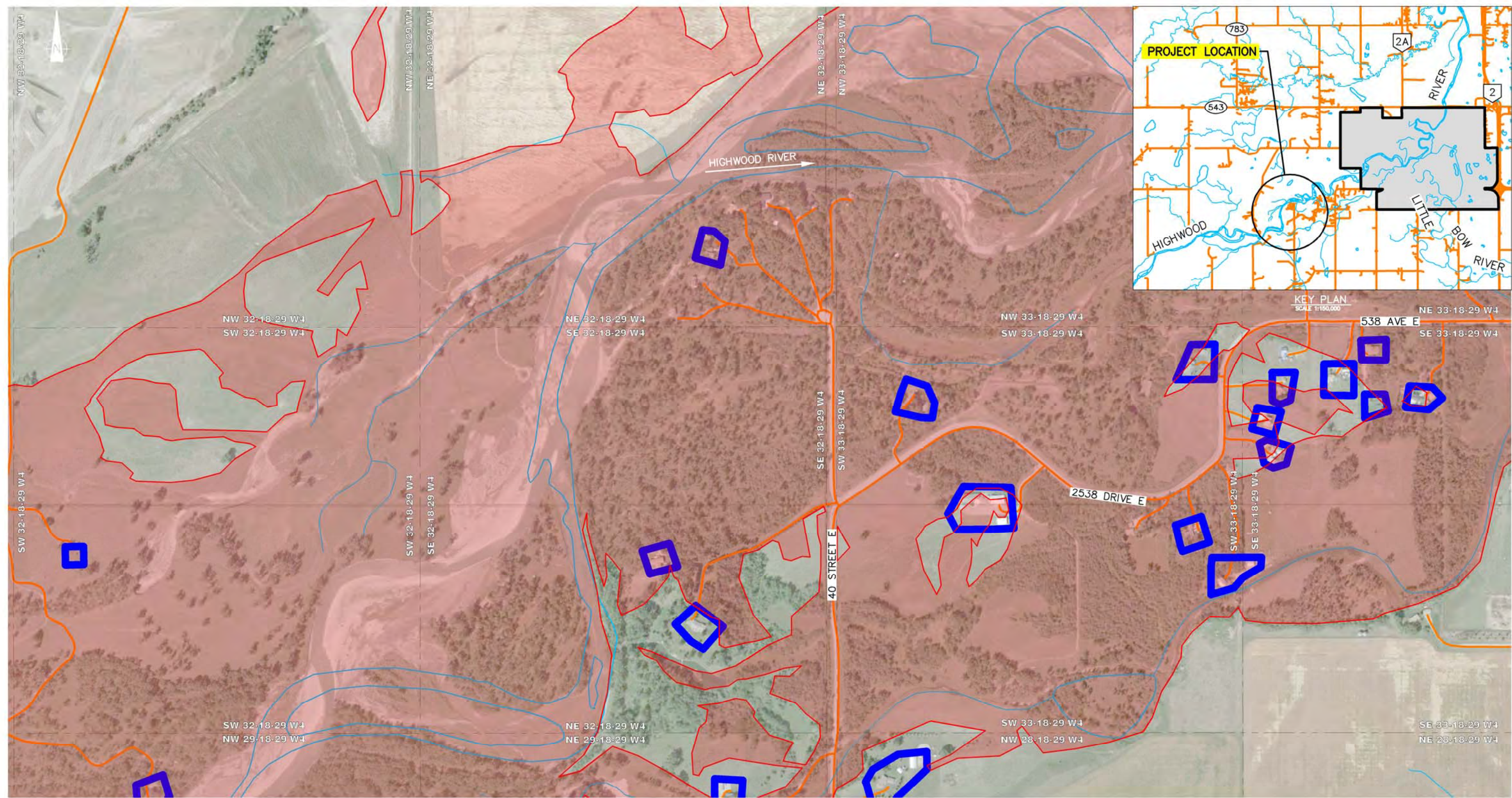
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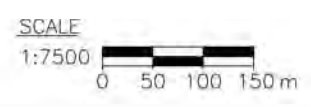
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- LEGEND:**
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  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



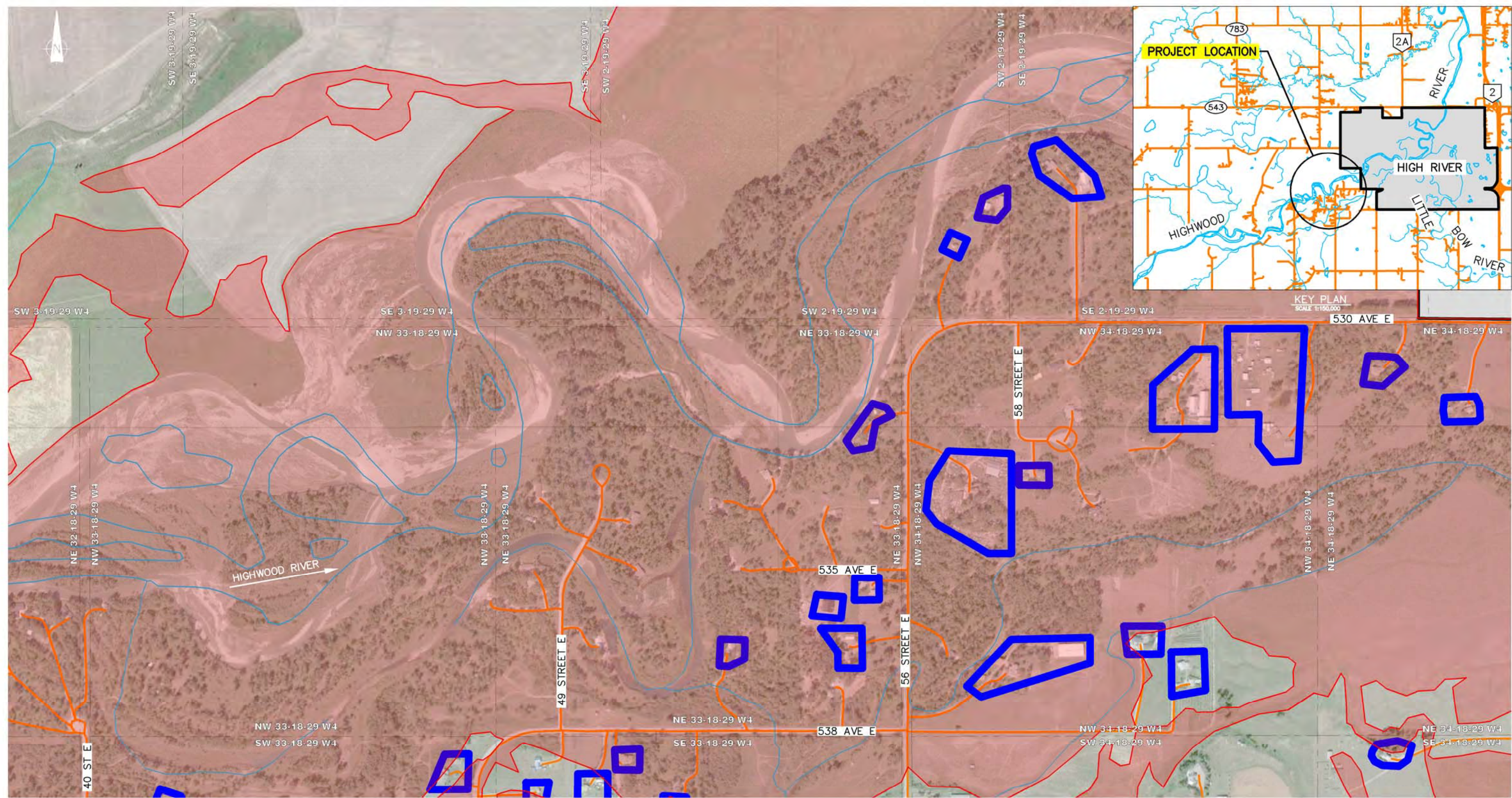
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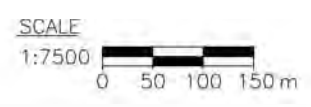
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  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



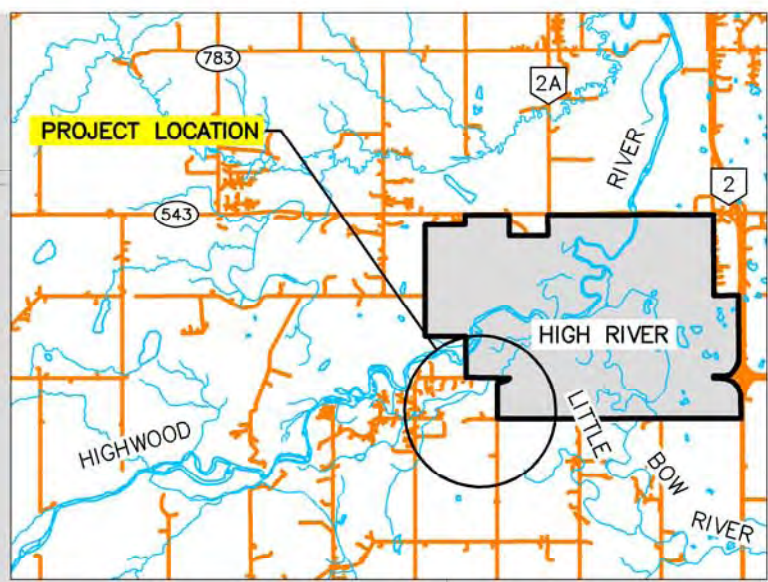
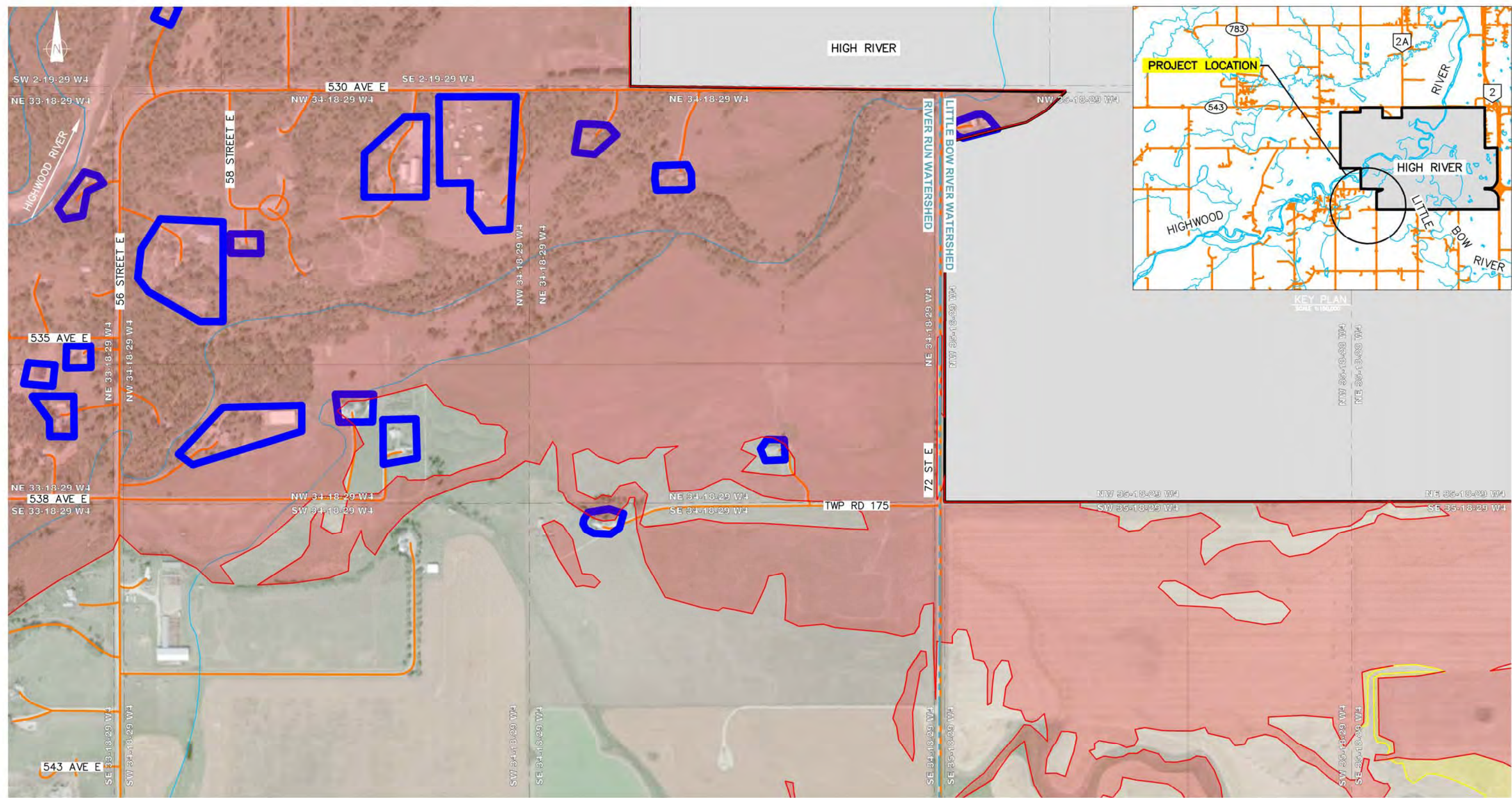
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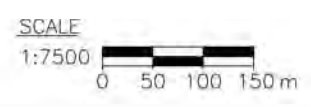
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  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
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  - WATERBODIES



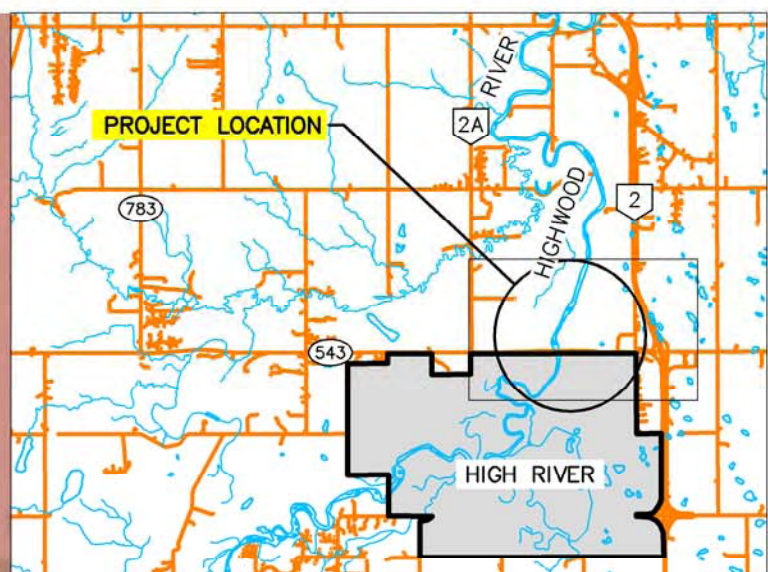
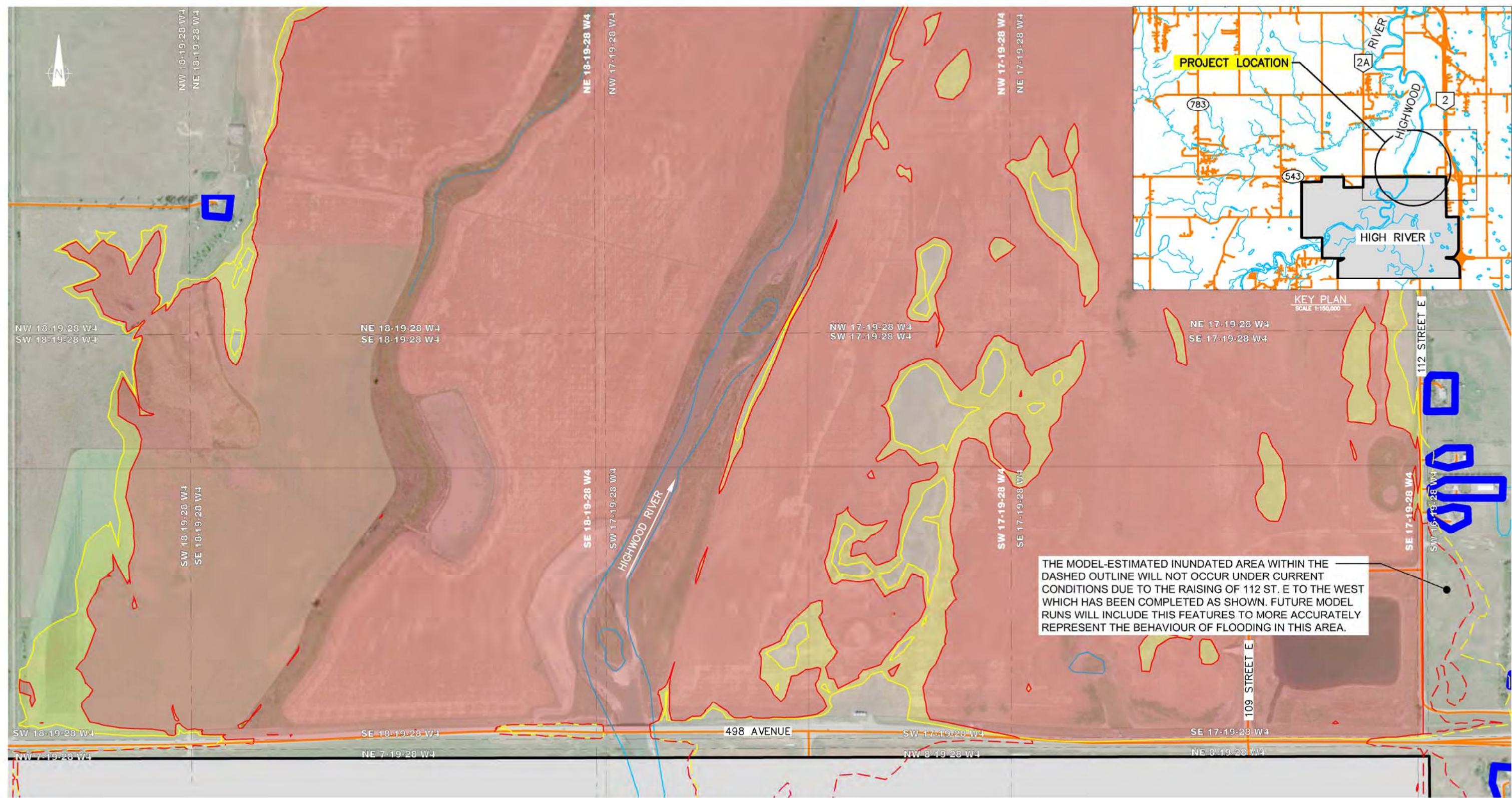
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M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - RIVER RUN (5 OF 5)				
Date:	APRIL 2016	File Path:	216703-F615.dwg	Figure No: 6.1.5
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				

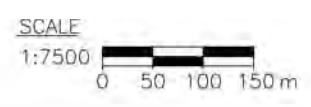


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THE MODEL-ESTIMATED INUNDATED AREA WITHIN THE DASHED OUTLINE WILL NOT OCCUR UNDER CURRENT CONDITIONS DUE TO THE RAISING OF 112 ST. E TO THE WEST WHICH HAS BEEN COMPLETED AS SHOWN. FUTURE MODEL RUNS WILL INCLUDE THIS FEATURES TO MORE ACCURATELY REPRESENT THE BEHAVIOUR OF FLOODING IN THIS AREA.

- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



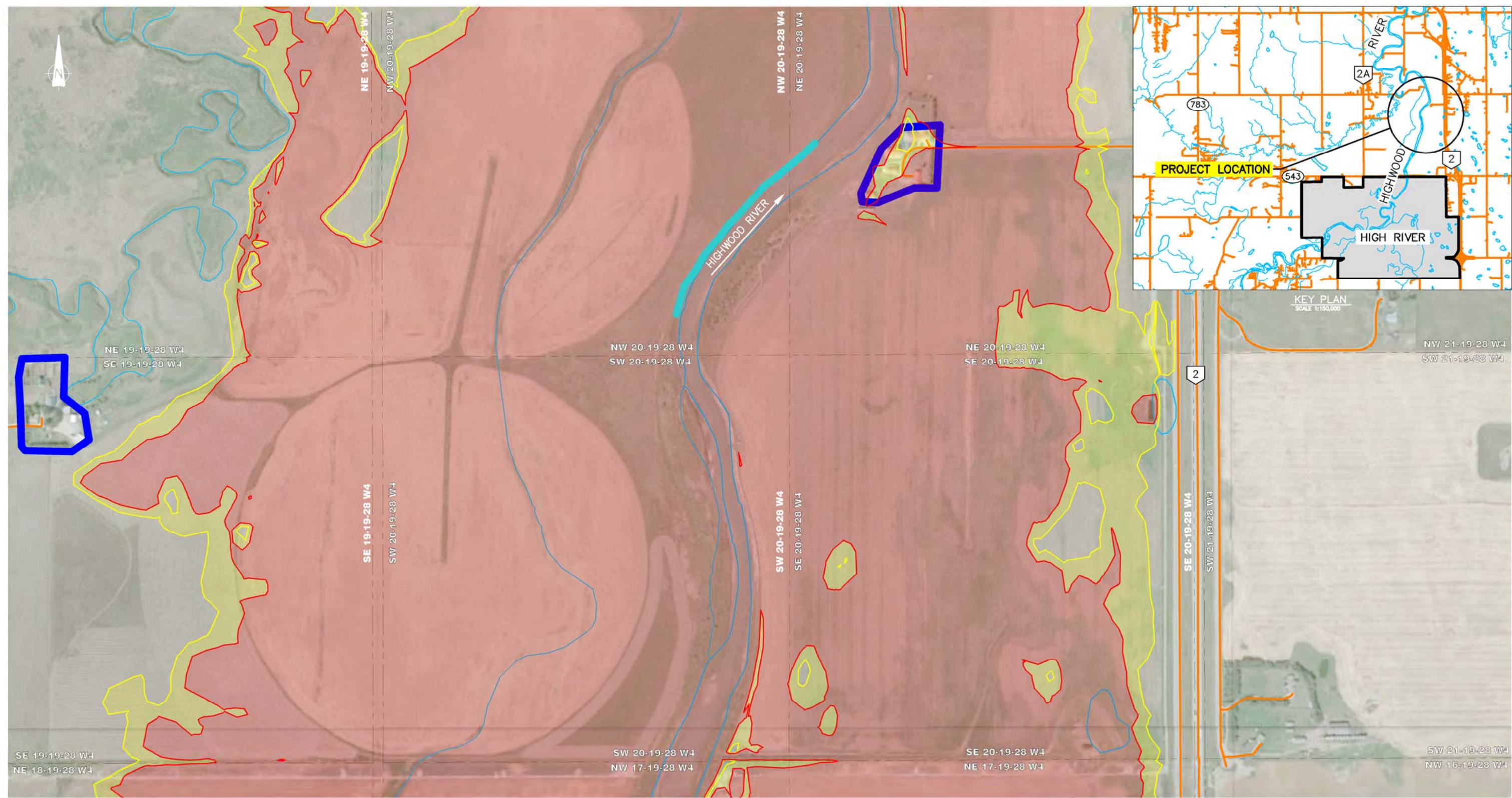
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Reviewed By:



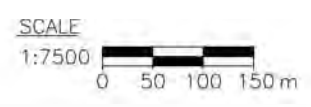
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (1 OF 17)				
Date:	APRIL 2016	File Path:	216703-F621.dwg	Figure No: 6.2.1
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				



\\NW\216703\216703-F622.dwg - Figure 6.2.2 - May, 18, 2016 3:54pm - corey.ferrets



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



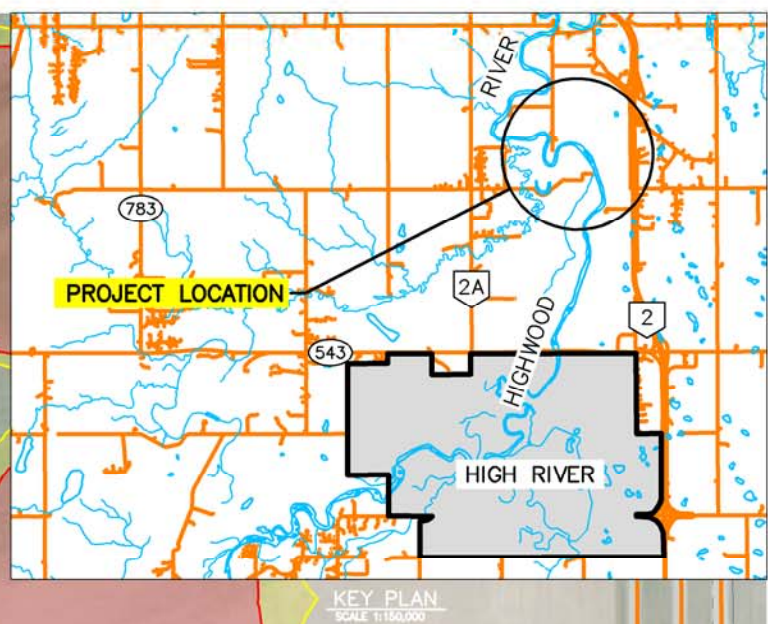
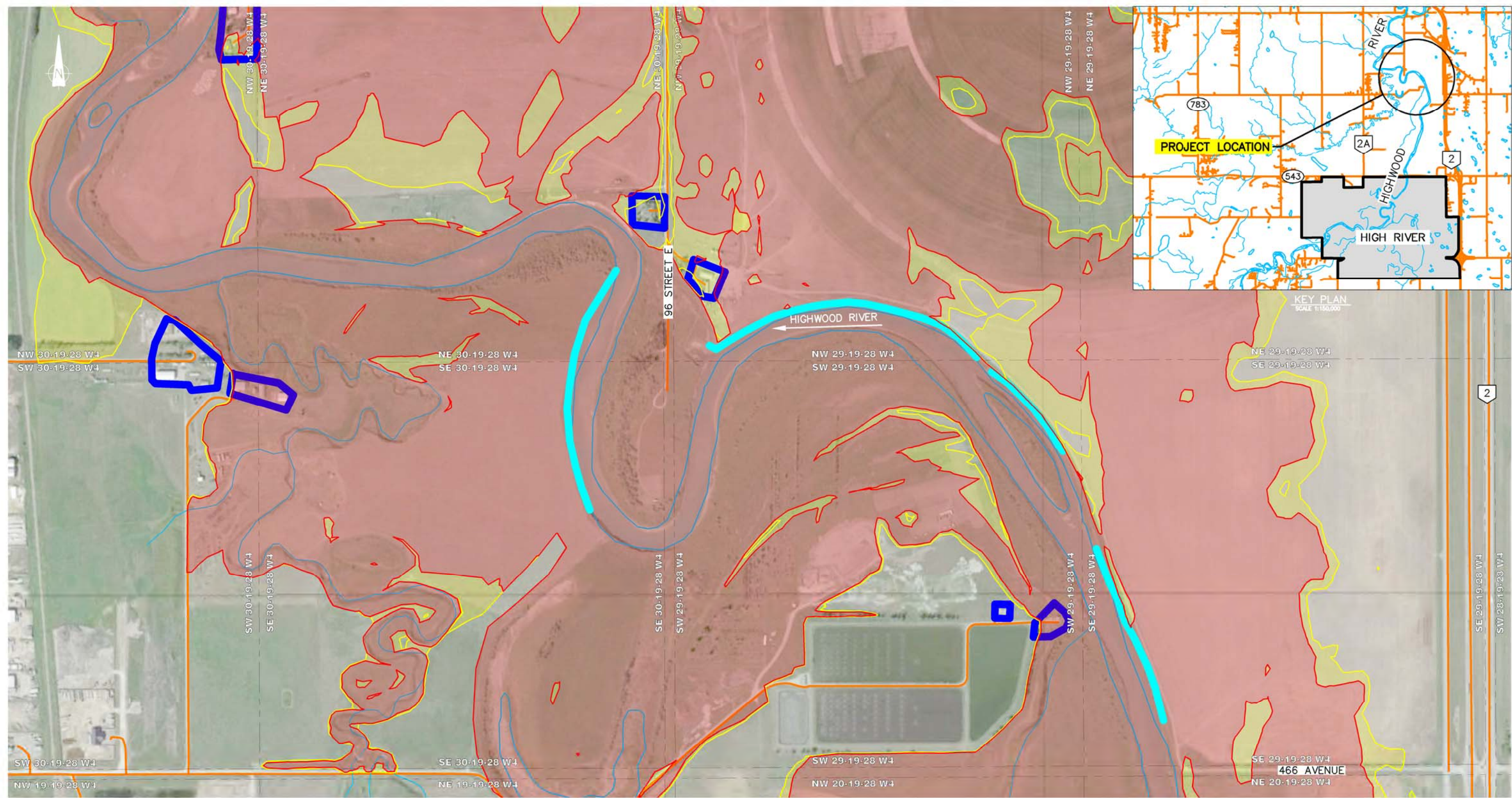
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Reviewed By:



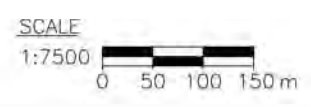
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (2 OF 17)				
Date:	APRIL 2016	File Path:	216703-F622.dwg	Figure No: 6.2.2
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				



\\NW\216703\216703-F623.dwg - May 19, 2016 10:48am - corey.fernets



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

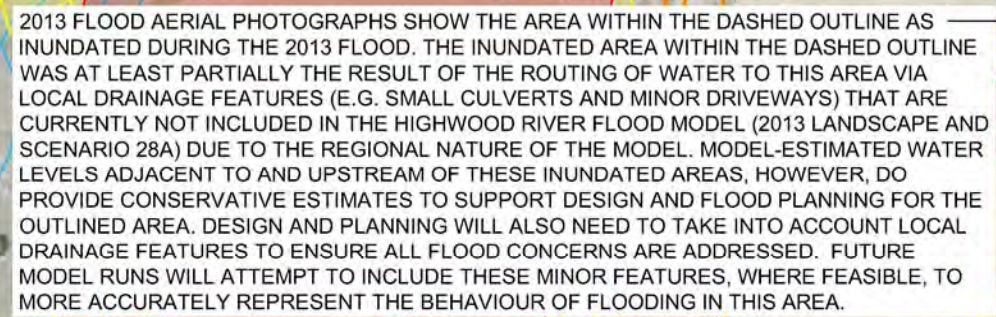


Created By:  
  
Reviewed By:









M.D. OF FOOTHILLS NO. 31							
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (3 OF 17)							
Date:	APRIL 2016	File Path:	216703-F623.dwg	Figure No:	6.2.3	Rev:	DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>							





**KEY PLAN**  
SCALE 1:150,000

 INCREMENTAL INCREMENTAL FLOOD INUNDATION ZONE  
 2013 FLOOD EXTENT  
 POTENTIAL BERM  
 HEIGHTENED EROSION VULNERABILITY ZONE  
 ROADS  
 WATERBODIES

SCALE  
1:7500



Reviewed By:

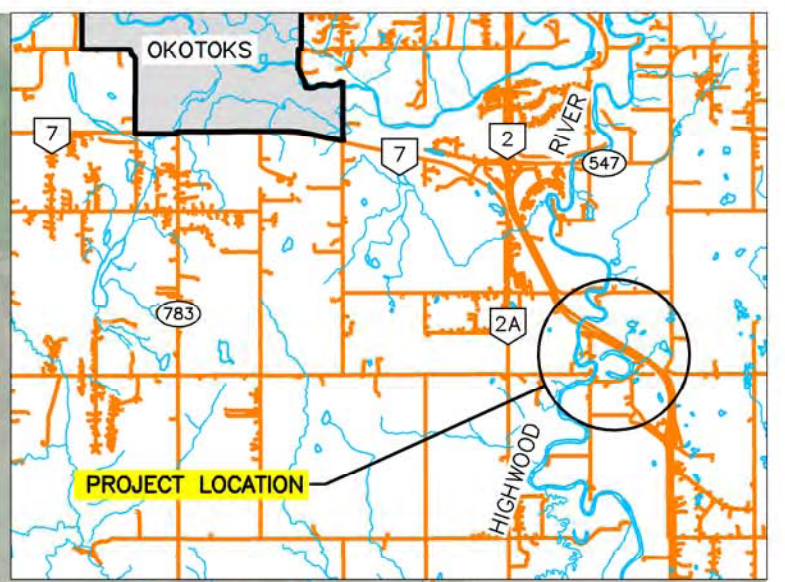
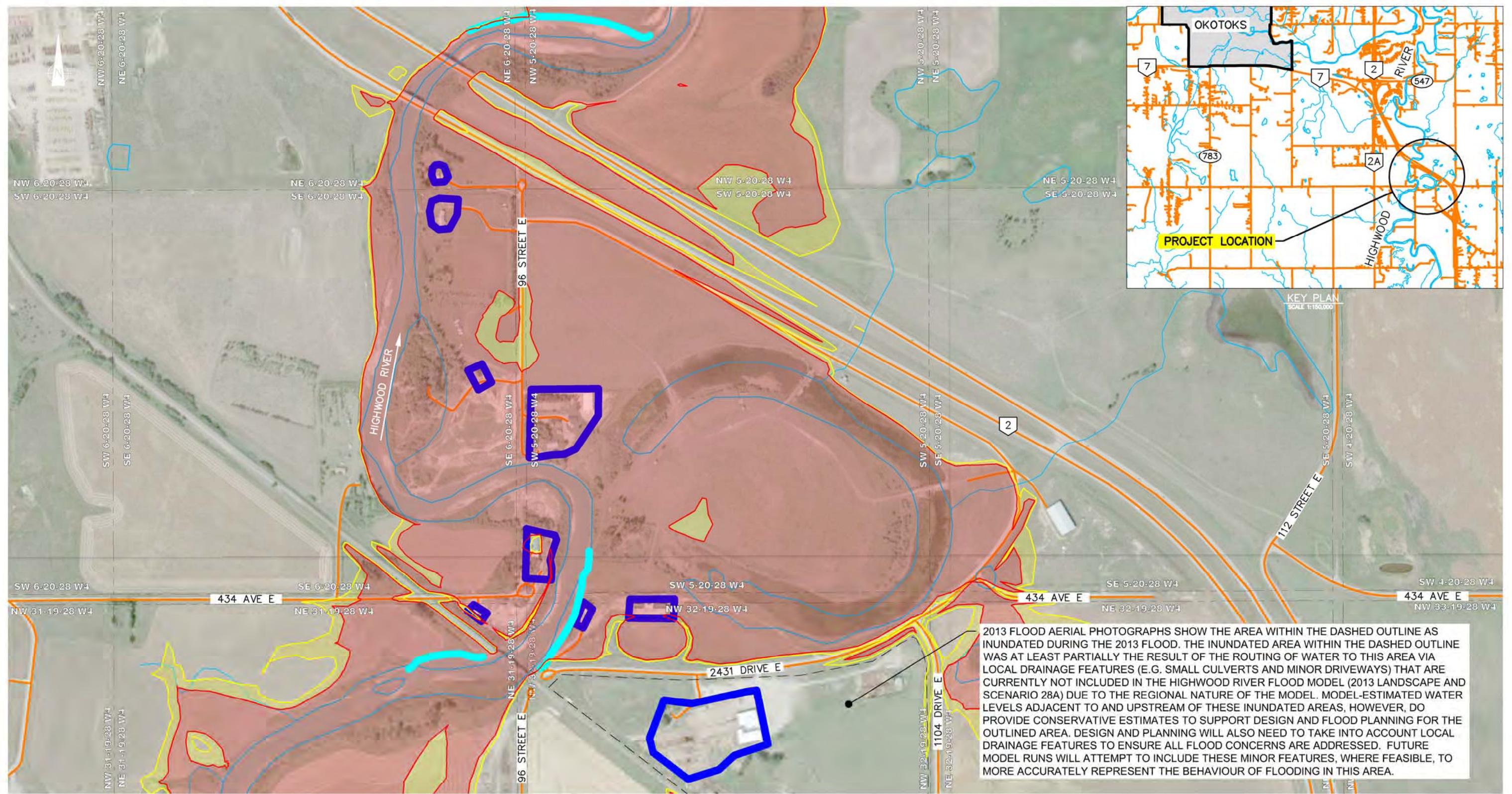


Date:	APRIL 2016	File Path:	216703-F624.dwg	Figure No:	6.2.4	Rev:	DRAFT
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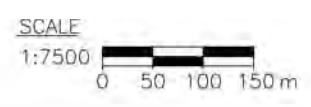


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2013 FLOOD AERIAL PHOTOGRAPHS SHOW THE AREA WITHIN THE DASHED OUTLINE AS INUNDATED DURING THE 2013 FLOOD. THE INUNDATED AREA WITHIN THE DASHED OUTLINE WAS AT LEAST PARTIALLY THE RESULT OF THE ROUTING OF WATER TO THIS AREA VIA LOCAL DRAINAGE FEATURES (E.G. SMALL CULVERTS AND MINOR DRIVEWAYS) THAT ARE CURRENTLY NOT INCLUDED IN THE HIGHWOOD RIVER FLOOD MODEL (2013 LANDSCAPE AND SCENARIO 28A) DUE TO THE REGIONAL NATURE OF THE MODEL. MODEL-ESTIMATED WATER LEVELS ADJACENT TO AND UPSTREAM OF THESE INUNDATED AREAS, HOWEVER, DO PROVIDE CONSERVATIVE ESTIMATES TO SUPPORT DESIGN AND FLOOD PLANNING FOR THE OUTLINED AREA. DESIGN AND PLANNING WILL ALSO NEED TO TAKE INTO ACCOUNT LOCAL DRAINAGE FEATURES TO ENSURE ALL FLOOD CONCERNS ARE ADDRESSED. FUTURE MODEL RUNS WILL ATTEMPT TO INCLUDE THESE MINOR FEATURES, WHERE FEASIBLE, TO MORE ACCURATELY REPRESENT THE BEHAVIOUR OF FLOODING IN THIS AREA.

- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

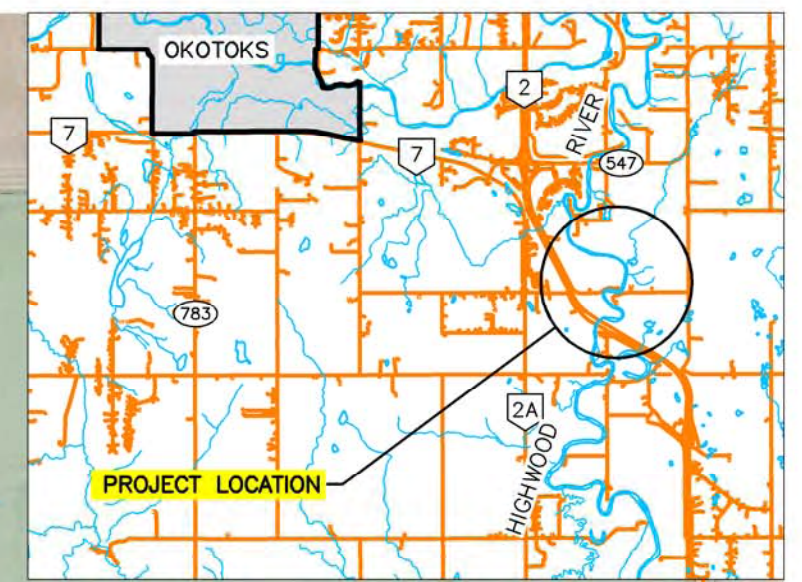


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Reviewed By:









M.D. OF FOOTHILLS NO. 31							
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (5 OF 17)							
Date:	APRIL 2016	File Path:	216703-F625.dwg	Figure No:	6.2.5	Rev:	DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>							






**KEY PLAN**  
SCALE 1:150,000

 INCREMENTAL INCREASED FLOOD INUNDATION ZONE  
 2013 FLOOD EXTENT  
 POTENTIAL BERM  
 HEIGHTENED EROSION VULNERABILITY ZONE  
 ROADS  
 WATERBODIES

SCALE  
1:7500



0 50 100 150 m



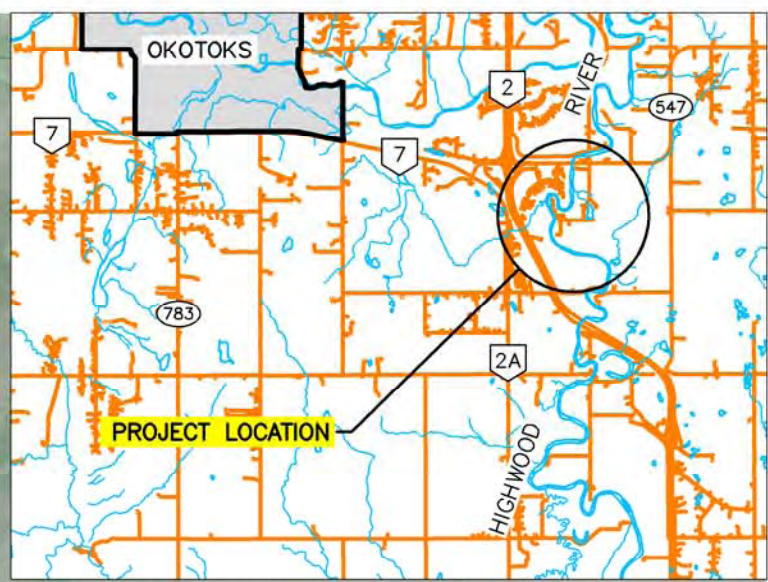
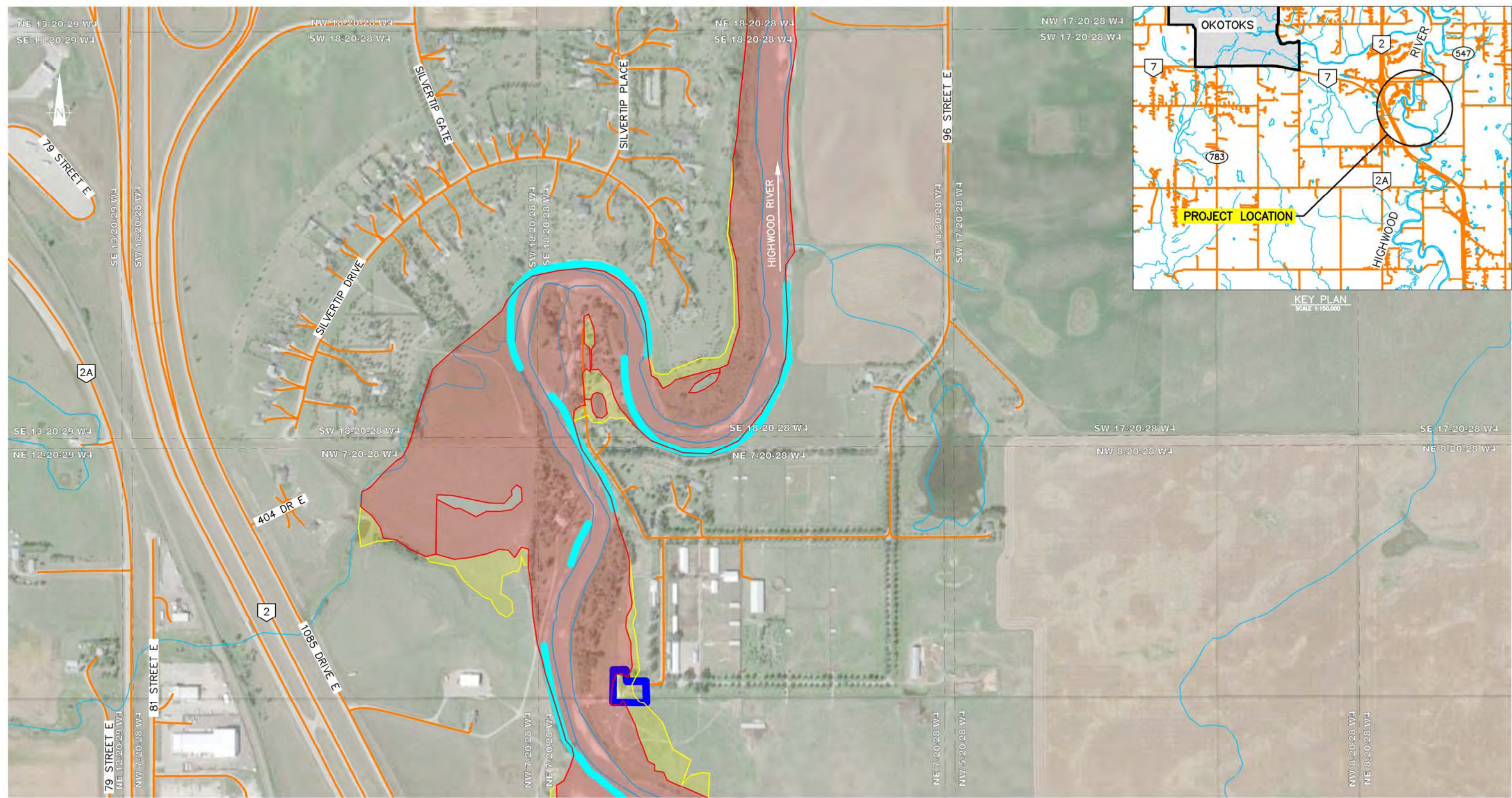
Created By:
Reviewed By:



<b>M.D. OF FOOTHILLS NO. 31</b>			
<b>INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (6 OF 17)</b>			
Date:	APRIL 2016	File Path:	216703-F626.dwg
Figure No:	6.2.6	Rev:	DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>			

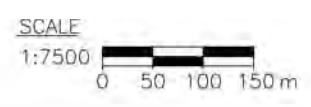


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KEY PLAN  
SCALE 1:150,000

- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

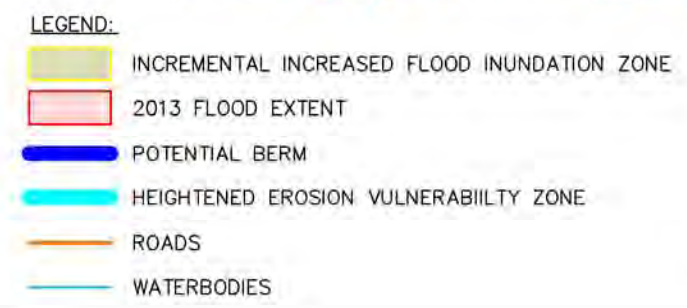


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Reviewed By:




M.D. OF FOOTHILLS NO. 31							
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (7 OF 17)							
Date:	APRIL 2016	File Path:	216703-F627.dwg	Figure No:	6.2.7	Rev:	DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>							





SCALE  
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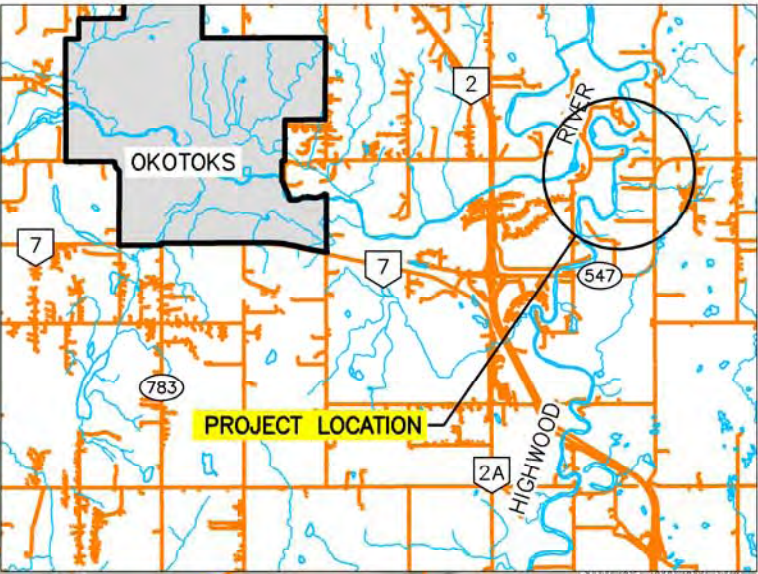
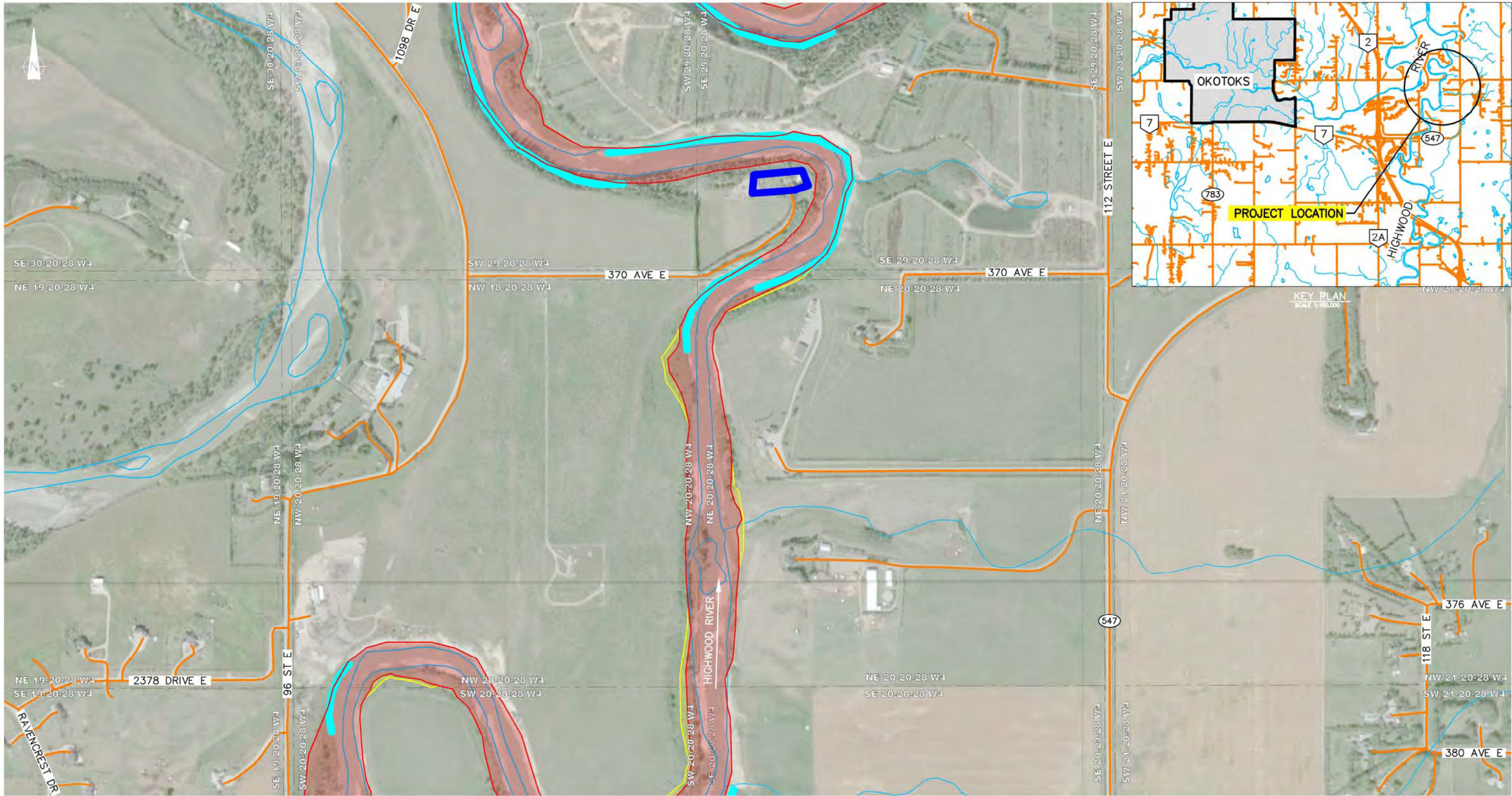
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Reviewed By:

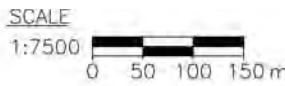


<b>M.D. OF FOOTHILLS NO. 31</b>			
<b>INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (8 OF 17)</b>			
Date:	APRIL 2016	File Path:	216703-F628.dwg
Figure No:	6.2.8	Rev:	DRAFT
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- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



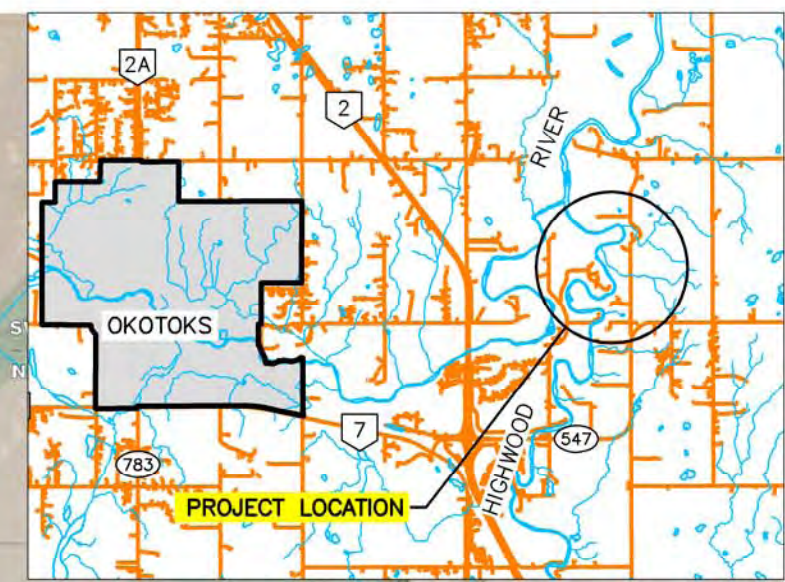
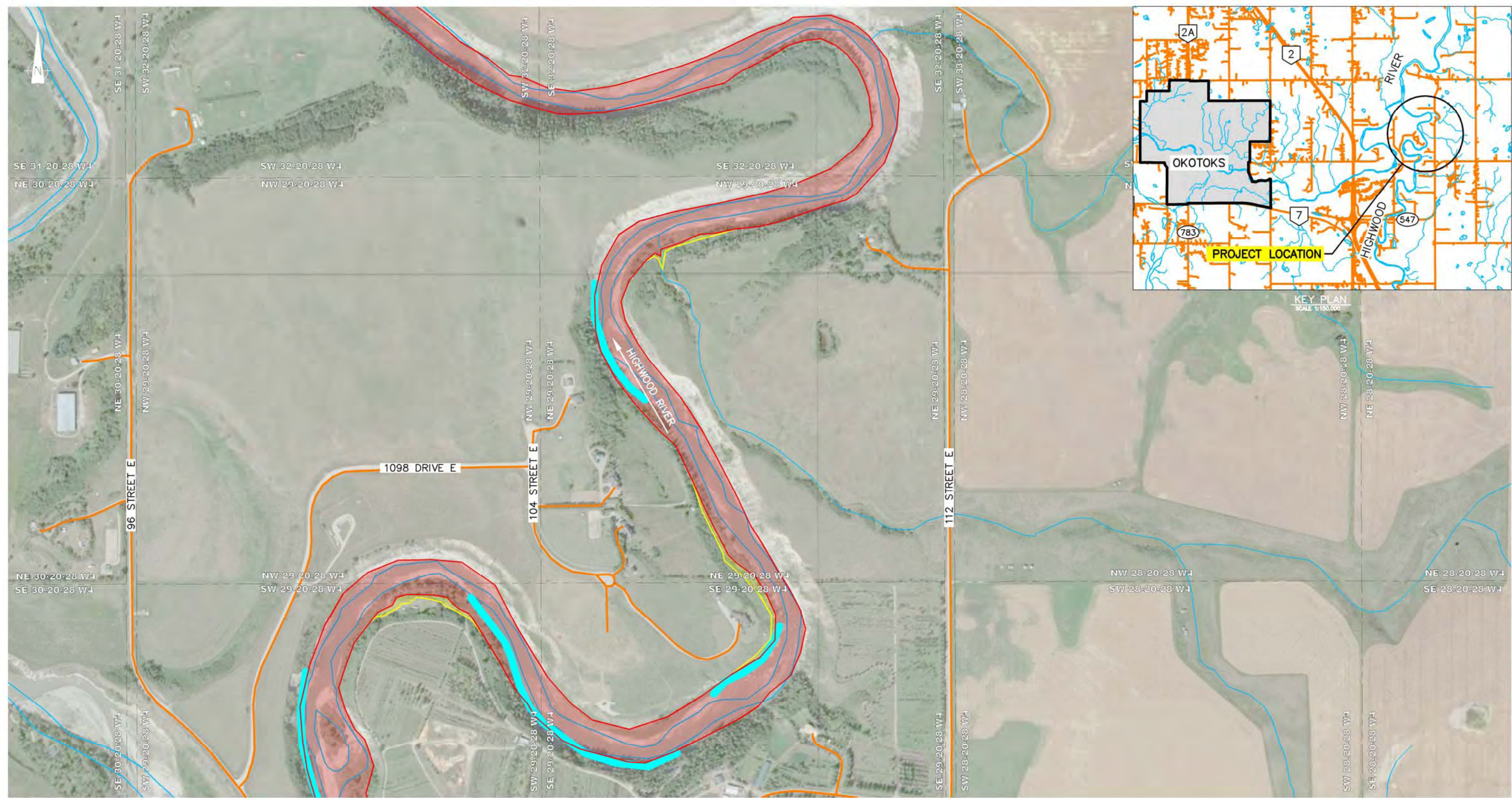
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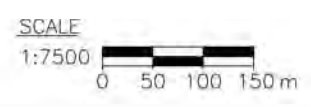
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (9 OF 17)				
Date:	MARCH 2016	File Path:	216703-F629.dwg	Figure No: 6.2.9
Rev:	DRAFT			
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- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

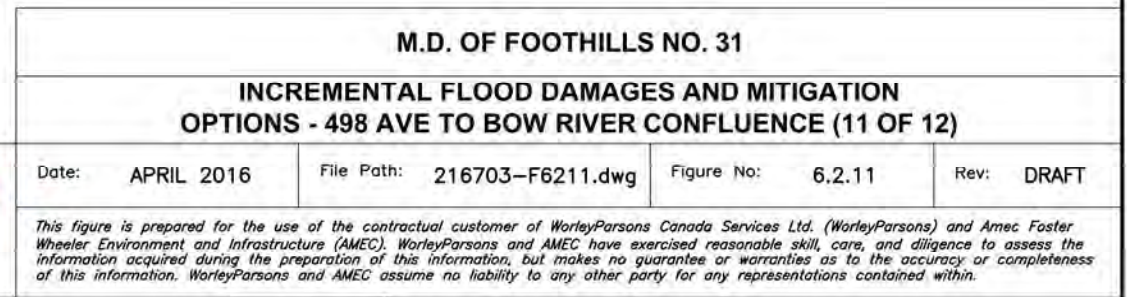
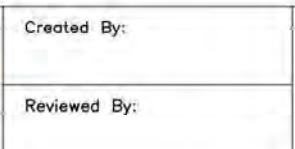
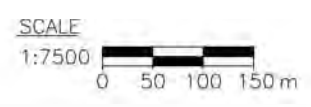


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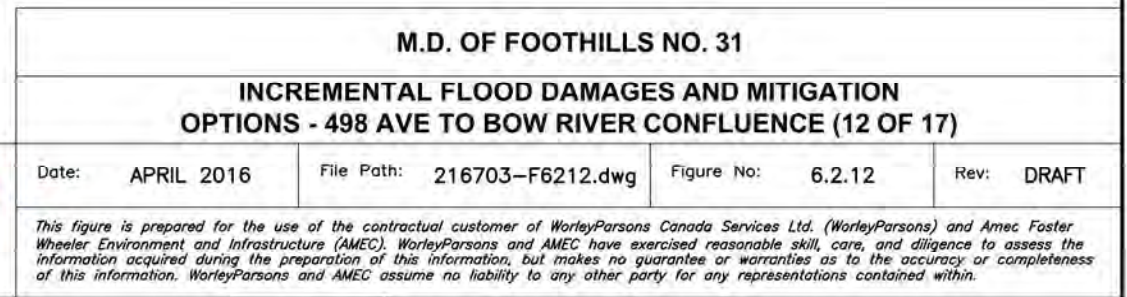
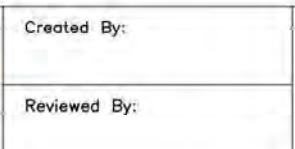
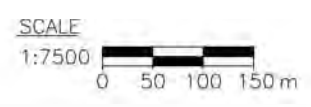


M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (10 OF 17)				
Date:	APRIL 2016	File Path:	216703-F6210.dwg	Figure No: 6.2.10
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				

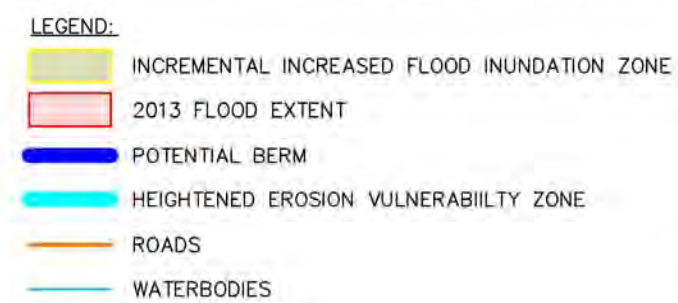












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Reviewed By:

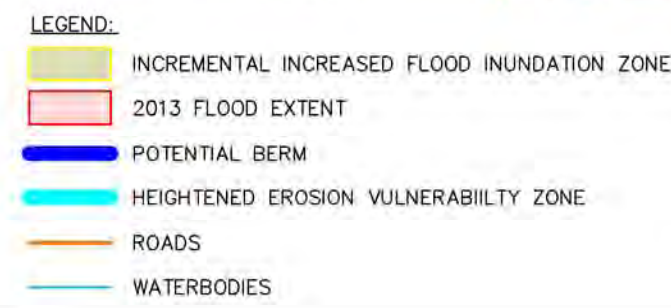


**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (13 OF 17)**


Date: APRIL 2016	File Path: 216703-F6213.dwg	Figure No: 6.2.13	Rev: DRAFT
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SCALE  
1:7500



0 50 100 150 m



**Advisian**  
WorleyParsons Group

Reviewed By:

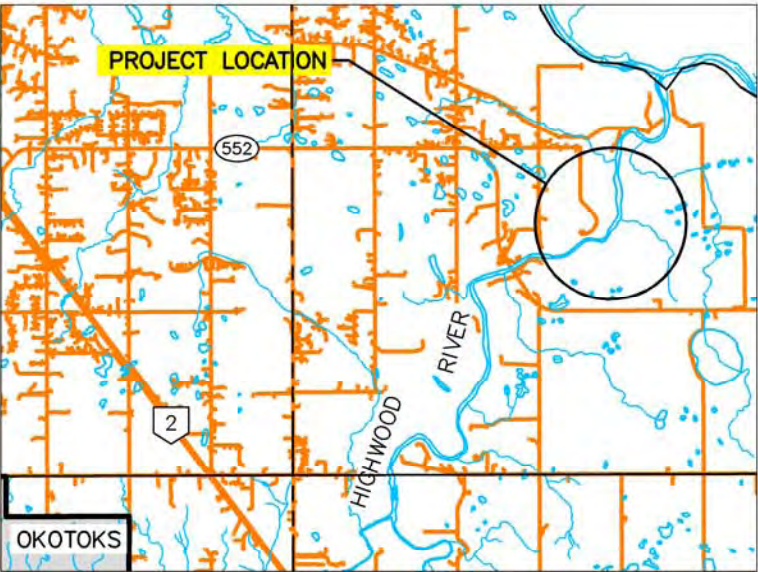
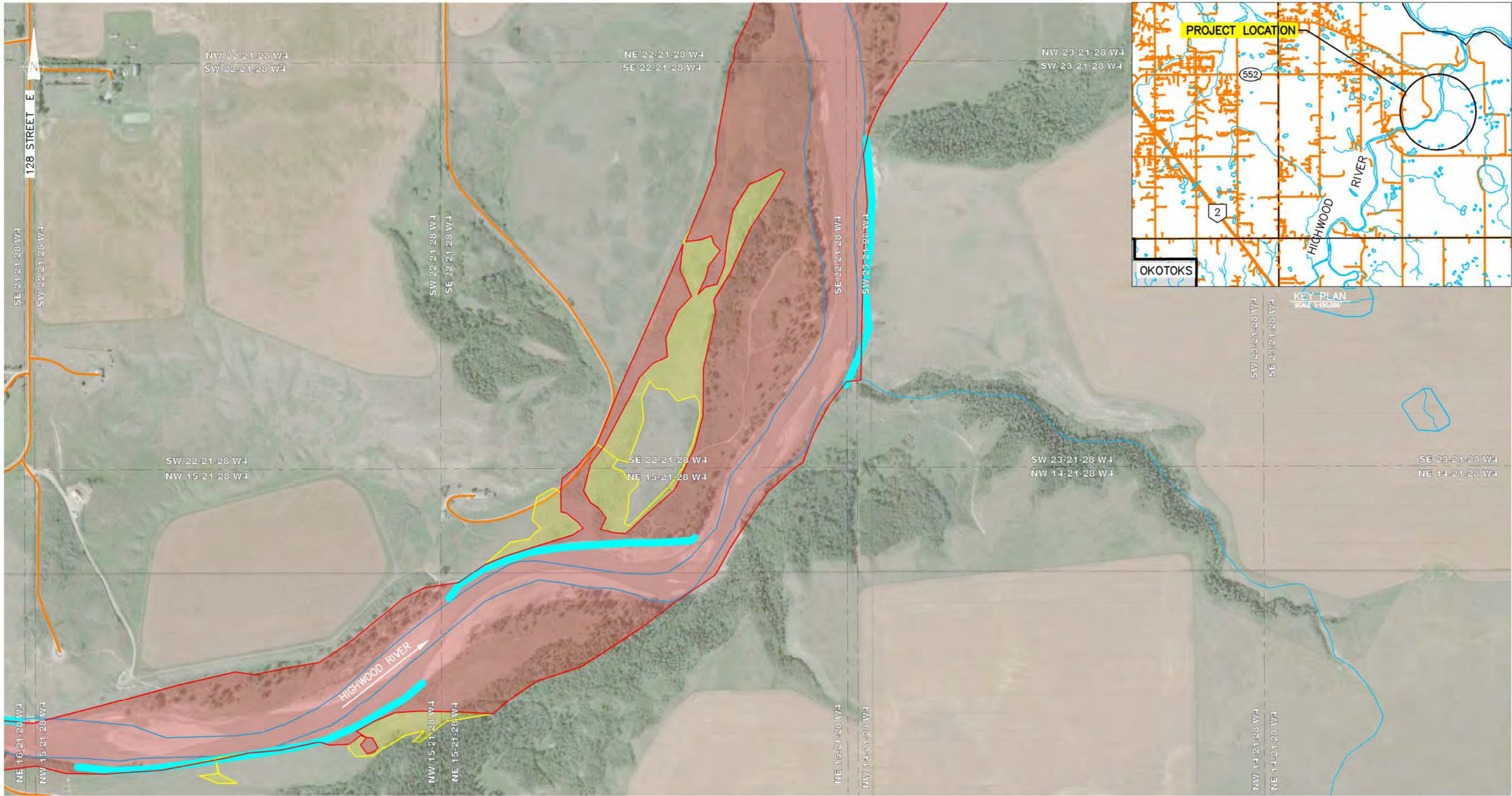


**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (14 OF 17)**

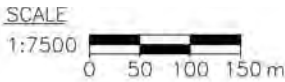
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- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



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Reviewed By:



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

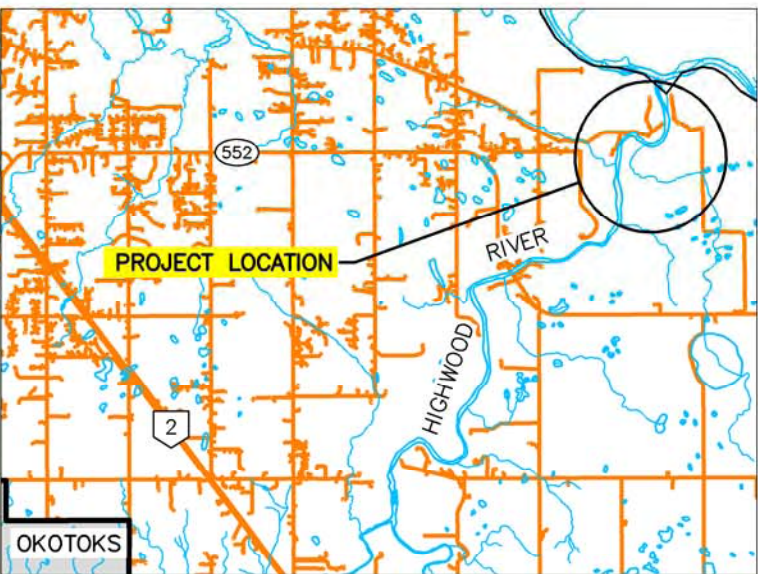
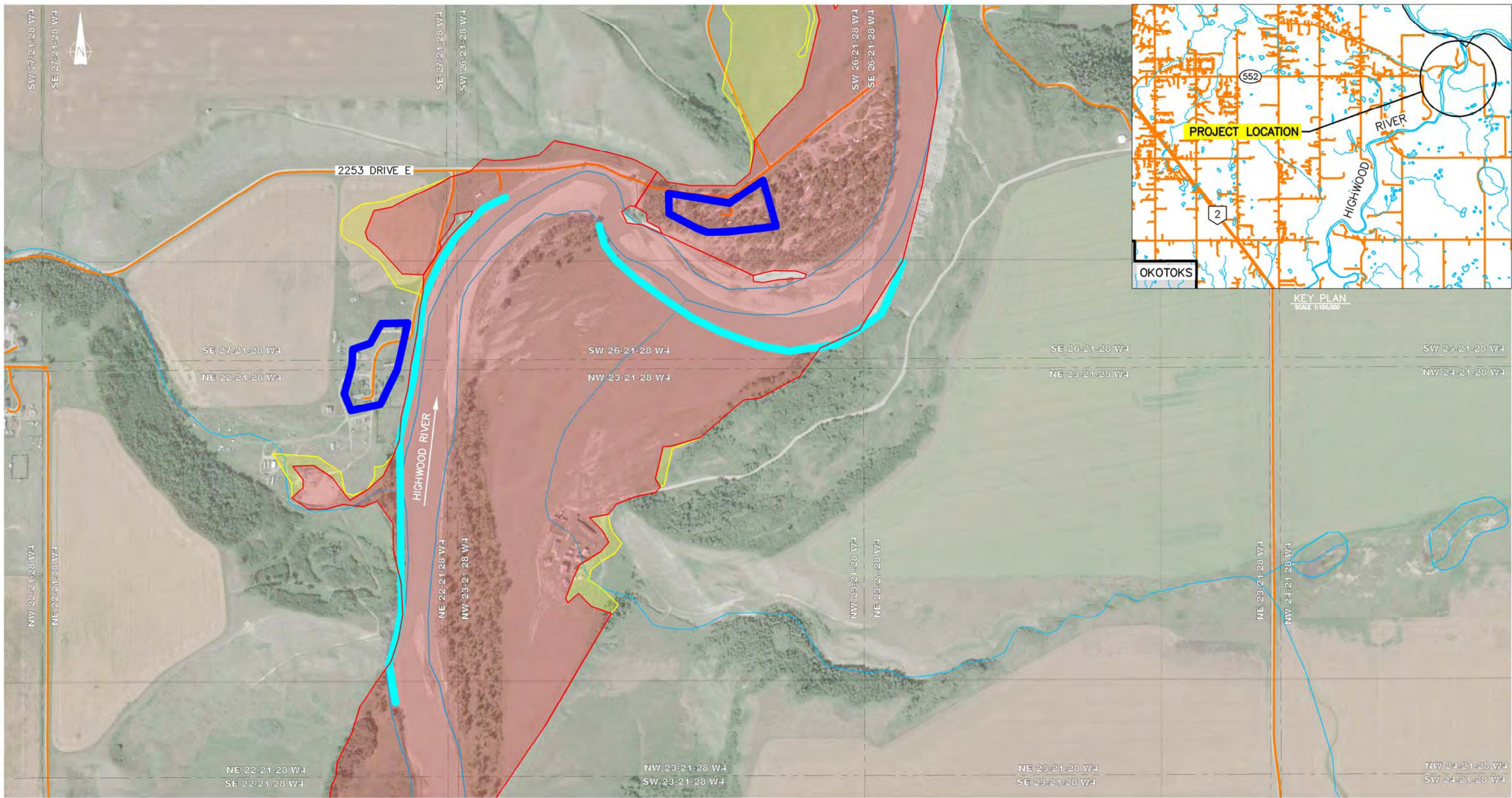
**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (15 OF 17)**

Date: APRIL 2016	File Path: 216703-F6215.dwg	Figure No: 6.2.15	Rev: DRAFT
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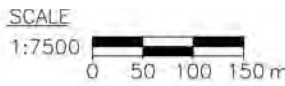
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1:7500 0 50 100 150 m



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



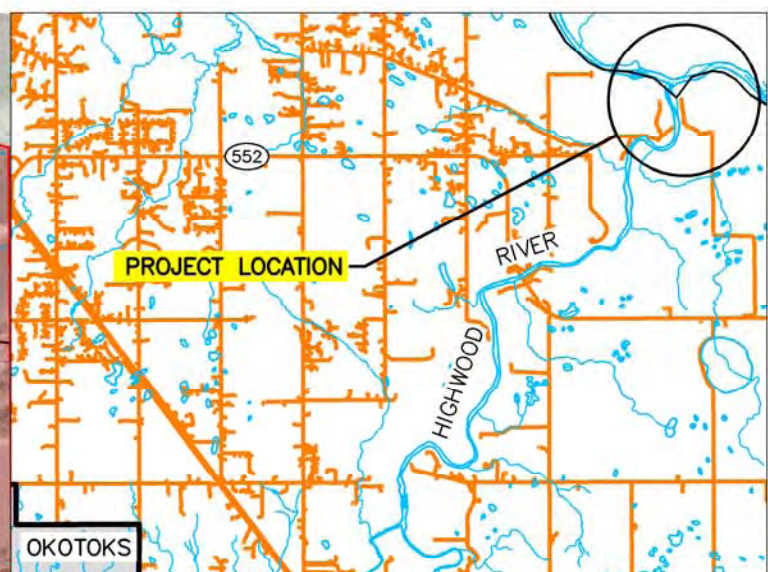
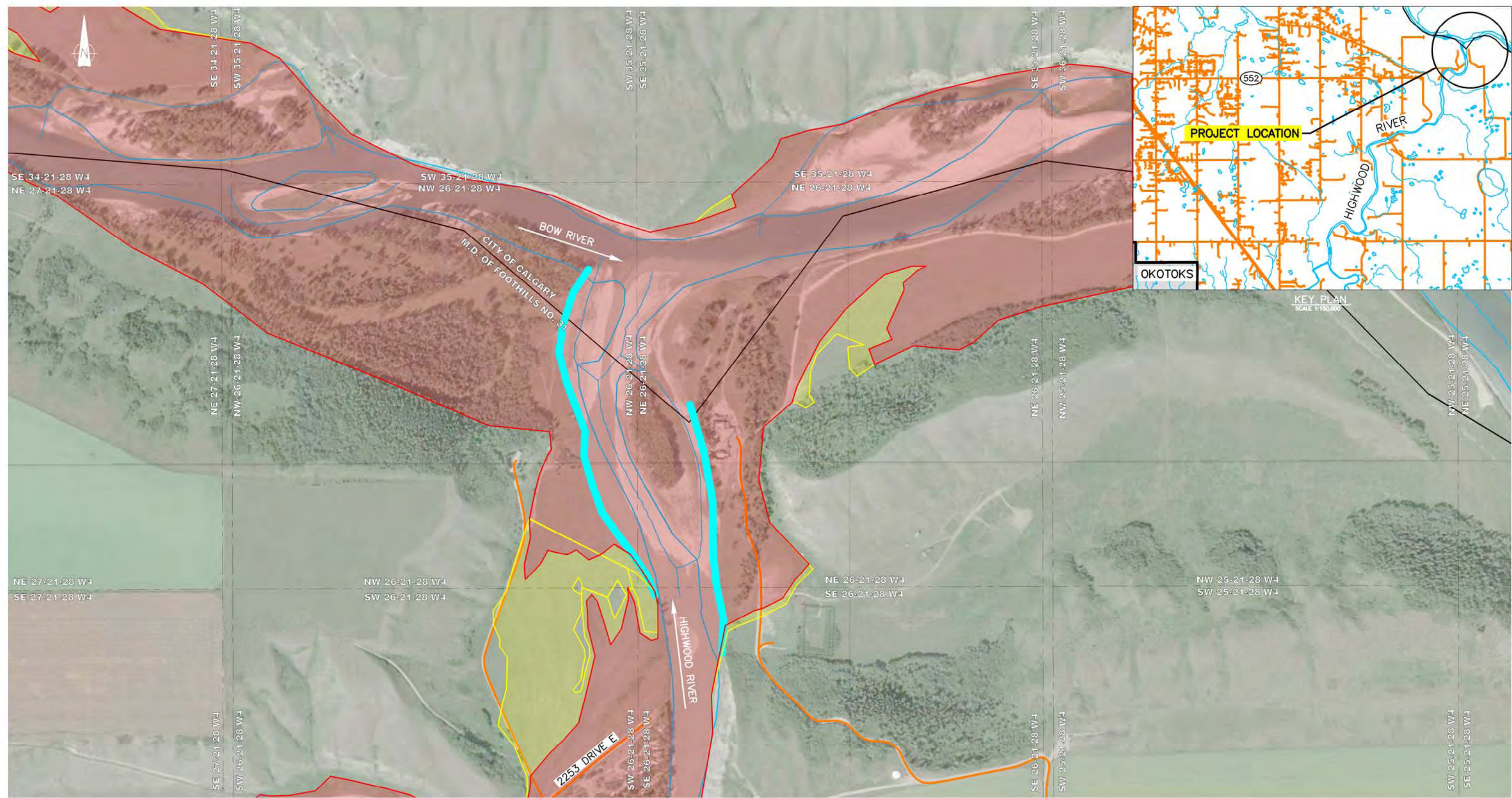
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Reviewed By:



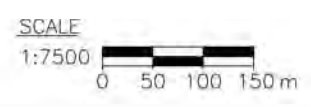
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (16 OF 17)				
Date:	APRIL 2016	File Path:	216703-F6216.dwg	Figure No: 6.2.16
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				



\\NW216703\216703-F6217.dwg - May 19, 2016 12:03pm - corey.ferrets



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



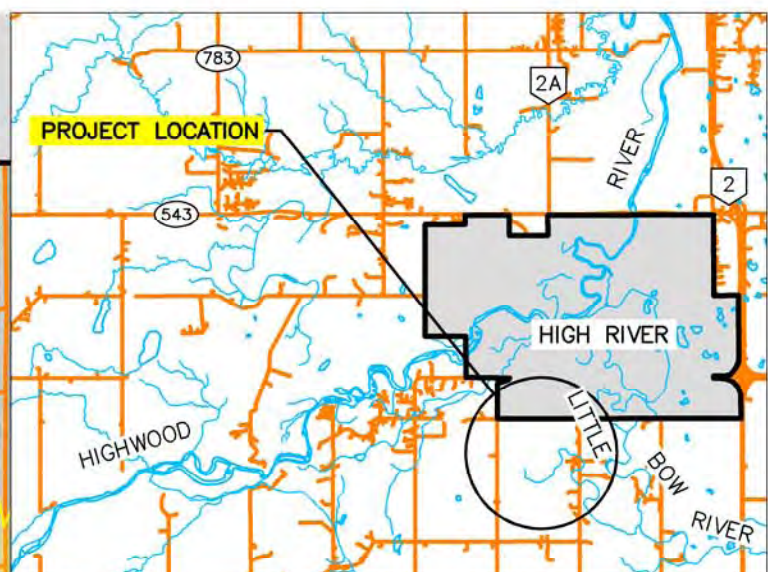
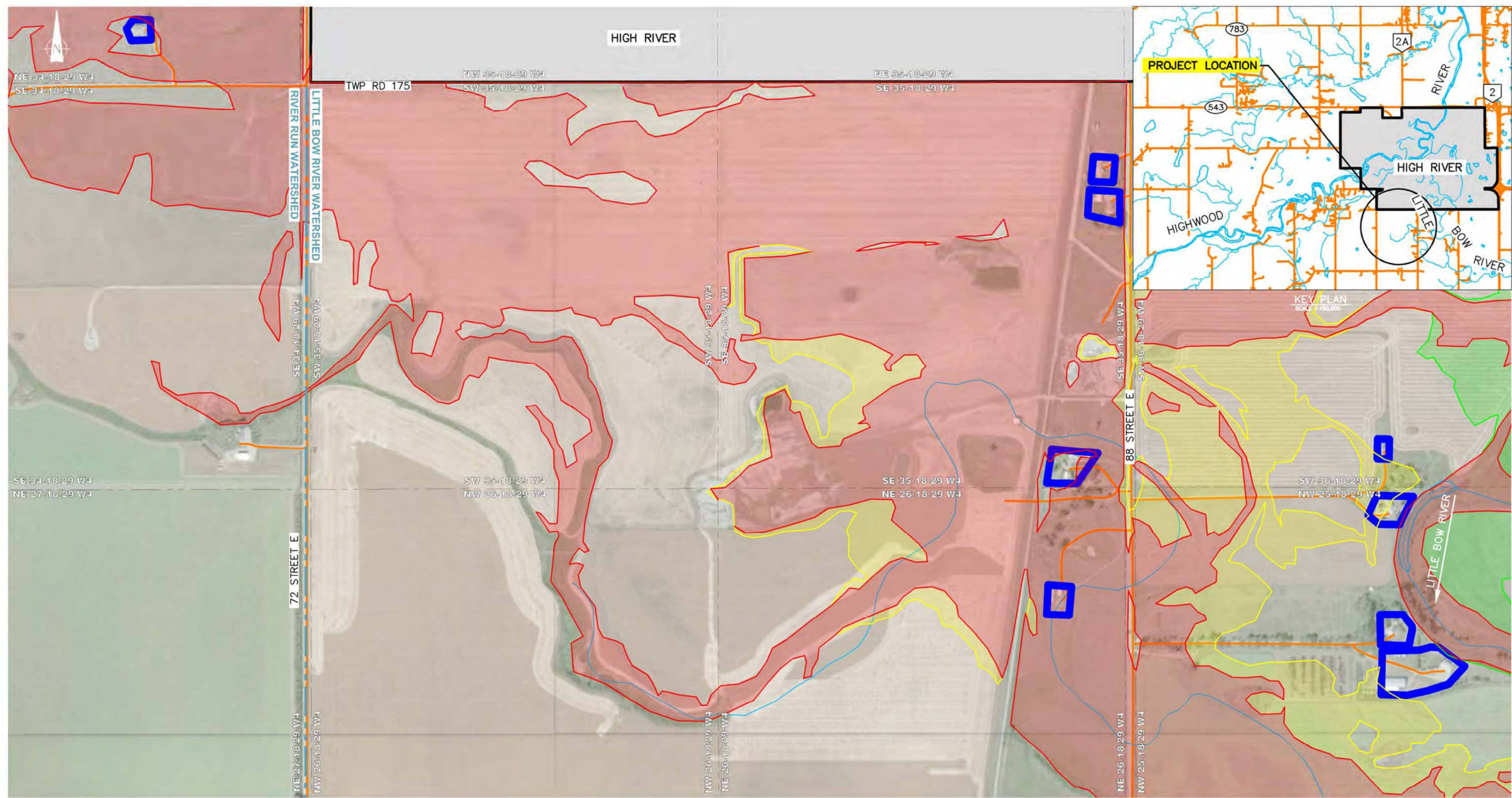
Created By:  
Reviewed By:



M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - 498 AVE TO BOW RIVER CONFLUENCE (17 OF 17)				
Date:	APRIL 2016	File Path:	216703-F6217.dwg	Figure No: 6.2.17
				Rev: DRAFT
This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.				

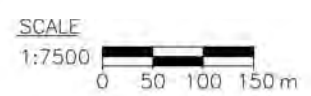


\\NW\216703\216703-F631.dwg - Figure 6.3.1 - May, 19, 2016 3:14pm - corej.ferrets



KEY PLAN  
SCALE 1:150,000

- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



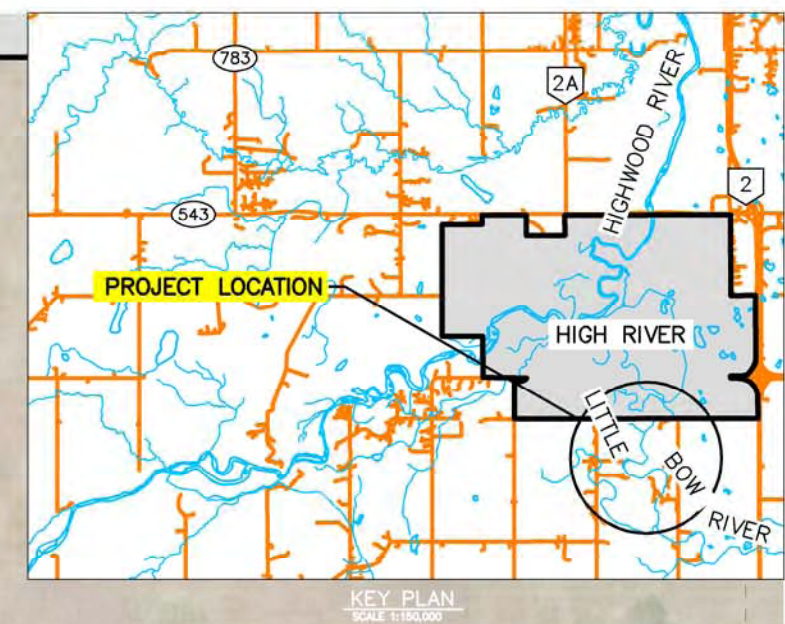
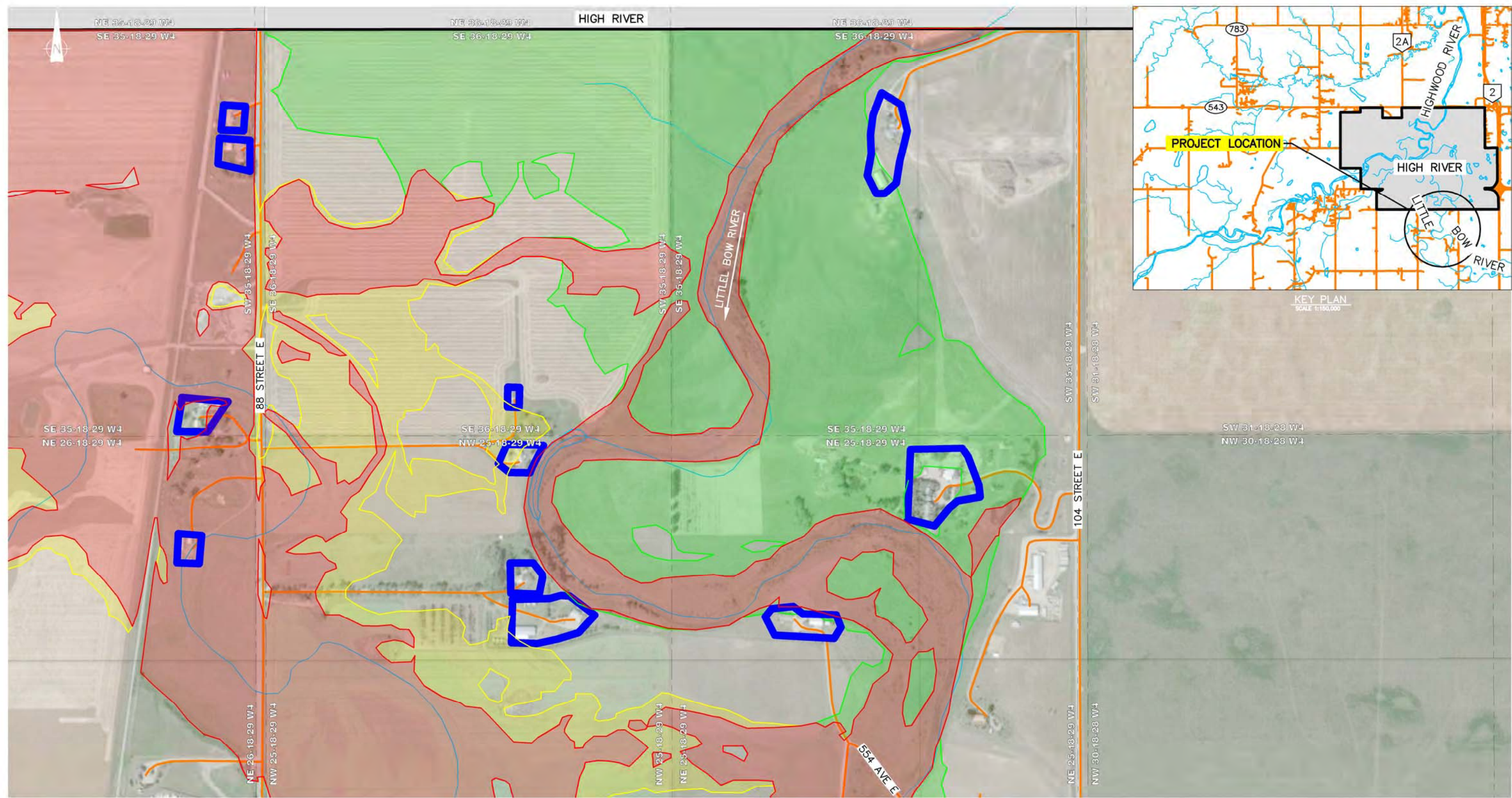
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Reviewed By:



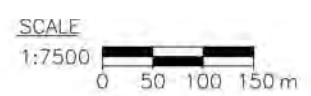
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (1 OF 15)				
Date:	APRIL 2016	File Path:	216703-F631.dwg	Figure No: 6.3.1
				Rev: DRAFT
This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.				



\\NW\216703\216703-F632.dwg - Figure 6.3.2 - May, 19, 2016 3:13pm - corej.ferrets



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



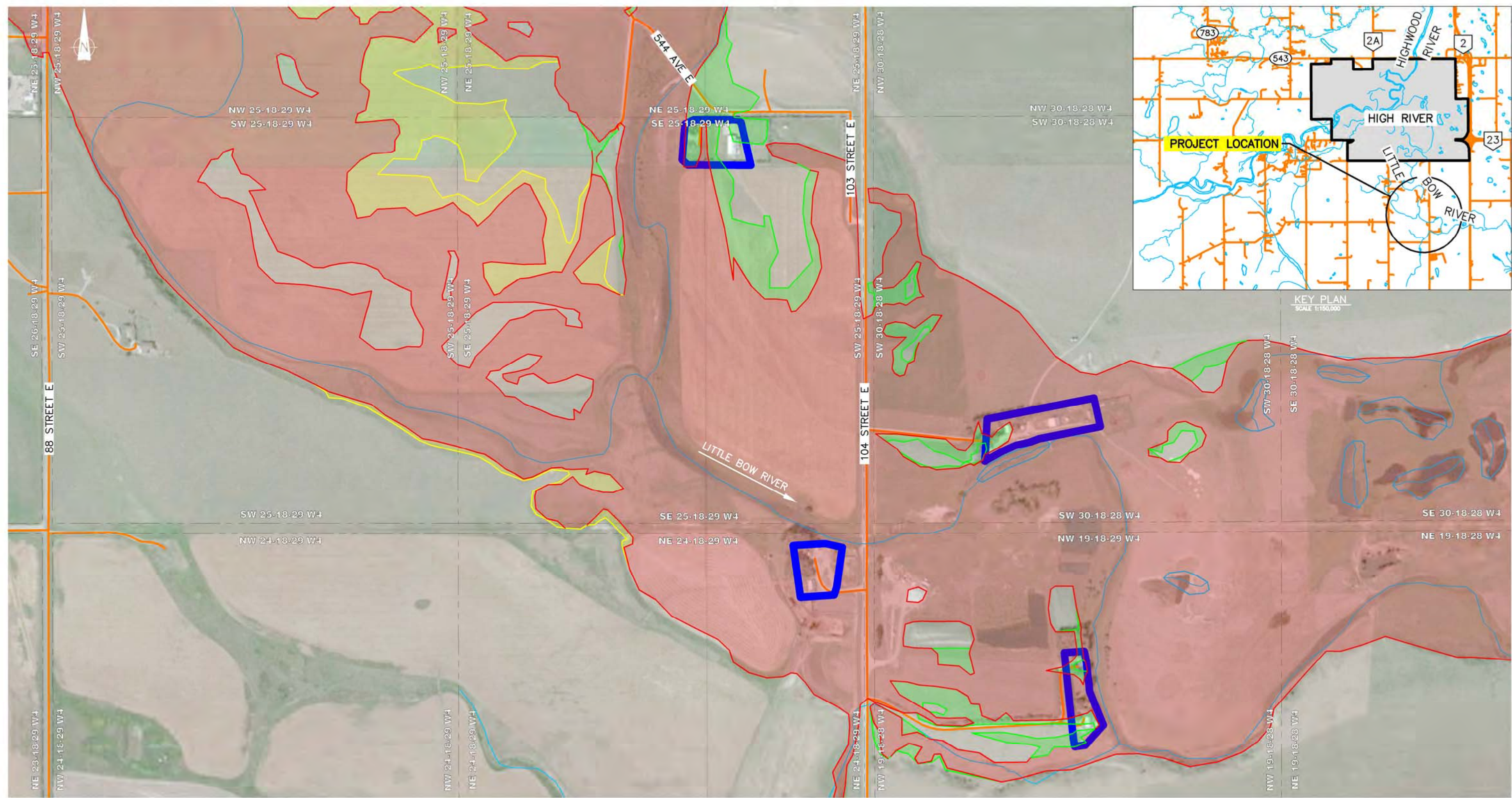
Created By:  
Reviewed By:



M.D. OF FOOTHILLS NO. 31			
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (2 OF 15)			
Date: FEBRUARY 2016	File Path: 216703-F632.dwg	Figure No: 6.3.2	Rev: DRAFT
This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.			

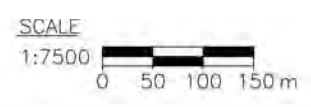


\\NW\216703\216703-F633.dwg - Figure 6.3.3 - May, 19, 2016 3:08pm - corey.ferrets



**LEGEND:**

- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
- 2013 FLOOD EXTENT
- INCREMENTAL DECREASED FLOOD INUNDATION ZONE
- POTENTIAL BERM
- HEIGHTENED EROSION VULNERABILITY ZONE
- ROADS
- WATERBODIES



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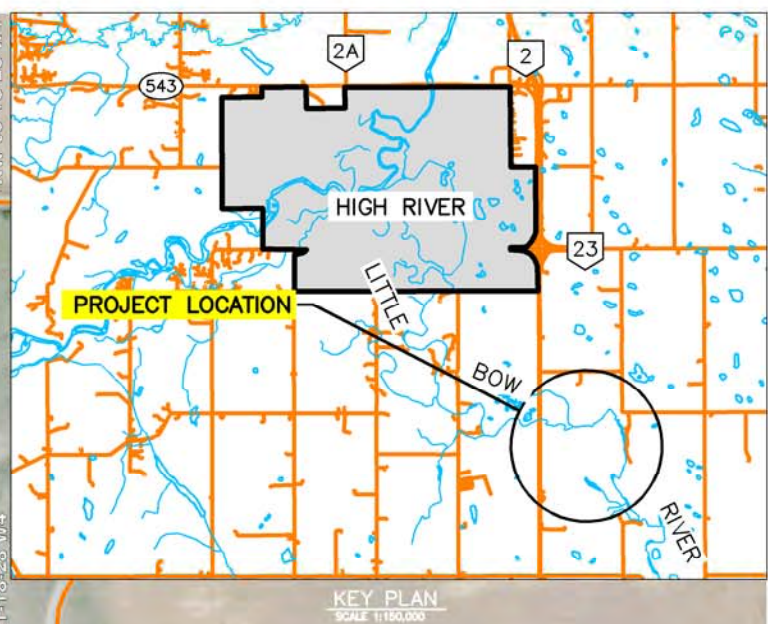
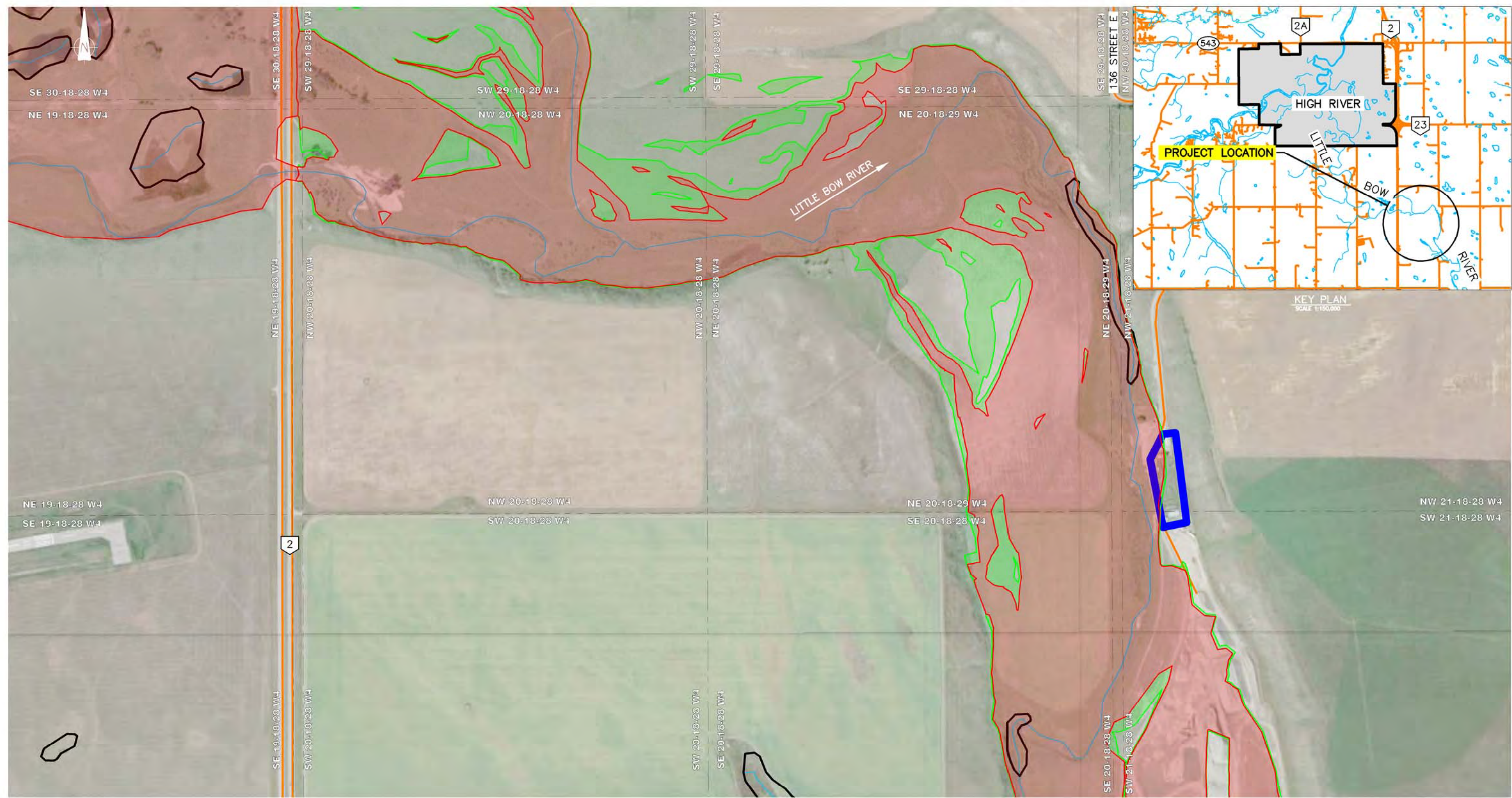
Reviewed By:

amec  
foster  
wheeler

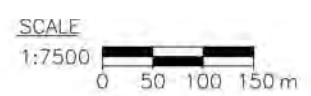
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (3 OF 15)				
Date:	APRIL 2016	File Path:	216703-F633.dwg	Figure No: 6.3.3
Rev:	DRAFT			
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				



\\NW\216703\216703-F634.dwg - Figure 6.3.4 - May, 19, 2016 3:04pm - corey.fernandes



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



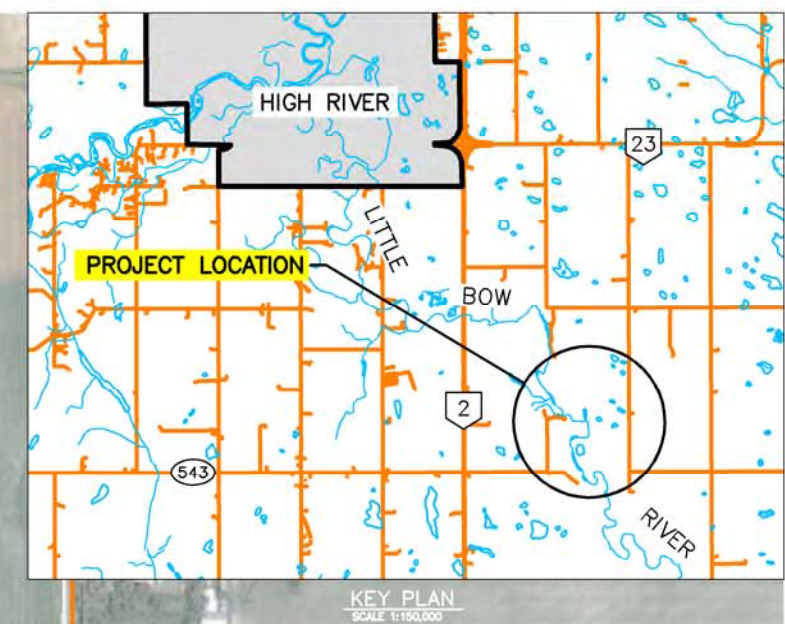
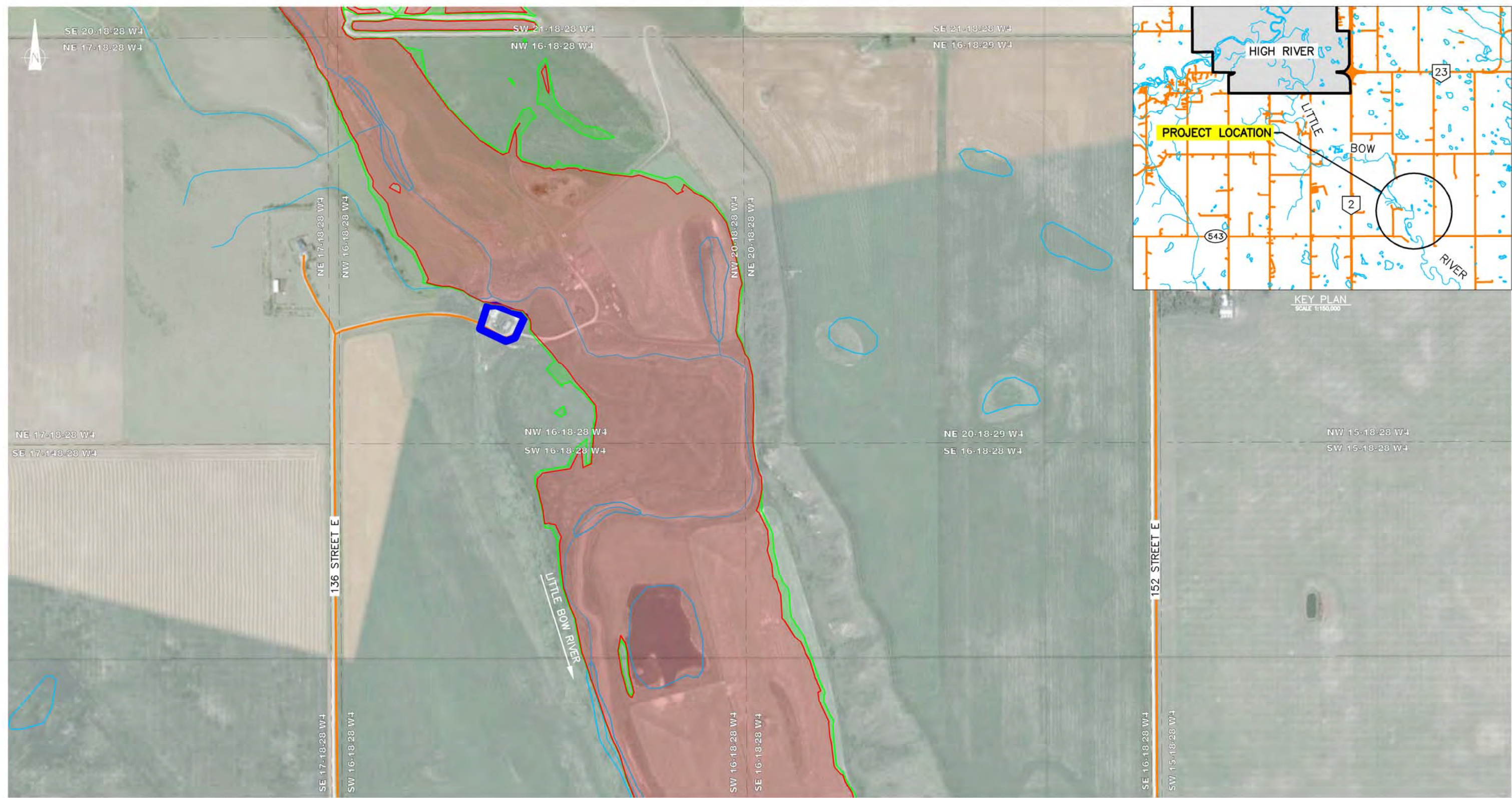
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Reviewed By:



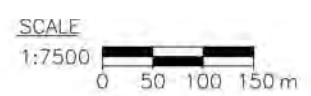
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (4 OF 15)				
Date:	APRIL 2016	File Path:	216703-F634.dwg	Figure No: 6.3.4
				Rev: DRAFT
This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.				



1:\CW\216703\216703-F635.dwg - Figure 6.3.5 - May, 19, 2016 3:03pm - corey.ferrets



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



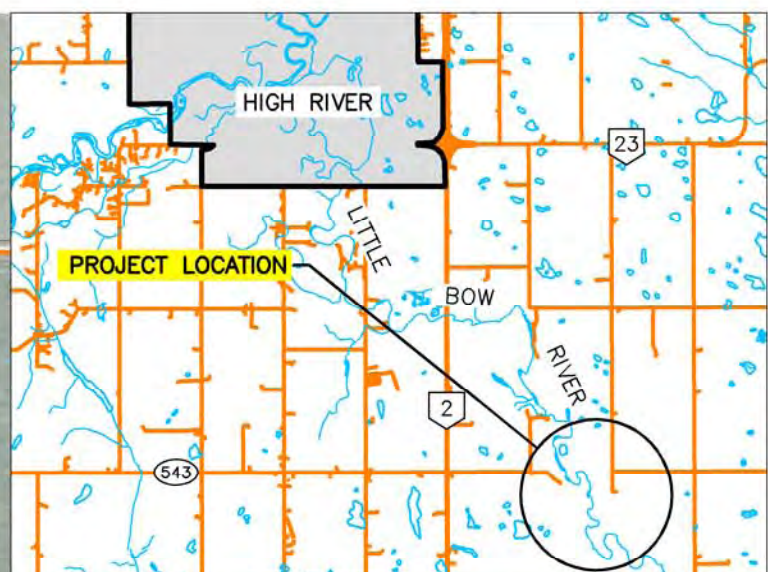
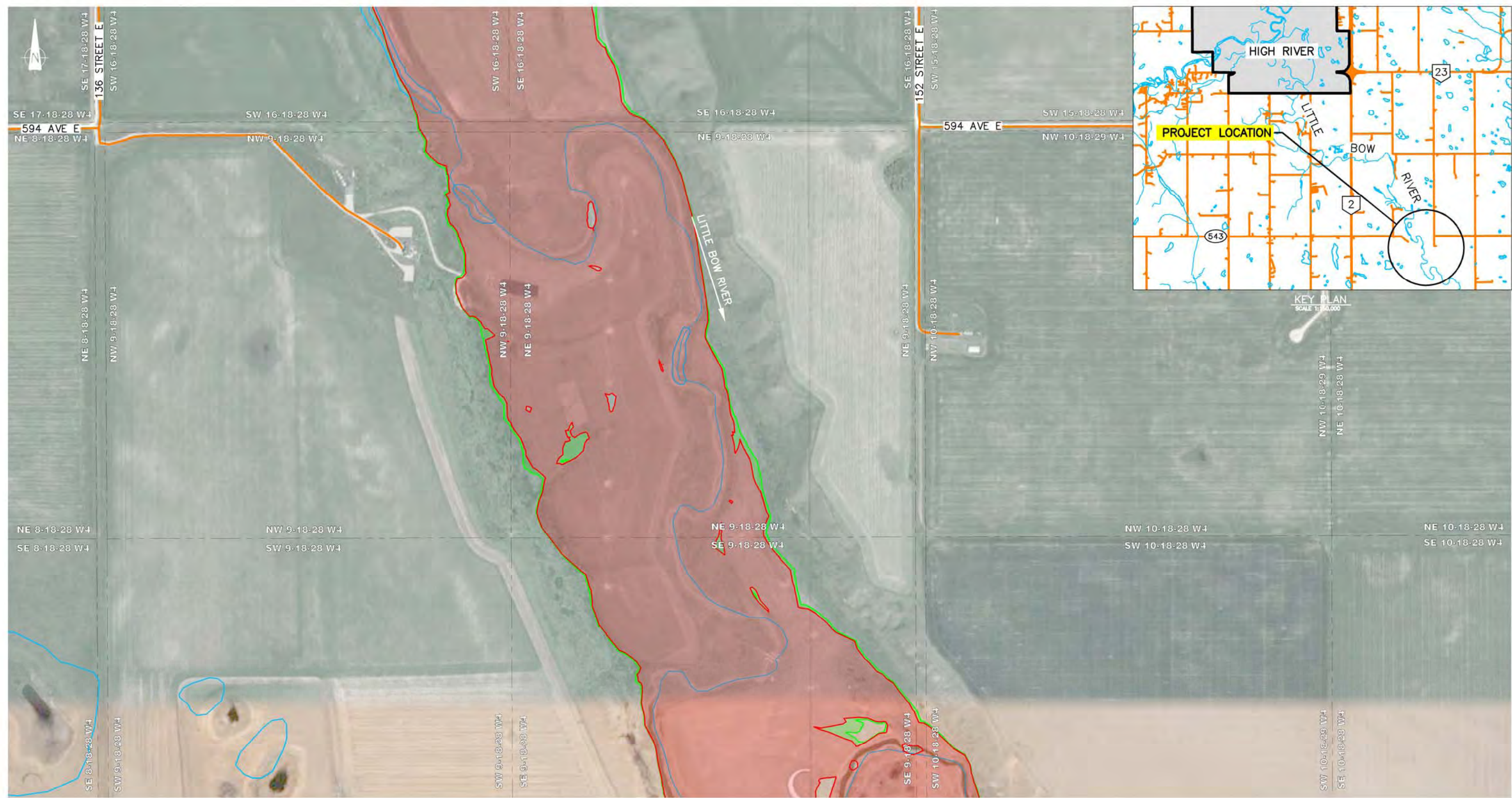
Created By:  
Reviewed By:



M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (5 OF 15)				
Date:	APRIL 2016	File Path:	216703-F635.dwg	Figure No: 6.3.5
Rev:	DRAFT			
This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.				

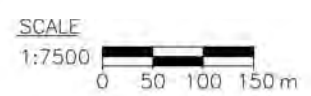


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KEY PLAN  
SCALE 1:100,000

- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES



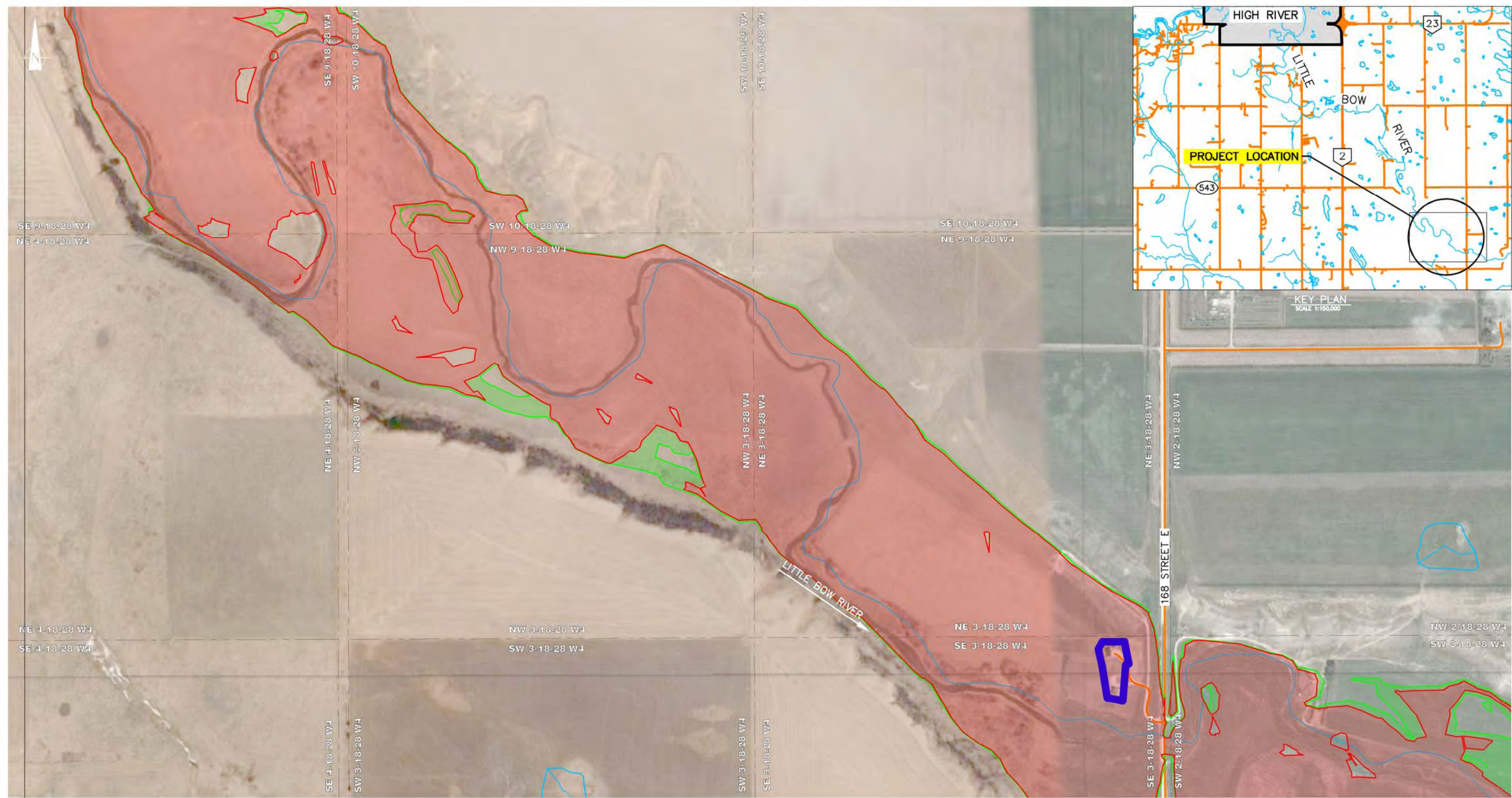
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Reviewed By:



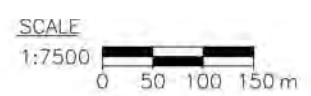
M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (6 OF 15)				
Date:	APRIL 2016	File Path:	216703-F636.dwg	Figure No: 6.3.6
				Rev: DRAFT
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\\NW\216703\216703-F637.dwg - Figure 6.3.7 - May, 19, 2016 3:01pm - corej.fernats



- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES





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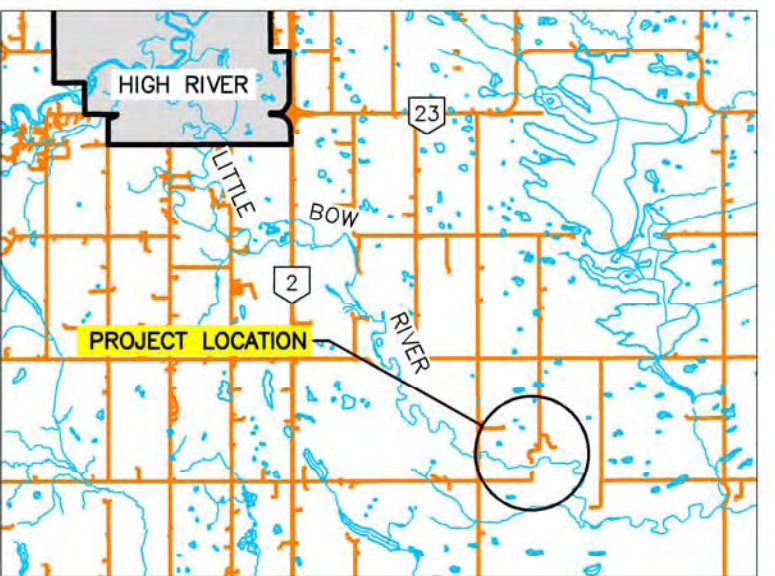
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





amec  
foster  
wheeler

M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (7 OF 15)				
Date:	APRIL 2016	File Path:	216703-F637.dwg	Figure No: 6.3.7
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				





KEY PLAN  
SCALE 1:150,000

-  INCREMENTAL INCREASED FLOOD INUNDATION ZONE
-  2013 FLOOD EXTENT
-  INCREMENTAL DECREASED FLOOD INUNDATION ZONE
-  POTENTIAL BERM
-  HEIGHTENED EROSION VULNERABILITY ZONE
-  ROADS
-  WATERBODIES

0 50 100 150 m



Reviewed By:



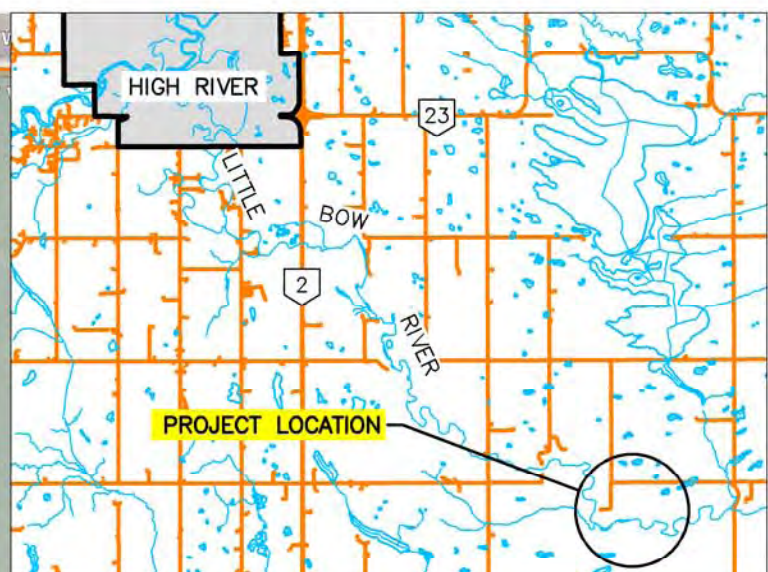
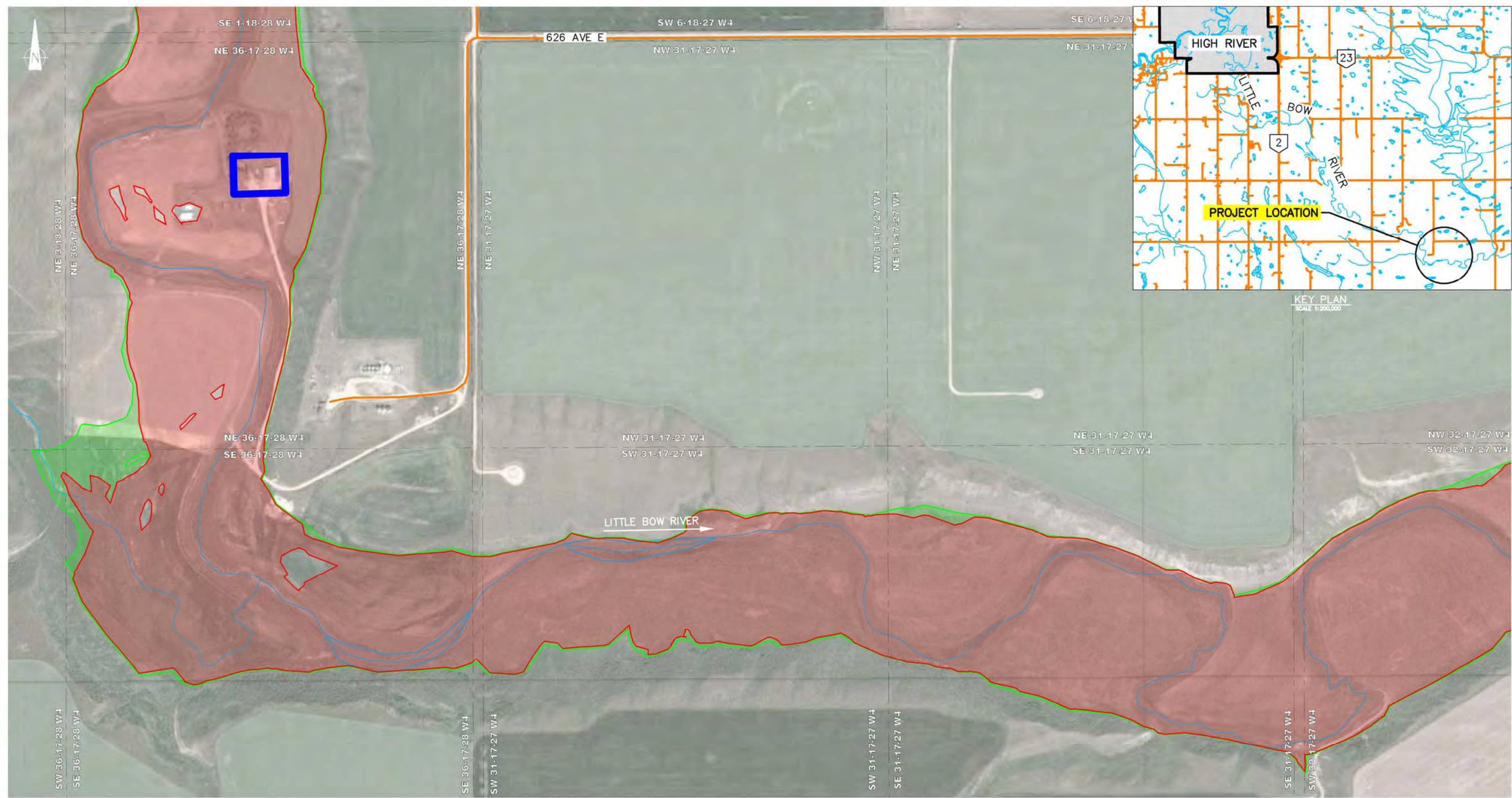
**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - LITTLE BOW RIVER (8 OF 15)**

Rev: DRAFT

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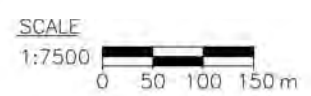


\\NW\216703\216703-F639.dwg - Figure 6.3.9 - May, 19, 2016 2:59pm - corey.ferrets



KEY PLAN  
SCALE 1:200,000

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- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

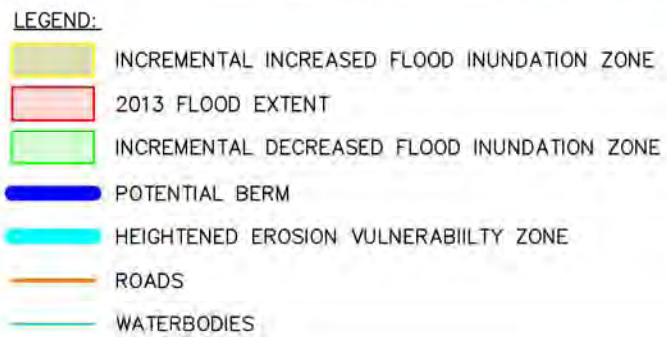


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M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (9 OF 15)				
Date:	APRIL 2016	File Path:	216703-F639.dwg	Figure No: 6.3.9
Rev:	DRAFT			
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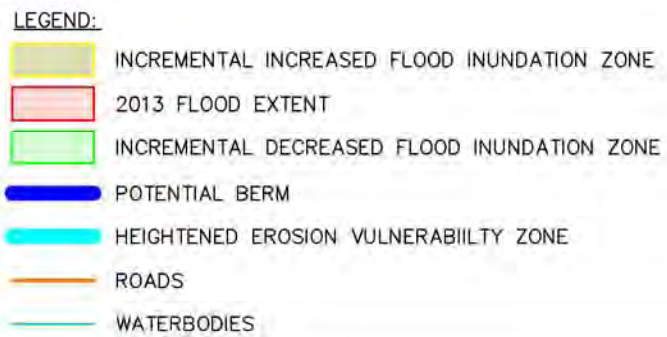


**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - LITTLE BOW RIVER (10 OF 15)**


Rev: DRAFT

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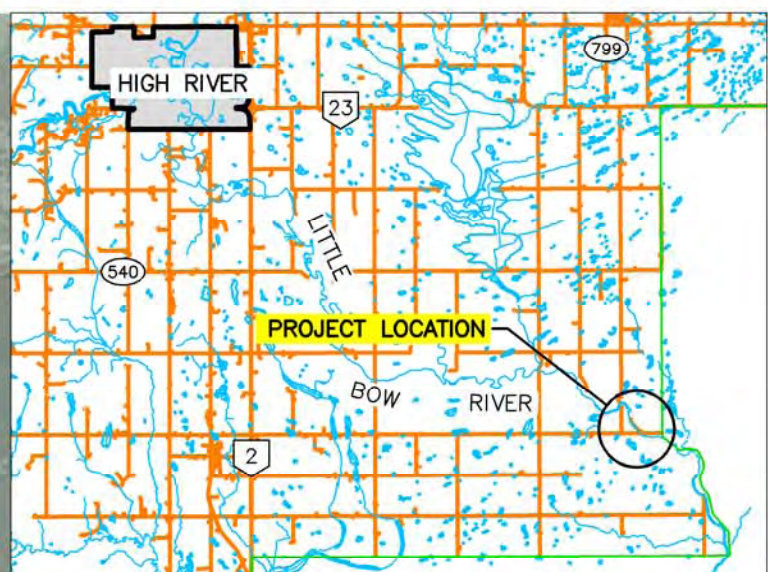
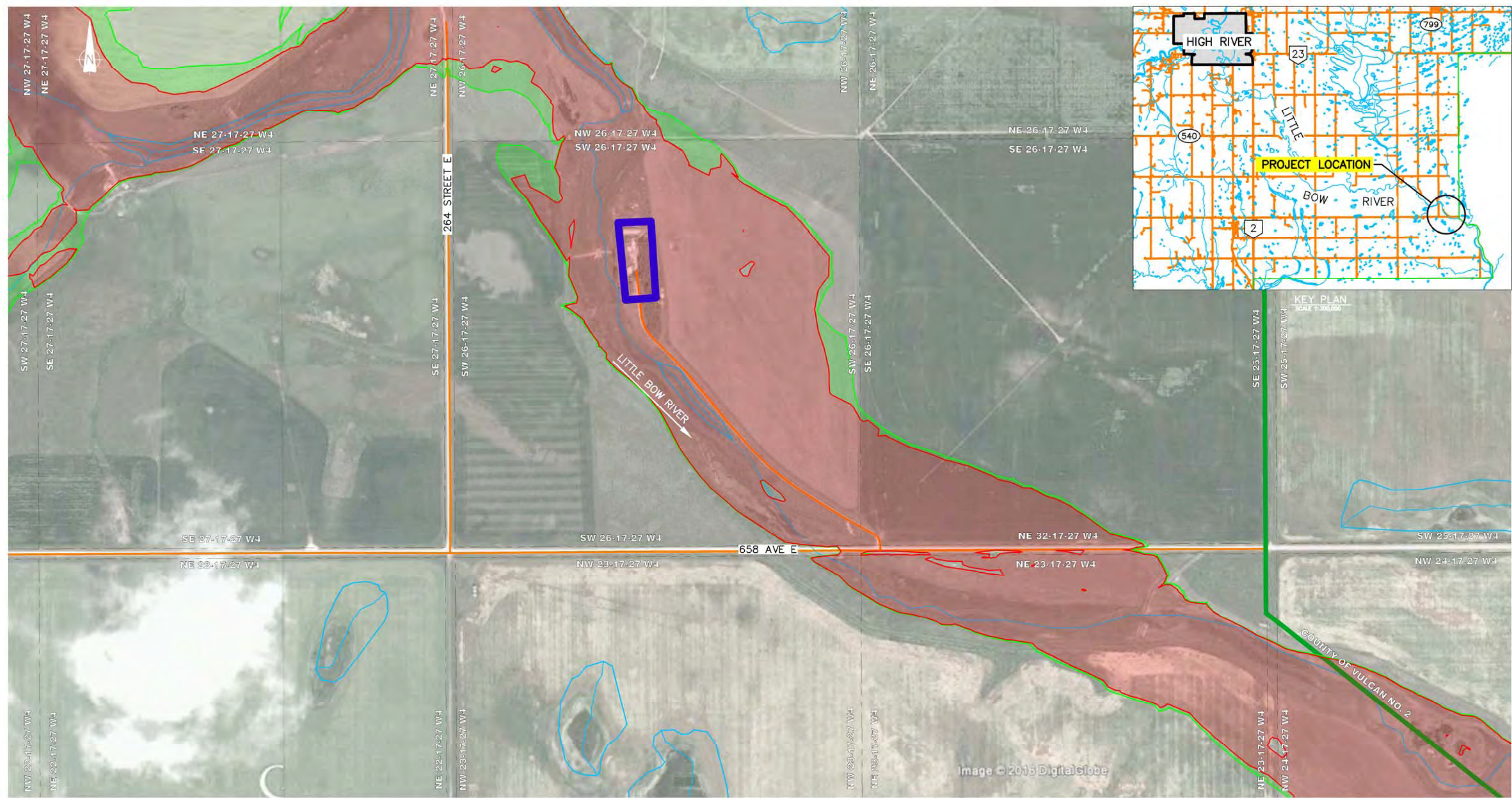
## INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (11 OF 15)

Rev: DRAFT

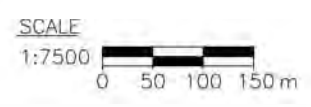
*This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.*



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- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

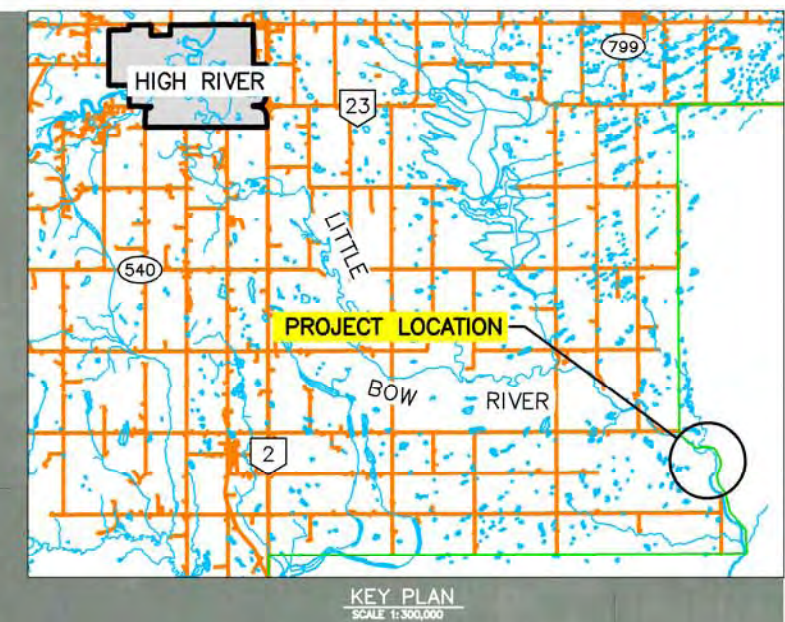
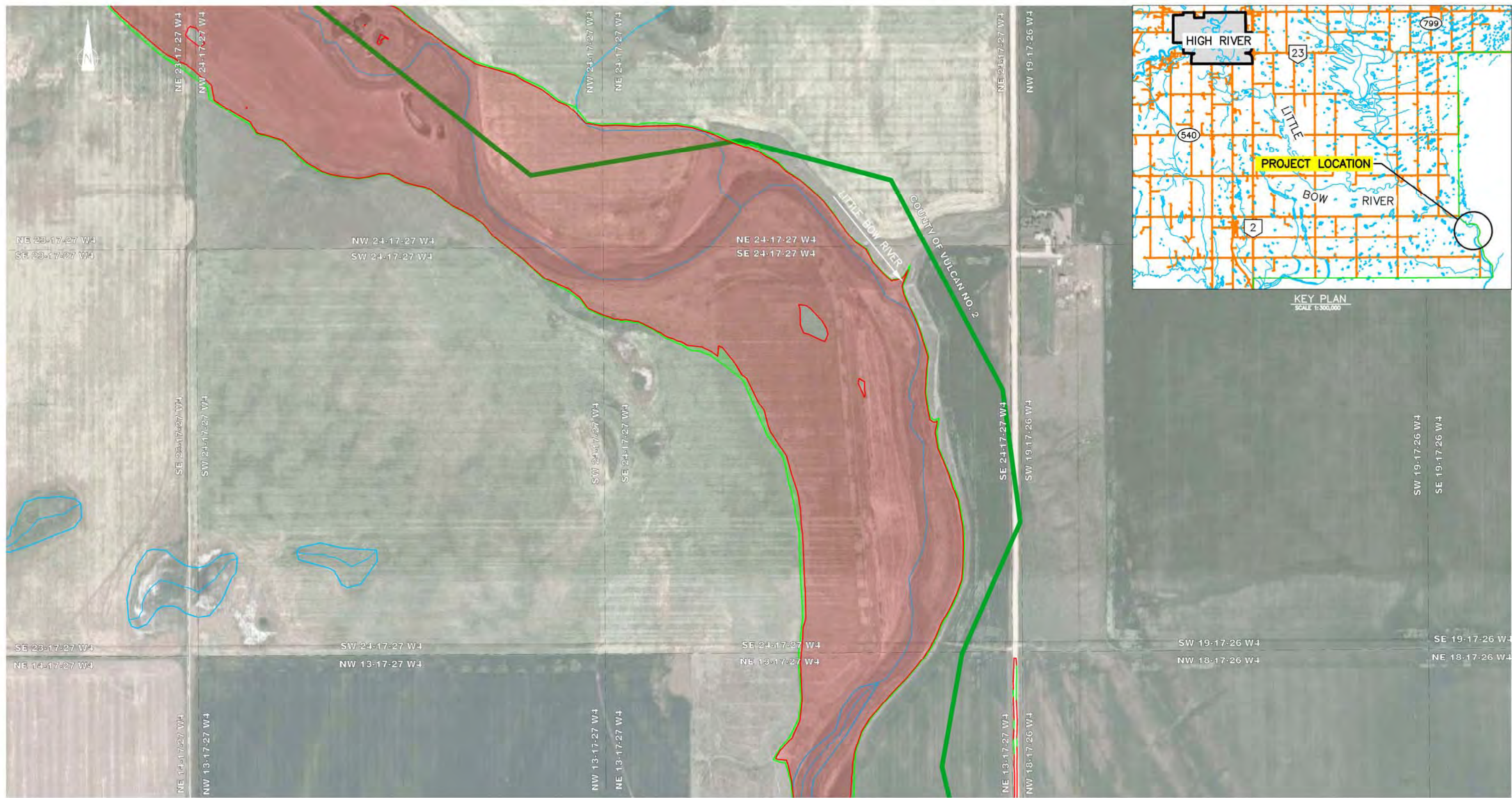


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Reviewed By:

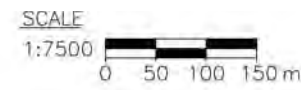


M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (12 OF 15)				
Date:	APRIL 2016	File Path:	216703-F6312.dwg	Figure No: 6.3.12
				Rev: DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>				





- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

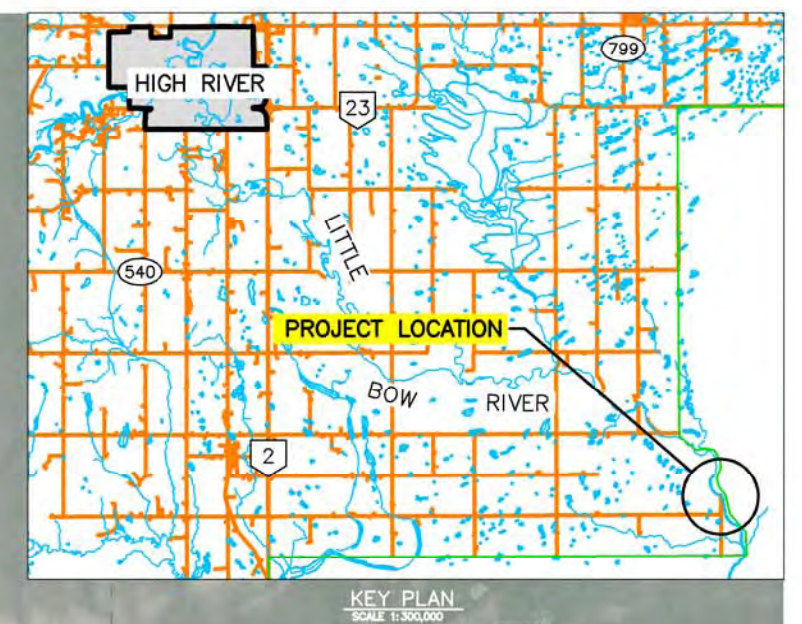


Created By:  
  
Reviewed By:




M.D. OF FOOTHILLS NO. 31				
INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (13 OF 15)				
Date:	APRIL 2016	File Path:	216703-F6313.dwg	Figure No: 6.3.13
				Rev: DRAFT
This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.				





SCALE  
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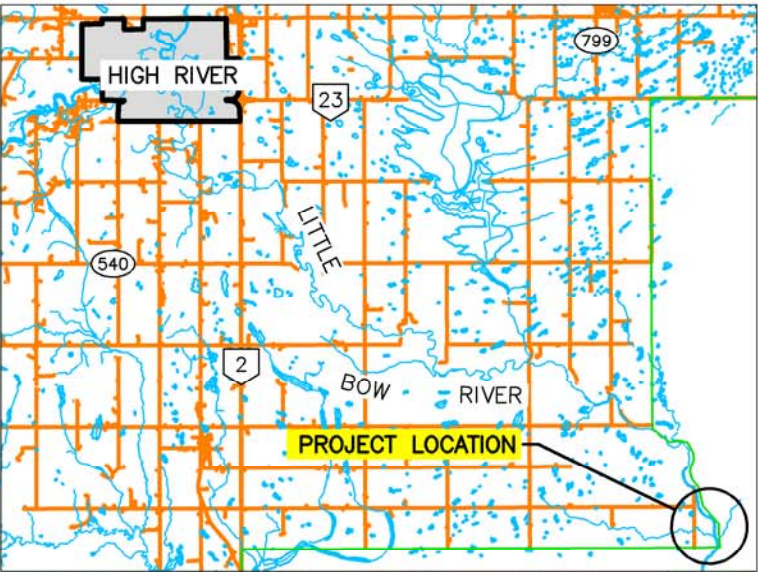
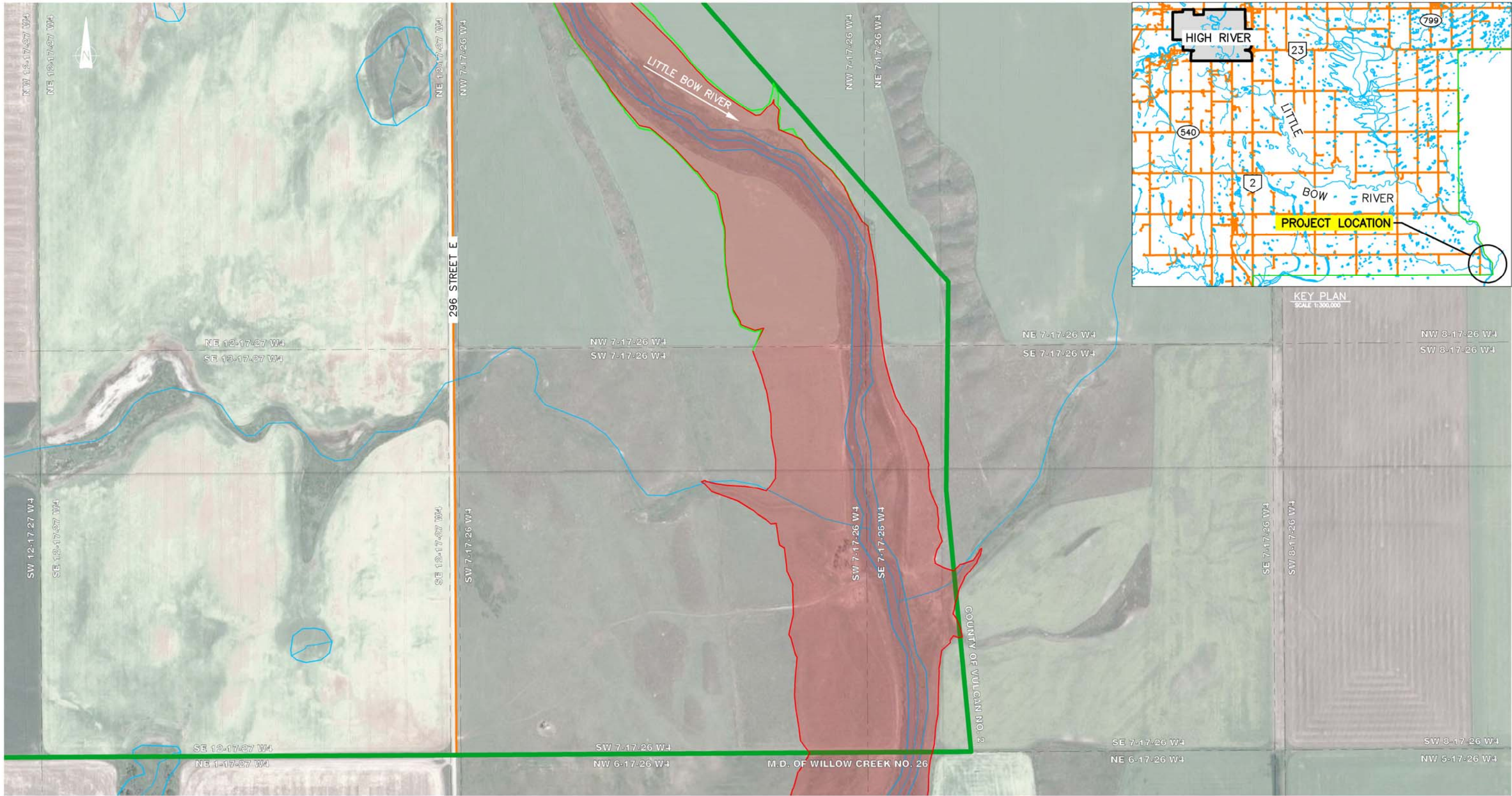


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<b>M.D. OF FOOTHILLS NO. 31</b>			
<b>INCREMENTAL FLOOD DAMAGES AND MITIGATION OPTIONS - LITTLE BOW RIVER (14 OF 15)</b>			
Date:	APRIL 2016	File Path:	216703-F6314.dwg
Figure No:	6.3.14	Rev:	DRAFT
<i>This figure is prepared for the use of the contractual customer of WorleyParsons Canada Services Ltd. (WorleyParsons) and Amec Foster Wheeler Environment and Infrastructure (AMEC). WorleyParsons and AMEC have exercised reasonable skill, care, and diligence to assess the information acquired during the preparation of this information, but makes no guarantee or warranties as to the accuracy or completeness of this information. WorleyParsons and AMEC assume no liability to any other party for any representations contained within.</i>			





- LEGEND:**
- INCREMENTAL INCREASED FLOOD INUNDATION ZONE
  - 2013 FLOOD EXTENT
  - INCREMENTAL DECREASED FLOOD INUNDATION ZONE
  - POTENTIAL BERM
  - HEIGHTENED EROSION VULNERABILITY ZONE
  - ROADS
  - WATERBODIES

SCALE  
1:7500  
0 50 100 150 m



**Advisian**  
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**M.D. OF FOOTHILLS NO. 31**

**INCREMENTAL FLOOD DAMAGES AND MITIGATION  
OPTIONS - LITTLE BOW RIVER (15 OF 15)**

Date: APRIL 2016

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