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SIKSIKA BOW RIVER HAZARD STUDY

Open Water Flood Inundation Mapping

Submitted to:
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REPORT

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Executive Summary

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in August 2017 to undertake the Siksika Bow River Hazard Study. The primary purpose of the study is to assess and identify river and flood hazards along the Bow River reach from the Highwood River confluence to a location approximately 2 km downstream of Bow City. The study is conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. The project stakeholders include the Government of Alberta; Siksika Nation; Municipal District of Foothills No. 31; the Counties of Newell, Rocky View, Vulcan and Wheatland; and the public.

The study consists of seven components. This report documents the methodology and results of the open water flood inundation mapping component, including the inundation maps for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods.

Along the Bow River study reach of 221 km, there are two irrigation diversion canals (i.e. Carseland Diversion of Bow River Irrigation District [BRID] and Bassano Dam Diversion of Eastern Irrigation District [EID]) and no major tributaries along the study reach. The downstream boundary of the hydraulic model terminates at a location 2 km downstream of Bow City.

The flood inundation maps were prepared using ArcGIS. The simulated flood water levels at the cross sections were used to create a continuous water surface. The edge of inundation was delineated by subtracting the LiDAR DTM from the water surface. The following two types of flood inundation were mapped:

- Direct inundation where there is a direct overland connection between the main river channels and inundated areas on the floodplains. This includes special areas where inundation is caused by single or multiple overtopping points.
- Flooding behind flood control structures.

A total of 158 residences along the Bow River study reach would be inundated during flood events with return periods of 5 years or higher. Simulations results and review of the recently collected aerial imagery indicate that most of these residences (approximately 148 houses) are situated on Siksika Nation land. The main residential and commercial areas to be affected by open water flooding along the Bow River study reach include those listed below:

- One farm house and the North Bow Lodge are situated on the left floodplains upstream of the Carseland Weir. The farm house would be inundated during the flood events with return period of 5 years or higher. The North Bow Lodge would be inundated during the flood events with return period of 100 years or higher.
- The residences and buildings between the Carseland Weir and Highway 547 (Arrowwood) bridge crossing, most of which are situated on the Siksika Nation land, would be inundated during the flood events with return period of 20 years or higher.
- The Wyndham-Carseland Provincial Park and Wyndham Carseland Campground would be inundated during the flood events with return period of 10 years or higher.

- The Hidden Valley Resort & Golf Course would be inundated during the flood events with return period of 10 years or higher. In addition, many houses and buildings between Highway 547 (Arrowwood) bridge crossing and Highway 842 (Cluny) bridge crossing would be inundated during the flood events with return period of 20 years or higher.
- Many houses and buildings between Highway 842 (Cluny) bridge crossing and Bassano Dam would be inundated during the flood events with return period of 20 years or higher.
- The S&J Montana's Campground on the left floodplain immediately downstream of the Highway 842 bridge crossing would be flooded during floods with return period of 10 years or higher.
- Potions of Bow City downstream of the Highway 539 bridge crossing would be flooded during flood events with return period of 200 years or higher.

Acknowledgements

Golder Associates Ltd. (Golder) acknowledges the contributions of the following staff of Alberta Environment and Parks (AEP):

- Mr. Kurt Morrison, AEP's project manager for the study, coordinated the participation from AEP, and provided technical advice and review of this report.
- Mr. Peter Onyshko, AEP's technical advisor for the study, provided technical review and guidance.

The contributions of the following Golder team members are acknowledged:

- Dr. Hua Zhang, Golder's project manager, was responsible for regular communications with AEP, and overseeing the HEC-RAS modelling, flood inundation mapping and preparation of this report.
- Dr. Dejiang Long, project director and senior reviewer, was responsible for providing senior inputs and review, quality control and assurance for the study, and reviewing this report.
- Mr. Jie Chen, a hydrodynamic modelling specialist and project engineer for this study, was responsible for conducting the HEC-RAS modelling, overseeing preparation of the flood inundation maps, and provided inputs to this report.
- Dr. Parnian Hosseini, a hydrodynamic modelling support for this study, was involved in conducting the HEC-RAS modelling analysis.
- Mr. Sean Kurash, a GIS specialist, was responsible for preparation of the flood inundation maps and provided inputs to this report.

Table of Contents

1.0 INTRODUCTION......1

1.1 Study Objectives......1

1.2 Study Area and Reach......1

1.3 Work Scope......1

2.0 AVAILABLE DATA......3

2.1 Flood Frequencies......3

2.2 DTM and Aerial Imagery......3

2.3 HEC-RAS Model......5

2.3.1 HEC-RAS Program......5

2.3.2 HEC-RAS Production Model......5

2.3.3 Model Boundary Conditions......6

2.3.4 Modelling Results......6

2.4 Flood Control Structures......6

3.0 FLOOD INUNDATION MAPS......7

3.1 Methodology......7

3.2 Preparation of Flood Inundation Maps......8

3.2.1 General......8

3.2.2 Manual Edits......8

3.2.2.1 Locations......8

3.2.2.2 2-Year Flood Event......8

3.2.2.3 5-Year Flood Event......9

3.2.2.4 10-Year Flood Event......9

3.2.2.5 20-Year Flood Event......10

3.2.2.6 35-Year Flood Event......10

3.2.2.7 50-Year Flood Event......11

3.2.2.8 75-Year Flood Event......11

3.2.2.9 100-Year Flood Event......12

3.2.2.10 200-Year Flood Event......12

3.2.2.11 350-Year Flood Event 13
3.2.2.12 500-Year Flood Event 13
3.2.2.13 750-Year Flood Event 13
3.2.2.14 1,000-Year Flood Event 14
3.3 Direct Flood Inundation Areas 14
3.3.1 Definition 14
3.3.2 Major Direct Inundation Areas for the 2- to 75-year Flood Events 14
3.3.3 Major Direct Inundation Areas for the 100-year Flood Event 15
3.3.4 Major Direct Inundation Areas for the 200-year to 1,000-year Flood Event 16
3.4 Inundation Due to Potential Flood Control Structure Failures 16
3.4.1 Mapping Approach 16
3.4.2 Hidden Valley Resort Berm 17
3.5 Areas Affected by Flooding 17
3.5.1 Residential Areas 17
3.5.2 Flooding of Commercial and Industrial Areas 19
3.5.3 Flooding of Bridges and Culverts 19
3.5.3.1 Considerations 19
3.5.3.2 Bow River 19
4.0 FLOOD DEPTH GRIDS 21
4.1 GIS Data Specifications 21
4.2 General Comments 21
5.0 CONCLUSIONS 22

TABLES

Table 1: Summary of Flood Peak Flows at the Flow Change Locations Used in the HEC-RAS Model 4
Table 2: Flood Control Structure along the Study Reach 6
Table 3: Manual Edits for the 2-Year Flood Event....................8
Table 4: Manual Edits for the 5-Year Flood Event....................9
Table 5: Manual Edits for the 10-Year Flood Event....................9
Table 6: Manual Edits for the 20-Year Flood Event....................10
Table 7: Manual Edits for the 35-Year Flood Event....................10
Table 8: Manual Edits for the 50-Year Flood Event....................11
Table 9: Manual Edits for the 75-Year Flood Event....................11
Table 10: Manual Edits for the 100-Year Flood Event....................12
Table 11: Manual Edits for the 200-Year Flood Event....................12
Table 12: Manual Edits for the 350-Year Flood Event....................13
Table 13: Manual Edits for the 500-Year Flood Event....................13
Table 14: Manual Edits for the 750-Year Flood Event....................14
Table 15: Manual Edits for the 1,000-Year Flood Event....................14
Table 16: Other Possible Residences Affected by Various Flood Events 18
Table 17: Flooding at the Bridges along the Bow River Study Reach 20

FIGURES

Figure 1: Study Area (Provided by AEP) 2
Figure 2: Illustration of Flood Control Structure Failure Inundation Areas 17

APPENDICES

APPENDIX A
Open Water Flood Inundation Maps

1.0 INTRODUCTION

1.1 Study Objectives

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in August 2017 to undertake the Siksika Bow River Hazard Study (the study). The primary purpose of the study is to assess and identify river and flood hazards along the Bow River reach (the study reach) from Highwood River confluence to a location approximately 2 km downstream of Bow City. The project stakeholders include the Government of Alberta; Siksika Nation; Municipal District of Foothills No. 31; the Counties of Newell, Rocky View, Vulcan and Wheatland; and the public.

The study was conducted under the provincial Flood Hazard Identification Program (FHIP). The study consists of seven primary components: (i) Survey and Base Data Collection, (ii) Hydraulic Model Creation and Calibration, (iii) Open Water Flood Inundation Map Production, (iv) Open Water Flood Hazard Identification, (v) Governing Design Flood Hazard Map Production, (vi) Flood Risk Assessment and Inventory, and (vii) Channel Stability Investigation. A stand-alone report was prepared for each of these components.

This report documents the methodology and results of the open water inundation mapping component. This report provides qualitative and limited quantitative information about flood inundation extents and special zones along the study reach.

1.2 Study Area and Reach

The study area is along the 221 km reach of the Bow River as shown in Figure 1. There are two irrigation diversion canals (i.e. Carseland Diversion of Bow River Irrigation District [BRID] and Bassano Dam Diversion of Eastern Irrigation District [EID]) and no major tributaries along the study reach. The downstream boundary of the hydraulic model terminates at a distance of 2 km downstream of Bow City.

The study area is situated in the Siksika Nation, the Hamlet of Bow City, and the lands in five municipal districts and counties, including Municipal District of Foothills No. 31, and the Counties of Newell, Rocky View, Vulcan and Wheatland.

1.3 Work Scope

The scope of the open water flood inundation mapping component includes the following tasks:

- Open water flood inundation map production,
- Flood water surface TIN development, and
- Flood depth grid creation.

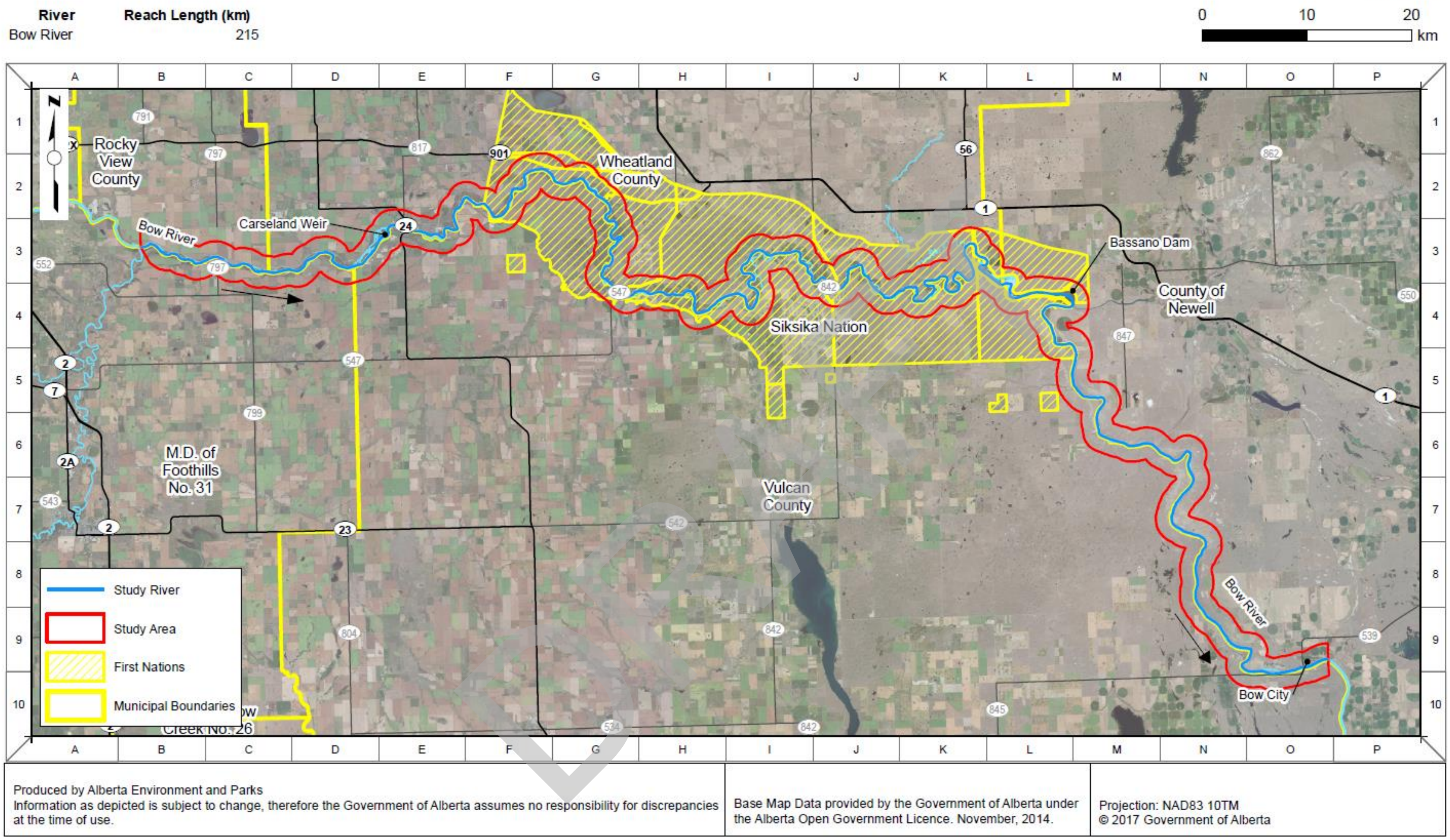

Figure 1: Study Area (Provided by AEP)

2.0 AVAILABLE DATA

2.1 Flood Frequencies

The Bow River originates in the Rocky Mountains and traverses the foothills before reaching Calgary on the edge of the Prairies. The stream flows through a mix of Alpine, Subalpine, Boreal Foothill and Aspen Parkland eco-regions. The land use in the river basin ranges from urban Calgary, to agricultural lands in parts of the foothills, and to forest in the remainder of the foothills and in the mountains.

The topography of Bow River basin extends from Rocky Mountains, following by Foothills (Porcupine Hills) to Western Alberta Plains with a ground elevation drop of more than 2,000 m. When moist-air from the southeast is lifted along the Foothills and Rocky Mountains, large amounts of rainfall may occur within the basin. This could result in extreme flooding, especially when the basin has been saturated by snowmelt.

The Bow River is joined by several tributaries upstream of the study area, including the Elbow River, Nose Creek, Fish Creek and Pine Creek within Calgary. The Elbow River is the largest tributary to the Bow River within Calgary, and flows into the Glenmore Reservoir before entering the Bow River, just downstream of downtown Calgary. The Highwood River is a major tributary to the Bow River downstream of Calgary. No major tributaries join the Bow River within the study reach.

There are two Water Survey of Canada (WSC) gauging stations within the study. The most upstream station (WSC Station No. 05BM002) is located below Carseland Dam and has a gross drainage area of 15,700 km^2 with an effective drainage of 14,700 $km^{2.}$ The second station (Station No. 05BM004) is below Bassano Dam and has a gross drainage area of 20,300 km^2 with an effective drainage area of 17,800 km^2.

Table 1 presents a summary of the flood frequency estimates at various locations along the study reach. These estimates are the instantaneous flood peak discharges for the natural/naturalized flow conditions, based on the results in the Bow, Elbow, Highwood, and Sheep River Hydrology Assessment Report (Golder 2017) and the analysis in the Hydraulic Model Creation and Calibration of the Siksika Bow River Hazard Study (Golder 2019a).

2.2 DTM and Aerial Imagery

A detailed description of the LiDAR DTM data and survey data is provided in the Survey and Base Data Collection Report (Golder 2018a).

The aerial imagery of the study area was collected in July 2018. The imagery has a 30 cm Ground Sampling Distance (GSD) resolution and is delivered as 4-band orthophotos and stereo images. The deliverables include aerial triangulation data, metadata, camera calibration reports, flight report and an index of the aerial imagery tiles.

Table 1: Summary of Flood Peak Flows at the Flow Change Locations Used in the HEC-RAS Model

Location	HEC-RAS River Station (m)	Flood Peak Discharges of Various Return Periods (m^3/s)												
		2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year
Bow River below Highwood River Confluence	221,217	604	917	1,210	1,580	1,950	2,230	2,590	2,880	3,750	4,690	5,420	6,390	7,180
Bow River below Carseland Dam	190,457	604	923	1,230	1,620	2,010	2,310	2,690	2,990	3,890	4,790	5,480	6,370	7,090
Bow River at Highway 547	147,557	599	925	1,240	1,630	2,030	2,330	2,720	3,030	3,950	4,870	5,560	6,470	7,210
Bow River at Highway 842	111,426	597	932	1,260	1,680	2,100	2,420	2,820	3,150	4,120	5,090	5,820	6,790	7,560
Bow River below Crowfoot Creek	81,122	591	932	1,260	1,680	2,100	2,420	2,830	3,160	4,130	5,100	5,840	6,810	7,580
Bow River below Bassano Dam	64,379	591	932	1,260	1,680	2,100	2,420	2,830	3,160	4,130	5,100	5,840	6,810	7,580
Bow River at Highway 539	4,112	581	913	1,230	1,620	2,010	2,300	2,660	2,950	3,790	4,620	5,240	6,030	6,660

2.3 HEC-RAS Model

2.3.1 HEC-RAS Program

The latest version of HEC-RAS program (Version 5.0.5, June 2018) was used to develop the one-dimensional hydraulic model for the study area. The HEC-RAS program was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE). The software has a graphical user interface, separate hydraulic analysis components, data storage and management capabilities, and graphics and reporting facilities.

The HEC-RAS program was designed to perform one-dimensional (1D), two dimensional (2D) or combined 1D and 2D hydraulic calculations for a full network of natural and constructed channels. The program supports steady-state and unsteady-state hydraulic simulations. HEC-RAS can be used to calculate water surface profiles for gradually varied flow. In this study, the HEC-RAS program was used to develop the 1D model which was run in steady-state mode.

The main assumptions in 1D steady-state modelling are listed below:

- Flow is steady;
- The variation of the river channel and floodplain geometries is represented by a series of cross sections;
- The water level is constant at each cross section;
- Flow is gradually varied except at hydraulic structures;
- The channel slope is less than 10%, and
- The flow is perpendicular to the cross section alignment.

The HEC-GeoRAS module (Version 10.1) was used to prepare cross section data based on the integrated DEM and river survey data (Golder 2018a). HEC-GeoRAS is an ArcGIS extension tool specifically designed to create a HEC-RAS import file from geospatial data.

2.3.2 HEC-RAS Production Model

A HEC-RAS production model was developed to simulate water surface profiles for the 13 flood events (i.e. 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year floods) based on the calibrated HEC-RAS model, which was described in the Hydraulic Model Creation and Calibration Report (Golder 2019a).

The production model was set up to include the hydraulic effects of the emergency spillway at Bassano Dam constructed post the 2013 flood event. The spillway details were not coded into the model. The HEC-RAS production model was set up to simulate the water level and flow control characteristics of all spillways at the Bassano Dam according to the flow rating curves supplied by the Eastern Irrigation District.

The Hydraulic Model Creation and Calibration Report (Golder 2019a) presents the derivation of the flood peak flows at the various flow change locations for the various flood events used in the HEC-RAS Production Model, including the analysis methods, assumptions and results.

The flood control structures in the study area were represented in the HEC-RAS model as levees. The top-of-levee elevations were based on the survey data (Golder 2018a) for simulating the flood frequency profiles.

2.3.3 Model Boundary Conditions

The HEC-RAS production model boundaries for simulating the surface water profiles are listed below:

- Discharges at the upstream end of the Bow River study reach; and
- The specified flood peak flow changes at the six cross sections as listed in Table 1.
- Assumed normal flow condition with an energy slope of 0.036% at the model downstream boundary.

2.3.4 Modelling Results

The open water flood profiles for the 13 flood events along the study reach of Bow River are presented in the Hydraulic Model Creation and Calibration Report (Golder 2019a).

The open water flood water levels for each cross section along the study reach of Bow River are listed in Appendix C of the Hydraulic Model Creation and Calibration Report. They were used to prepare the flood inundation maps for each of the 13 flood events presented in this report.

2.4 Flood Control Structures

One flood control structure was identified along the study reach. Only structures regularly maintained by stakeholders and designed to provide a certain level of flood protection were included in this study. Private flood protection berms, if any, have not been included in this study.

The flood control structure is comprised of interlocking concrete blocks, which is located along the right bank of the Bow River adjacent to the Hidden Valley Resort & Golf Course, just upstream of the Highway 842 Bridge near Cluny (see Table 2). The location of this structure is presented in the Survey and Base Data Collection Report (Golder 2018a).

Table 2: Flood Control Structure along the Study Reach

No.	Side of River[a]	Length	Name	Description	Type
1	Right	1,540 m (upper berm) 500 m (lower berm)	Concrete Berm	Concrete block structure adjacent to Hidden Valley Resort	Berm

Note: (a) Right and left sides of the river are relative to an observer looking downstream.

3.0 FLOOD INUNDATION MAPS

3.1 Methodology

The flood inundation maps were prepared based on the following information:

- Simulated water levels at individual cross sections for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events;
- Locations and extents of individual cross sections;
- Topography from the recent LiDAR survey;
- Aerial imagery of the study area collected in July 2018; and
- Information about permanent flood control structures, consideration of past overland flow areas, and other relevant information.

The cross sections in ArcGIS were attributed with the water level output from the HEC-RAS production model. The model cross sections were extended where required to cover the maximum extents of inundated areas. Water levels between cross sections were linearly interpolated using a Triangulated Irregular Network (TIN) interpolation technique, and a water surface TIN was created for each inundation scenario.

Inundation extents were delineated by intersecting the water surface TINs and the LiDAR survey data. The delineated inundation areas were then carefully reviewed and modified for the following scenarios:

- Scenario 1 (S1) – Single Overtopping Point: At locations where inundated areas are connected to the main channel at a single overtopping point (spill point), the inundation extent was re-evaluated using a constant water level which is equal to that at the spill point.
- Scenario 2 (S2) – Multiple Overtopping Points: If there are multiple overtopping points related to a single overflow area, the inundation extent was based on the hydraulic gradient in the main channel between the overtopping points. The inundation extent upstream of the most upstream overtopping point and downstream of the most downstream overtopping point were evaluated using the estimated water levels at these bounding spill points.
- Scenario 3 (S3) – Single Overtopping Point Causing Overtopping Downstream: At some locations, Scenario 1 can lead to the following situation: if the area behind the single overtopping location would be (after some time) completely inundated and pooled with a constant water level elevation similar to the water level at the spill point, this may cause a second overtopping further downstream and flow back into the main channel, because at that point the water level behind the embankment may be higher than that in the main channel. In this case, the inundation extent was re-evaluated using a linear interpolation between the water level at the upstream spill point and the ground elevation at the downstream re-entry point.
- Scenario 4 (S4) – Potential Flood Inundation due to Flood Control Structure Failure: In areas where permanent flood control structures (see Section 2.4) have been identified and are not overtopped, the protected areas are shown as potentially flooded. The inundation extent is determined by assuming that the flood control structure is ineffective.

3.2 Preparation of Flood Inundation Maps

3.2.1 General

One set of flood inundation maps was prepared for each of the 13 flood events. The study area is covered by a total of 41 sheets (11 inch x 17 inch). The mapping scale is 1:10,000 except for the 12 mapping sheets (i.e. Figure Nos. 14 to 25) with the scale of 1:15,000. The maps were prepared using the local 3-Degree Transverse Mercator (3TM) zone and the Canadian Spatial Reference System North American Datum of 1983 (NAD83 CSRS) coordinate system and datum.

The maps include the 2018 aerial imagery and other base data (roads and railways) provided by AEP. The resulting inundation maps for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events are presented in Appendix A.

The flood inundation maps were prepared in a geographical information system (ESRI ArcGIS 10.3). The maps including all layers were provided to AEP as digital files in the ESRI ArcGIS file format.

3.2.2 Manual Edits

3.2.2.1 Locations

Flood inundation mapping at a number of locations required manual edits in the areas listed below:

- Some areas under the four scenarios described in Section 3.1;
- Some inundated areas along the tributaries;
- The area in Hidden Valley Resort which would be inundated due to backwater from downstream locations; and
- All areas behind the flood control structures (e.g. concrete block structures adjacent to Hidden Valley Resort).

The details of manual edits for each flood event are discussed in the following sections. The manual edits can be seen in the digital GIS assets delivered with this report.

3.2.2.2 2-Year Flood Event

The 2-year flood flows would be contained in the river channels along most of the study reach. Table 3 summarises the major manual edits made for the 2-year flood event.

Table 3: Manual Edits for the 2-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Between Cross Sections 34 and 37	Left	Scenario 1
2	Between Cross Sections 45 and 49	Left	Scenario 1
3	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
4	Between Cross Sections 109 and 113	Right	Scenario 1
5	Between Cross Sections 133 and 149	Right	Scenario 1
6	Between Cross Sections 185 and 187	Right	Scenario 1
7	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam

3.2.2.3 5-Year Flood Event

The major manual edits made for the 5-year flood event are summarized in Table 4.

Table 4: Manual Edits for the 5-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 128 and 133	Left	Scenario 1, Inundated area mapped as backwater for oxbow
3	Between Cross Sections 148 and 151	Right	Scenario 1
4	Between Cross Sections 155 and 161	Left	Scenario 1
5	Between Cross Sections 169 and 173	Left	Scenario 1
6	Between Cross Sections 185 and 187	Right	Scenario 1
7	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam

3.2.2.4 10-Year Flood Event

The major manual edits made for the 10-year flood event are summarized in Table 5.

Table 5: Manual Edits for the 10-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 226 and 233	Right	Scenario 1, potential flood control structure failure upstream of direct inundation
3	Between Cross Sections 239 and 243	Left	Scenario 1
4	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam

3.2.2.5 20-Year Flood Event

The major manual edits made for the 20-year flood event are summarized in Table 6.

Table 6: Manual Edits for the 20-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 75 and 78	Right	Scenario 1
3	Between Cross Sections 81 and 85	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
4	Between Cross Sections 84 and 85	Left	Scenario 1
5	Between Cross Sections 161 and 164	Left	Scenario 1
6	Between Cross Sections 164 and 168	Left	Scenario 1
7	Between Cross Sections 216 and 219	Right	Scenario 1
8	Between Cross Sections 237 and 243	Left	Scenario 1
9	Between Cross Sections 250 and 252	Right	Scenario 1, Inundated area in the oxbow mapped as backwater
10	Between Cross Sections 267 and 274	Left	Scenario 3
11	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam

3.2.2.6 35-Year Flood Event

The major manual edits made for the 35-year flood event are summarized in Table 7.

Table 7: Manual Edits for the 35-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 84 and 85	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
3	Between Cross Sections 132 and 137	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
4	Between Cross Sections 145 and 149	Right	Scenario 1
5	Between Cross Sections 164 and 168	Left	Scenario 1
6	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam

3.2.2.7 50-Year Flood Event

The major manual edits made for the 50-year flood event are summarized in Table 8.

Table 8: Manual Edits for the 50-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 127 and 129	Left	Scenario 1
3	Between Cross Sections 132 and 137	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
4	Between Cross Sections 267 and 280	Left	Scenario 3
5	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
6	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

3.2.2.8 75-Year Flood Event

The major manual edits made for the 75-year flood event are summarized in Table 9.

Table 9: Manual Edits for the 75-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 127 and 129	Left	Scenario 1
3	Between Cross Sections 132 and 137	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
4	Between Cross Sections 212 and 214	Left	Scenario 3
5	Between Cross Sections 245 and 250	Right	Scenario 3
6	Between Cross Sections 267 and 280	Left	Scenario 3
7	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
8	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

3.2.2.9 100-Year Flood Event

The major manual edits made for the 100-year flood event are summarized in Table 10.

Table 10: Manual Edits for the 100-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Downstream of Cross Section 58	Right	Removed inundation area in the Irrigation Canal near Carseland Weir
2	Between Cross Sections 127 and 129	Left	Scenario 1
3	Between Cross Sections 132 and 136	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
4	Between Cross Sections 267 and 270	Right	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
5	Between Cross Sections 267 and 280	Left	Scenario 3
6	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
7	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

3.2.2.10 200-Year Flood Event

The major manual edits made for the 200-year flood event are summarized in Table 11.

Table 11: Manual Edits for the 200-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Between Cross Sections 1 and 6	Right[1]	Scenario 3, Inundated area in the high ground channel mapped based on the Highwood River Hazard Project
2	Between Cross Sections 132 and 136	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
3	Between Cross Sections 267 and 270	Right	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
4	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
5	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

Note: 1. The inundated area in the high ground channel was mapped mainly based on the results presented in the Open Water Flood Inundation Mapping Report (Golder 2019b).

3.2.2.11 350-Year Flood Event

The major manual edits made for the 350-year flood event are summarized in Table 12.

Table 12: Manual Edits for the 350-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Between Cross Sections 1 and 6	Right[1]	Scenario 3, Inundated area in the high ground channel mapped based on the Highwood River Hazard Project
2	Between Cross Sections 132 and 136	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
3	Between Cross Sections 267 and 270	Right	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
4	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
5	Between Cross Sections 330 and 339	Right[2] (Access Road)	Parallel break lines were added to separate the water surfaces upstream and downstream of the Bassano Dam
6	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

Notes: 1) The Inundated area in the high ground channel was mapped mainly based on the results presented in the Open Water Flood Inundation Mapping Report (Golder 2019b).
2) For the inundation area adjacent to the Bassano Dam site, parallel break lines were added to separate the water surfaces upstream and downstream of the historic spillway. For the 350-year flood event, the access road along the dam crest would be overtopped between cross sections 333 and 334.

3.2.2.12 500-Year Flood Event

The major manual edits made for the 500-year flood event are summarized in Table 13.

Table 13: Manual Edits for the 500-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Between Cross Sections 1 and 6	Right[1]	Scenario 3, Inundated area in the high ground channel mapped based on the Highwood River Hazard Project
2	Between Cross Sections 132 and 136	Left	Scenario 1, Inundated area for a very large low-lying area mapped as backwater
3	Between Cross Sections 267 and 270	Right	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
4	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
5	Between Cross Sections 330 and 339	Right[2] (Access Road)	Parallel break lines were added to separate the water surfaces upstream and downstream of the Bassano Dam
6	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

Notes:1) The Inundated area in the high ground channel was mapped mainly based on the results presented in the Open Water Flood Inundation Mapping Report (Golder 2019b).
2) For the 500-year flood event, the access road along the dam crest would be overtopped from 220 m upstream of Cross Section 334 to 50 m downstream of Cross Section 334.

3.2.2.13 750-Year Flood Event

The major manual edits made for the 750-year flood event are summarized in Table 14.

Table 14: Manual Edits for the 750-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Between Cross Sections 1 and 6	Right [1]	Scenario 3, Inundated area in the high ground channel mapped based on the Highwood River Hazard Project
2	Between Cross Sections 267 and 270	Right	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
3	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
4	Between Cross Sections 330 and 339	Right (Access Road)	A very large portion of the access road would be overtopped along the dam crest
5	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

Notes: 1) The Inundated area in the high ground channel was mapped mainly based on the results presented in the Open Water Flood Inundation Mapping Report (Golder 2019b).

3.2.2.14 1,000-Year Flood Event

The major manual edits made for the 1,000-year flood event are summarized in Table 15.

Table 15: Manual Edits for the 1,000-Year Flood Event

Location I.D.	Location	Floodplain	Description
1	Between Cross Sections 243 and 250	Right	Scenario 3
2	Between Cross Sections 267 and 270	Right	Scenario 1, Inundated area in the unnamed tributary mapped as backwater
3	Between Cross Sections 335 and 336	Right	Removed inundation area in the Irrigation Canal near Bassano Dam
4	Between Cross Sections 330 and 339	Right (Access Road)	The entire access road would be overtopped along the dam crest
5	Between Cross Sections 419 and 420	Left	Scenario 1, Inundated area in the unnamed tributary mapped as backwater

3.3 Direct Flood Inundation Areas

3.3.1 Definition

The direct flood inundation areas are attributed to direct overland flow connection to the main channel flow, including Scenarios 1, 2 and 3.

3.3.2 Major Direct Inundation Areas for the 2- to 75-year Flood Events

Reach between the Upstream Boundary and Carseland Weir

There are some low-lying areas and back/side channels on the floodplains where ponding water would occur. Small to large portions of the floodplains would be flooded during the flood events. The inundated areas on the floodplains would be direct flood inundation areas.

Reach between Carseland Weir and Highway 547 (Arrowwood) Bridge Crossing

There are some low-lying areas and back/side channels on the floodplains where ponding water would occur. Most of the floodplains would be direct inundation areas. During floods with return period of 10 years or higher, the areas of Wyndham-Carseland Provincial Park and Wyndham Carseland Campground on both sides of the

Highway 24 bridge crossing would be inundated. During floods with return period of 20 years or higher, the Highway 547 embankment through the low-lying area on the right floodplain would be inundated.

Reach between Highway 547 (Arrowwood) Bridge Crossing and Highway 842 (Cluny) Bridge Crossing

There are some low-lying areas and back/side channels on the floodplains where ponding water would occur. Most of the floodplains would be direct inundation areas. During floods with return period of 10 years or higher, the area behind the Hidden Valley Resort Berm upstream of the Highway 842 bridge crossing would be inundated. During floods with return period of 20 years or higher, sections of local access roads through the Siksika Nation would be inundated.

Reach between Highway 842 (Cluny) Bridge Crossing and Bassano Dam

There are several small low-lying areas on the floodplains where ponding water would occur. The inundated areas on the floodplains would be direct flood inundation areas. During floods with return period of 10 years or higher, the S&J Montana's Campground on the left floodplain immediately downstream of the Highway 842 bridge crossing would be inundated. During floods with return period of 20 years or higher, several sections of local access roads would be inundated.

Reach between Bassano Dam and Bow City

This river reach has an incised channel, generally confined on both sides by the valley walls. It has limited floodplains. The inundated areas on the floodplains would be direct inundation areas. There are only a few small low-lying areas where ponding water would occur at the confluences of local tributaries.

3.3.3 Major Direct Inundation Areas for the 100-year Flood Event

Reach between the Upstream Boundary and Carseland Weir

Most of the floodplains would be inundated. The inundated areas on the floodplains would be direct flood inundation areas.

Reach between Carseland Weir and Highway 547 (Arrowwood) Bridge Crossing

Most of the floodplains would be direct inundation areas. The areas of Wyndham-Carseland Provincial Park and Wyndham Carseland Campground on both sides of the Highway 24 bridge crossing would be inundated. Sections of local access roads would be inundated. The Highway 547 embankment through the low-lying area on the right floodplain would be inundated.

Reach between Highway 547 (Arrowwood) Bridge Crossing and Highway 842 (Cluny) Bridge Crossing

Most of the floodplains would be direct inundation areas. The entire area behind the Hidden Valley Resort Berm upstream of the Highway 842 bridge crossing would be inundated. Sections of local access roads through the Siksika Nation would be inundated.

Reach between Highway 842 (Cluny) Bridge Crossing and Bassano Dam

There are several small low-lying areas where ponding water would occur. The inundated areas on the floodplains would be direct flood inundation areas. The S&J Montana's Campground on the left floodplain immediately downstream of the Highway 842 bridge crossing would be inundated. Several sections of local access roads would be inundated. The Bassano Dam embankment would not be overtopped.

Reach between Bassano Dam and Bow City

This river reach has limited floodplains. The inundated areas on the floodplains would be direct inundation areas. There are several small low-lying areas where ponding water would occur at the confluences of local tributaries. There is no development in these low-lying areas at confluences of tributaries

3.3.4 Major Direct Inundation Areas for the 200-year to 1,000-year Flood Event

Reach between the Upstream Boundary and Carseland Weir

The floodplains would be inundated. The inundated areas on the floodplains would be direct flood inundation areas. During floods with return period of 350 years or higher, the high ground channel at the Highwood River confluence with Bow River would be inundated. During floods with return period of 200 years or higher, the Johnson's Island Fuse Plug Dike on the left side of the Carseland Dam would be overtopped.

Reach between Carseland Weir and Highway 547 (Arrowwood) Bridge Crossing

The floodplains would be direct inundation areas. During floods with return period of 200 years or higher, the Carseland Irrigation Canal reach upstream of Highway 24 embankment would be inundated. The areas of Wyndham-Carseland Provincial Park and Wyndham Carseland Campground on both sides of the Highway 24 bridge crossing would be inundated. Sections of local access roads would be inundated. The Highway 547 embankment through the low-lying area on the right floodplain would be inundated.

Reach between Highway 547 (Arrowwood) Bridge Crossing and Highway 842 (Cluny) Bridge Crossing

The floodplains would be direct inundation areas. The area behind the Hidden Valley Resort Berm upstream of the Highway 842 bridge crossing would be flooded. Sections of local access roads through the Siksika Nation would be inundated.

Reach between Highway 842 (Cluny) Bridge Crossing and Bassano Dam

There are several small tributary areas where ponding water would occur. The inundated areas on the floodplains would be direct flood inundation areas. The S&J Montana's Campground on the left floodplain immediately downstream of the Highway 842 bridge crossing would be inundated. Several sections of local access roads would be inundated. The Bassano Dam embankment would not be overtopped if the Bassano Dam Emergency Spillway is operated following its future operation plan (EID 2018).

Reach between Bassano Dam and Bow City

This river reach has limited floodplains. The inundated areas on the floodplains would be direct inundation areas. There are several small tributary areas where ponding water would occur.

3.4 Inundation Due to Potential Flood Control Structure Failures

3.4.1 Mapping Approach

Inundation due to potential flood control structure failures was mapped based on main channel water levels. Areas behind flood control structures were mapped as flood control structure failures only if the flood water levels in the main river channels are higher than the natural ground or the toe of the control structure as shown in Figure 2.

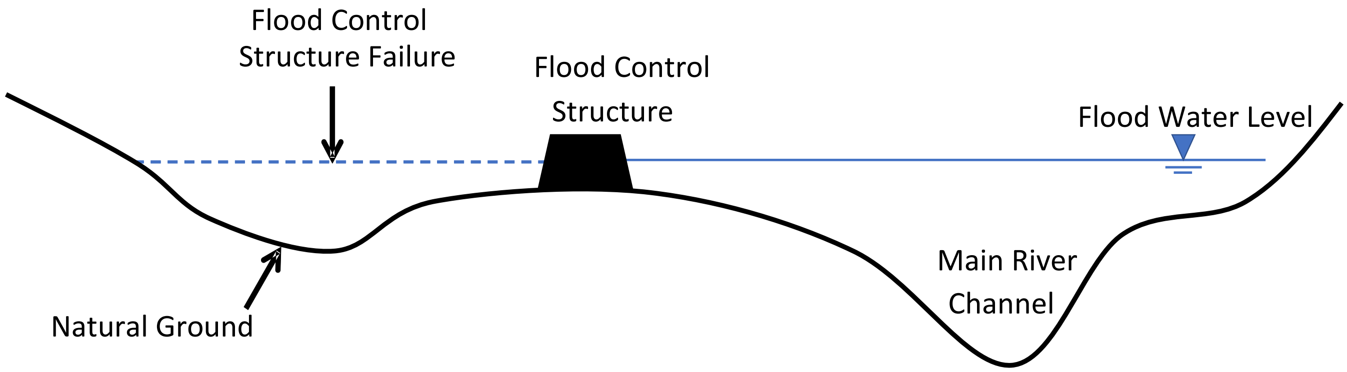

Figure 2: Illustration of Flood Control Structure Failure Inundation Areas

3.4.2 Hidden Valley Resort Berm

There is one flood control structure (i.e. Hidden Valley Resort Berm) along the study reach as described in Section 2.4. The Hidden Valley Resort & Golf Course could be subject to potential flood control structure failure during floods with return period of 2 to 5 years. The areas protected by the Hidden Valley Resort Berm could become direct inundation areas due to backwater from downstream flood flows or flow overtopping during floods with return period of 10 years or higher (see Section 3.3).

3.5 Areas Affected by Flooding

3.5.1 Residential Areas

Floodplains between the Upstream Boundary and Carseland Weir

There is no major residential area situated on the floodplains along this reach. There is one farm house on the left floodplain which would be inundated during the flood events with return period of 5 years or higher (see Table 16).

Floodplains between Carseland Weir and Highway 547 (Arrowwood) Bridge Crossing

There is no major residential area situated on the floodplains along this reach. There are many farm houses and buildings on the floodplains which would be inundated during the flood events with return period of 20 years or higher. Most of those are situated on the Siksika Nation land (see Table 16).

Floodplains between Highway 547 (Arrowwood) Bridge Crossing and Highway 842 (Cluny) Bridge Crossing

There is one major residential area (i.e. Hidden Valley Resort) situated on the floodplains along this reach, which would be inundated during the flood events with return period of 10 years or higher. In addition, over 20 houses and buildings on the floodplains would be inundated during the flood events with return period of 20 years or higher (see Table 16).

Reach between Highway 842 (Cluny) Bridge Crossing and Bassano Dam

There is no major residential area situated on the floodplains along this reach. There are more than 10 houses and buildings on the floodplains, which would be inundated during the flood events with return period of 20 years or higher (see Table 16).

Reach between Bassano Dam and Bow City

Potions of Bow City downstream of the Highway 539 bridge crossing would be inundated during floods with return period of 200 years or higher. There is one house on the right floodplain which would be inundated during the flood events with return period of 500 years or higher (see Table 16).

Other Residences

A total of 158 possible residences would be inundated during the flood events with period return period of 5 years or higher as summarized in Table 18. Most of these residences (approximately 148 houses) are situated on the Siksika Nation land, based on our review of the project aerial imagery.

Table 16: Other Possible Residences Affected by Various Flood Events

Residence Location I.D.	Residence Description [1]	Floodplain	No. of Adjacent Cross Section	Note
1	North Bow Lodge near Cross Section 27	Left	27	
2	Residence near Cross Section 39	Left	39 - 40	
3	Residence near Cross Section 67	Right	67 - 68	
4	Residences near Cross Section 71	Right	71	
5	Residences between Cross Sections 72 and 73	Right	72 - 73	2 residences
6	Residence near Cross Section 74	Right	74	
7	Residence near Cross Section 75	Right	75	
8	Residence near Cross Section 104	Right	104	
9	Residences between Cross Sections 123 and 124	Left	123 - 124	2 residences
10	Residences between Cross Sections 125 and 126	Left	125 - 126	2 residences
11	Residence near Cross Section 127	Left	127	
12	Residences between Cross Sections 127 and 128	Left	127 - 128	18 residences
13	Residences between Cross Sections 128 and 129	Left	128 - 129	2 residences
14	Residences between Cross Sections 128 and 129	Left	132 - 133	3 residences
15	Residence between Cross Sections 136 and 137	Left	136 - 137	
16	Residences between Cross Sections 154 and 156 upstream of Highway 547 (Arrowwood) Bridge	Right	154 - 156	8 residences
17	Residence near Cross Section 156 upstream of Highway 547 (Arrowwood) Bridge	Left	156	
18	Residence near Cross Section 158 downstream of Highway 547 (Arrowwood) Bridge	Right	158	
19	Residences between Cross Sections 160 and 169 downstream of Highway 547 (Arrowwood) Bridge	Left	160 - 169	16 residences
20	Residence near Cross Section 172	Left	172	
21	Residence near Cross Section 187	Left	187	
22	Residence near Cross Section 211	Right	211	
23	Residences near Cross Section 215	Right	215	2 residences
24	Residences between Cross Sections 220 and 228	Left	220 - 228	29 residences
25	Residences between Cross Sections 237 and 246 downstream of Highway 842 (Cluny) Bridge	Left	237 - 246	40 residences
26	Residences between Cross Sections 243 and 252	Right	243 - 252	7 residences
27	Residences between Cross Sections 266 and 273	Left	266 - 273	5 residences
28	Residences between Cross Sections 301 and 311	Left/Right	301 - 313	7 residences
29	Residence near Cross Section 359	Right	359	

Note: 1. These residences were identified using the aerial imagery.

3.5.2 Flooding of Commercial and Industrial Areas

Floodplains between the Upstream Boundary and Carseland Weir

The North Bow Lodge situated on the left floodplain would be inundated during the flood events with return period of 100 years or higher.

Floodplains between Carseland Weir and Highway 547 (Arrowwood) Bridge Crossing

The Wyndham-Carseland Provincial Park and Wyndham Carseland Campground would be inundated during floods with return period of 10 years or higher.

Floodplains between Highway 547 (Arrowwood) Bridge Crossing and Highway 842 (Cluny) Bridge Crossing

The Hidden Valley Resort Golf Course, situated on the right floodplains along this reach, would be inundated during the flood events with return period of 10 years or higher.

Reach between Highway 842 (Cluny) Bridge Crossing and Bassano Dam

The S&J Montana's Campground on the left floodplain immediately downstream of the Highway 842 bridge crossing would be inundated during floods with return period of 10 years or higher.

3.5.3 Flooding of Bridges and Culverts

3.5.3.1 Considerations

A bridge is considered affected by flood when flood waters reach its low chord. There is no culvert crossing along the Bow River study reach.

3.5.3.2 Bow River

None of the bridges along the Bow River study reach would be affected during flood events with return period of 50 years or lower. These is one bridge (i.e. Highway 547 [Arrowwood] Bridge) which would be affected during the 100-year flood and higher.

Table 19 provides a summary of the simulated water levels at the four bridges for the various flood events, as well as the flow velocities and clearances during the 100-year flood event.

Table 17: Flooding at the Bridges along the Bow River Study Reach

Bridge Station (m)	Name	Minimum Deck Elevation (m)	Minimum Low Chord Elevation (m)	Simulated Water Levels at the Bridges for the Various Flood Events (m)													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for the 100-year Flood Event [1] (m)	Flood Event Causing Pressure Flow (Return Period)
				2-year	5-year	10-year	20-year	35-year	50-year	75-year	100-year	200-year	350-year	500-year	750-year	1,000-year			
190459	Highway 24 Bridge	909.91	909.66	903.85	904.56	905.10	905.66	906.14	906.46	906.81	907.10	907.78	908.34	908.67	909.07	909.35	5.37	2.56	> 1,000-year
147553	Highway 547 (Arrowwood) Bridge	856.70	854.66	851.44	852.27	852.93	853.59	854.11	854.41	854.76	855.02	855.71	856.23	856.58	857.00	857.30	1.85	-0.36	75-year
111407	Highway 842 (Cluny) Bridge	819.63	818.28	813.55	814.54	815.25	815.95	816.53	816.91	817.36	817.68	818.56	819.45	820.07	820.69	821.44	2.66	0.60	200-year
4112	Highway 539 Bridge	751.56	747.51	742.42	743.27	743.94	744.65	745.28	745.71	746.21	746.58	747.52	748.35	748.92	749.61	750.14	2.66	0.93	200-year

Note 1: The clearances for the 100-year flood event are the elevation differences between bridge low chord elevations and simulated water levels. Negative clearance values indicate that the water surface would be above the low chord and that pressure flow would occur.

4.0 FLOOD DEPTH GRIDS

4.1 GIS Data Specifications

The following GIS data is provided to AEP for each of the 13 flood events:

- Inundation polygons;
- Water surface elevations TINs;
- Water surface elevation rasters; and
- Flood depth rasters.

All GIS data was created in ArcGIS 10.3 compatible format in the native study coordinate system (Canadian Spatial Reference System, North American Datum of 1983 (CSRS NAD83), Epoch 2002 and 3-Degree Transverse Mercator projection with the Central Meridian of 111° (3TM 111)). All raster files have a spatial resolution of 0.5 m.

The inundation polygons and raster files were stored in ArcGIS file geodatabases, Version 10.3. The flood water level TINs were stored as ArcGIS terrain datasets in the file geodatabases, Version 10.3.

4.2 General Comments

The flood water level data provided as terrains and rasters, covers all areas between cross section lines and in special inundation areas within the study area including dry areas.

The flood water depth rasters only include the areas with a water depth of more than 0.01 m.

5.0 CONCLUSIONS

The calibrated HEC-RAS model and the LiDAR DTM provided a good basis for simulating the flood levels and preparing the flood inundation maps for the 13 open water flood events (i.e. 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water floods), including direct flood inundation areas and other indirect flood inundation areas.

The simulation results show that many residential and commercial/industrial areas along the Bow River study reach would be affected by open water flooding, particularly within the Siksika Nation.

Report Signature Page

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APPENDIX A

Open Water Flood Inundation Maps

TO BE PRIVIDED SEPARATELY

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