REPORT

Stand Off Flood Study

Study Summary Report

Submitted to:

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Distribution List

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Executive Summary

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder), a member of WSP in June 2020 to conduct the Stand Off Flood Study (the study). The primary purpose of the study is to assess and identify river and flood hazards in the vicinity of Stand Off, through Kainai Nation and Cardston Country. This study is part of 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. Project stakeholders include the Government of Alberta, Kainai Nation, Cardston County, and the general public.

This report documents the methodology and results for all components of the study which are listed below:

- Survey and base data collection;
- Open water hydrology assessment;
- Open water hydraulic modelling;
- Open water flood inundation mapping; and
- Design flood hazard mapping.

The total length of the Belly River study reach is approximately 18.6 km, the total length of the Unnamed Tributary study reach is approximately 8.5 km. An additional reach of approximately 3.5 km was included in the HEC-RAS hydraulic model beyond the upstream end of the required study reach to simplify the boundary set up at upstream boundary of the Belly River for a coupled 1D/2D model.

The first survey was conducted along the Belly River in July 2021, and the second survey was conducted along the Unnamed Tributary in August 2021 to collect bathymetric and hydraulic structure data for the model setup.

A hydrology assessment was completed to provide the flood peak discharge estimates for the study area as inputs to the HEC-RAS model.

A coupled 1D/2D HEC-RAS hydraulic model was developed for the study area. The HEC-RAS model setup for the study area was informed by supplementary rough two-dimensional modelling without including channel bathymetry, bridges and culverts in the geometry. The HEC-RAS model includes the Belly River and Unnamed Tributary within the study area. The model was calibrated and validated based on the following:

- Low flow conditions (i.e., water levels and discharges) measured during the July 2021 survey.
- High flow conditions associated with the 1975 and 2010 flood events on the Belly River using highwater marks collected by AEP.
- High flow conditions associated with the 1995, 2004 and 2016 flood events on the Belly River using anecdotal highwater information collected during this study.

The calibrated Belly River channel Manning's *n* value was 0.030 for flood flow conditions. In the absence of flood data or highwater marks for model calibration for Unnamed Tributary, a channel Manning's *n* value of 0.050 was estimated for flood flow conditions. The Manning's *n* values for the floodplain areas were estimated and selected based on the land use types. The calibrated model was used to simulate the water surface profiles for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events in the study area.

The model sensitivity was evaluated for the 100-year flood event. The results of the sensitivity analysis show that variations of the channel and floodplain roughness values have small impacts on the simulated water levels along the Belly River and Unnamed Tributary study reaches. Changes of the energy slope at the downstream boundary have also small impacts on the simulated flood levels.

The coupled 1D/2D HEC-RAS model produces a continuous water surface of directly inundated areas for each simulated flood event. Directly inundated areas were mapped where there is a direct connection between the main river channel and inundated areas on the floodplains. This includes areas where inundation is caused by topographic or structural overtopping points as well as backwater flooding. Because the water level for 1000-year flood is lower than the ground elevation of flood control structure, no areas of potential flooding due to flood control structures failure were identified. Flood inundation and hazard maps were prepared for the study reaches of the Belly River and Unnamed Tributary using ArcGIS.

Based on the simulation results, various residential areas along the right floodplain of Belly River would be flooded starting at the 10-year flood and various commercial areas would be flooded starting at 75-year flood.

The floodway was defined based on the 1 m depth, 1 m/s velocity and main channel criteria with some professional judgment. The results of the design flood hazard mapping are the delineation of floodway and flood fringe zones including high hazard flood fringe areas. Based on the flood hazard maps, one residential house on the right floodplain is situated within the floodway zone along the Belly River study reach.

Acknowledgements

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

- Mr. Muhammad Durrani, AEP's project manager for the study, coordinated the participation from AEP, provided technical advice and guidance for the overall project and review of this report.
- Mr. Lance Katan, provided support in management of the study, while providing technical advice for the overall project 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 staff from Golder are acknowledged:

- Mr. Jie Chen, Golder's supporting project manager, was responsible for regular communications with AEP and overseeing the HEC-RAS modelling, flood inundation mapping, flood hazard mapping as well as preparation of this report.
- Dr. Hua Zhang, Golder's project manager, was responsible for overseeing HEC-RAS modelling.
- Dr. Dejiang Long, senior advisor and reviewer for this study, was responsible for providing senior inputs and review, quality control and assurance for the study.
- Dr. Wolf Ploeger, project director and senior reviewer for this study, was responsible for providing senior inputs and review, quality control and assurance for the study, and reviewing this report.
- Dr. Getu Biftu, senior hydrologist, was responsible for open water hydrology assessment.
- Dr. Tebikachew Tariku, a hydrodynamic modelling support, was responsible for conducting HEC-RAS modelling, preparing flood hazard maps, and preparation of this report.
- Mr. Amir Gharavi, a hydrodynamic modelling support, was involved in performing field surveys and conducting HEC-RAS modelling.
- Mr. Peter Thiede, a GIS specialist, was responsible for preparing the flood inundation maps and flood hazard maps to this report.
- Mr. Carmen Orosz, field survey lead for this study, was responsible for field survey and hydraulic structure data collection.

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1.0 INTRODUCTION

1.1 Study Background

Golder Associates Ltd. (Golder), a member of WSP was commissioned by Alberta Environment and Parks (AEP) in June 2021 to undertake the Stand Off Flood Study (the study). The primary purpose of the study is to assess and identify flood hazards in the vicinity of Stand Off, through Kainai Nation and Cardston County. The original study reach covered an 18.6 km long reach of the Belly River. During the filed inspection, Kainai Nation requested that the flood study should also include an 8.5 km long reach of the Unnamed Tributary flowing through Stand Off.

The study was 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 flood hazards. Key project stakeholders include the Government of Alberta, Kainai Nation and Cardston County.

The project involves working with Kainai Nation. There is no previous provincial flood hazard study or mapping within the study area.

This study is comprised of multiple components and deliverables. This report documents the methodology and results of all major study components listed below.

1. Survey and Base Data Collection
2. Open Water Hydrology Assessment
3. Open Water Hydraulic Modelling
4. Open Water Flood Inundation Mapping
5. Design Flood Hazard Mapping.

1.2 Study Objectives

The overall goal of the study is to enhance public safety and support the assessment and identification of flood hazards in the study area. The study results are intended to reduce potential future flood damages and associated disaster assistance costs, to mitigate flood impacts by informing land use planning decisions, and for emergency preparation.

This report summarizes the work of all five study components. The tasks and deliverables associated with this study are listed below:

- river cross-section surveys;
- hydraulic structure data collection;
- flood history documentation;
- open water flood hydrology assessment;
- HEC-RAS hydraulic model creation for open water modelling;
- floods simulations, water surface profile creation, and sensitivity analysis;
- open water flood inundation mapping; and
- floodway criteria and flood hazard mapping.

1.3 Study Area

Figure 1-1 provides an overview of the study area including the following:

- an 18.6 km long Belly River reach, extending from the eastern boundary of SE-31-5-25-W4M to the southern boundary of SW-27-6-25-W4M;
- an 8.5 km long Unnamed Tributary reach, extending from a location immediately downstream of a local road to its confluence with the Belly River.

An additional 3.5 km length of the study reach was included in HEC-RAS hydraulic model beyond the upstream end of the required study reach to simplify the boundary setup at upstream boundary of the Belly River for a coupled 1D/2D model reach. The downstream boundary of the hydraulic model terminates on the Belly River approximate 3.6 km downstream of Highway 2 Bridge.

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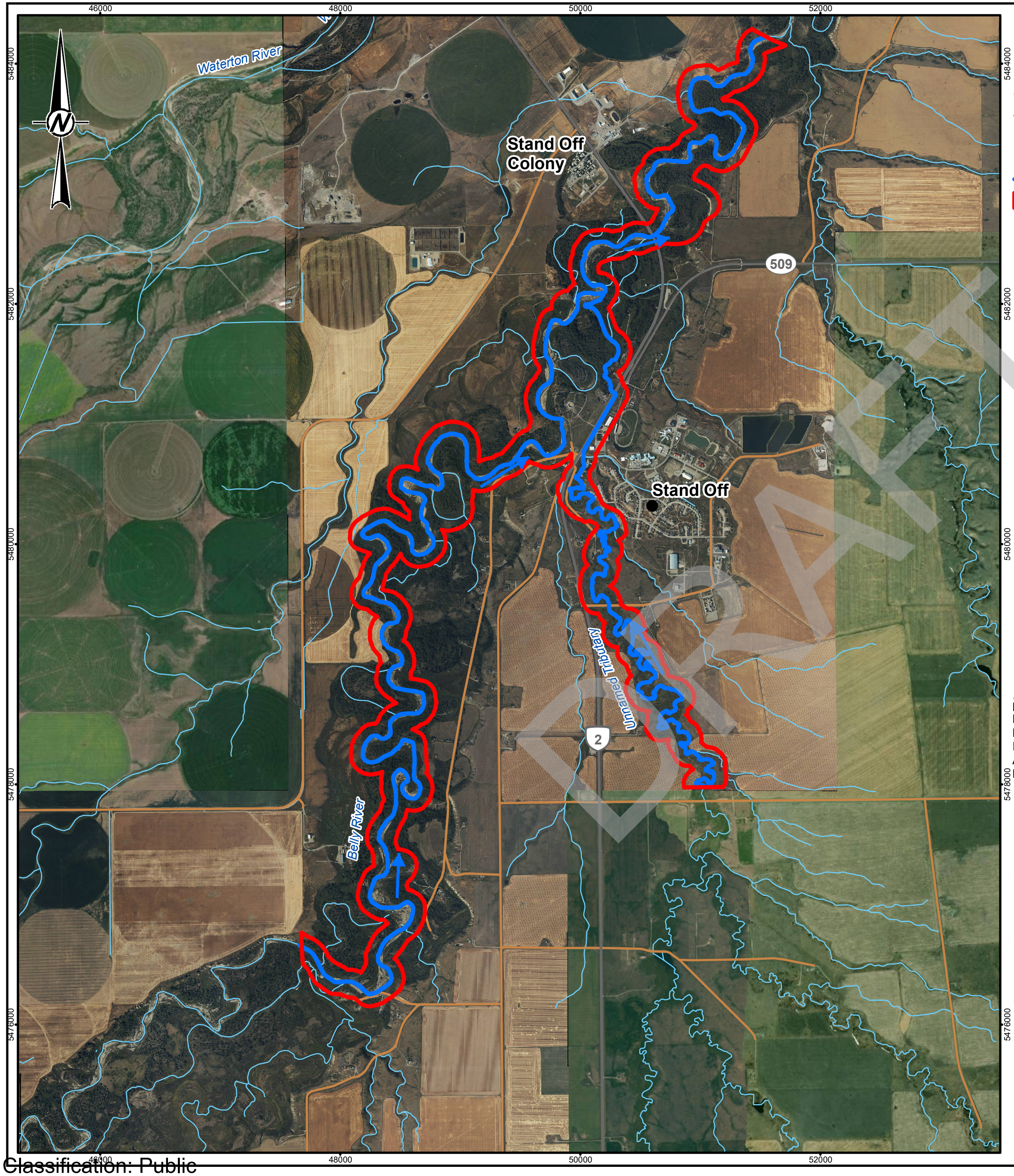

LEGEND

- ● POPULATED PLACE
- — PRIMARY HIGHWAY
- — SECONDARY HIGHWAY
- — LOCAL ROAD
- ➡ FLOW DIRECTION
- — WATERCOURSE
- — SURVEY REACH
- ☐ FLOOD HAZARD STUDY AREA

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CLIENT

ALBERTA ENVIRONMENT AND PARKS

PROJECT

STAND OFF FLOOD STUDY

TITLE

LOCATION MAP OF THE STUDY AREA

CONSULTANT

wsp GOLDER

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PREPARED	NB
REVIEWED	JC
APPROVED	WP

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2.0 SURVEY AND BASE DATA COLLECTION

2.1 General

Golder conducted surveys of the Belly River and Unnamed Tributary within the study area during two separate periods. The first survey was conducted along the Belly River from July 9 to 14, 2021. Survey data was collected at 83 cross sections and for one hydraulic structure. The second survey was conducted along the Unnamed Tributary at 18 cross sections and three hydraulic structures on August 27, 2021.

The survey scope included the following:

- survey of channel cross sections and hydraulic structures;
- survey of flood control structures; and
- measurement of discharge and water surface profile.

In addition, five Alberta Survey Control Monuments (ASCM) were surveyed upon the request of AEP in support of Light Detection and Ranging (LiDAR) remote sensing data collection (by others), for confirming that the LiDAR-based digital terrain model (DTM) meets FHIP accuracy standards and that there is consistency between the LiDAR and ground surveys.

A site reconnaissance was conducted by representatives from AEP and Golder on July 7, 2021. The field visit involved the following:

- Reviewed and confirmed the preliminary survey plan;
- Confirmed the locations and numbers of channel cross sections and hydraulic structures to be surveyed;
- Identified potential flood control structures; and
- Familiarized with the study area.

2.2 Procedures and Methodology

2.2.1 Survey Equipment and Control

The survey equipment used in collecting the topographic, bathymetric, and structure data for this study included the following:

- Real-time Kinematic (RTK) Global Positioning System (GPS): A Trimble® R8 RTK base station and Trimble® R10 RTK rover units, the latter of which were paired to Trimble® TSC3 hand-held data collectors running Trimble Access® survey software, were used to survey ground features, water levels, and the channel bed in areas where hydraulic conditions allowed the surveyors to wade the channel and walk on the banks. The RTK system was also used to survey the following:
  - Control points and benchmarks within the study area.
  - Bridge and culvert structures.
- Acoustic Doppler Velocimeter (ADV): A SonTek FlowTracker2® ADV in combination with a top-set wading rod was used to conduct discharge measurements on the Belly River and Unnamed Tributary.

The proposed locations of all cross sections were identified in a digital georeferenced vector format. The survey crew utilized them on the data collectors to guide the survey. A georeferenced survey plan was uploaded into the data collector to aid the surveyor in maintaining precise spacing and alignment of cross sections along each study reach.

All surveyed points were acquired by wading the channel and walking on the banks. Each survey data point collected was attributed a specific code. A schematic of survey point codes and corresponding descriptions is shown in Figure 2-1. It includes a complete list of survey codes for the RTK and total station.

The data collected using typical ground-based and acoustic-based technologies were referenced to the ASCM benchmarks (i.e., ASCM 69658, ASCM 80002, ASCM 292284, ASCM 590240) situated within the study area. There was no calibration of the collected survey data.

Two local benchmarks were established within the study area at the beginning of the survey. The survey crew checked the data accuracy at the local benchmark at the start and end of each survey day.

All survey data was collected in the local 3-Degree Transverse Mercator (3TM) 114° W coordinate system and referenced to NAD83 (CSRS) horizontal and the CGVD28 vertical datums. The RTK survey data outputs provided an orthometric elevation with correct northing and easting coordinates. The survey data were acquired by pre-loading geoid files into the survey equipment. Ellipsoidal heights were transformed to CGVD28 orthometric heights using the HTv2.0 geoid model.

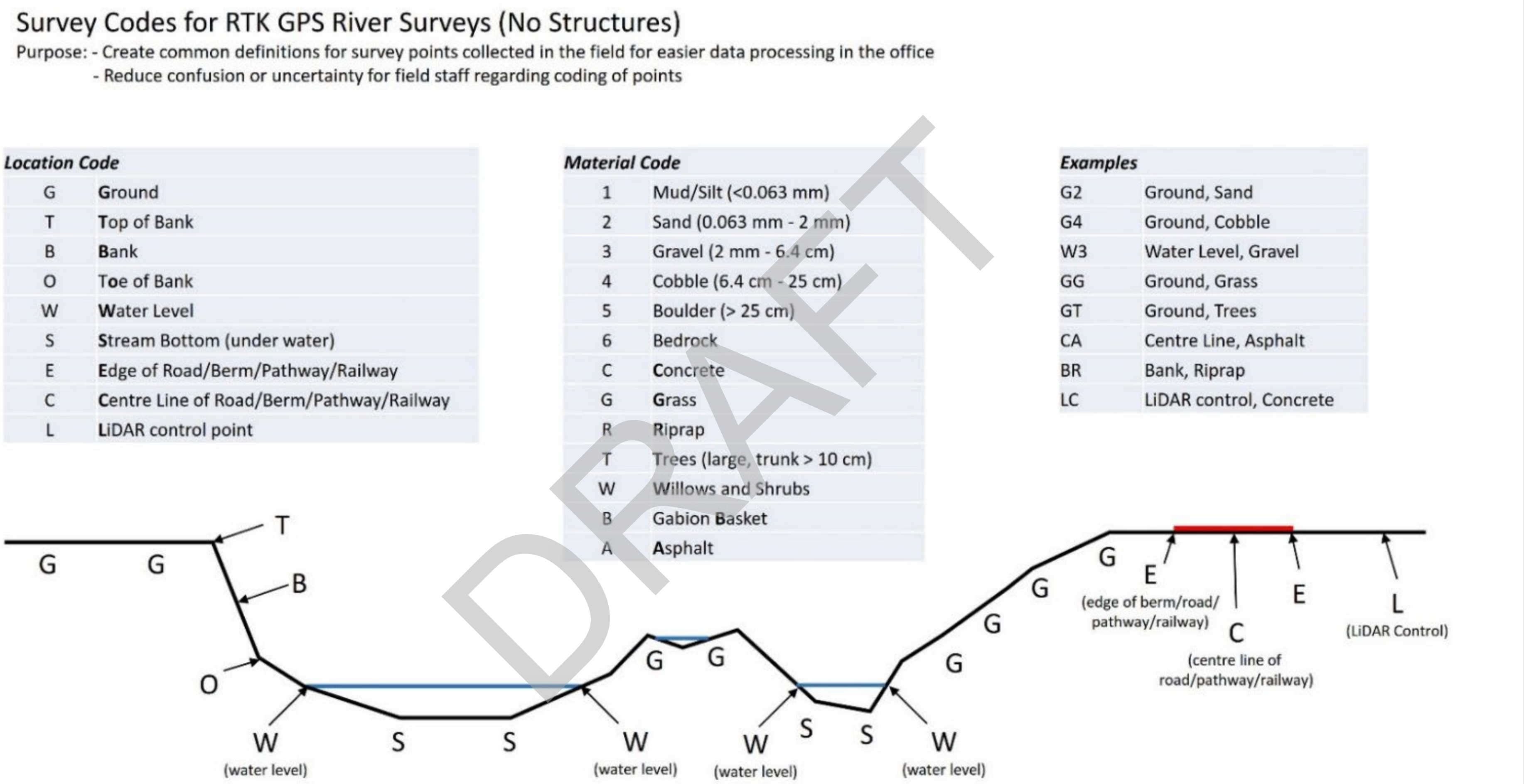
2.2.2 River Cross Sections and Longitudinal Profiles

The locations of representative cross sections were selected to capture the variations in the physical characteristics of the channel and floodplains that could affect flood levels along the study reaches. Considerations of changes in the channel width, cross section area, channel slope, channel bed and bank materials, and the presence of any confluences or islands, flood control structures, bridges, and other channel irregularities contributed to the selection of the cross-section locations.

The alignment of each cross section was established so that it would be orientated perpendicular to the direction of river flow. A shapefile showing the alignment of each cross section was provided to the survey crew and uploaded to the data collectors to provide guidance where to acquire data.

Each survey point collected with the RTK utilized a schematic of survey point codes and corresponding locations as shown in Figure 2-1. It also includes a complete list of survey codes for the RTK.

The quality and accuracy of all survey data were checked by using a Trimble data extraction and processing tool. All survey data was imported into ArcGIS to allow for validation and further processing. Data with horizontal or vertical accuracies of greater than ±0.05 m was rejected. Daily quality and accuracy checks were conducted in the office. In cases where multiple points with low accuracy were detected at a cross section, the survey crew repeated that survey the next day.



Survey Codes for RTK GPS River Surveys (No Structures)

Purpose: - Create common definitions for survey points collected in the field for easier data processing in the office
- Reduce confusion or uncertainty for field staff regarding coding of points

Location Code	
G	**G**round
T	**T**op of Bank
B	**B**ank
O	T**o**e of Bank
W	**W**ater Level
S	**S**tream Bottom (under water)
E	**E**dge of Road/Berm/Pathway/Railway
C	**C**entre Line of Road/Berm/Pathway/Railway
L	**L**iDAR control point

Material Code	
1	Mud/Silt (<0.063 mm)
2	Sand (0.063 mm - 2 mm)
3	Gravel (2 mm - 6.4 cm)
4	Cobble (6.4 cm - 25 cm)
5	Boulder (> 25 cm)
6	Bedrock
C	**C**oncrete
G	**G**rass
R	**R**iprap
T	**T**rees (large, trunk > 10 cm)
W	**W**illows and Shrubs
B	Gabion **B**asket
A	**A**sphalt

Examples	
G2	Ground, Sand
G4	Ground, Cobble
W3	Water Level, Gravel
GG	Ground, Grass
GT	Ground, Trees
CA	Centre Line, Asphalt
BR	Bank, Riprap
LC	LiDAR control, Concrete

Figure 2-1: Schematic of Survey Point Locations and Code Descriptions

The Belly River and Unnamed Tributary were surveyed by wading the channels. The flow of the Belly River was relatively low and many sections of the Unnamed Tributary are completely dry during the survey.

The main objective of the cross-section survey was to enable accurate definition of the main channel geometry. Limited overbank floodplain areas were also surveyed to overlap with the LiDAR survey where LiDAR coverage was assured. The cross sections were extended into the overbank areas during the hydraulic model development phase using the topographic (LiDAR) data provided by AEP. Enough data points were collected along each cross section to properly define the channel geometry and the near-bank floodplain.

Each recorded survey data point included Northing and Easting coordinate positions, water surface, and/or ground elevation and was attributed with a survey code that denotes its location (e.g., bank, stream bottom, edge of water, water level, top of bank, etc.).

The following procedures were adhered to when conducting a bathymetric survey by wading:

- RTK rover units were used to collect cross-sectional information from a location approximately 2 to 5 m beyond top of the bank on one side of the river channel, to a location approximately 2 to 5 m beyond top of bank on the other side. A minimum of 15 survey data points were established across the channel, and care was taken to reference points where the transverse bed slope changed significantly.
- Special attention was paid to surveying topographic slope breaks along the banks.
- Each of the surveyed data points was attributed with field codes that described substrate and vegetation types (see Figure 2-1).
- The water surface elevation was surveyed at all points along the cross section where the water had contact with the bank.

Reach-representative photographs were taken at key locations within the study area during the site reconnaissance and field survey. The photographs, which include salient details and features at surveyed cross sections, are georeferenced with appropriate metadata.

2.2.3 Discharge and Water Level Measurements

Discharge and water levels along the study reaches were measured during the field program to support low-flow hydraulic model calibration.

Flow was not measured in the Unnamed Tributary because no water was moving during the field survey. Many sections on the Unnamed Tributary were completely dry. There was stagnant water in some sections.

One discharge measurement on the Belly River was completed. There appeared to be no noticeable changes to the channel flow during the survey. The flow measurement was performed by wading the channel with a handheld Acoustic Doppler Velocimeter (*SonTek FlowTracker2® ADV*) and top-set wading rod in accordance with standard WSC protocols, including the following:

- Selected a suitable measurement location.
- Chose an even number of transects with equal left-to-right transects and right-to-left transects.
- Ensured that the data set of each transect is within a maximum standard deviation of five percent.

The measurement procedure involved the following:

- Survey points were selected to result in a minimum of 20 panels (flow segments across the stream thus requiring a minimum of 21 velocity measurement points).

- Velocity readings were taken at 0.6 of the total depth at measurement locations, because flow depth was less than 1.0 m in all cases.
- Survey points were selected such that no panel discharge exceeded 10 percent of the total discharge (six panels were within the 5-10 percent range; the remaining 17 panels were all less than five percent).

2.2.4 Hydraulic Structures

All hydraulic structures within the study area were surveyed. Applicable structures include road bridges and roadway culverts.

The features of each bridge structure surveyed included the following:

- Length of span (corner points, abutment to abutment)
- Width of bridge (corner points, outside to outside)
- Top of curb or solid guard rail elevations
- Low chord elevations
- Number and width of piers
- Location of piers and the distance of each pier relative to the left abutment
- Type of piers (e.g., concrete, pile bent, steel column)
- Shape of pier (e.g., round nose, wedge, circular)
- Top of road surface profile

The following data were collected on the roadway culverts within the study area:

- Number of culverts
- Barrel length
- Culvert opening dimensions
- Upstream and downstream invert elevations
- Culvert type (e.g., corrugated steel pipe, concrete box, timber-framed)
- Culvert shape (e.g., circular, arch, elliptical, square, rectangular)
- Entrance condition (e.g., projecting from fill, mitered to conform to slope)
- Top of roadway profile

The hydraulic structures were surveyed using RTK rover unit in clear sky areas where it was possible to connect to the GPS satellites. Georeferenced photographs of each hydraulic structure were taken during the field program. Two cross sections were surveyed at each bridge or culvert, each located within a short distance upstream and downstream of the bridge face or culvert opening. Ground and structure data were also collected at the inlet and outlet of the culvert to capture key elevations and dimensions.

2.3 Survey Standards and Accuracy

Quality assurance and quality control (QA/QC) of collected data were conducted in the field at the time of data collection and in the office during data processing. QA/QC of field data was conducted as described below.

- Position and elevation from the RTK rover unit were checked for accuracy each day, based on the ASCM benchmarks mentioned previously. All survey data collected during the field program were tied to an ASCM benchmarks. Temporary benchmarks were established by the field crew along the watercourses as required to maintain data accuracy.
- The field crew was provided with a shapefile showing cross section alignment for the purpose of guiding the survey along the selected cross sections.
- The RTK data collectors were set up to provide a warning when calculated maximum error exceeded 0.05 m for a manually recorded point. When notified, the surveyor either adjusted their location or waited for a better solution before surveying a point.

The RTK control network is considered accurate to within ±0.02 m at 95 percent confidence in both horizontal and vertical directions. A high level of accuracy was maintained throughout the field program by calibrating the spatial position and elevation of each RTK rover unit to an ASCM benchmark daily. Furthermore, the daily protocol required that the survey crew calibrate to, and then open and close on, an ASCM benchmark to maintain positional accuracy.

The collected survey data were imported into a Geographic Information System (GIS) to allow for validation and further processing. In addition to the QA/QC procedures for field data collection, the technical lead for the field program reviewed the survey data within 24 hours of it being collected to check for outliers (including erroneous or missing data) and to ensure appropriate coverage along each cross section and on the hydraulic structures.

2.4 Cross Sections and Longitudinal Profiles

The surveyed length of the Belly River was approximately 18.6 km and the survey length of the Unnamed Tributary was 8.5 km. An overview of the surveyed cross section locations is provided in Figures A-1 to A-4 of APPENDIX A. A total of 101 cross sections were surveyed within the study area. Table 2-1 provides a summary of surveyed cross sections.

Table 2-1: Surveyed Cross Sections within the Study Area

Waterbody	Reach Description	Cross Section ID	No. of Cross Sections	Average Cross Section Spacing (m)
Belly River	18.6 km long reach extending 15 km upstream and 3.6 km downstream of Highway 2 bridge	B-1 to B-83	83	200
Unnamed Tributary	8.5 km long reach extending upstream from the Belly River confluence	U-1 to U-18	18	500

The profiles of the surveyed main channel thalweg and measured water levels along the Belly River and Unnamed Tributary were presented in Figure 2-2 and Figure 2-3.

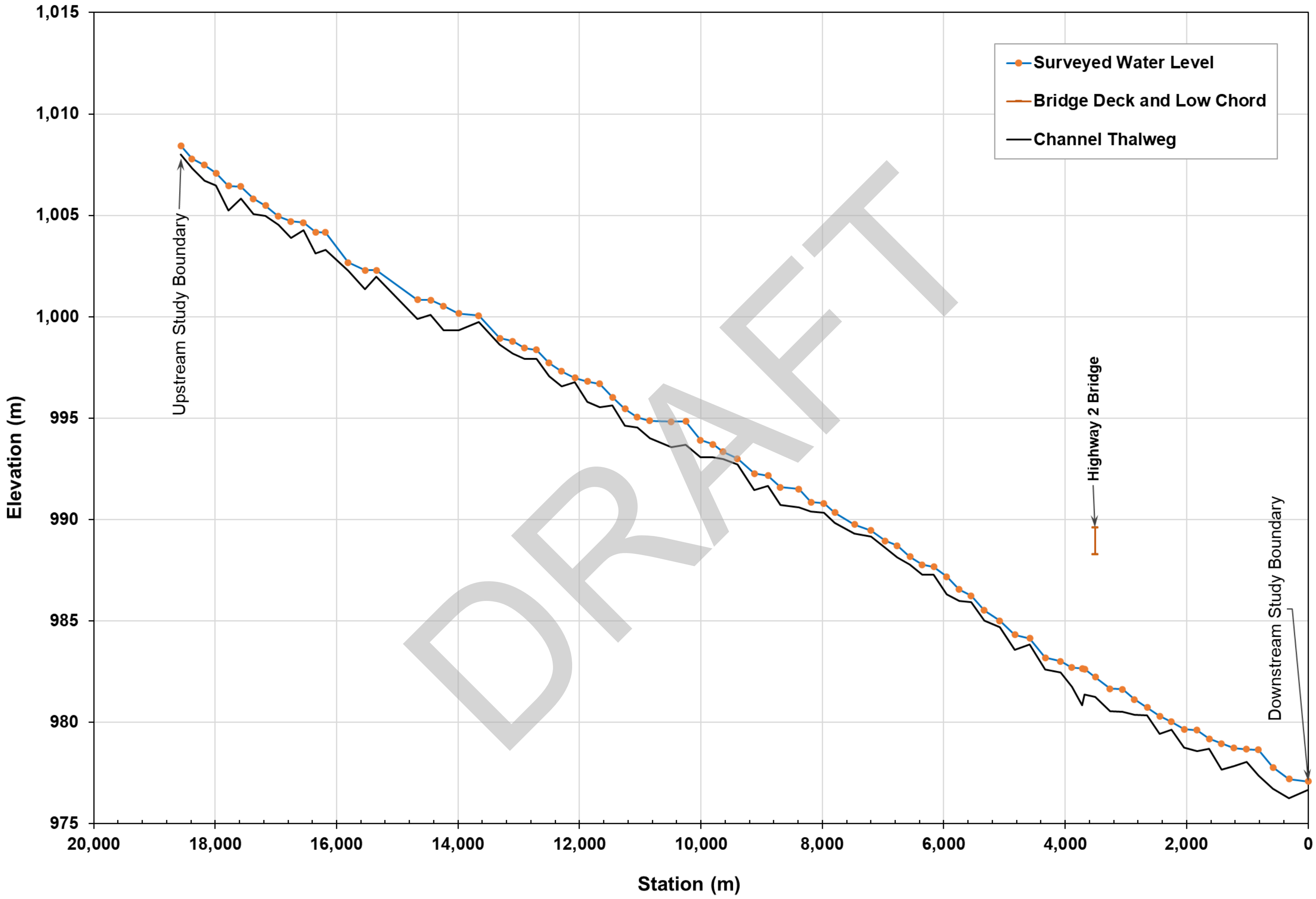
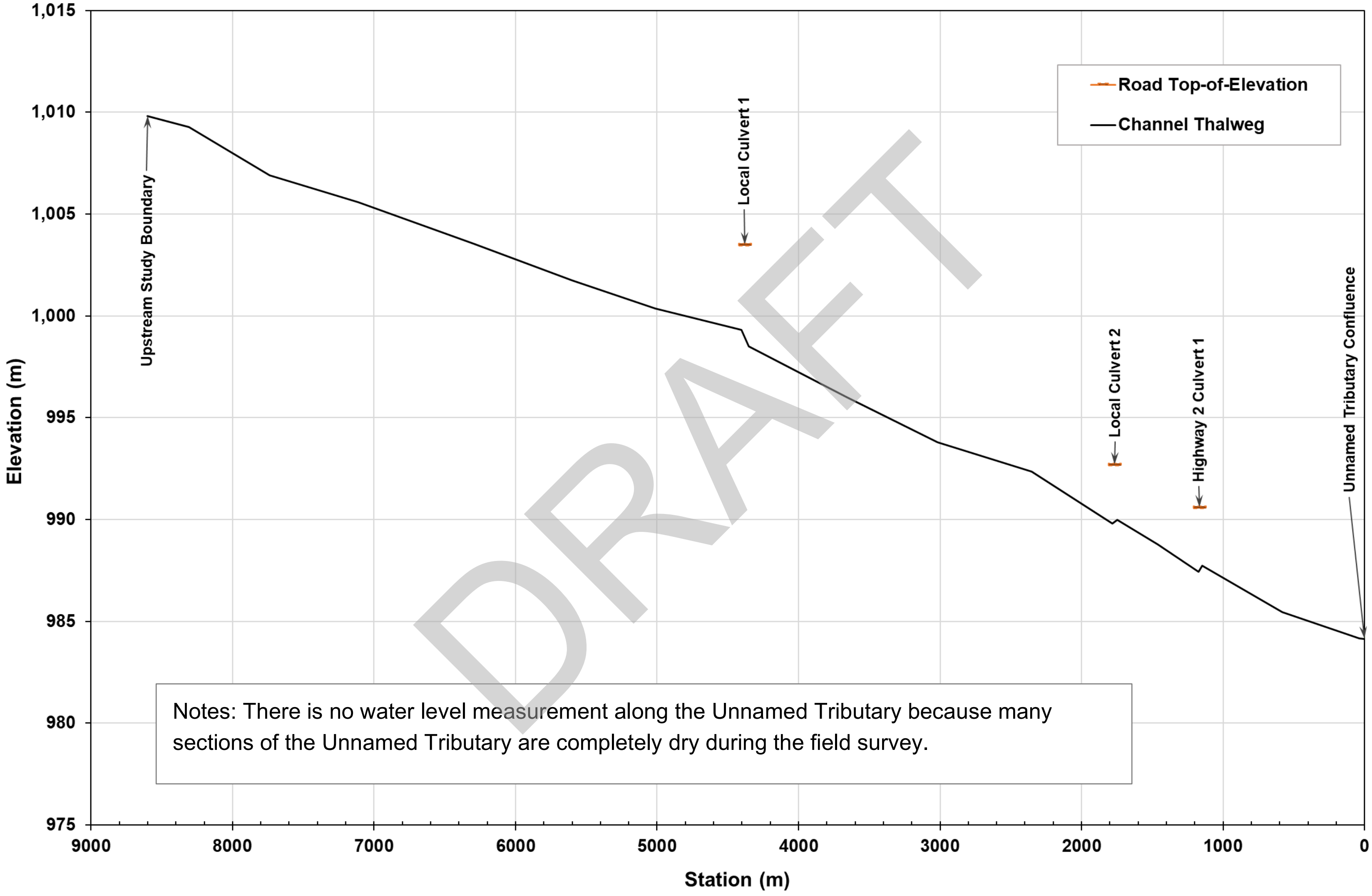


Figure 2-2: Surveyed Channel Thalweg and Surface Water Profile along the Belly River



Notes: There is no water level measurement along the Unnamed Tributary because many sections of the Unnamed Tributary are completely dry during the field survey.

Figure 2-3: Surveyed Channel Thalweg along the Unnamed Tributary

2.5 Discharge and Water Level Measurements

One discharge measurement was completed along the Belly River on July 13, 2021. Water levels were recorded during the cross-section surveys. Table 2-2 provides a summary of the discharge and water level measurement data.

No discharge and water level measurements were completed along the Unnamed Tributary because no water was moving during the field survey. Many sections on the Unnamed Tributary were completely dry.

Table 2-2: Discharge and Water Level Measurements

Waterbody	Date	Discharge Measurement Location	Water Level Measurement Locations		Measured Discharge (m^3/s)
			From Cross Section	To Cross Section	
Belly River	July 13, 2021	100 m downstream of XS68	B-1	B-83	1.57

2.6 Hydraulic Structures

There are six hydraulic structures (i.e., one bridge and five culverts) in the study area. A summary of these hydraulic structures is provided in Table 2-3.

Table 2-3: Hydraulic Structures within the Study Area

Waterbody	Structure ID	Structure Name / Location	Type	No. of Spans	Corresponding Figure Number in Appendix B
Belly River	HS-01	Highway 2 Bridge	Traffic	3	B-1
Unnamed Tributary	HS-02	Local Culvert 1	Traffic	None	B-2
	HS-03	Local Culvert 2	Traffic	None	B-3
	HS-04	Highway 2 Culvert 1	Traffic	None	B-4
Belly River Right Floodplain	HS-05	Highway 2 Culvert 2	Traffic	None	B-5
	HS-06	Highway 509 Culvert	Traffic	None	B-6

Bridge and culvert locations are shown in Figures A-1 to A-4 of APPENDIX A. The site photographs, survey data point locations, and salient information for each hydraulic structure are shown in Figures B-1 to B-6 of APPENDIX B.

2.7 Flood Control Structures

There is one flood control structure identified on the Belly River by Kainai Nation. No flood control structure was identified on the Unnamed Tributary (see Table 2-4). A detailed description of the flood control structure is provided in a separate memorandum (Golder 2021) in APPENDIX C.

Table 2-4: Flood Control Structure

Name	Approximate Length of Structure (m)	Type of Structure	Description
Rural Water Pumphouse Berm	120	Berm	Around the Pumphouse on the Belly River right floodplain

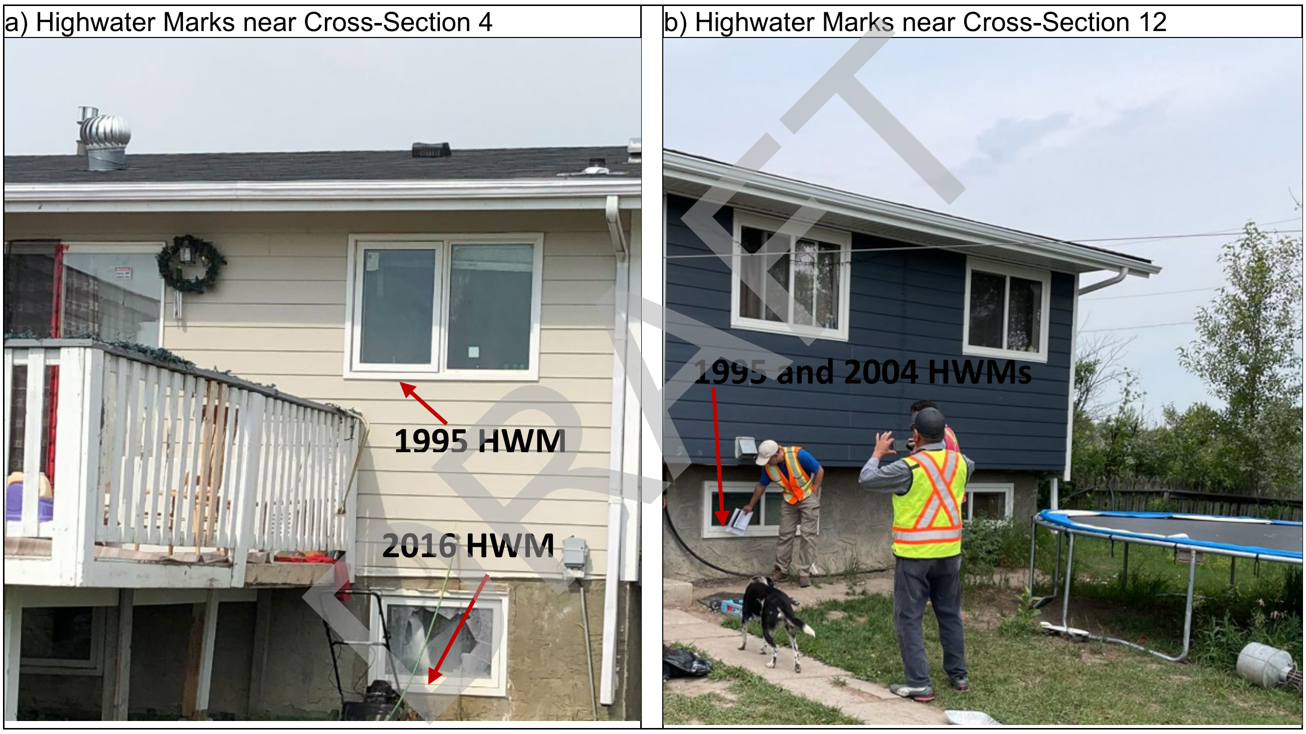
2.8 Highwater Marks

Four anecdotal highwater marks (HWMs) were identified by local residents within the study area during the field inspection on July 7, 2021. They include two HWMs for the 1995 flood event, one HWM for the 2004 flood event and one HWM for the 2016 flood event. One HWM each for the 1995 and 2004 flood event were identified at the same location by the owner of the house. A description of these four HWMs are provided in

Table 2-5 and Figure 2-4 provides information about the HWM locations at the residences. The elevations of the HWMs were surveyed during the field survey. The locations of all HWMs are shown in Figure 2-5.

Table 2-5: Anecdotal Highwater Marks

HWM No.	Elevation (m)	Flood Event	Description
1	1012.58	1995	Water reach at bottom of the window frame on main floor at the residence, approximately 80 m from Cross-Section 4 during 1995 flood event
2	1006.61	1995	Water reach at bottom of the window frame on the basement, approximately 250 m from Cross-Section 12 during 1995 flood event
3	1006.61	2004	Water reach at bottom of the window frame on the basement, approximately 250 m from Cross-Section 12 during 2004 flood event
4	1010.64	2016	Water reach at bottom of the window frame on the basement, approximately 80 m from Cross-Section 4 during 2016 flood event


a) Highwater Marks near Cross-Section 4

b) Highwater Marks near Cross-Section 12

Figure 2-4: Highwater Marks Identified during Field Inspection

2.9 Additional Base Data

Additional base data collected in support of hydraulic modelling and mapping included the following:

- LiDAR topographic data collected by Airborne Imaging in October 2020 and provided by AEP.
- Recent orthorectified aerial imagery which was acquired by Orthoshop Geomatics Ltd. (OGL) in September 2020 and provided by AEP.

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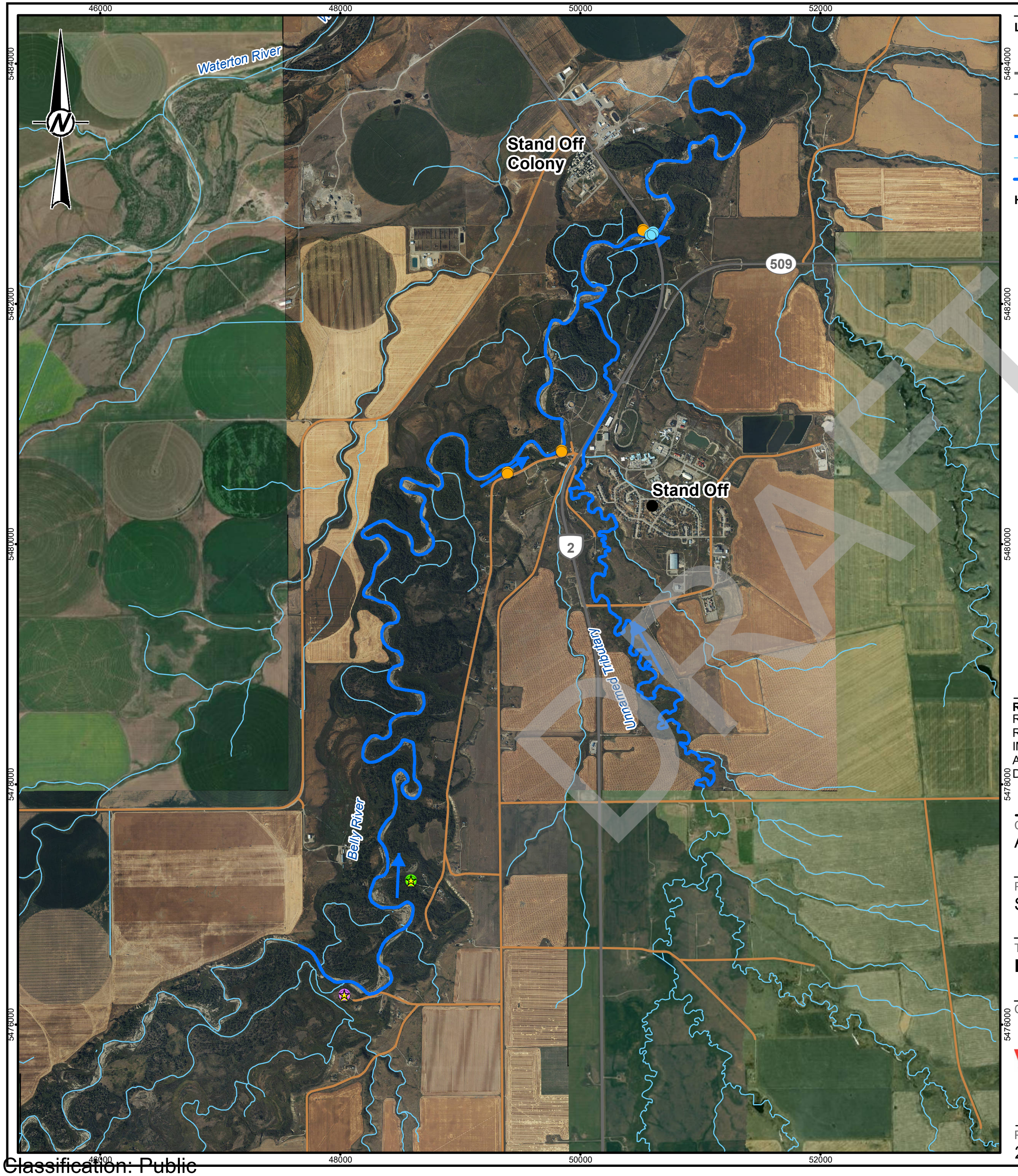

LEGEND

● POPULATED PLACE
PRIMARY HIGHWAY
SECONDARY HIGHWAY
LOCAL ROAD
FLOW DIRECTION
WATERCOURSE
SURVEY REACH

HIGHWATER MARK

● 1975
☆ 1995
● 2004
● 2010
● 2016

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

TITLE
LOCATIONS OF HIGHWATER MARKS

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-28
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
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3.0 OPEN WATER HYDROLOGY ASSESSMENT

3.1 Overview

Documentation of a detailed open water hydrology assessment for Stand Off, including the Belly River and Unnamed Tributary, is provided in APPENDIX D. The sections below provide a summary of that assessment.

3.2 Flooding History

3.2.1 General Information

The Belly River originates in the Rocky Mountains of northwestern Montana and flows northeastward through the foothills and into the plains of southwestern Alberta. It has a drainage area of approximately 1,210 km^2 at Stand Off. The catchment area is comprised of two distinct terrain types, a mountainous area upstream, and a flatter, mostly agricultural area downstream.

Water is diverted from Belly River at the Mountain View Leavitt Aetna (MVLA) diversion approximately 33 km upstream of the Belly River Diversion (BRD), and at the United Irrigation District (UID) diversion approximately 15 km upstream of the BRD (Figure 3-1). Immediately upstream of the BRD, Belly River flow is augmented from the Waterton Reservoir (i.e., the Waterton-Belly Diversion Canal). At the BRD, water is diverted to the Belly-St. Mary Diversion Canal to supply water to the downstream irrigation system.

The Unnamed Tributary to Belly River has a natural drainage area of approximately 81.8 km^2. However, runoff from the head watershed area of approximately 20.1 km^2 is diverted through the BRD. Therefore, the drainage area that currently contributes runoff to the Unnamed Tributary is approximately 61.7 km^2 and mostly flat agricultural area.

3.2.2 Open Water Flood History

Stand Off has experienced Belly River flooding periodically. The largest flood on record occurred in 1995, with other major floods in 1948, 1951, 1953, 1964, 1975, 2002, 2010, and 2014. Annual floods occurred mostly in June or late May, with approximately 94% of the annual maximum recorded in these two months. The recorded highest instantaneous discharge of 570 m^3/s and the highest daily discharge of 340 m^3/s both occurred in 1995 at Belly River near Glenwood.

Based on the review of the regional hydrologic data, flooding in the Belly River basin could be caused by snowmelt, rainfall and snowmelt, or rainfall alone. However, the majority of the recorded annual instantaneous peak flows used for the regional analysis occurred during summer months, indicating that these floods were associated with rainfall events.

No gauging data and Alberta Transport flood history are available for the Unnamed Tributary.

3.3 Open Water Flood Frequency Analysis

The flood frequency estimates for the Belly River in the study reach were derived by extending the natural and naturalized flood flow series for Belly River near Stand Off (i.e., WSC Station No. 05AD002, drainage area of 1,210 km^2, and for the period of 1909 to 1985) based on the recorded flows for Belly River near Glenwood (i.e., WSC Station No. 05AD041, drainage area of 653 km^2, and for the period of 1985 to 2020), Belly River near Mountain View (i.e., WSC Station No. 05AD005, drainage area of 319 km^2, and for the period of 1911 to 2019), and Lee Creek at Cardston (i.e., WSC Station No. 05AE002, drainage area of 312 km^2, and for the period of 1909 to 2019).

A regional hydrological analysis was used to develop flood peak discharge estimates based on drainage areas, for the Unnamed Tributary. Empirical relationships between drainage areas and flood peak discharges were established based on available regional flow records for the various return periods ranging from 2 to 1,000 years. The relationships were then used to derive the flood frequency estimates for the tributaries in the study area.

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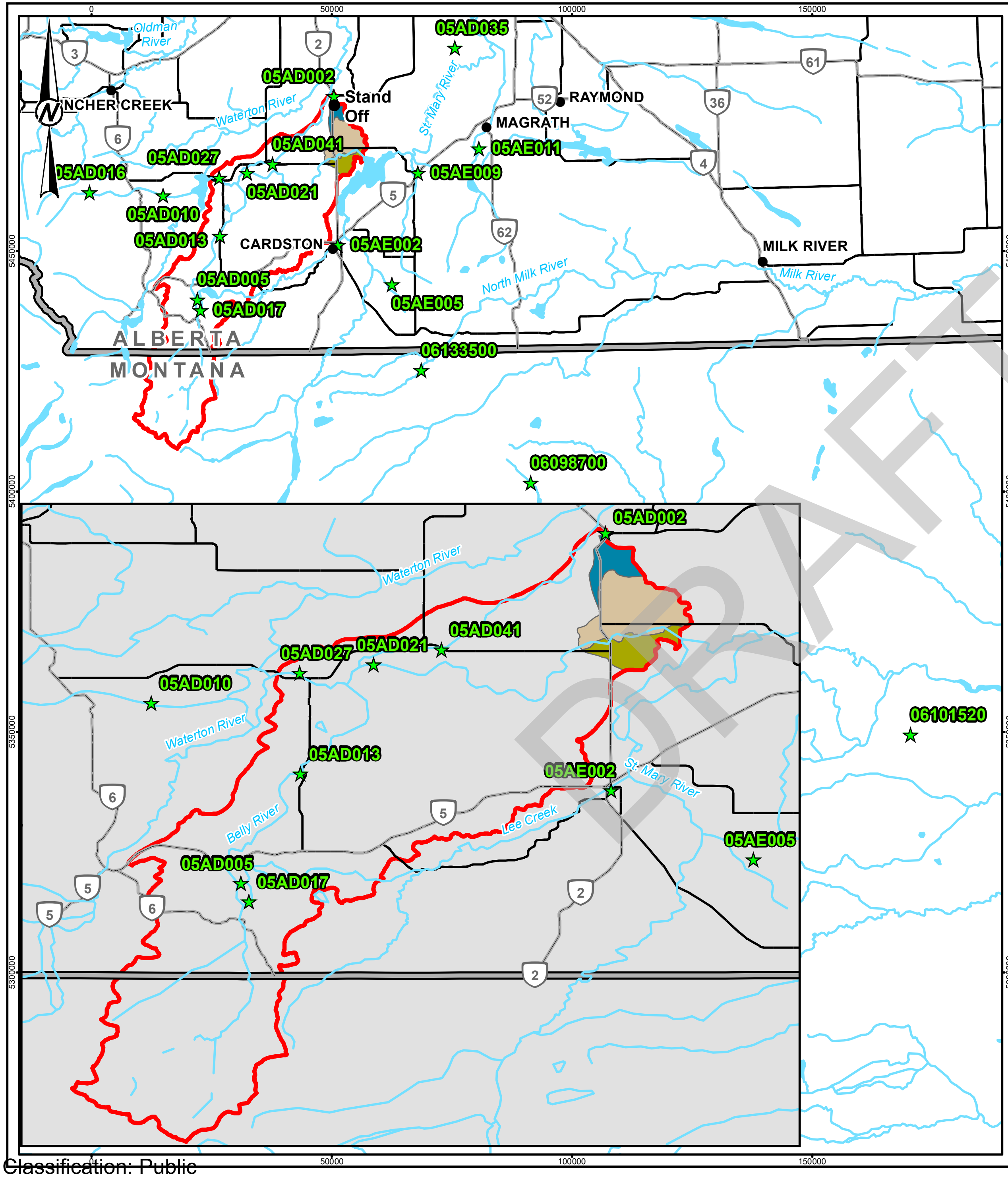

LEGEND

- ● POPULATED PLACE
- ★ HYDROMETRIC GAUGING STATION
- — WATERCOURSE
- 🟦 WATERBODY
- — PRIMARY HIGHWAY
- — SECONDARY HIGHWAY
- — LOCAL ROAD
- ▭ PROVINCIAL/STATE BOUNDARY
- 🟥 BELLY RIVER

UNNAMED CREEK NEAR STANDOFF

- 🟦 DOWNSTREAM
- 🟫 UPSTREAM BELOW DIVERSION
- 🟩 UPSTREAM DIVERTED

0 30 60

1:1,250,000 KILOMETRES

REFERENCE(S)

HYDROMETRIC STATIONS OBTAINED FROM WATER SURVEY OF CANADA (WSC) AND USGS.
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PROJECT
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BELLY RIVER WATERSHED AT STAND OFF

CONSULTANT

WSP GOLDER

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Table 3-1 summarizes the flood peak discharge estimates and the associated upper and lower 95% confidence intervals for various return periods from 2 to 1,000 years. The annual maximum instantaneous discharge series used in the flood frequency analyses, the various frequency distributions, and the best-fit distributions along with their 95% confidence intervals are provided in APPENDIX D.

Table 3-1: Flood Peak Discharge Estimates and their 95% Confidence Intervals for Belly River and the Unnamed Tributary near Stand Off

Return Periods (years)	Annual Probability of Exceedance (%)	Belly River near Stand Off (using EV2 Distribution)			Unnamed Tributary to Belly River		
		Value (m^3/s)	Lower 95% Limit (m^3/s)	Upper 95% limit (m^3/s)	Value (m^3/s)	Lower 95% Limit (m^3/s)	Upper 95% limit (m^3/s)
2	50	70.6	64.2	80.2	4.5	3.5	5.6
5	20	115	98	138	10.8	8.0	14.0
10	10	160	130	194	16.8	12.0	23.3
20	5.0	220	171	271	24.4	16.1	37.8
35	2.9	283	212	353	31.9	19.7	56.0
50	2.0	332	242	418	37.4	22.1	71.6
75	1.3	399	280	505	44.4	24.8	94.0
100	1.0	454	312	580	49.9	26.8	115
200	0.50	619	401	814	65.3	31.9	185
350	0.29	796	482	1,067	80.2	36.4	272
500	0.20	934	547	1,274	91.1	39.7	346
750	0.13	1,120	627	1,567	105	43.0	457
1,000	0.10	1,275	689	1,807	116	45.7	557

3.3.1 Comparison to Previous Studies

A comparison of the flood frequency estimates obtained in this study for the Belly River at Stand Off, and the Unnamed Tributary with the studies previously completed by Alberta Environment and Parks (AEP 1996 and 2011a) as well as KCB (2013), is provided in Table 3-2.

Table 3-2: Comparison of the Flood Frequency Estimates of Various Studies

Return Period (years)	Belly River near Glenwood (m^3/s)			Belly River at Stand Off (m^3/s)		
	AEP(1) (1996)	AEP(2) (2011)	KCB(3) (2013)	AEP(1) (1996)	AEP(2) (2011)	This Study
2	139	40.6	70.5	139	40.6	70.6
5	-	-	-	-	-	115
10	203	223	166	203	223	160
20	268	316	227	268	316	220
50	354	446	340	354	446	332
100	421	547	456	421	547	454
200	487	650	608	487	650	619
1,000	642	894	1,160	642	894	1,275

Notes:
1. The AEP (1996) study involved use of the recorded data up to 1995 and combined the recorded data from Glenwood and Stand Off stations.
2. The AEP (2011a) study involved use of the recorded data without explicitly accounting for diversions (i.e., flow not naturalized).
3. The KCB (2013) study involved use of the recorded data up to 2011.

The flood frequency estimates were based on the recorded data up to 1995 in the AEP study (1996) and up to 2011 in the AEP study (2011a) and KCB study (2013). The current study is based on the published flow data up to 2020. In addition, this study includes the analyses to update the relationships between annual maximum daily and annual maximum instantaneous discharges.

The result of flood frequency estimates for this study are consistent with AEP (1996) and KCB (2013) estimates for return periods up to 100 years. The 200-year and 1000-year estimates in the AEP (1996) study were lower than those in this study, likely because the data series did not include some of the large floods in 2002, 2010 and 2014. The comparison of the studies shows that the main differences in the flood frequency estimates are due to the different lengths of the recorded data used in the flood frequency analyses and the selections of different frequency curve distributions as well as the selections of different frequency curve distributions and approaches used to naturalize the flow series.

4.0 OPEN WATER HYDRAULIC MODELLING

4.1 Overview

The following sections describe the methodology and results of the open water hydraulic modelling component. The scope of this component includes summary of available data and stream/valley features in the study area, hydraulic model setup, hydraulic model calibration and validation, selection of Manning's *n* roughness values, sensitivity analysis, and generation of open water flood frequency profiles. The results of this component are used in the flood inundation mapping, flood hazard identification, and governing design flood hazard mapping components.

4.2 Available Data

4.2.1 Digital Terrain Model

Digital Terrain Model (DTM) data was provided by AEP for this study. The DTM was derived from survey-verified high-accuracy Light Detection and Ranging (LiDAR) remote sensing data set acquired during October 2020 by Airborne Imaging.

4.2.2 Existing Model

There is no previous provincial hydraulic model developed or flood hazard study completed for the study area.

4.2.3 Highwater Marks

AEP collected two sets of historic open water flood highwater mark (HWM) data (1975 and 2010) along the Belly River study reach. In addition, four anecdotal highwater marks (HWMs) were identified by local residents during field inspection (see Section 2.8). The available HWMs for this study are listed in Table 4-1 and locations of all HWMs are shown in Figure 2-5. There is no HWM data available along the study reach of the Unnamed Tributary.

Table 4-1: Available Highwater Mark Reports and Data

No.	Report Title/Data Description	Flood Year	Author or Source
1	Appendix C – Belly River at Standoff	1975	Alberta Environment
2	High Water Mark Report - Belly River	2010	Alberta Environment
3	Anecdotal Highwater Marks	1995/2004/2016	Local Residences

4.2.4 Gauge Data and Rating Curve

There is no active Water Survey of Canada (WSC) hydrometric gauging station located on the Belly River or Unnamed Tributary within the study area. However, there is a discontinued WSC hydrometric gauging station located on the Belly River within the study area (i.e., WSC Station 05AD002 - Belly River near Stand Off, period of record 1909 to 1985). This station is located on the right bank of the Belly River, approximately 90 m upstream of the Highway 2 bridge. The rating curve for this station was provided by WSC with an assumed datum (26.25 m); however, there is no conversion established between the assumed datum and geodetic vertical datums such as CGVD28. Therefore, the rating curve at this station could not be used for the model calibration.

4.2.5 Flood Photography

AEP collected flood photographs along the Belly River as part of the June 1975 flood event documentation which provided insight into the event. Site flood photographs were taken as part of the AEP highwater marks surveys.

4.3 River and Valley Features

4.3.1 Channel Characteristics

The Belly River study reach is approximately 18.6 km long. It extends from the upstream study boundary (eastern boundary of SE-31-5-25-W4M), through Stand Off, to a location approximately 3.6 km downstream of the Highway 2 bridge crossing. The Belly River meanders with large sinuosity and has multiple channels including oxbow channels (i.e., old cut-off channel segments) and side channels within the study area, resulting in a complex flow pattern with multiple flow paths during high flows. The Belly River has a typical channel bottom width of 31 m, bankfull width of 65 m, and bankfull depth of 2.5 m along the study reach. It has an average channel bed slope of 0.17% and an average sinuosity of 1.9. The channel bed and bank materials consist of mainly gravel, sand, silt and clay with some boulders. In some areas, channel banks are unstable, and localized erosion were observed.

The Unnamed Tributary study reach is approximately 8.5 km long. It extends from the upstream study boundary (downstream of a local road, SW-3-6-25-W4M) to its confluence with the Belly River near Stand Off. The Unnamed Tributary has a single, narrow, well-defined channel. The study reach has a typical channel bottom width of 1 m, bankfull width of 5 m, and bankfull depth of 1 m. It has an average channel bed slope of 0.3% and an average sinuosity of 1.8. The channel bed and bank materials consist of mainly gravel, sand, silt and clay. The river banks are well vegetated.

4.3.2 Floodplain Characteristics

The Belly River study reach meanders in relative wide and flat floodplains. There are presence of remnant, side and sub-channels that are typically dry under normal flow conditions and become active under high flow conditions. The floodplain width is typically 1100 m with a range of 800 to 1200 m. The vegetation cover on the floodplains within the study area consists mainly of grasses, bushes, and trees. Parts of the floodplains are used as farmland.

The Unnamed Tributary study reach meanders within a floodplain width of approximately 180 m with a range of 100 to 300 m. The vegetation cover on the floodplains within the study area consists mainly of grass and scattered willows. The floodplains areas are mainly farmland and pasture.

4.3.3 Anthropogenic Features

Stand Off is located approximately 43 km southwest of Lethbridge and 30 km north of Cardston on Highway 2. It is situated in the Blood (Kainai) Indian reserve and has a population of 4,570 (Blood 148, IRI), according to the 2016 Census of Population conducted by Statistics Canada. The floodplain land use areas are mainly farmland.

4.3.4 Bridges and Culverts

The man-made structures along the study reach of the Belly River and Unnamed Tributary which are relevant for hydraulic modeling are listed in Table 4-2 and APPENDIX B. There is one highway bridge crossing on the Belly River; and three culvert crossings on the Unnamed Tributary, one drainage culvert on Highway 2 and one drainage culvert on Highway 509.

Table 4-2: Bridge and Culvert Crossings within the Study Area

No.	Name	Description	Type
1	Highway 2 Bridge	Highway 2 bridge Crossing Downstream of Stand Off (see Figure B-1 in APPENDIX B)	3-Span
2	Highway 2 Culvert 1	Highway 2 culvert Crossing Downstream of Stand Off (see Figure B-2 in APPENDIX B)	Arch culvert, 4.34 m span x 2.17 m rise
3	Local Culvert 1	Local culvert at Unnamed Tributary near Stand Off (see Figure B-3 in APPENDIX B)	3 culverts with 1.2 m diameter
4	Local Culvert 2	Local culvert at Unnamed Tributary Upstream of Stand Off (see Figure B-4 in APPENDIX B)	3 culverts with 1.2 m diameter
5	Highway 2 Culvert 2	Highway 2 culvert for local drainage (see Figure B-5 in APPENDIX B)	2 culverts with 1.2 m diameter
6	Highway 509 Culvert	Highway 509 culvert for local drainage (see Figure B-6 in APPENDIX B)	1 culvert with 0.75 m diameter

4.3.5 Weirs and Dams

There are no weirs or dams along the study reach of the Belly River and Unnamed Tributary.

4.3.6 Flood Control Structure

There is one flood control structure within the study area. The flood control structure is an earth berm located on the right bank of the Belly River protecting the Rural Water Pumphouse near Stand Off Trading Post. The structure is approximately 120 m long (see Table 4-3). A detail description of the flood control structure is provided in APPENDIX C. There are no flood control structures (e.g., berm or dike) along the Unnamed Tributary.

Table 4-3: Flood Control Structure within the Study Area

Stream	Name	Length (m)	Side of River (a)	Type of Structure	Description
Belly River	Rural Water Pumphouse Berm	120	Right	Berm	An earth berm around Rural Water Pumphouse on Belly River right floodplain

a) Left or right refer to directions as seen by an observer looking downstream.

4.4 Model Construction

4.4.1 Methodology

The HEC-RAS program (Version 6.1, September 2021) was used to develop the coupled one/two-dimensional (1D/2D) hydraulic model for the study area.

The HEC-GeoRAS module (Version 10.5) was used to prepare cross-section data for 1D component based on the recent LiDAR and river survey data. HEC-GeoRAS is an ArcGIS extension tool specifically designed to create a HEC-RAS import file from geospatial data. The 2D component was developed within the HEC-RAS program.

4.4.2 HEC-RAS Program

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. HEC-RAS is a commonly-used program in North America and around the world.

The HEC-RAS program was designed to perform one-dimensional (1D), two dimensional (2D) or coupled 1D and 2D (1D/2D) hydraulic calculations for a full network of natural and constructed channels. The program supports steady-state and unsteady-state hydraulic simulation. HEC-RAS can be used to calculate water surface profiles for gradually varied flow. In this study, the program was used for coupled 1D/2D unsteady-state simulation. A supplementary rough 2D model was developed initially to support the field survey planning and inform the coupled 1D/2D model setup.

The program can be used to simulate the effects of various obstructions such as bridges, culverts, weirs, levees and other structures. The program is capable of simulating the water surface profiles associated with subcritical, supercritical and mixed flow regimes.

Compared to the 1D HEC-RAS modelling approach that is based on cross sections and would require simplifications, approximations and professional judgement to adequately simulate the complex flow conditions, the coupled 1D/2D HEC-RAS model offers the following benefits:

- A 1D component maintains benefits of the 1D HEC-RAS model (e.g., adequate representation of hydraulic structures such as bridges, culverts and other structures, as well as accurate simulation of the main channel hydraulics).
- A 2D modelling for the floodplain areas will allow the highwater marks at individual locations to be appropriately compared with the simulated water levels for model calibration.
- A 2D modelling for large and flat floodplain will reduce the uncertainty in defining the alignment of cross section and the selection of appropriate ineffective flow areas for large floodplains in the model domain.
- A 2D modelling will lower the risk of profiles crossing at the locations where ineffective area would be activated when flood control structures, levees or roads would be overtopped.

4.4.3 General Model Setup

4.4.3.1 Model Domain

It is generally desirable to use a single geometry file to simulate floods of various return periods. Therefore, the model domain needs to be defined to cover inundation extents of the largest flood event to be simulated. The model domain extent was defined in consideration of the simulation results of a supplemental rough HEC-RAS 2D model, which was set up based on the LiDAR DEM without inclusion of the channel bathymetry, to provide conservative water level estimates.

To avoid manual flow distribution on the left floodplain, channel and right floodplain at the upstream model boundary, a short river reach (i.e., approximately 3.5 km on the Belly River) beyond the upstream end of the proposed study reach was included in the model.

4.4.3.2 Coupled 1D/2D Model

The coupled 1D/2D modelling approach includes the following:

- 1D cross sections were defined along the main channel of the Belly River study reach based on surveyed river cross sections.
- 2D model areas were defined for the left and right floodplains of the Belly River with the average mesh size of 20 x 20 m with local refinement along key structures, side channels and oxbow channels. Particularly, the mesh in the area near Red Crow Park was further refined to support appropriate simulation of overland conditions for certain flood events.
- Some of key linear structures in the 2D domain were set up as weirs to more accurately simulate the flow pattern near those structures. These structures include: Highway 2, Highway 509, several local roads on

the right flood plain and a berm on the left floodplain near Stand Off Colony (Stand Off Hutterite Colony). The mesh near these structures were also refined to a resolution of 5 m to better represent their physical features.

- The Unnamed Tributary was modelled in 2D domain. The LiDAR DTM along the Unnamed Tributary was enhanced to include the surveyed channel bathymetry. The 2D model area along Unnamed Tributary has an average mesh size of 5 m to 15 m.
- The 1D and 2D model domains were connected along a series of lateral structures that follow roughly the top of banks for the Belly River.

To simplify the boundary setup at the upstream boundary of the Belly River, the upstream boundary was extended further upstream about 3.5 km beyond the AEP study boundary (see Figure 4-1). The 1D cross sections were extended gradually upstream until they cover the entire river and floodplain. The advantages of the setup are:

- One upstream boundary. The inflow hydrograph will be input in the upstream 1D cross section. Otherwise, three upstream boundaries (one for left floodplain, one for channel, one for right floodplain) would have been necessary.
- Avoid the manual flow distribution on the left floodplain, channel and right floodplain. The model will simulate the flow distribution automatically by transferring flow gradually from the 1D model to the 2D models on the left and right floodplains.

The downstream boundary of the HEC-RAS model is located at the downstream end of the AEP study reach.

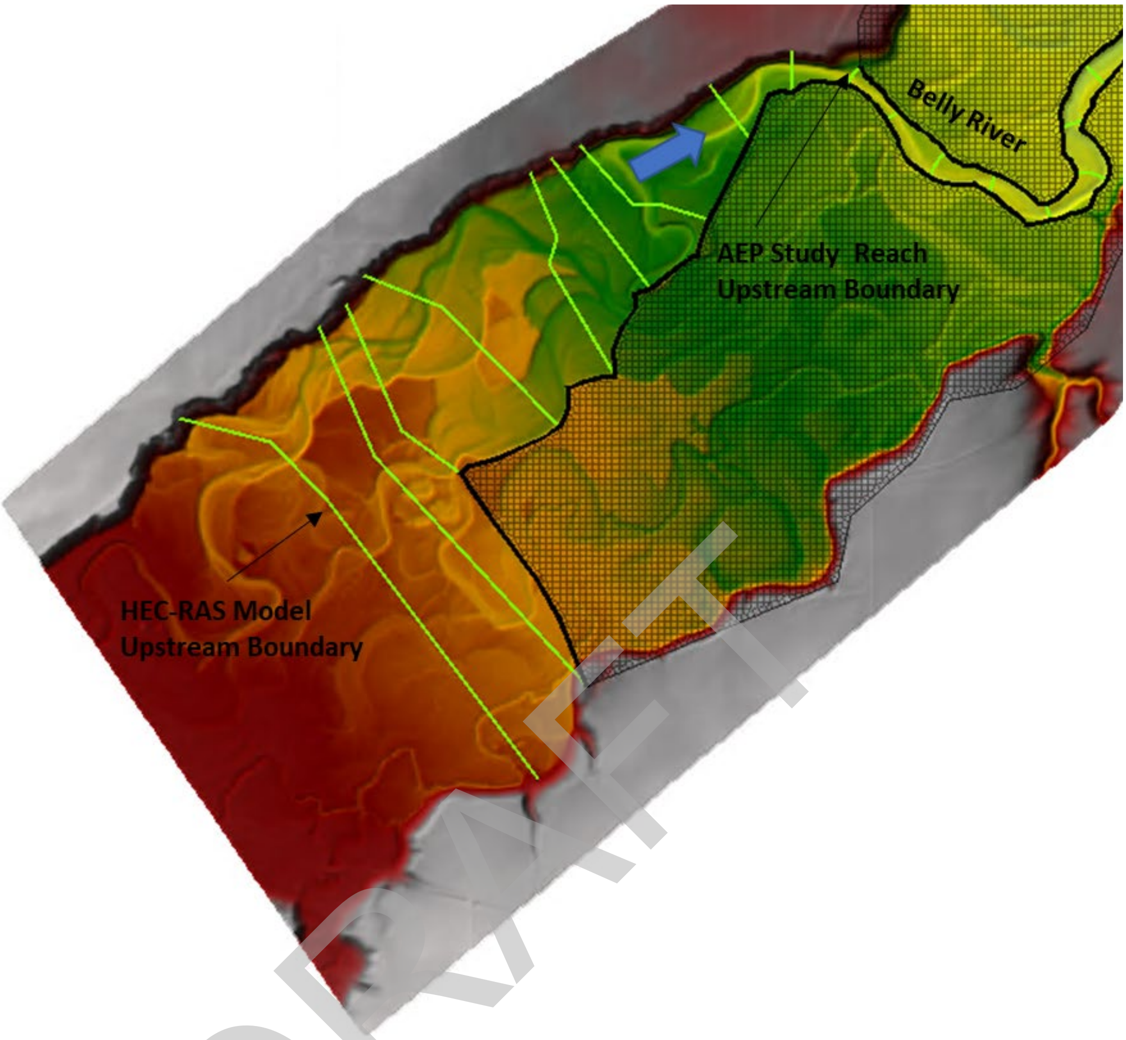


Figure 4-1: Upstream Boundary of the Belly River in Coupled 1D/2D Model

4.4.3.3 Reach and Branch

There is one 1D study reach along the Belly River in the model. The Unnamed Tributary is joining the Belly River between XS 59 and XS 60, approximately 1.2 km upstream of Highway 2 bridge. However, since the Unnamed Tributary is modelled with the 2D model domain, no flow change locations have to be defined along the 1D model reach.

4.4.3.4 Boundary Conditions

The coupled 1D/2D HEC-RAS model requires specification of boundary conditions at all open and internal boundaries. The open boundaries of the hydraulic model are listed below:

- Discharges at the upstream model boundaries of the Belly River (1D) and Unnamed Tributary (2D);
- Normal flow condition (with an estimated energy slope of 0.17%) at three downstream model boundaries of the Belly River (one for the left floodplain, one for the main channel, one for the right floodplain); and
- Normal flow condition (with an estimated energy slope of 0.20%) at the northern edge of the 2D model domain, where the water would spill towards the Waterton River watershed for very high flood events.

4.4.4 Geometric Data Base

4.4.4.1 1D Model – Belly River Cross-Sections

The locations of the cross sections in the model were selected based on the locations of the surveyed cross sections and modelling requirements. The cross-section data was obtained from the following sources:

- River survey data collected for this study (see Section 2.0).
- 2020 LiDAR data provided by AEP.

HEC-GeoRAS was used to define the main channel, flow paths, bank lines, bank stations, cross section, river stations, and Manning's roughness *n*. The total length of the Belly River study reach is 18.6 km. The study reach is represented by 83 cross sections in the model.

4.4.4.2 2D Model

The Belly River right and left floodplains, and the Unnamed Tributary study reach were modelled using the 2D model. The surveyed cross sections along the Unnamed Tributary were used to develop a continuous interpolated bathymetry surface that was integrated with the LiDAR DTM. The 2D model area was covered with a mesh size ranging from 5 x 5 m to 20 x 20 m. Larger elements were used on relatively flat floodplains, and smaller elements were used along the Unnamed Tributary main channel and in areas where topographic details are important to adequately simulate the local hydraulic conditions.

Breaklines were used in the 2D model domain along linear features such as roads, oxbow channels and side channels. Weirs were also used in the 2D model domain along the key structures such as the highway roads which have a higher elevation than the ground surface.

The 2D model domain is connected to the 1D model reach of the Belly River using 22 lateral structures. These lateral structures allow for flow exchanges from the 1D model into the 2D model and vice-versa.

4.4.4.3 Roughness Coefficients

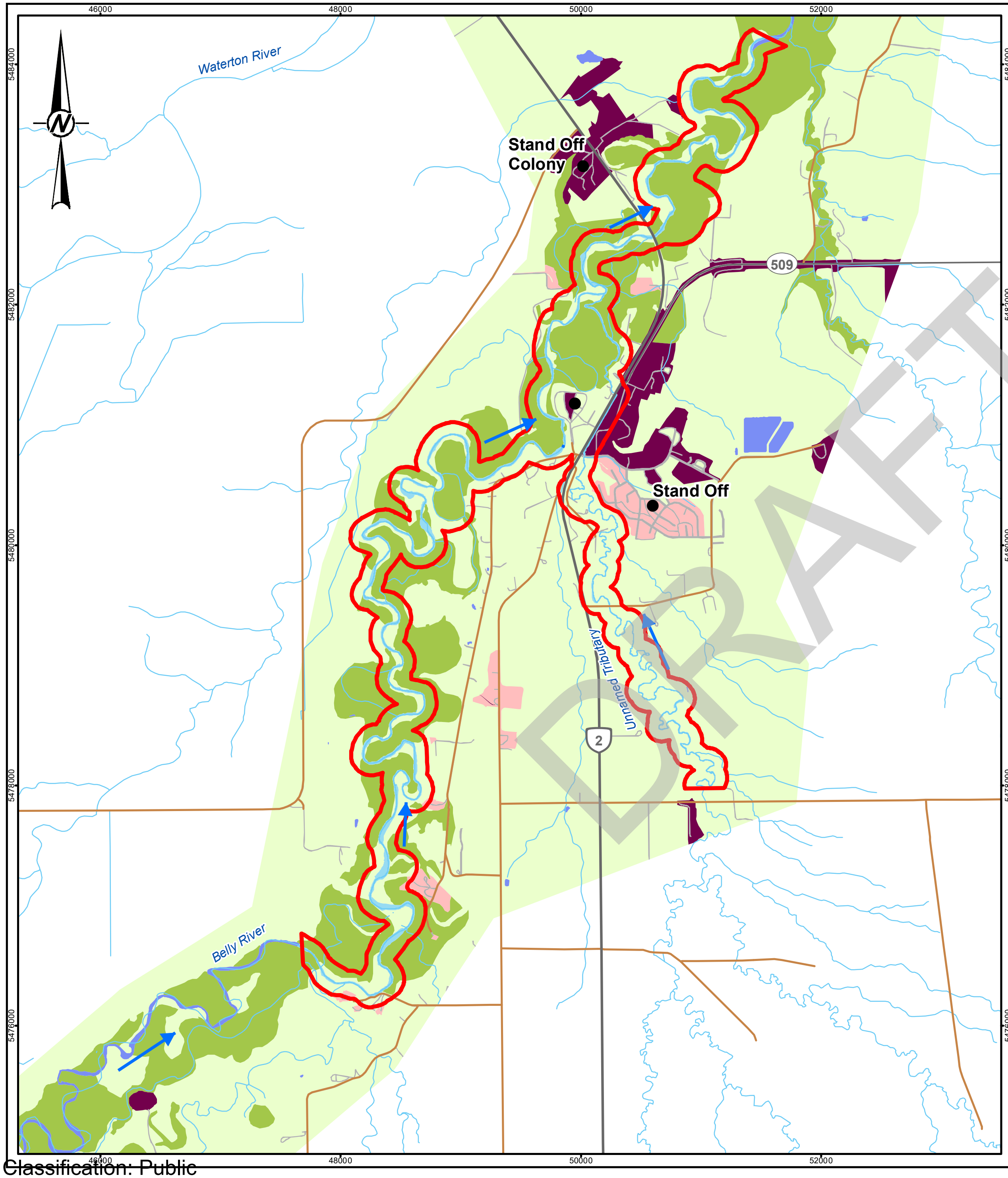
The left and right bank stations defining the main channel were determined using HEC-GeoRAS based on the 2020 LiDAR data, 2020 aerial imagery and survey data. Manning's *n* values were specified using the distributed roughness approach, which allows for multiple, varying roughness values within study area. The initial roughness distribution was specified based on the following data:

- Bank lines established from the LiDAR data, aerial imagery and surveys to identify the main channels
- Land use information from the Government of Alberta.

Seven roughness classes were used for the model setup. The initial Manning's *n* values assigned to the classes are listed in Table 4-4. These initial values were selected based on channel bed materials, and vegetation types (Chow 1959; USACE 2021c). These roughness values were modified at some locations during the model calibration. The roughness values were specified in the cross sections within the 1D component and the 2D component using HEC-GeoRAS and RAS Mapper. The distribution of the roughness classes is shown in Figure 4-2.

Table 4-4: Roughness Classes and Initial Manning's *n* Values

Number	Description	Initial Manning’s n Value
1	River Channel	0.025
2	Urban Mixture (Residential)	0.080
3	Urban Mixture (Industrial)	0.060
4	Street	0.030
5	Grassland and Farmland	0.050
6	Pond	0.030
7	Trees/Bush	0.150



LEGEND

● POPULATED PLACE

━ PRIMARY HIGHWAY

— SECONDARY HIGHWAY

— LOCAL ROAD

➡ FLOW DIRECTION

— WATERCOURSE

▭ FLOOD HAZARD STUDY AREA

■ RIVERS-MAIN CHANNEL

■ GRASSLAND/FARMLAND

■ POND

■ TREES/BUSHES

■ URBAN MIXTURE (RESIDENTIAL)

■ URBAN MIXTURE (INDUSTRIAL)

■ STREET

0 1.5 3

1:50,000 KILOMETRES

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PROJECT
STAND OFF FLOOD STUDY

TITLE
DISTRIBUTION OF ROUGHNESS CLASSES

CONSULTANT

wsp GOLDER

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REVIEWED	JC
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4.4.4.4 Hydraulic Structures

4.4.4.4.1 Bridges

The bridge geometries used in the HEC-RAS model were defined based on the river and bridge surveys conducted in July and August 2021 (Section 2.0).

One existing bridges along the Belly River reach (Section 4.3.4) was represented in the HEC-RAS model. The bridge deck, pier and abutment information were included in the model. Losses through bridges were calculated in the model using the energy equation (i.e., standard step method). Flows over the bridge and approach embankment were calculated using the standard weir equation.

At the bridge location, ineffective areas upstream and downstream of the bridges were carefully defined. This included definition of permanent and non-permanent ineffective areas where appropriate.

The initial values of the contraction and expansion coefficients at the bridge was selected to be 0.3 and 0.5, respectively. These are typical values listed in the HEC-RAS User Manual.

4.4.4.4.2 Culvert

There are three culverts along the Unnamed Tributary reach, and two culverts on the floodplains within the 2D model domain (Highway 2 and Highway 509). The culverts were represented in the HEC-RAS model based on the survey data. The pertinent culvert information, including size, length, upstream invert and downstream invert elevations, was specified in the model. For the culverts in the 2D domain, entrance and exit loss coefficient of 0.5 and 1 were used, respectively.

4.4.4.4.3 Weirs and Dams

There are no weirs or dams in the study area that are represented in the HEC-RAS model.

4.4.4.5 Flood Control Structure

There is one flood control structure in the study area that is represented in the 2D model domain. Flood control structures within the 2D model domain were represented as breaklines.

4.4.5 Model Calibration

4.4.5.1 Methodology

The Manning’s *n* and contraction/expansion coefficients are the two primary model calibration parameters. Selection of initial Manning’s *n* values included consideration of river bed/bank materials, vegetation cover, site information collected during the field inspection, and Golder’s experience from previous hydraulic modelling studies.

Manning’s *n* values may reduce with increased stage. Both low flow and high flow calibrations were performed to determine appropriate Manning’s *n* values across a wide range of flows. The following scenarios were included in the model calibration and validation:

- Low Flow Calibration: The surveyed water levels and measured flows during the river surveys were used for the low flow calibration. There is no flow and water level information available for low flow calibration of Unnamed Tributary.
- High Flow Calibration: Available HWMs and peak flow estimates for the 1975 and 2010 flood events on the Belly River were used for the high flow calibration. These two flood events were selected because they were the largest events in recent history and were well-documented in terms of peak flow estimates and available HWMs. There is no HWM information available for high flow calibration of Unnamed Tributary.

- High Flow Validation: Available anecdotal HWMs and peak flow estimates from other historic flood events were used for the model validation.

The model calibration process involved multiple iterations to adjust the model parameter values, conduct simulations, and compare the simulated water levels to the HWMs (for the high flow calibration), or the surveyed water levels (for the low flow calibration). The objective of the model calibration was to achieve good matches between the simulated water levels and the HWMs or measured water levels.

The model validation process involved simulation of the flood conditions not used in the model calibration, by maintaining the calibrated model parameter values, and comparing the simulated water levels to the surveyed or recorded water levels. The objective of the model validation was to confirm if the calibrated model can be reliably used to simulate other flood flow conditions.

4.4.5.2 Low Flow Calibration

The Belly River channel roughness values were calibrated based on the water level and discharge data measured on July 10 to 13, 2021. The surveyed river discharge was 1.57 m^3/s which was 2.2 % of the 2-year flood peak discharge at the Belly River (71 m^3/s).

Figure 4-3 compares the simulated water surface profile to the surveyed water levels for the surveyed low flow conditions. The average difference between the simulated and surveyed water levels was 0.00 m, and the range of differences between -0.74 m and +0.57 m. The calibrated channel Manning's value was 0.05 for the July 13 flow conditions on the Belly River.

There is no measured discharge and water level for the Unnamed Tributary because no water was moving during the field survey. Low flow calibration was not performed for the Unnamed Tributary. The channel Manning's *n* value was selected to be 0.05, in consideration of the river bed/bank material types, vegetation cover on the banks, site information observed during the site inspection and surveys, and Golder's experience with similar modelling studies.

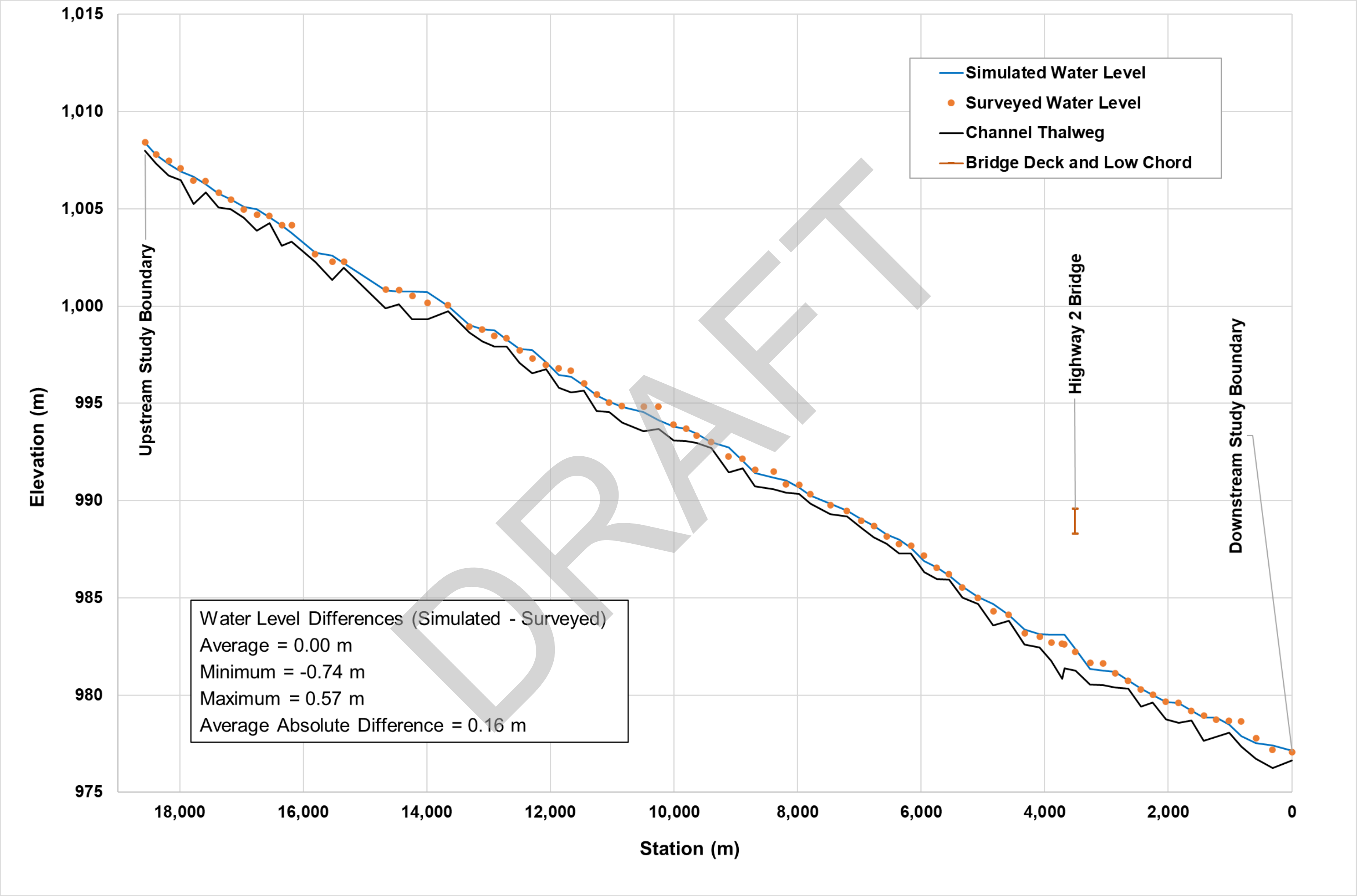

Figure 4-3: Comparison of Simulated Water Surface Profile to Surveyed Water Levels on Belly River for the Surveyed Low Flow Condition

4.4.5.3 High Flow Calibration

The HEC-RAS model for the Belly River study reach was calibrated based on the 1975 and 2010 HWMs. The estimated flood peak discharges on the Belly River were 394 m^3/s on June 20, 1975; and 225 m^3/s on June 22, 2010. The 1975 and 2010 floods on the Belly River at Stand Off have estimated return periods of about 75 and more than 20 years, respectively. Table 4-5 lists the discharges used for simulating the 1975 and 2010 flood events.

Table 4-5: Peak Flow Estimates for the 1975 and 2010 Flood Events on Belly River

Flood Event	Instantaneous Flood Peak Flow (m^3/s)	Remark
1975	394	Recorded data at WSC Station 05AD002
2010	225	Estimated by Golder

Firstly, the 1975 HWMs were used to closely match the simulated water levels for adjusting the initial values of the channel and floodplains Manning's *n* and bridge contraction/expansion coefficients, where necessary. The 2010 HWMs were subsequently used to adjust the values of the floodplain Manning's *n* and the bridge contraction/expansion coefficients. The model calibration was achieved by adjusting the model parameter values in a way that the simulated water levels were in good match with the 1975 and 2010 HWMs. Floodplain roughness values were found to have small effects on the model calibration.

The model was run with fixed discharge for each simulation until steady state was reached. Simulated water levels from the last timestep were then extracted from the HEC-RAS model. The amount of overflow from the Belly River to the floodplains are automatically determined by the coupled 1D/2D model through lateral structures. Since there are no cross sections within the 2D model domain, the simulated water levels were extracted from the 2D model when the surveyed HWMs are located in the floodplain. .

Figure 4-4 and Figure 4-5 compares the simulated water surface profile to the surveyed HWMs for the 1975 and 2010 flood events along the Belly River. Table 4-6 summarizes the differences between the simulated and surveyed HWMs for the 1975 and 2010 flood events. The calibrated channel Manning's *n* value for the high flow conditions is 0.030, which is within the typical range of roughness values for similar rivers with gravel, sand, silt and clay bed materials under high flow conditions (Chow 1959).

Table 4-6: Comparison of Simulated and Surveyed Highwater Marks along the Belly River Study Reach for 1975 and 2010 Flood Events

No	Approximate HEC-RAS Stations (m)	Simulated Water Level [a] (m)	Surveyed Water Level (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Flood Event
1	7,575	992.78	992.24	0.54	394	1975
2	6,733	991.24	990.89	0.35	394	1975
3	3,753	986.26	986.21	0.05	394	1975
4	3,726	984.97	985.17	-0.20	225	2010
5	3,686	984.73	984.90	-0.17	225	2010

Note:

a) Extracted from 2D model or interpolated from cross sections.

There is no historic HWM data available along the study reach of the Unnamed Tributary for model calibration. Therefore, Manning's *n* value of 0.05 for the Unnamed Tributary channel was selected for flow simulations based on published range of values for similar streams (e.g., HEC-RAS Hydraulic Reference) as well as Golder's modelling experience and professional judgement.

4.4.5.4 High Flow Validation

The calibrated model was validated based on the information for the 1995, 2004 and 2016 flood events. Four anecdotal highwater marks (HWMs) along the Belly River were identified within the study area during the field inspection. The model was validated for the Belly River study reach only since no additional HWM was available for the Unnamed Tributary.

The flood peak discharges on the Belly River were estimated for three flood events by Golder and presented in Table 4-7.

Table 4-7: Peak Flow Estimates for the 1995, 2004 and 2016 Flood Events on Belly River

Flood Event	Instantaneous Flood Peak Flow (m^3/s)	Remark
1995	570	Estimated by Golder
2004	14.7	Estimated by Golder
2016	22.6	Estimated by Golder

1995 Flood

Figure 4-6 compares the simulated water surface profile based on the calibrated channel Manning's *n* values of 0.030 to the surveyed anecdotal HWM data along the Belly River. Table 4-8 summarizes the differences between the simulated and surveyed HWMs. One HWMs is in good agreement with the simulated water level. However, a large discrepancy between the simulated and measured water level was observed for the HWM near the upstream boundary, which could be related to the uncertainty of the anecdotal HWM and the estimated peak flows.

2004 and 2016 Floods

The simulated results indicates that the floods were contained in main channel for 2004 and 2016 flood events and the locations of HWMs for 2004 and 2016 flood events are dry based on simulation results. One anecdotal HWM for 2004 flood event was indicated to have the same water level as 1995 flood event at the same location. In consideration to the large difference of peak discharge between 1995 flood event (570 m³/s) and 2004 flood event (14.7 m³/s), it was deemed that the flooding at the residence in 2004 was caused by local flooding or local tributary rather than the direct flooding from the Belly River.

Table 4-8: Comparison of Simulated Water Levels and HWMs along the Belly River for 1995 Flood Event

No	Approximate HEC-RAS Stations (m)	Simulated Water Level [a] (m)	Surveyed Water Level (m)	Difference (Simulated - Surveyed) (m)	Measured Discharge (m^3/s)	Flood Event Date
1	18,227	1,010.34	1,012.58	-2.24	570	1995
2	16,395	1,006.44	1,006.61	-0.17	570	1995

Note:

a) Extracted from 2D model or interpolated from cross sections.

4.4.5.5 Summary of Calibration Results

The HEC-RAS model for the Belly River study reach was calibrated for the low flow and high flow conditions. The calibrated model was subsequently validated with anecdotal HWMs. The results are summarized below:

- The low flow calibration results show that the channel Manning’s *n* values for the low flow conditions are much higher than those for high flow conditions. Because the calibrated model is primarily used for flood modelling, the calibrated Manning’s *n* values for the high flow conditions were used in subsequent flood simulation.
- The high flow calibration results show that the simulated water levels compare well to the available HWMs on the Belly River. The channel and floodplain Manning’s *n* values, as well as contraction and expansion loss coefficients at bridges and other locations, were calibrated based on the 1975 and 2010 flood HWMs.
- A constant Manning’s *n* value of 0.030 for the Belly River main channel can be reliably used for simulating flood flows. The calibrated channel Manning’s *n* value is within the typical range of roughness values for similar rivers (Chow 1959).

No high flow data is available for calibrating the HEC-RAS model for the Unnamed Tributary study reach. Therefore, a Manning’s *n* value of 0.05 for the Unnamed Tributary channel was selected as a reasonable value for flood flow simulations.

In conclusion, the calibrated HEC-RAS model, set up with one geometry file, can be reliably used in this study for simulating various flood events with return periods ranging from 2 to 1,000 years.

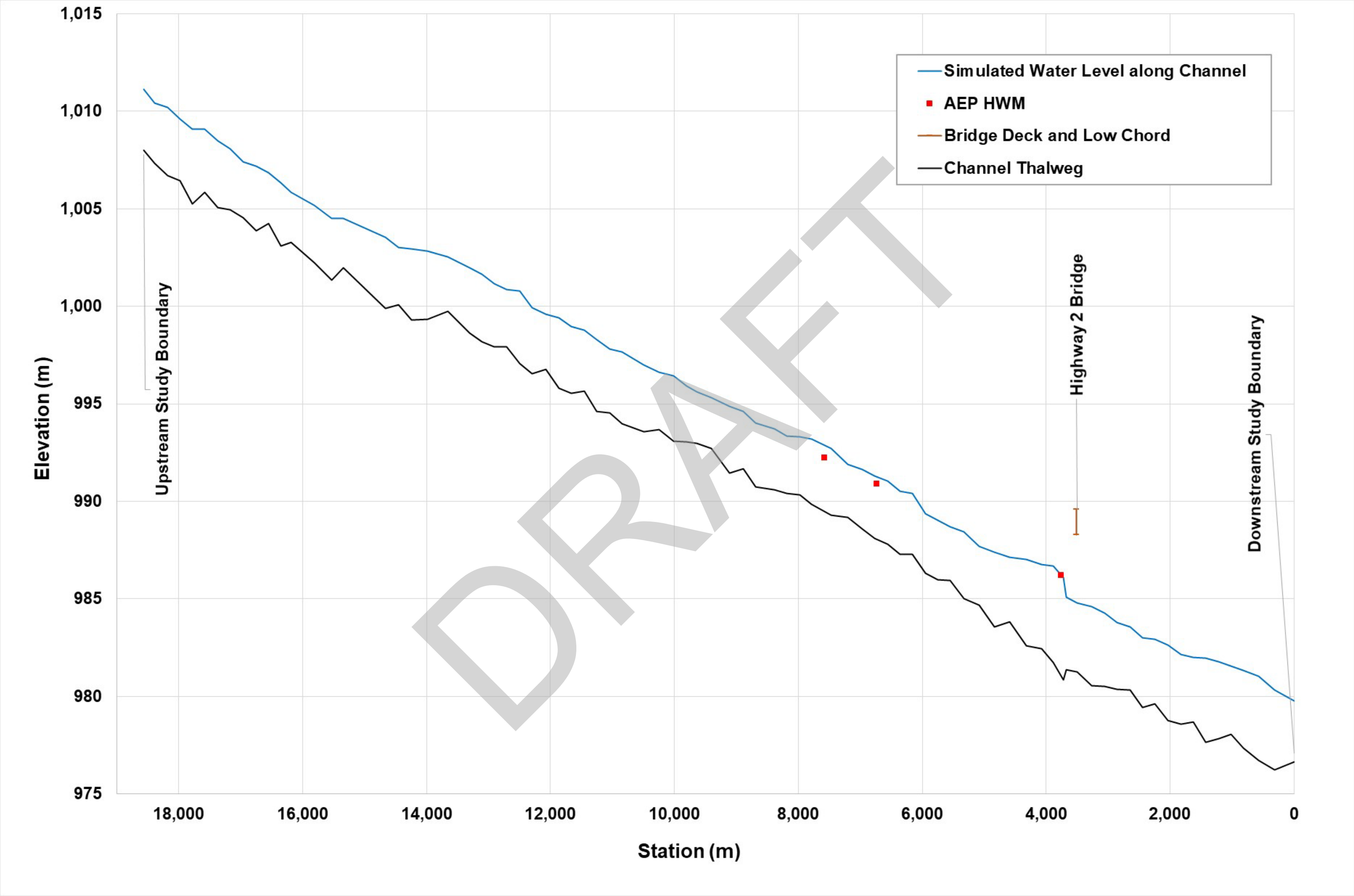

Figure 4-4: Comparison of the Simulated Belly River Water Surface Profiles and Surveyed HWMs for the 1975 Flood Event

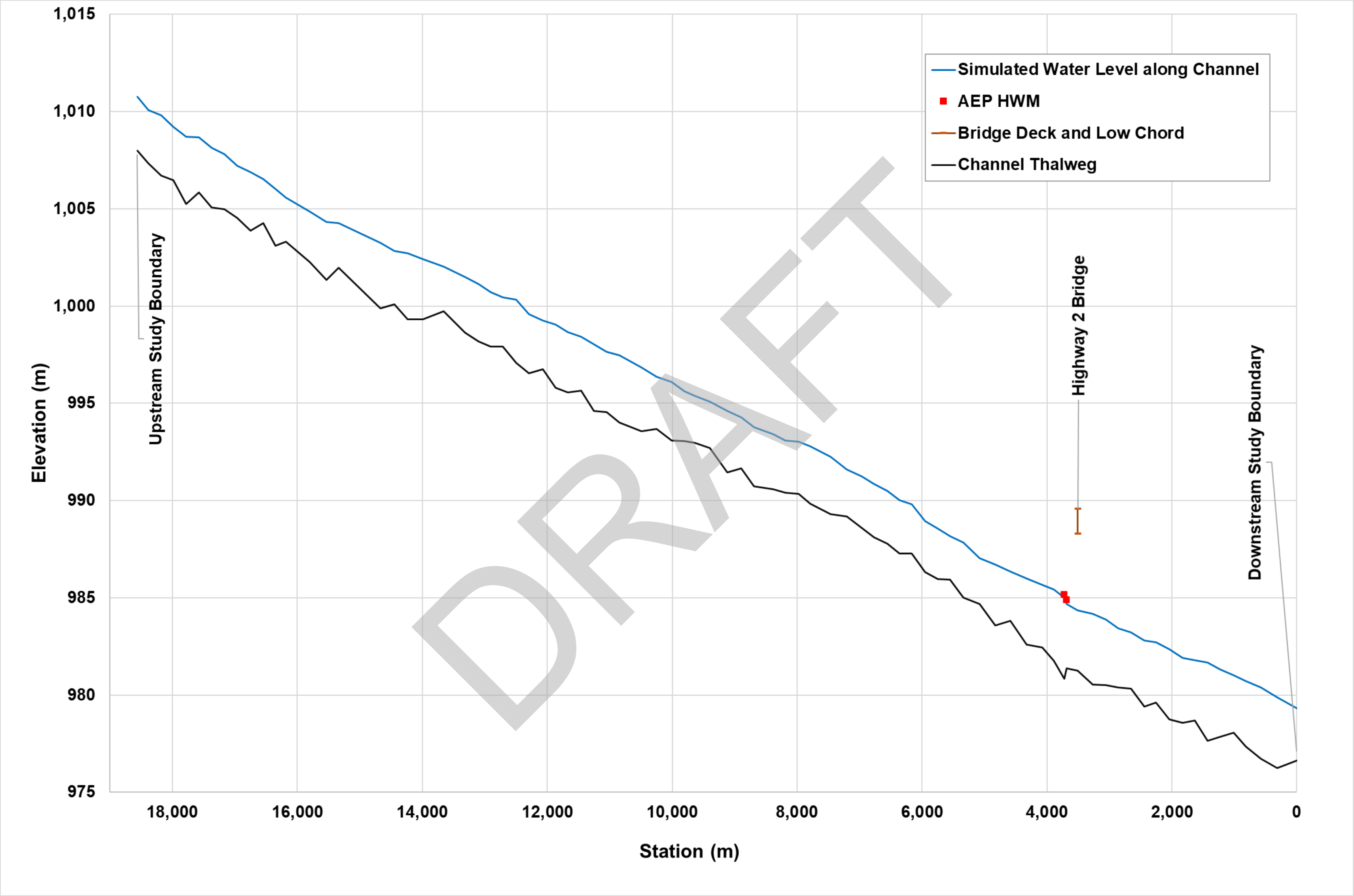

Figure 4-5: Comparison of the Simulated Belly River Water Surface Profiles and Surveyed HWMs for the 2010 Flood Event

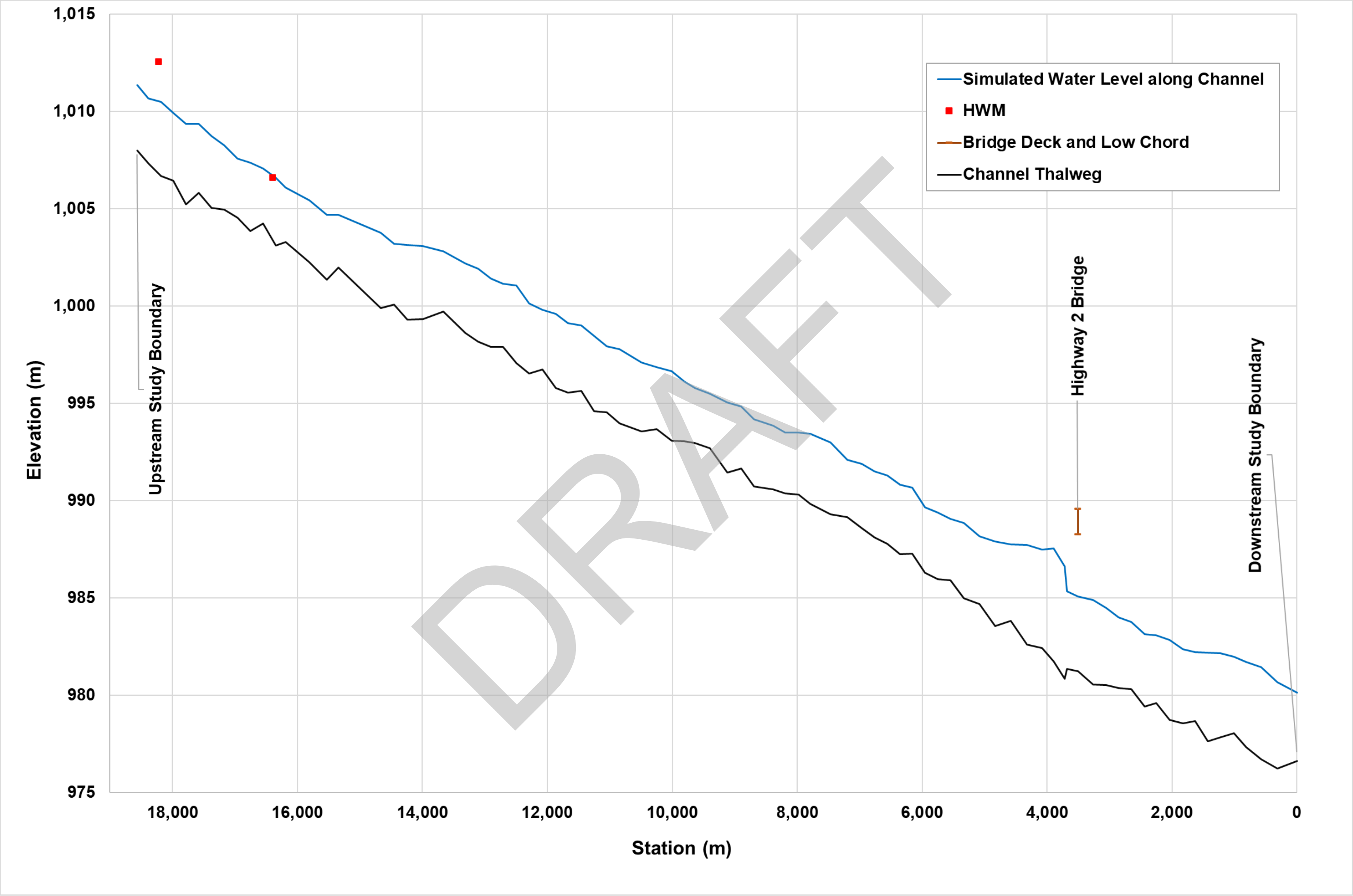

Figure 4-6: Comparison of the Simulated Belly River Water Surface Profiles and Surveyed HWMs for the 1995 Flood Event

4.4.6 Model Parameters and Options

4.4.6.1 Manning's Roughness Values

Channel Roughness

A constant Manning's *n* value of 0.03 was selected for the Belly River main channel, and a constant Manning's n value of 0.05 for the Unnamed Tributary channel. The selections were based on the model calibration and validation results (see Section 4.4.5.1), literature values, and Golder's modelling experience and professional judgement.

The selected Manning's *n* values are in the reasonable range in comparison to typical values of comparable streams (Chow 1959).

Overbank Roughness

The selected overbank Manning's *n* values for the various land use types in the floodplain areas, are presented in Table 4-9.

Table 4-9: Selected Manning's *n* Values for Various Land Use Types

Land Use	Selected Manning's *n* Value
Urban Mixture (Residential)	0.080
Urban Mixture (Industrial)	0.060
Street	0.025
Grassland and Farmland	0.060
Pond	0.030
Trees/Bush	0.120

4.4.6.2 Expansion and Contraction Coefficients

Typical coefficients of 0.1 and 0.3 for contraction and expansion losses were used for cross sections along the 1D model reach of the Belly River except for cross sections at bridges and culverts, where contraction and expansion coefficients of 0.3 and 0.5 were used, respectively.

4.4.6.3 Obstructions and Ineffective Flow Areas

The ineffective flow areas were identified and defined so that one geometry file could be used to simulate the various flood events with return periods of 2 to 1,000 years. The ineffective flow areas were defined in considerations of local topography, structure configurations, and flow connection between adjacent cross sections.

The following three types of ineffective flow areas were implemented in the model setup:

- Topographical low areas such as ponds: permanent ineffective flow areas are specified to block off low-lying areas that do not effectively convey flows.
- Bridge decks and embankments: permanent ineffective flow areas are specified at the cross sections upstream and downstream of the bridges to block off the flow areas if the water level is lower than the top-of-embankment elevation.

4.4.7 Open Water Flood Frequency Profiles

4.4.7.1 Production Model

The HEC-RAS production model was based on the calibrated and estimated Manning’s *n* values. The flood peak discharges used in the HEC-RAS production model were based on the hydrology assessment presented in Section 3.0. Surface water profiles were simulated using the production model for the 2-, 5-, 10-, 20-, 35, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events.

4.4.7.2 Flow Change Location

There is no flow change location along the study reach.

4.4.7.3 Flood Peak Discharges

The flood peak discharges listed in Table 4-10 were assigned at the upstream boundaries of the Belly River and Unnamed Tributary in the production model

Table 4-10: Summary of the Flood Peak Discharges Used in the Production Model

Location	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
Belly River Upstream Boundary	70.6	115	160	220	283	332	399	454	619	796	934	1,120	1,275
Unnamed Tributary Upstream Boundary	4.5	10.8	16.8	24.4	31.9	37.4	44.4	49.9	65.3	80.2	91.1	105	116

4.4.7.4 Model Boundary Conditions

The specified boundary conditions of the HEC-RAS production model are listed below:

- The flood peak discharges specified at the upstream model boundaries for the Belly River and Unnamed Tributary as listed in Table 4-10.
- Normal flow condition with an energy slope of 0.17% specified at the model downstream boundary on the Belly River.
- Normal flow condition with an energy slope of 0.20% specified at the model downstream boundary at north edge of model domain.

4.4.7.5 Open Water Flood Frequency Profiles

Belly River

The simulated open water flood profiles along the study reach of the Belly River are presented in Figure E-1 in APPENDIX E. The simulated open water flood water levels at individual cross sections are listed in Table E-1 in APPENDIX E.

Unnamed Tributary

The simulated open water flood profiles along the study reach of the Unnamed Tributary are presented in Figure E-2 in APPENDIX E. The simulated open water flood water levels at individual cross sections are listed in Table E-2 in APPENDIX E. Since there are no cross sections within the 2D model domain, water levels were extracted from the 2D model results along the Unnamed Tributary main channel in regular intervals of 100 m. The channel stations were presented in the inundation maps.

4.4.8 Model Sensitivity

A model sensitivity analysis was conducted to evaluate the effects of changing model roughness values and downstream boundary conditions on the simulated water levels. The 100-year flood peak discharge was used for the model sensitivity analysis. The sensitivity analysis results were used to quantify the level of uncertainty associated with the simulated flood levels along the study reach of the Belly River and Unnamed Tributary.

The analysis of model sensitivity to Manning's *n* involves the following two sets of Manning's *n* values for the river channels and floodplains and one set of downstream boundary condition:

- ±10% changes of the base channel Manning's *n* values only
- ±10% changes of the base floodplain Manning's *n* values only
- ±20% changes of the specified energy slope for the downstream boundary

The differences between the simulated water levels for the 100-year flood along the study reach of the Belly River, are graphically presented in Figures F-1 to F-3 in APPENDIX F. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of ±0.03 m along the entire study reach, based on the differences in the simulated flood levels for a ±10% change to the base channel Manning's *n* value only.
- The uncertainty in the simulated flood levels, on average, is within a range of -0.02 to +0.04 m along the entire study reach, based on the differences in the simulated flood levels for a ±10% change to the base floodplain Manning's *n* values only.
- A ±20% change to the energy slope at the downstream boundary influences the simulated flood levels by ±0.02 m for approximately 1.0 km upstream of the downstream boundary.

The differences between the simulated water levels for the 100-year flood along the study reach of the Unnamed Tributary, are graphically presented in Figures F-4 to F-6 in APPENDIX F. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels, on average, is within a range of ±0.02 m along the entire study reach, based on the differences in the simulated flood levels for a ±10% change to the base channel Manning's *n* values only.
- The uncertainty in the simulated flood levels, on average, is within a range of ±0.02 m along the entire study reach, based on the differences in the simulated flood levels for a ±10% change to the base floodplain Manning's *n* values only.

5.0 FLOOD INUNDATION MAPS

5.1 Scope

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

- Open water flood inundation map production;
- Water surface elevation rasters; and
- Flood depth grid creation.

5.2 Methodology

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

- Simulated water levels for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events;
- Topography from the 2020 LiDAR survey; and
- Aerial imagery of the study area obtained in September 2020.

Direct flood inundation areas are identified either as being part of the actively-flowing river channels or flooded overbank areas directly connected to the actively-flowing areas. The following general procedure was used in ArcGIS to develop the inundation extent of the 13 open water flood events:

- Flood inundation boundaries, water level grids and depth grids are exported from the 1D/2D HEC-RAS model. The last time step results were exported from HEC-RAS to ensure that the model reached a steady state.
- Areas that are not directly connected to the main river channels are manually removed. Areas where there is no direct overland connection but a hydraulic connection through culverts or other features, may be included in the inundation extent.

5.3 Inundation Polygon Modifications

5.3.1 Open Water Inundation Mapping

One set of open water flood inundation maps was prepared for each of the 13 flood events. The study area is covered by a total of four sheets in tabloid format (11 x 17 in). The mapping scale are 1:10,000. 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 2020 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 a separate document (i.e., APPENDIX G: Open Water Flood Inundation Map Library).

The flood inundation maps were prepared in a geographical information system (ESRI ArcGIS 10.7). The maps including all layers were provided to AEP as digital files in the ESRI ArcGIS file format.

5.3.2 Manual Edits

Flood inundation mapping at some locations required manual edits to produce reasonable inundation extents. These manual edits are summarized in Table 5-1.

Table 5-1: Manual Edits for Flood Inundation Polygons

River	Floodplain	Closest Cross Section Number	Description	Flood Events
Belly River	Right	6 - 7	Inundated area between overflow from Belly River and floodplain was manually connected	10-Year flood event
	Right	17 - 18	Local road would be overtopped, and inundated area along the local road was manually connected	10-Year flood event
	Right	19 - 23	Local road would be overtopped, and inundated area along the local road was manually connected	35-Year flood event
	Right	23 - 25	Local road would be overtopped, and inundated area along the local road was manually connected	35- to 200-Year flood events
	Right	39 - 40	Local road would be overtopped, and inundated area along the local road was manually connected	20- to 100-Year flood events
	Right	48 - 49	Local road would be overtopped, and inundated area along the local road was manually connected	20- to 50-Year flood events
	Right	50 - 51	Return flood was manually connected with the Belly River	20-Year flood event
	Right	54 - 55	Flood from the Unnamed Tributary was manually connected with the Belly River floodplain	10-Year flood event
	Right	59 - 61	Highway 2 would be overtopped, and inundated area along Highway 2 was manually connected	350-Year flood event
	Left	64 - 65	The dike would be overtopped, and inundated area along the dike was manually connected	200-Year flood event
	Left	65 - 66	Highway 2 would be overtopped, and inundated area and flood extent along Highway 2 was manually updated	200- to 1000-Year flood events
Unnamed Tributary	Left	-	Return flood was manually connected with the Unnamed Tributary downstream of Highway 2 Culvert 1	20-Year flood event
	Right	-	Flood overtopping on Highway 509 at Highway 2 intersect was manually connected.	20- to 50-Year flood events
	Right	-	Highway 509 flood overtopping and flood extent was manually updated	20- to 1000-Year flood events
	Right	-	Inundated area downstream of Highway 509 culvert was manually connected	20-Year flood event

5.4 Areas Affected by Floods

5.4.1 Residential and Commercial Areas Affected by Floods

The residential and commercial areas affected by direct inundation are described below. Detailed inundation maps are provided in APPENDIX G.

Belly River

- Highway 2 on the right and left floodplain of Belly River would be overtopped during flood events with return periods of 200-year or higher.
- The residential area on the right floodplain between cross-section 4 and 5, and around cross-section 16 would be inundated during the flood events with return periods of 10-year or higher.
- The residential houses on the right floodplain around cross-section 9 would be inundated during the flood events with return periods of 200-year or higher.

- The residential houses on the right floodplain between cross-section 10 and 13 would be inundated during the flood events with return periods of 20-year or higher.
- The residential houses on the right floodplain around cross-section 10 and east of local road, between cross-section 13 and 14, around cross-section 19, and between cross-section 27 and 28 would be inundated during the flood events with return periods of 200-year or higher.
- The residential houses on the right floodplain between cross-section 29 and 39 would be inundated during the flood events with return periods of 350-year or higher.
- The residential houses on the right floodplain between cross-section 41 and 49, and around cross-section 64 would be inundated during the flood events with return periods of 35 years or higher.
- Standoff Trading Post and Kainai Food Store parking area on the right floodplain around cross-section 51 would be inundated during the flood events with return periods of 350 years or higher.
- Rural water pumphouse and Red Crow Park on the right floodplain around cross-section 51 and 53 would be inundated during the flood events with return periods of 75 years or higher.
- The residential house on the right floodplain around cross-section 60 would be inundated during the flood events with return periods of 200 years or higher.
- Standoff Hutterite Colony on the left floodplain would be inundated during the flood events with return periods of 200 years or higher.

Unnamed Tributary

- Highway 509 would be overtopped on the right floodplain during flood events with return periods of 20-year or higher.
- Portions of Highway 2 would be overtopped near Local Culvert 2 on the left floodplain during flood events with return periods of 10-year or higher.
- The residential house on the left floodplain around station 3500 m would be inundated during the flood events with return periods of 35 years or higher.
- The house on the right floodplain around Local Culvert 2 would be inundated during the flood events with return periods of 5-year or higher.
- Kainai Sport Center and Kainai Memorial Agriplex on the right floodplain of the Unnamed Tributary would be inundated during the flood events with return periods of 350 years or higher.
- The residential houses on the left and right floodplain of the Unnamed Tributary below Highway 2 Culvert 1 would be inundated during the flood events with return periods of 50 years or higher.
- Albert's Gas Bar & Confectionery on the right floodplain downstream of Highway 509 Culvert would be inundated during the flood events with return periods of 100 years or higher.

5.4.2 Flooding of Bridges and Culverts

A bridge is considered affected by flood when the flood water reaches its low chord. A culvert is considered affected by flood when the flood water reaches the road surface. Highway 2 Bridge would not be affected for all 13 flood events. All culverts along the Unnamed Tributary would be affected during flood events with return periods of 2 to 75 years or higher.

The simulated water levels at the bridges along the Belly River and culverts along the Unnamed Tributary for the various flood events, as well as the flow velocities and clearances during the 100-year flood event, are summarized in Table 5-2.

5.5 Flood Depth Grids

5.5.1 GIS Data Specifications

The following GIS data were provided to AEP for each of the 13 open water flood events:

- Inundation polygons
- Water surface elevation rasters
- Flood depth rasters

All GIS data were created in ArcGIS 10.7 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 114). All raster files have a spatial resolution of 0.5 m.

The inundation polygons and raster files were stored in ArcGIS file geodatabases, Version 10.7.

5.5.2 General Comments

The flood water level data, provided as rasters, cover 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.

Table 5-2: Flooding at the Bridges and Culverts along the Belly River Study Reach

Bridge /Culvert Station (m)	Name	Minimum Deck/Road Surface Elevation (m)	Minimum Low Chord/ Culvert Top Elevation (m)	Simulated Water Levels at the Bridges/Culverts for the Various Flood Events (m)													Average Flow Velocity for the 100-year Flood Event (m/s)	Clearance for 100-year Flood Event1 (m)	Return Period of Flood Event Causing Pressure Flow or Overtopping Road Surface (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	1000-year			
3705	Highway 2 Bridge	989.6	988.3	983.9	984.3	984.7	985.1	985.5	985.9	986.4	986.6	986.9	987.1	987.2	987.3	987.4	4.04	2.0	> 1,000 years
-	Highway 2 Culvert 1	990.6	989.6	988.9	989.5	989.9	990.2	990.3	990.4	990.5	990.5	990.6	990.6	990.7	990.7	990.7	2.19	0.10	10 years
-	Local Culvert 1	1003.5	1000.9	1000.6	1002.0	1003.6	1003.8	1003.9	1004.0	1004.0	1004.1	1004.2	1004.3	1004.3	1004.4	1004.5	2.50	-0.60	5 years
-	Local Culvert 2	992.7	991.2	991.2	992.6	992.9	993.0	993.1	993.1	993.1	993.2	993.2	993.2	993.3	993.3	993.3	2.50	-0.50	2 years
-	Highway 2 Culvert 2	988.6	988.0	-	-	-	987.3	987.7	987.9	988.0	988.1	988.3	988.4	988.6	988.8	989.0	0.80	-0.50	75 years
-	Highway 509 Culvert	990.0	986.7	-	-	-	988.5	988.5	988.5	988.6	988.6	988.16	988.7	988.7	988.8	988.8	0.01	-1.40	20 years

Notes: The clearances for the 100-year flood event are the elevation differences between bridge low chord elevations or culvert road surface elevations and simulated water levels. A negative value indicates that the water depth above the low chord for a bridge or above the road surface for a culvert.

6.0 DESIGN FLOOD HAZARD MAPPING

6.1 Flood Hazard Mapping Approach

AEP is implementing a new approach to flood hazard mapping, which is different from the approach used for previous flood studies and no longer includes an encroachment analysis**.** The major technical changes are described in detail in Section 6.1 in the Terms of Reference (TOR) (AEP 2021) and outlined below.

- Encroachment analysis will no longer be used to define floodway limits or determine 1:100 design flood levels. The 0.3 m water level rise criterion is no longer used to define the floodway limit.
- Existing floodways from previous flood studies will not typically get larger when flood hazard maps are updated. For areas with previously-defined floodways, the initial new floodway location will typically correspond to the existing floodway. The floodway can only get larger or smaller if it is deemed necessary with new modelling results based on consultation with local authorities.
- Areas with deeper and faster moving water outside the floodway will be identified within the flood fringe. A new high hazard flood fringe zone will highlight parts of the flood fringe with deeper or faster moving water than the rest of the flood fringe. The new high hazard flood fringe zone will be defined where the water is 1 m deep or greater, the local velocities are 1 m/s or faster in the flood fringe zone.
- The protection provided by dedicated flood berms will be reflected in new flood hazard maps. Areas behind flood berms will still be mapped as flooded if they are overtopped, but areas at risk of flooding behind dedicated flood berms that are not overtopped will be mapped as a protected flood fringe zone.
- Flood hazard maps will show areas at risk of more severe flooding than just the 1:100 design flood. Areas of incremental flood risk outside of the 1:100 flood hazard area will be highlighted, including the 1:200 and 1:500 floods.

6.2 Design Flood

The 100-year open water flood was selected as the design flood in accordance with the Flood Hazard Identification Program (FHIP) Guidelines (AEP 2011b). The 100-year flood water levels simulated in flood frequency analysis (Section 4.4.7.5) were selected as the final design flood levels. The design flood levels for Belly River cross sections, and for 100 m stationing intervals along Unnamed Tributary are provided in APPENDIX E.

6.3 Floodway and Flood Fringe Terminology

The flood hazard area is the area of land that will be flooded during the design flood event. The flood hazard area is typically divided into two zones: floodway and flood fringe. Flood hazard maps can also show additional flood hazard information, including areas of high hazard within the flood fringe and incremental areas at risk for more severe floods such as the 200-year and 500-year floods. Flood hazard mapping is typically used for long-term flood hazard area management and land-use planning. The floodway and flood fringe zones are defined as follows:

- **Floodway**: When a floodway is first defined on a flood hazard map, it typically represents the area of highest flood hazard where flows are deepest, fastest, and most destructive during the 100-year design flood. The floodway generally includes areas where the water is 1 m deep or greater and the local velocities are 1 m/s or faster. The floodway typically includes the main channel of a stream and a portion of the adjacent overbank area. Previously mapped floodways do not typically become larger when a flood hazard map is updated, even if the flood hazard area gets larger or design flood levels get higher. New development is discouraged in the floodway and may not be permitted in some communities.

- **Flood Fringe**: The flood fringe is the portion of the flood hazard area outside of the floodway. The flood fringe typically represents areas with shallower (less than 1 m deep), slower (less than 1 m/s velocity), and less destructive flooding during the 100-year design flood. However, areas with deep or fast moving water may also be identified as high hazard flood fringe within the flood fringe. Areas at risk behind flood berms may also be mapped as protected flood fringe areas. New development in the flood fringe may be permitted in some communities.

6.4 Floodway Determination Criteria

In areas being mapped for the first time, the floodway typically represents the area of highest hazard where flows are deepest, fastest, and most destructive during the design flood. The following criteria, based on those described in current FHIP guidelines, are used to delineate the floodway in such cases:

- Areas in which the depth of water exceeds 1 m or the flow velocities are greater than 1 m/s shall be part of the floodway.
- Exceptions may be made for small backwater areas, ineffective flow areas, and to support creation of a hydraulically smooth floodway.
- For reaches of supercritical flow, the floodway boundary should correspond to the edge of inundation or the main channel, whichever is larger.

Areas of deeper or faster moving water outside of the floodway are identified as high hazard flood fringe. These high hazard flood fringe zones are identified in all areas, whether they are newly-mapped or have an existing floodway.

The depth and velocity criteria used to define high hazard flood fringe zones will be aligned with the 1 m depth and 1 m/s velocity floodway determination criteria for newly-mapped areas.

All areas protected by dedicated flood berms that are not overtopped during the design flood are excluded from the floodway. Areas behind flood berms will still be mapped as flooded if they are overtopped, but areas at risk of flooding behind dedicated flood berms that are not overtopped will be mapped as a protected flood fringe zone.

The governing criteria for Belly River and the Unnamed Tributary were based on the depth and velocity criteria as presented on the Floodway Criteria Maps in APPENDIX H.

6.5 Floodway Criteria Maps

Floodway criteria maps show the basis for determining the floodway, high hazard flood fringe zone, protected flood fringe areas and flood fringe zone for the design flood and documenting the results of water levels, depths and flow velocities. The floodway criteria maps include the following information:

- inundation extents of the 100-year design flood;
- areas meeting or exceeding the 1 m depth floodway criterion for the design flood;
- areas meeting or exceeding the 1 m/s velocity floodway criterion for the design flood;
- proposed floodway boundary for the design flood;
- locations of the main channel top of bank at each cross section;
- location and extent of all cross sections used in the HEC-RAS model with appropriate labels;
- background aerial imagery collected in 2020; and

- roads, bridges, culverts and flood control structures as applicable.

The open water design flood water surface elevations and flow velocities were generated from the coupled 1D/ 2D HEC-RAS model. The model was run until it reached steady state conditions. The last simulation time step was then used to extract the flood water surface elevations and flow velocities directly from the RAS Mapper tool of the HEC-RAS model.

The floodway boundary was delineated in a way that is considered hydraulically smooth. For the Belly River, most of the active side channels and oxbow channels were included into floodway. The rationale for doing this is that the Belly River is considered to be morphodynamically active with potential future channel migration in some areas. For the Unnamed Tributary, most of the floodplain inundated by 100-year flood were included in the floodway as the channel meanders with large sinuosity and the floodplain is currently mostly used as undeveloped farmland and pasture.

The floodway criteria maps were produced using the same template as the inundation maps. The maps are provided in APPENDIX H.

6.5.1 Flood Hazard Maps

The flood hazard maps display the areas in the floodway and flood fringe zones. The floodway was determined as part of the floodway criteria mapping. Flood hazard maps can also show additional flood hazard information, including areas of high hazard within the flood fringe and incremental areas at risk for more severe floods, like the 200-year and 500-year floods. Flood hazard mapping is typically used for long-term flood hazard area management and land-use planning. All areas within the floodway boundary are shown as part of the floodway, even if the water levels of the design flood would not indicate a location as inundated (i.e., “islands” of dry ground within the floodway shown on the floodway criteria maps are not present on the flood hazard maps).

The flood hazard maps were produced using the same template as the inundation maps. The maps are provided in APPENDIX H.

Areas in the Floodway

There is only one residential house on the right floodplain around cross-section 64 or Highway 2 Bridge located within the floodway.

Areas in the High Hazard Flood Fringe

There is no residence or key structure located within the high hazard flood fringe.

Areas in the Flood Fringe

Residential and commercial development in the flood fringe zones within the study area are listed below:

- Portion of Highway 509 on the right floodplain.
- Portion of Highway 2 near Local Culvert 2 on the left floodplain of the Unnamed Tributary.
- The residential houses on the right floodplain between cross-section 4 and 5, cross-section 10 and 13, around cross-section 16, between cross-section 41 and 49, around cross-section 64.
- Rural water pumphouse and Red Crow Park on the right floodplain.
- The residential house on the left floodplain of the Unnamed Tributary around station 3500 m.
- The house on the right floodplain of the Unnamed Tributary around Local Culvert 2.
- The residential houses on the left and right floodplain of Unnamed Tributary below Highway 2 Culvert 1.

- Albert’s Gas Bar & Confectionery on the right floodplain downstream of Highway 509 Culvert.

6.6 Design Flood Grids

6.6.1 Water Surface Elevation Grids

The water surface elevation grid was output directly from the RAS Mapper tool of the HEC-RAS model. The water surface elevation grid has the same resolution (0.5 m) and alignment as the DTM. The water surface elevation raster was then clipped to the directly-inundated areas. The results from the last time step of the simulation were used, when the model had reached steady state conditions.

6.6.2 Flood Depth Grids

The flood depth grid was created by subtracting the water surface elevation grid from the DTM. The flood depth grid has the same resolution (0.5 m) and alignment as the DTM. The extent of the depth grid is limited to the directly-inundated areas.

6.6.3 General Comments

All GIS data were created in ArcGIS Version 10.7 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 114° (3TM 114)].

6.7 Quantitative Climate Change Assessment

A cursory examination of potential increases in 100-year design water levels associated with climate change were performed to understand the possible impacts of climate changes on flood levels. The effect of the 100-year flood conditions more severe than the baseline was assessed under the following two flow scenarios:

1) 100-year open water discharge +10%.

2) 100-year open water discharge +20%.

No hydraulic modelling parameters were varied other than discharges under the open-water conditions. Water level profiles were produced along the study reach for the two additional flow scenarios. The water level differences compared to the baseline 100-year open water discharge were calculated and summarized below. These water level differences were identified as potential “freeboards” that could be applied to the design water levels to account for flow changes that could result from climate change.

- For the Belly River, the average increases in the open water flood levels are 0.08 m for a 10% increase in flow, and 0.15 m for a 20% increase in flow.

- For the Unnamed Tributary, the average increases in the open water flood levels are 0.05 m for a 10% increase in flow, and 0.09 m for a 20% increase in flow.

The above analyses are not based on a regional climate change impact assessment but on a simplified assumption that climate changes would result in increased flood peak flows. The presented values can be viewed as a general range of potential climate change “freeboard” that could be considered in addition to the computed design flood water levels.

The difference between the simulated water levels for 100-year climate-affected flood along the Belly River and Unnamed Tributary study reaches, are presented in Figure I-1 and I-2 in APPENDIX I. The simulated climate-affected open water flood water levels at individual cross sections are compared to the baseline 100-year open water discharge in Table I-1 and I-2 in APPENDIX I.

7.0 CONCLUSIONS

7.1 Survey and Base Data Collection

Topographic, bathymetric, and supporting base data required for this study were collected in accordance with the requirements by AEP. The following conclusions are made:

- *Cross Section Surveys* – Cross section survey data collected in July and August 2021 meet the current study requirements with regard to cross-section spacing and alignment, extents of cross sections on the floodplains, labeling of survey points, and data accuracy.
- *Hydraulic and Flood Control Structure Surveys* – Hydraulic structure survey data collected in July and August 2021 meet the study requirements and include the necessary details for the hydraulic modelling.
- *Digital Terrain Model* – The differences in elevation between the selected survey points and the DTM data are considered to be within an acceptable range. Therefore, the DTM is considered suitable for overbank cross section data extraction and flood mapping.

7.2 Open Water Hydrology Assessment

The results of the open water hydrology assessment completed in this study support the following conclusions:

- The flood frequency estimates obtained in this study are the most up-to-date for the Belly River at Stand Off and Unnamed Tributary. These estimates provide the updated flood hydrology information as inputs to the other components of the study (e.g., hydraulic modelling). Estimates of flood peak discharges were obtained for various return periods ranging from 2 to 1,000 years, including the 95% upper and lower confidence intervals.
- This study is based on the derived flow data up to 2020 by extending the natural and naturalized flood flow series for Belly River near Stand Off gauging station (for the period of 1909 to 1985).
- A regional hydrological analysis was used to develop flood peak discharge estimates based on drainage areas, for the Unnamed Tributary.

7.3 Open Water Hydraulic Modelling

7.3.1 Selection of Manning's *n* Values

The coupled 1D/2D HEC-RAS model, set up for the study reaches of the Belly River and the Unnamed Tributary, was calibrated and validated based on the available low flow, and high flow data. The calibrated HEC-RAS model can be reliably used in this study for simulating various flood events with return periods ranging from 2 to 1,000 years.

The calibrated channel Manning's *n* value for high flow conditions is 0.03 along the Belly River study reach. No high flow data were available for calibrating the hydraulic model for the Unnamed Tributary. Therefore, a representative Manning's *n* value of 0.05 was estimated for the Unnamed Tributary channels. These Manning's *n* values are within the typical range of roughness values for similar streams (Chow 1959).

The Manning's *n* values for the floodplain areas were estimated and calibrated based on the land use types.

7.3.2 Model Sensitivity

The model sensitivity analysis was conducted for the 100-year flood event to evaluate the effects of changing model roughness values and downstream boundary conditions on the simulated water levels. The results of the sensitivity analysis indicate the following:

- The uncertainty in the simulated flood levels for changing roughness values, on average, is within a range of ±0.04 m along the Belly River study reach, and ±0.02 m along the Unnamed Tributary study reach.
- The ±20% changes of the energy slope at the downstream boundary of Belly River influence the simulated flood levels by ±0.02 m along approximately 1 km reach immediately upstream from the downstream boundary of Belly River.

7.3.3 Flood Profiles

The HEC-RAS model is a reliable tool for simulating the flood profiles of the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750- and 1,000-year flood events in the study area.

7.4 Flood Inundation Mapping

The HEC-RAS model results and the LiDAR DTM were used for preparing 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.

Based on the simulation results, the main areas to be affected by open water flooding have been identified as follows:

- Various residential areas along the right floodplain of the Belly River would be flooded starting at the 10-year flood or greater.
- Water from the 200-year flood or greater would overtop the Highway 2 on the right and left floodplain of the Belly River.
- Water from the 20-year flood or greater would overtop the Highway 509 on the right floodplain.
- Water from the 10-year flood or greater would overtop portion of Highway 2 near Local Culvert 2 on the left floodplain of the Unnamed Tributary.
- Standoff Trading Post and Kainai Food Store parking area on the right floodplain of the Belly River would be inundated during the flood events with return periods of 350 years or higher.
- Rural Water Pumphouse and Red Crow Park on the right floodplain of the Belly River would be inundated during the flood events with return periods of 75 years or higher.
- Standoff Colony on the left floodplain of the Belly River would be inundated during the flood events with return periods of 200 years or higher.
- Kainai Sport Center and Kainai Memorial Agriplex on the right floodplain of the Unnamed Tributary would be inundated during the flood events with return periods of 350 years or higher.

7.5 Design Flood Hazard Mapping

The 100-year open water flood is selected as the design flood on the Belly River in accordance with the Flood Hazard Identification Program (FHIP) Guidelines (AEP 2011b). The floodway was determined as part of the floodway criteria mapping.

Areas in the Floodway

There is one residential house located within the floodways along the Belly River study reach.

Areas in the High Hazard Flood Fringe

There are no residences or key structure within high hazard flood fringe zones.

Areas in the Flood Fringe

Residential and commercial areas in the flood fringe zones within the study area are listed below.

- Portion of Highway 509 on the right floodplain.
- Portion of Highway 2 near Local Culvert 2 on the left floodplain of the Unnamed Tributary.
- The residential houses on the right floodplain between cross-section 4 and 5, cross-section 10 and 13, around cross-section 16, between cross-section 41 and 49, around cross-section 64.
- Rural Water Pumphouse and Red Crow Park on the right floodplain.
- The residential house on the left floodplain of the Unnamed Tributary around station 3500 m.
- The house on the right floodplain of the Unnamed Tributary around Local Culvert 2.
- The residential houses on the left and right floodplain of the Unnamed Tributary below Highway 2 Culvert 1.
- Albert’s Gas Bar & Confectionery on the right floodplain downstream of Highway 509 Culvert.

7.6 Quantitative Climate Change Assessments

Potential effects of climate change on open water floods were assessed through a sensitivity analysis of flood water level differences due to 10- and 20-percent increases in the 100-year flood peak discharge. These water level differences were identified as potential “freeboards” that could be applied to the design water levels to account for flow changes that could result from climate change. The results of the climate change effect assessment are summarized below:

- For the Belly River, the average increases in the open water flood levels are 0.08 m for a 10% increase in flow, and 0.15 m for a 20% increase in flow.
- For the Unnamed Tributary, the average increases in the open water flood levels are 0.05 m for a 10% increase in flow, and 0.09 m for a 20% increase in flow.

The analysis in this study was not based on a regional climate change impact assessment but on a simplified assumption that climate changes would result in increased flood peak discharges.

Signature Page

This report was prepared and reviewed by the undersigned.

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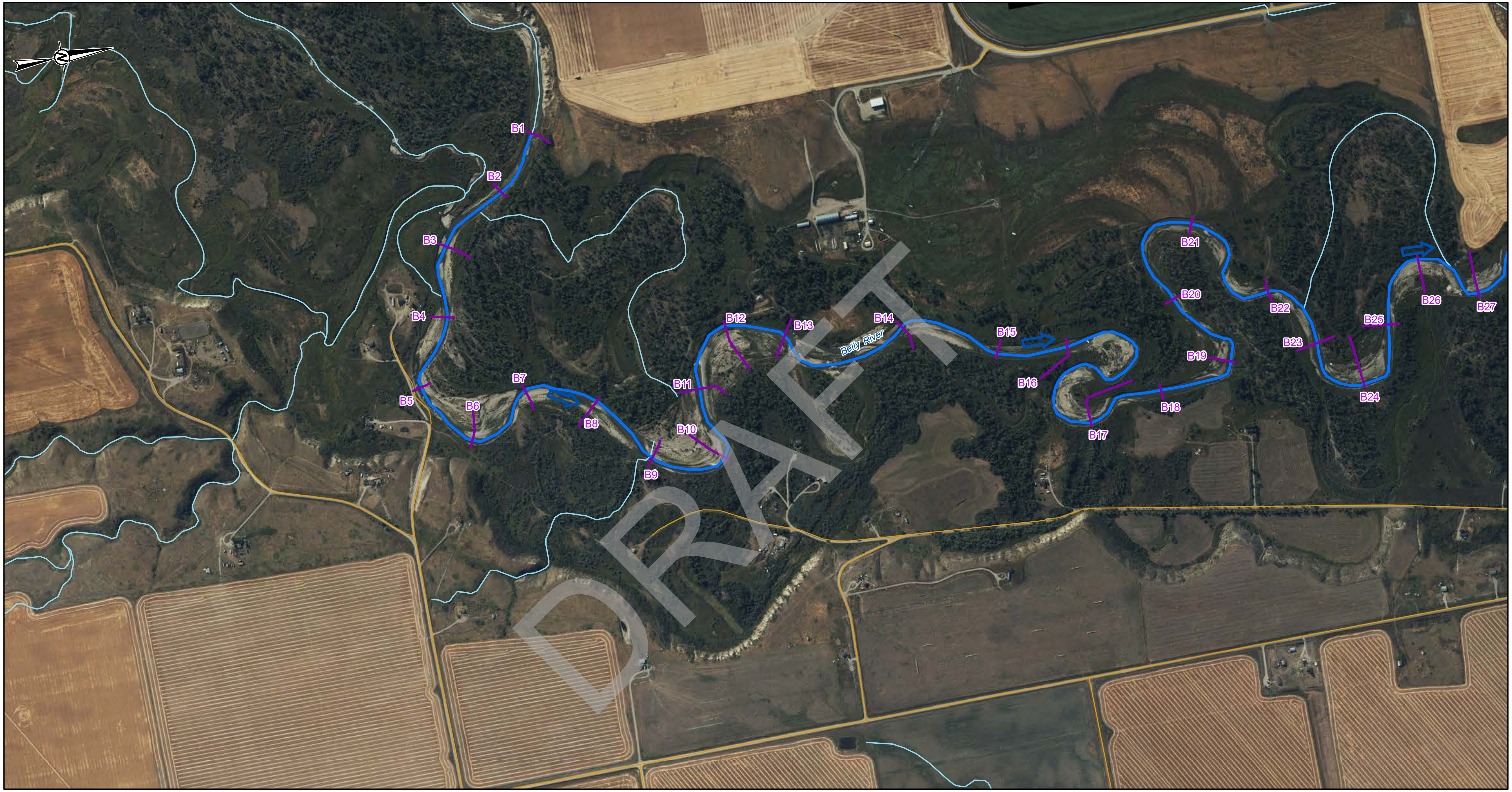
APPENDIX A

Locations of Cross Sections and Hydraulic Structures



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- ⇨ FLOW DIRECTION
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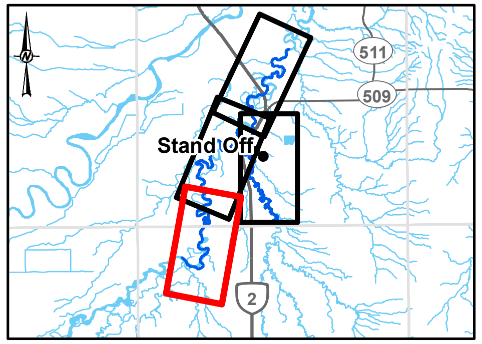
- — SECONDARY HIGHWAY
- — LOCAL ROAD
- — WATERCOURSE
- — SURVEY REACH
- — SURVEYED CROSS SECTION



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PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-22
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

TITLE
LOCATIONS OF CROSS SECTIONS, HYDRAULIC AND FLOOD CONTROL STRUCTURES

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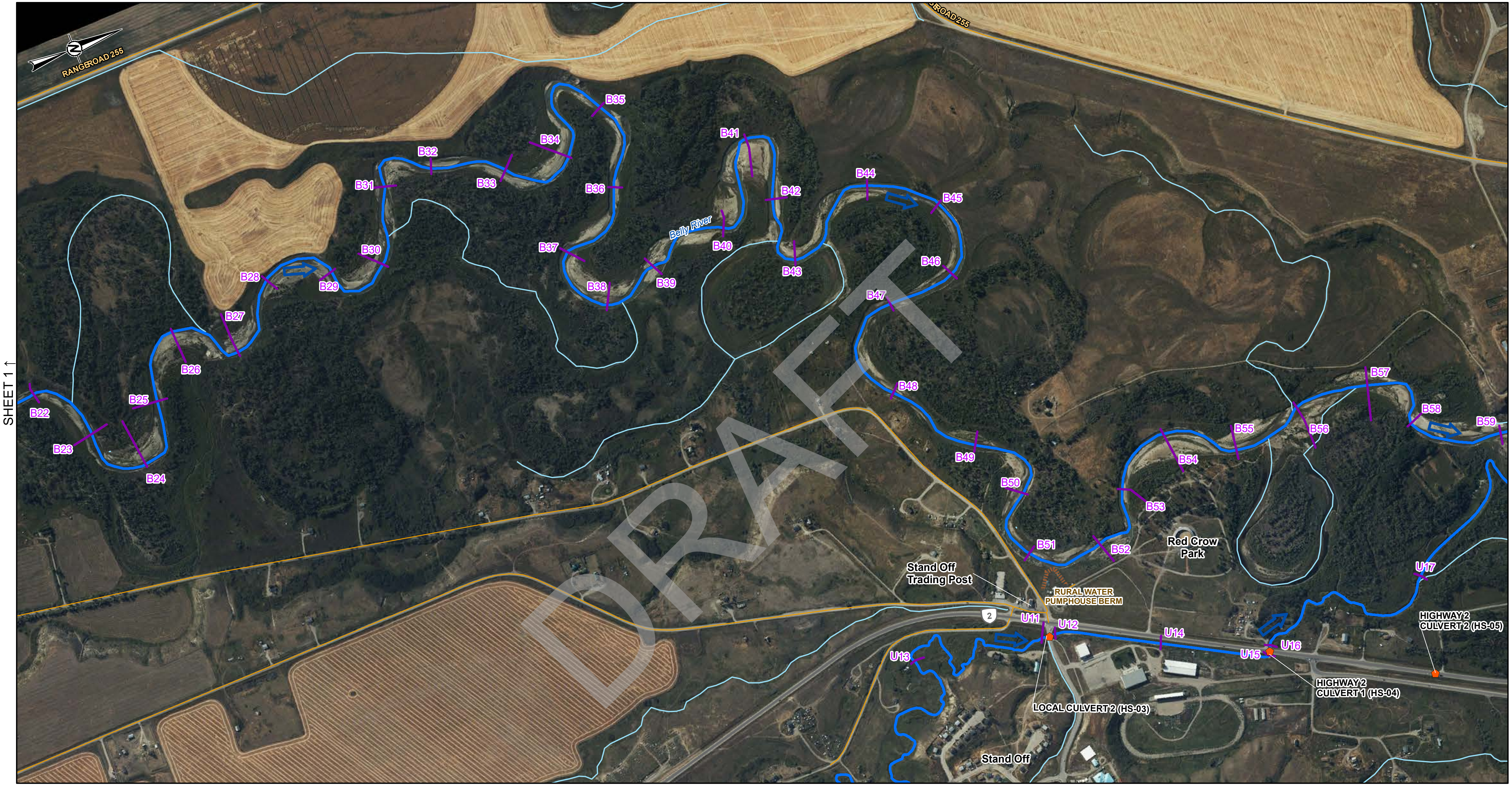

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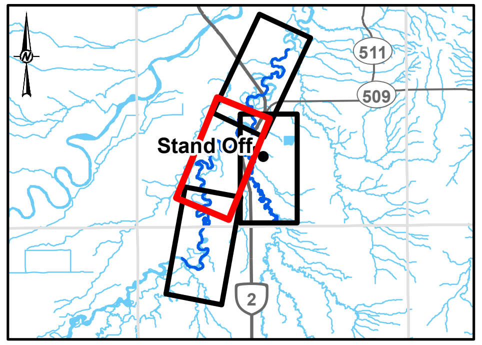

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PROJECT
STAND OFF FLOOD STUDY

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LOCATIONS OF CROSS SECTIONS, HYDRAULIC AND FLOOD CONTROL STRUCTURES

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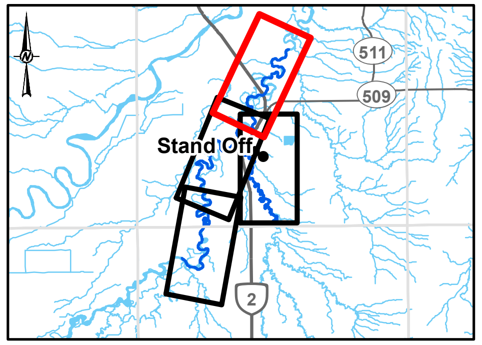
— LOCAL ROAD
— WATERCOURSE
— SURVEY REACH
— SURVEYED CROSS SECTION



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PROJECT
STAND OFF FLOOD STUDY

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REVIEWED	JC
APPROVED	WP

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LOCATIONS OF CROSS SECTIONS, HYDRAULIC AND FLOOD CONTROL STRUCTURES

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—	WATERCOURSE
—	SURVEY REACH
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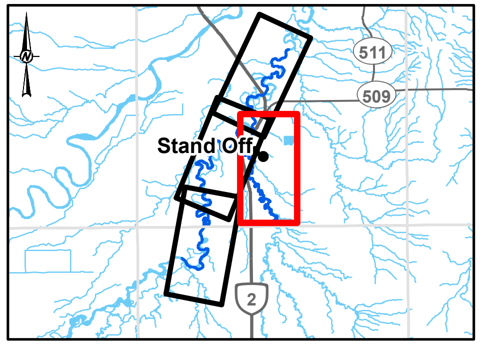

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PROJECT
STAND OFF FLOOD STUDY

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Classification: Public

APPENDIX B

Hydraulic Structure Datasheets

TITLE

HYDRAULIC STRUCTURE DATASHEET - HIGHWAY 2 BRIDGE

LOCATION	BELLY RIVER
DESCRIPTION	HIGHWAY 2 BRIDGE
TOTAL LENGTH OF SPAN (m)	80
DECK WIDTH OF BRIDGE (m)	12
AVERAGE TOP OF CURB OR SOLID GUARD RAIL ELEVATION (m)	989.6
AVERAGE LOW CHORD ELEVATION (m)	988.3
BRIDGE OBSTRUCTION HEIGHT (m)	1.4
NUMBER OF PIERS	2

PIER	CENTRE STATION (m)	WIDTH (m)	TYPE	SHAPE
1	67.3	0.85	CONCRETE	OBLONG
2	93.3	0.85	CONCRETE	OBLONG

LEGEND

●	STRUCTURE SURVEY POINT
➡	FLOW DIRECTION
—	PRIMARY HIGHWAY

PHOTO 1 RIGHT BANK UPSTREAM LOOKING AT BRIDGE

PHOTO 2 RIGHT BANK UPSTREAM LOOKING AT BRIDGE

NOTE(S)
ALL DETAILS OF STRUCTURE SURVEY WILL BE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
STRUCTURE SURVEY AND STRUCTURE PHOTOS BY GOLDER ASSOCIATES LTD. JULY 2021.

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-17
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	**B-1**

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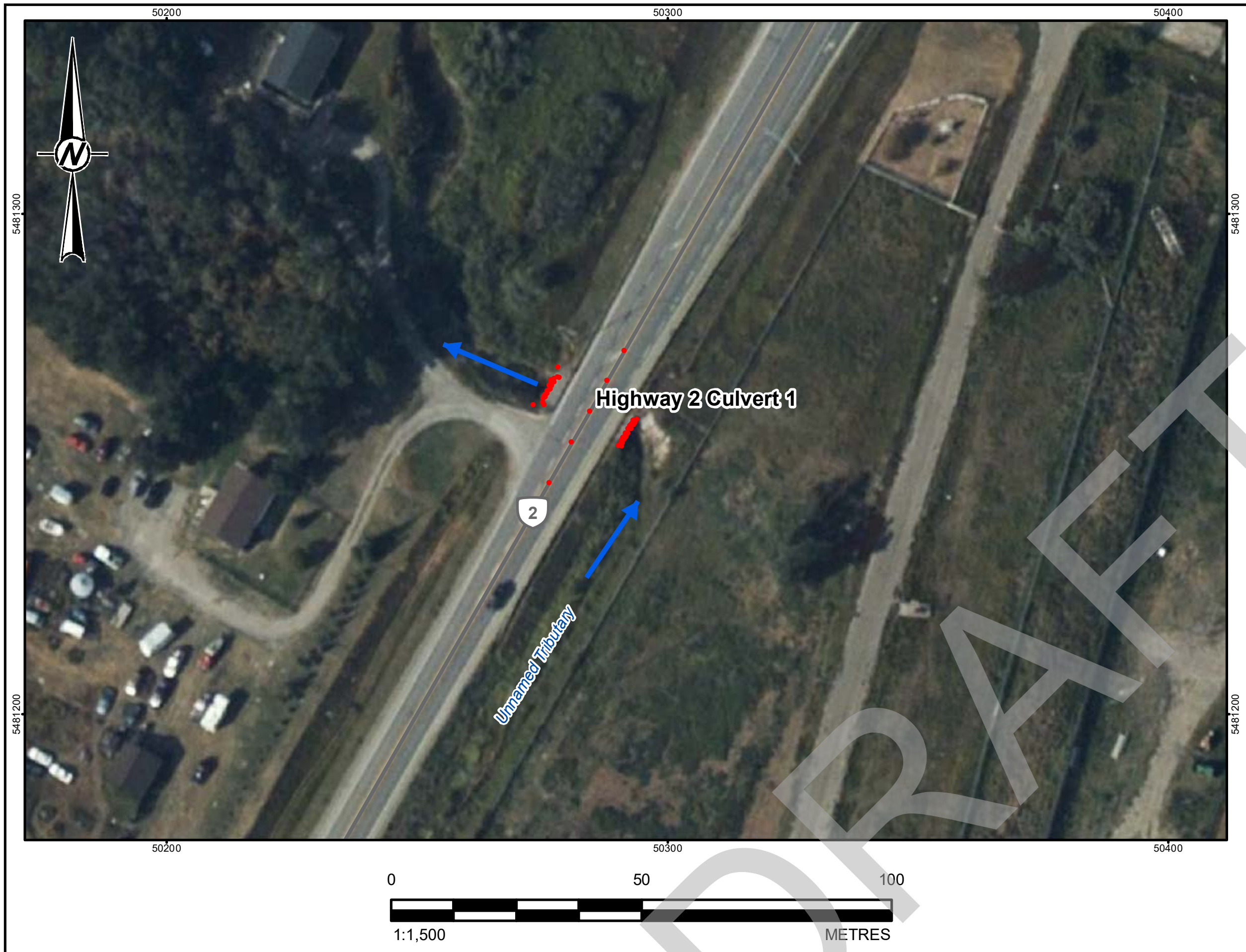

TITLE

HYDRAULIC STRUCTURE DATASHEET - HIGHWAY 2 CULVERT 1

LOCATION	UNNAMED TRIBUTARY
DESCRIPTION	HIGHWAY 2 CULVERT 1
TOTAL LENGTH OF CULVERT (m)	17.5
RISE OF CULVERT (m)	2.17
SPAN OF CULVERT (m)	4.34
DIAMETER OF CULVERT (m)	-
CULVERT TYPE	ARCH
CULVERT INVERT ELEVATION - UPSTREAM (m)	987.4
CULVERT INVERT ELEVATION - DOWNSTREAM (m)	987.3

LEGEND

●	STRUCTURE SURVEY POINT
➡	FLOW DIRECTION
—	PRIMARY HIGHWAY

NOTE(S)
ALL DETAILS OF STRUCTURE SURVEY WILL BE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

PHOTO 1 LEFT BANK UPSTREAM LOOKING AT CULVERT

PHOTO 2 LEFT BANK UPSTREAM LOOKING AT CULVERT

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-17
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PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	B-2

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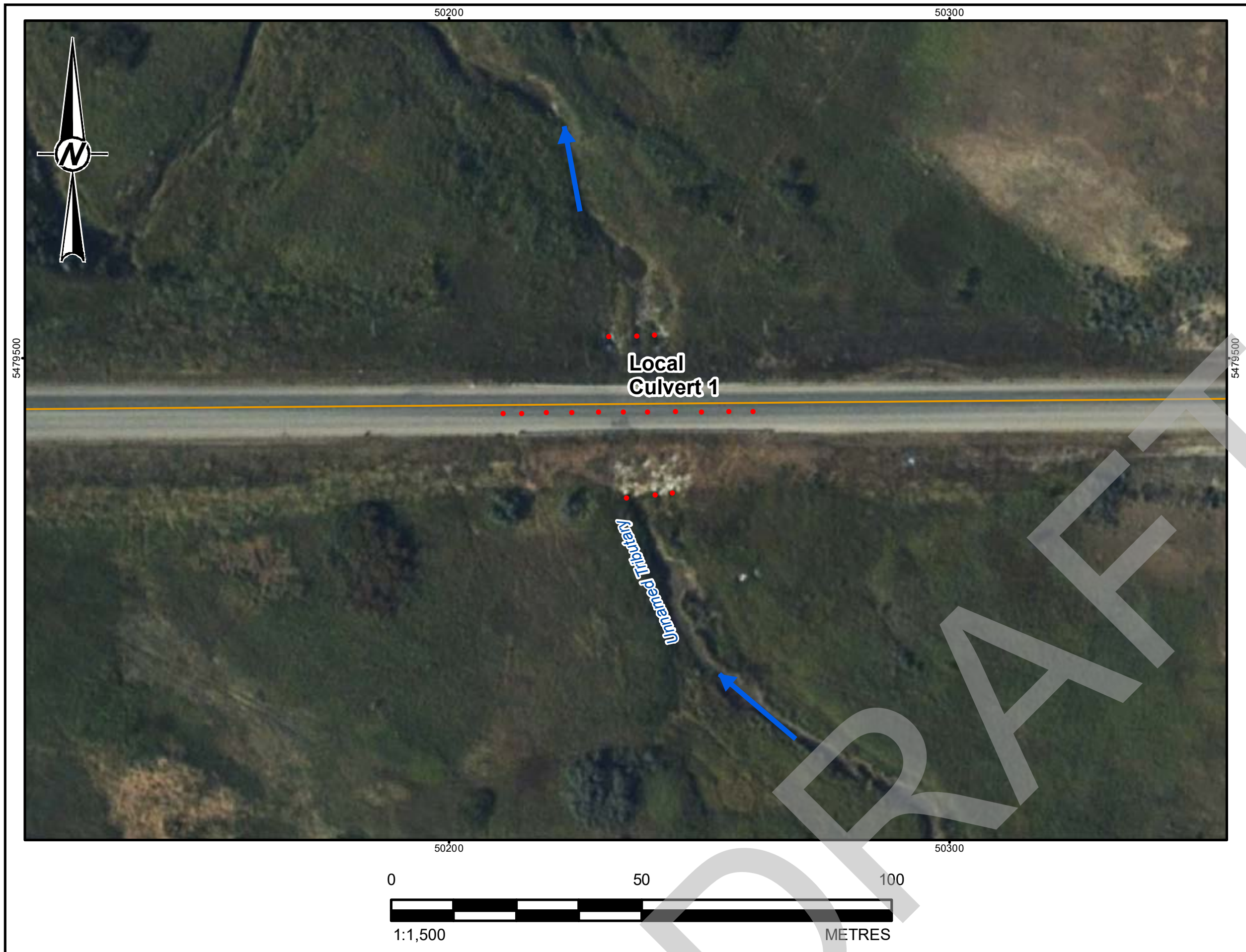

TITLE

HYDRAULIC STRUCTURE DATASHEET - LOCAL CULVERT 1

LOCATION			UNNAMED TRIBUTARY
DESCRIPTION			LOCAL CULVERT 1
BARREL NO.	1	2	3
TOTAL LENGTH OF CULVERT (m)	32.3	31.8	31.8
RISE OF CULVERT (m)	-	-	-
SPAN OF CULVERT (m)	-	-	-
DIAMETER OF CULVERT (m)	1.2	1.2	1.2
CULVERT TYPE			CIRCULAR
CULVERT INVERT ELEVATION - UPSTREAM (m)	999.7	999.3	999.5
CULVERT INVERT ELEVATION - DOWNSTREAM (m)	998.5	999.1	999.1

LEGEND

● STRUCTURE SURVEY POINT
➡ FLOW DIRECTION
— LOCAL ROAD

NOTE(S)
ALL DETAILS OF STRUCTURE SURVEY WILL BE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
STRUCTURE SURVEY AND STRUCTURE PHOTOS BY GOLDER ASSOCIATES LTD. JULY 2021.

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

PHOTO 1 RIGHT BANK UPSTREAM LOOKING AT CULVERT

PHOTO 2 RIGHT BANK DOWNSTREAM LOOKING AT CULVERT

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-17
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	B-3

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TITLE

HYDRAULIC STRUCTURE DATASHEET - LOCAL CULVERT 2

LOCATION			UNNAMED TRIBUTARY
DESCRIPTION			LOCAL CULVERT 2
BARREL NO.	1	2	3
TOTAL LENGTH OF CULVERT (m)	22.15	22.15	22.15
RISE OF CULVERT (m)	-	-	-
SPAN OF CULVERT (m)	-	-	-
DIAMETER OF CULVERT (m)	1.2	1.2	1.2
CULVERT TYPE			CIRCULAR
CULVERT INVERT ELEVATION - UPSTREAM (m)	990.0	990.0	990.0
CULVERT INVERT ELEVATION - DOWNSTREAM (m)	989.9	990.0	990.0

LEGEND

●	STRUCTURE SURVEY POINT
➜	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY

NOTE(S)
ALL DETAILS OF STRUCTURE SURVEY WILL BE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
STRUCTURE SURVEY AND STRUCTURE PHOTOS BY GOLDER ASSOCIATES LTD. JULY 2021.

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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

PHOTO 1 LEFT BANK UPSTREAM LOOKING AT CULVERT

PHOTO 2 RIGHT BANK DOWNSTREAM LOOKING AT CULVERT

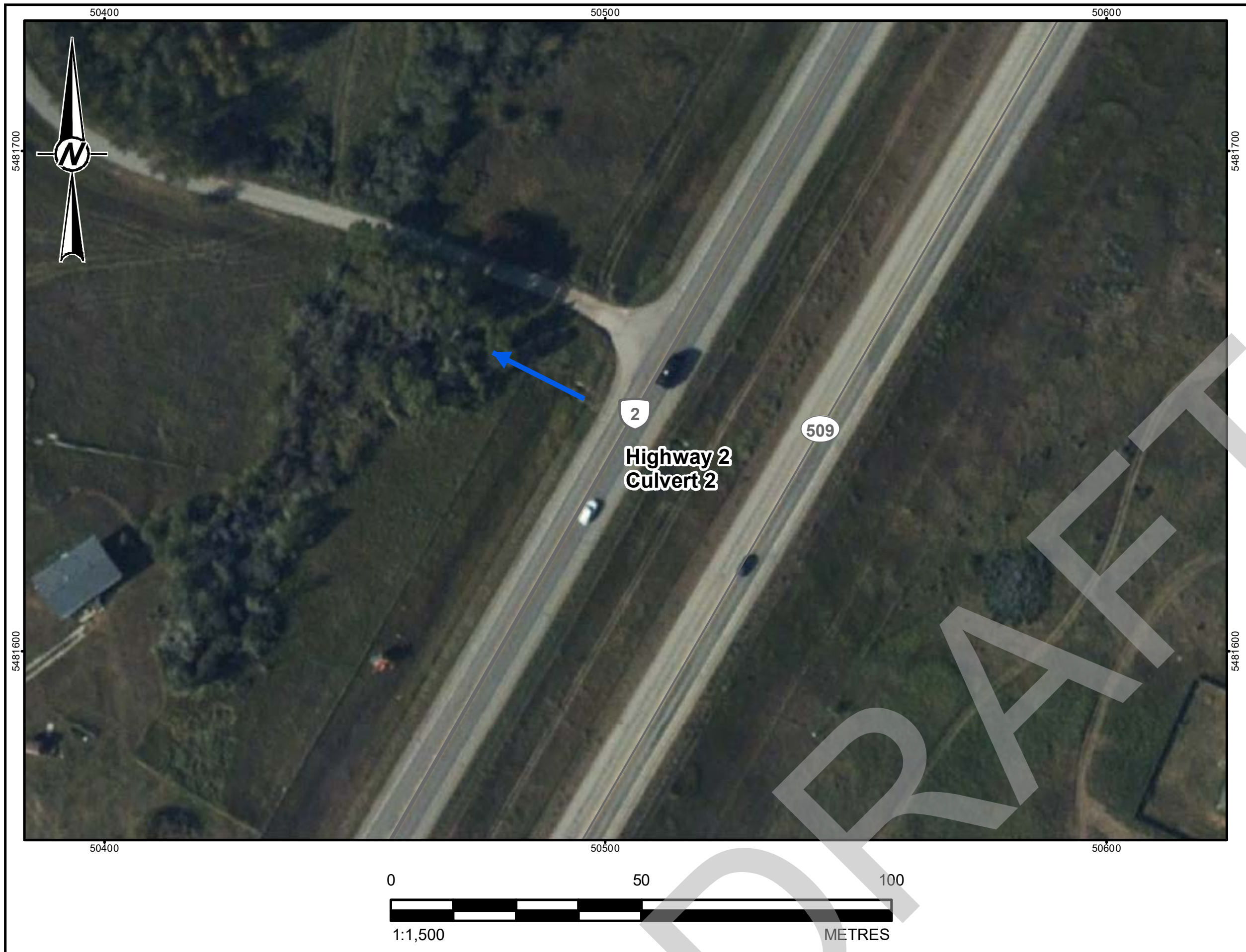
CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-17
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	**B-4**



TITLE
HYDRAULIC STRUCTURE DATASHEET - HIGHWAY 2 CULVERT 2

LOCATION		HIGHWAY 2
DESCRIPTION		HIGHWAY 2 CULVERT2
BARREL NO.	1	2
TOTAL LENGTH OF CULVERT (m)	20.9	20.9
RISE OF CULVERT (m)	-	-
SPAN OF CULVERT (m)	-	-
DIAMETER OF CULVERT (m)	1.2	1.2
CULVERT TYPE		CIRCULAR
CULVERT INVERT ELEVATION - UPSTREAM (m)	986.83	986.81
CULVERT INVERT ELEVATION - DOWNSTREAM (m)	986.54	986.54

LEGEND

➡	FLOW DIRECTION
—	PRIMARY HIGHWAY
─	SECONDARY HIGHWAY

NOTE(S)
ALL DETAILS OF STRUCTURE SURVEY WILL BE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

PHOTO 1 UPSTREAM LOOKING AT CULVERTS

PHOTO 2 DOWNSTREAM LOOKING AT CULVERTS

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ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
wsp GOLDER

YYYY-MM-DD	2022-06-15
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	**B-5**

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TITLE

HYDRAULIC STRUCTURE DATASHEET - HIGHWAY 509 CULVERT

LOCATION	HIGHWAY 509
DESCRIPTION	HIGHWAY 509 CULVERT
BARREL NO.	1
TOTAL LENGTH OF CULVERT (m)	-
RISE OF CULVERT (m)	-
SPAN OF CULVERT (m)	-
DIAMETER OF CULVERT (m)	0.75
CULVERT TYPE	CIRCULAR
CULVERT INVERT ELEVATION - UPSTREAM (m)	985.92
CULVERT INVERT ELEVATION - DOWNSTREAM (m)	985.02

LEGEND

➡	FLOW DIRECTION
—	SECONDARY HIGHWAY

PHOTO 1 LEFT BANK UPSTREAM LOOKING AT CULVERT

PHOTO 2 LEFT BANK DOWNSTREAM LOOKING AT CULVERT

NOTE(S)
ALL DETAILS OF STRUCTURE SURVEY WILL BE USED FOR HYDRAULIC MODELLING.

REFERENCE(S)
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CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT
wsp GOLDER

YYYY-MM-DD	2022-06-22
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	B-6

APPENDIX C

Flood Control Structure

GOLDER
MEMBER OF WSP

TECHNICAL MEMORANDUM

DATE August 10, 2021 **Project No.** 21467363

TO Muhammad Durrani
Alberta Environment and Parks

FROM Jie Chen and Hua Zhang, Golder Associates Ltd. **EMAIL Jie_Chen@golder.com**

TECHNICAL MEMORANDUM ON FLOOD CONTROL STRUCTURE FOR THE STAND OFF FLOOD STUDY

1.0 INTRODUCTION

1.1 Study Background

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in June 2021 to conduct the Stand Off Flood Study. The purpose of the study is to assess and identify flood hazards along the Belly River through Kainai Nation and Cardston County. The Belly River study reach extends approximately 17 km, from the eastern boundary of SE-31-5-25-W4M to the southern boundary of SW-27-6-25-W4M, including Stand Off.

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 key stakeholders for this project are the Government of Alberta, Kainai Nation, and Cardon County. The project includes working with Kainai Nation.

The Stand Off Flood Study includes multiple components and deliverables. This memo documents the flood control structure and overall survey methodology of the survey, which supports the hydraulic modelling, flood mapping, flood hazard mapping components.

2.0 SURVEY PROGRAM

2.1 General

As part of the field survey program, we were accompanied by Mr. Muhammad Durrani of AEP and Mr. Jonathan Day Chief and his colleagues from Kainai Nation to conduct a field inspection along the Belly River on July 7, 2021. During the field inspection, a flood control structure was identified within the study area by Kainai Nation.

The survey of river cross sections, hydraulic structures, and the flood control structure within the study area was conducted between July 9 and July 14, 2021. Three ASCM benchmarks were surveyed as part of this study and were used and confirmed the precision to use for the surveyed data.

2.2 Flood Control Structure

There is one flood control structures on the Belly River near Stand Off. The location of this flood control structure within the study area is described in Table 1 and shown in Figure 1. The flood control structure is a berm located on the right floodplain of the Belly River protecting the Rural Water Pumphouse near Stand Off Trading Post. This flood control structure is approximately 120 m long. The survey points were taken from the top of the berm approximately every 4 m. We extracted one cross-sectional profile of the berm based on the survey data collected for this study.

Table 1: Locations of Flood Control Structure

Location	Approximate Length of Structure (m)	Type of Structure	Description
Belly River	120	Berm	Rural Water Pumphouse on Belly River right floodplain

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LEGEND

- ━ ROAD
- ━ PRIMARY HIGHWAY
- ↔ BERM PROFILE LOCATION
- → FLOW DIRECTION
- ▨ FLOOD CONTROL STRUCTURE

NOTE(S)

FLOOD CONTROL STRUCTURE SURVEY COMPLETED TO SUPPORT HYDRAULIC MODELLING AND FLOOD MAPPING.

FOR MORE DETAILS SEE SECTION 2.6.

REFERENCE(S)

FLOOD CONTROL STRUCTURE SURVEY BY GOLDER ASSOCIATES LTD. JULY 2021. ROADS OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED. IMAGERY COPYRIGHT © 20180905 ESRI AND ITS LICENSORS. SOURCE: TOWN OF CARDSTON. USED UNDER LICENSE, ALL RIGHTS RESERVED. DATUM: NAD 83 CSRS PROJECTION: 3TM 114

LOCATION	BELLY RIVER
APPROX. LENGTH OF STRUCTURE (m)	120
TYPE OF STRUCTURE	BERM

0 30 60

1:1,000 METRES

TITLE

A BERM AROUND THE RURAL WATER PUMPHOUSE ON BELLY RIVER RIGHT FLOODPLAIN

DESCRIPTION

ALONG RURAL WATER PUMPHOUSE

CLIENT

ALBERTA ENVIRONMENT AND PARKS

PROJECT

STAND OFF FLOOD STUDY

CONSULTANT

GOLDER

YYYY-MM-DD	2021-08-10
DESIGNED	J. CHEN
PREPARED	S. KURASH
REVIEWED	H. ZHANG
APPROVED	H. ZHANG

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	1000	0	1

3.0 CLOSURE

This memorandum was prepared and reviewed by the undersigned.

Golder Associates Ltd.

Jie Chen, M.Sc., P.Eng.
Water Resources Engineer

Hua Zhang, Ph.D., P.Eng.
Associate, Senior Water Resources Engineer

https://golderassociates.sharepoint.com/sites/148471/project files/5 technical work/6-reporting & documentation/2-flood control structure memo/final/stand off flood control structure memo.docx

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APPENDIX D

Technical Memorandum on Open Water Hydrology Assessment

GOLDER
MEMBER OF WSP

TECHNICAL MEMORANDUM

DATE January 21, 2022 **Project No.** 21467363-02

TO Muhammad Durrani, M. Eng., P. Eng.
Alberta Environment and Parks

CC Jie Chen, Hua Zhang and Dejiang Long, Golder Associates Ltd.

FROM Getu Biftu, Golder Associates Ltd. **EMAIL gbiftu@golder.com**

OPEN WATER HYDROLOGY ASSESSMENT – STAND OFF FLOOD STUDY

1.0 INTRODUCTION

1.1 Study Area and Scope

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in May 2021 to conduct the Stand Off Flood Study (the study). The purpose of the study is to assess and identify river and flood hazards along an approximately 17 km reach of Belly River and an approximately 8.6 km reach of the Unnamed Tributary of Belly River (Figure 1) through Kainai Nation and Cardston County, including Stand Off.

The study is part of 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. Project stakeholders include the Government of Alberta, Kainai Nation, Cardston County, and the Public.

The study comprises multiple components and deliverables. This memorandum documents the methodology and results of the open water hydrology assessment that will support the hydraulic modelling and open water flood mapping. The individual tasks associated with this hydrology assessment component include the following:

- **Data Series Preparation:** Compile peak flow information available for the gauged locations and prepare flood flow data series.
- **Flow Naturalization:** Generate natural and naturalized flood flow series for Belly River at Stand Off (i.e., at the Water Survey of Canada [WSC] Station No. 05AD002).
- **Flood Frequency Analysis:** Conduct frequency analyses to estimate flood flows for return periods ranging from 2 to 1,000 years using the recorded and derived flood peak flow data for the available periods of record up to 2020.
- **Climate Change Commentary:** Provide comments and insight into how climate change processes may impact the flood peak discharges and flood frequency estimates.

The flood frequency estimates obtained in this study are the most up-to-date for the various locations in the study area. These estimates provide the updated flood hydrology information as flow inputs to hydraulic modelling in the study.

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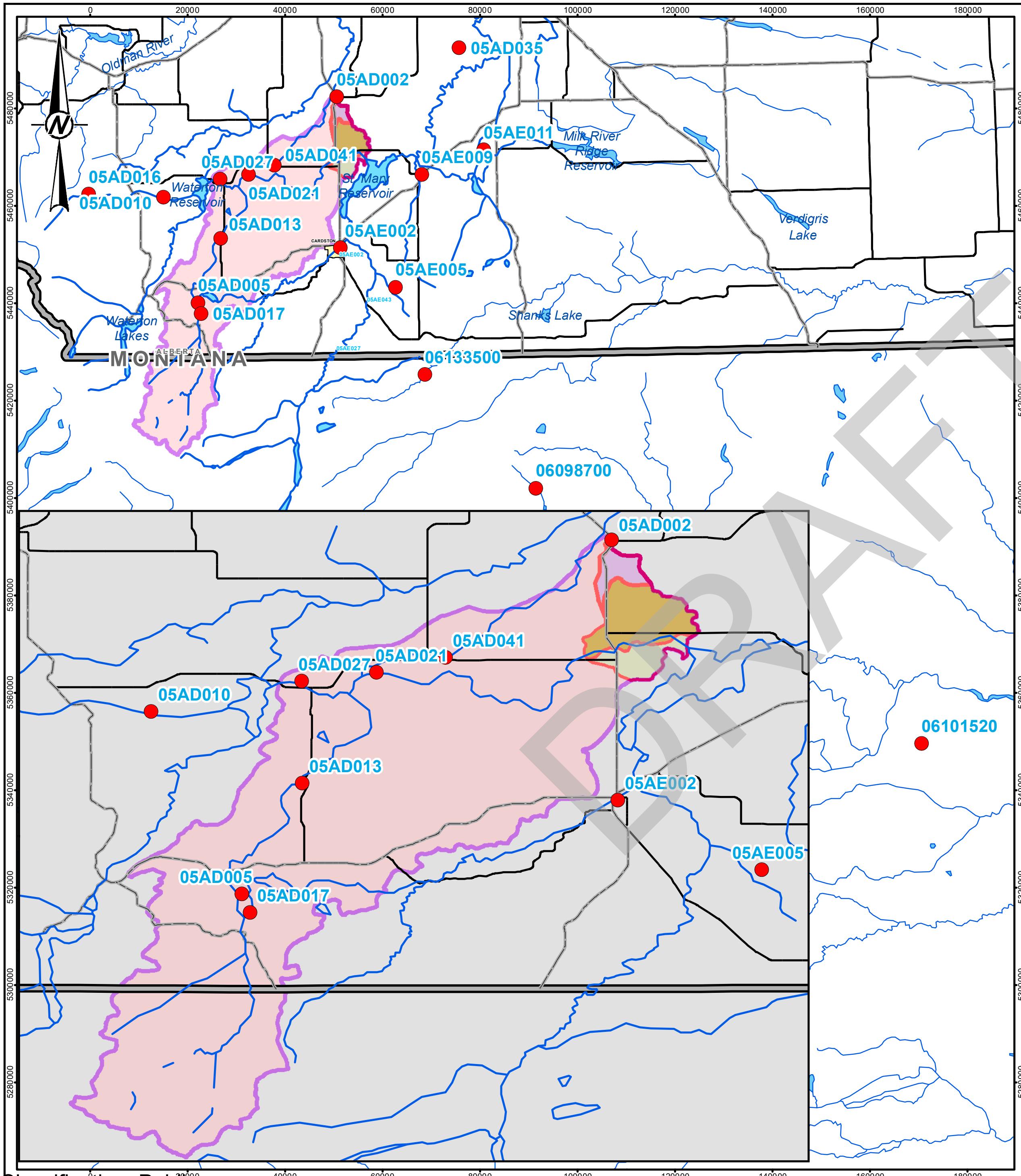

LEGEND

- ● HYDROMETRIC GAUGING STATION
- WATERCOURSE
- WATERBODY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- ▭ PROVINCIAL/STATE BOUNDARY
- ▭ POPULATED PLACE
- ▭ BELLY RIVER

UNNAMED CREEK NEAR STANDOFF

- 🟪 DOWNSTREAM
- 🟨 UPSTREAM BELOW DIVERSION
- 🟩 UPSTREAM DIVERTED

0 30 60 90

1:1,250,000 KILOMETRES

REFERENCE(S)

HYDROMETRIC STATIONS OBTAINED FROM WATER SURVEY OF CANADA (WSC) AND USGS.
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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
STANDOFF FLOOD HAZARD STUDY

TITLE
BELLY RIVER WATERSHED AT STAND OFF

CONSULTANT

GOLDER

YYYY-MM-DD	2022-01-05
DESIGNED	BM
PREPARED	BM
REVIEWED	GB
APPROVED	GB

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	2000	0	1

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25mm

0

Classification: Public

1.2 Study Objectives and Results

The primary study objective is to identify and assess river-related hazards. The objective of the open water hydrology assessment is to generate flood peak discharge estimates along the study reach of Belly River and Unnamed Tributary of Belly River. The results of the frequency analysis include estimates of the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1,000-year open water flood peak discharges.

1.3 Watershed Setting and Historical Floods

Belly River originates in the Rocky Mountains of northwestern Montana and flows northeastward through the foothills and into the plains of southwestern Alberta. It has a drainage area of approximately 1,210 km^2 at Stand Off. The catchment area is comprised of two distinct terrain types, a mountainous area upstream, and a flatter, mostly agricultural area downstream.

Water is diverted from Belly River at the Mountain View Leavitt Aetna (MVLA) diversion approximately 33 km upstream of the Belly River Diversion (BRD), and at the United Irrigation District (UID) diversion approximately 15 km upstream of the BRD (Figure 1). Immediately upstream of the BRD, Belly River flow is augmented from the Waterton Reservoir (i.e., the Waterton-Belly Diversion Canal). At the BRD, water is diverted to the Belly-St. Mary Diversion Canal to supply water to the downstream irrigation system.

The largest flood on record occurred in 1995, with other major floods in 1948, 1951, 1953, 1964, 1975, 2002, 2010, and 2014. Annual floods occurred mostly in June or late May, with approximately 94% of the annual maximum recorded in these two months. The recorded highest instantaneous discharge of 570 m^3/s and the highest daily discharge of 340 m^3/s both occurred in 1995 at Belly River near Glenwood.

The Unnamed Tributary to Belly River has a natural drainage area of approximately 81.8 km^2. However, runoff from the head watershed area of approximately 20.1 km^2 is diverted through the BRD. Therefore, the drainage area that currently contributes runoff to the Unnamed Tributary is approximately 61.7 km^2 and mostly flat agricultural area.

2.0 AVAILABLE FLOW DATA

2.1 Recorded Data

The flood frequency estimates for the Belly River in the study reach were derived by extending the natural and naturalized flood flow series for Belly River near Stand Off (i.e., WSC Station No. 05AD002, drainage area of 1,210 km^2, and for the period of 1909 to 1985) based on the recorded flows for Belly River near Glenwood (i.e., WSC Station No. 05AD041, drainage area of 653 km^2, and for the period of 1985 to 2020), Belly River near Mountain View (i.e., WSC Station No. 05AD005, drainage area of 319 km^2, and for the period of 1911 to 2019), and Lee Creek at Cardston (i.e., WSC Station No. 05AE002, drainage area of 312 km^2, and for the period of 1909 to 2019).

A summary of the basic hydrologic information used to obtain the flood frequency estimates for the study area is provided in Table 1. The data details are provided in Appendix A. The regional hydrometric stations were selected based on their proximity (i.e., relatively close to the study area), size (i.e., reasonable range of gross and effective drainage areas that can be used to establish the regional relationships), and physiographic characteristics (e.g., similar drainage characteristics).

Table 1: Summary of Gauged Stations Considered in the Study

WSC Station Number	WSC Station Name	Latitude	Longitude	Approximate Distance from the Study Area (km)	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Period of Record	Length of Record (years)
05AD005	Belly River near Mountain View	49°05'58"	113°41'51"	57	319	319	1911 – 2019	106
05AD017	Mountain View Irrigation District Canal	49°04'46"	113°41'20"	57	N/A	N/A	1935 – 2020	86
05AD013	United Irrigation District Canal near Hill Spring	49°13'04"	113°37'59"	42	N/A	N/A	1923 – 2020	98
05AD027	Waterton – Belly Diversion Canal	49°19'37"	113°38'01"	30	N/A	N/A	1968 – 2020	53
05AD021	Belly-St. Mary Diversion Canal	49°20'09"	113°33'14"	25	N/A	N/A	1959 – 2020	62
05AD041	Belly River near Glenwood	49°21'07"	113°28'49"	20	653	538	1985 – 2020	35
05AD002	Belly River near Stand Off	49°28'40"	113°18'10"	1	1,210	1,130	1909 – 1985	59
05AE002	Lee Creek at Cardston	49°11'58"	113°17'47"	32	312	312	1909 – 2019	100

N/A = Not Applicable.

The portion of the Belly River drainage area upstream of the Waterton Reservoir represents approximately 26% (i.e., 319 km^2 at WSC Station No. 05AD005) and has substantial flow contributions for small and moderate magnitudes of floods downstream. The contribution of runoff from the catchment areas between Belly River near Mountain View and the downstream stations is often relatively small. However, during several major floods (i.e., the 1951, 1953, 1995, 2002, 2010 and 2014 floods), the downstream catchment areas had substantial runoff contributions to the flood flows as shown in Figure 2.

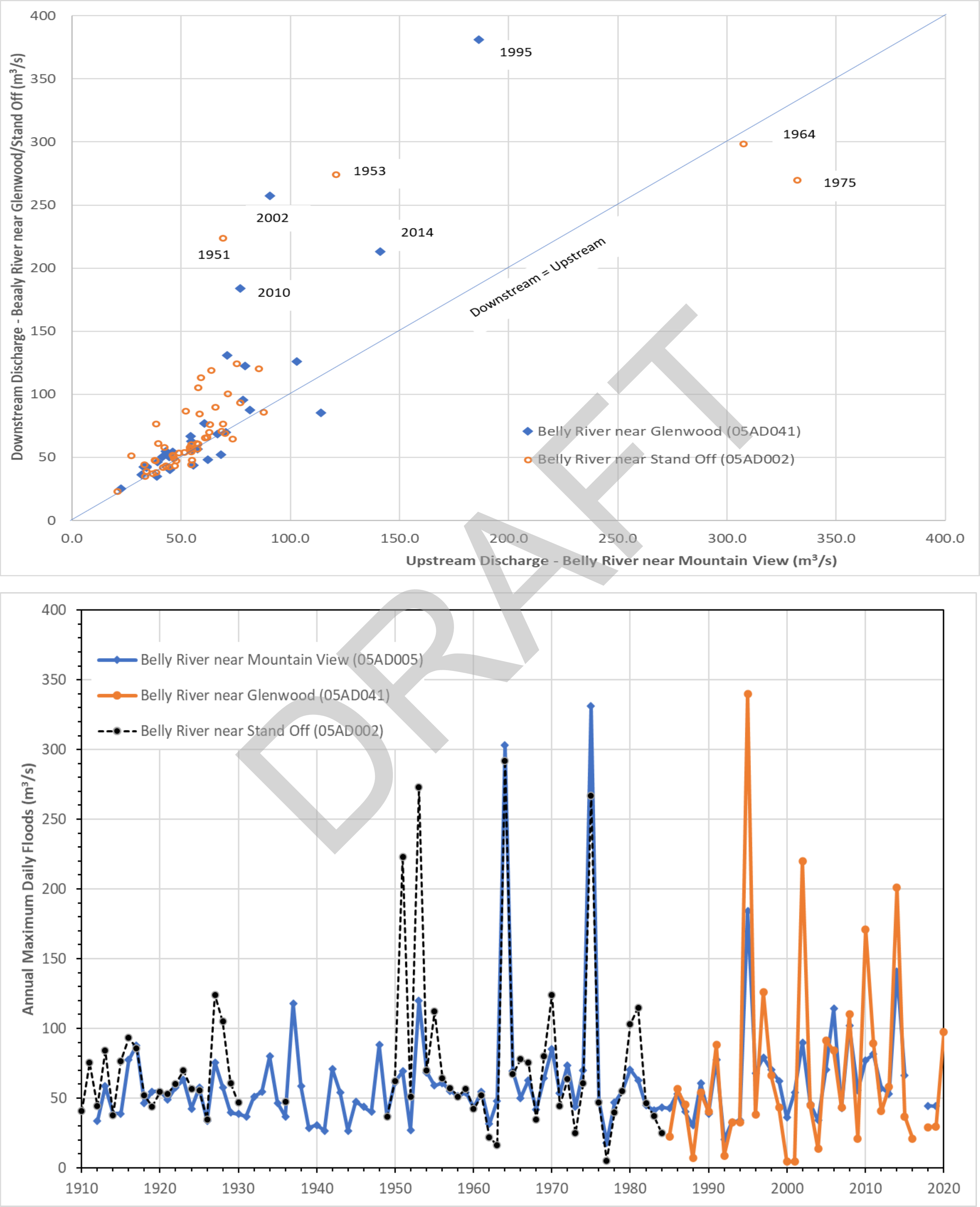

Figure 2: Comparison of Recorded Annual Maximum Daily Flows for Belly River

2.2 Naturalized Flow Series

Belly River flows near Stand Off have been regulated and affected by the operations of the Waterton-Belly Diversion Canal since 1968, the Belly-St. Mary Diversion Canal since 1959, and the United Irrigation District Canal since 1923. The additional water withdrawal from Belly River and its tributaries includes diversion of flows for irrigation districts. Therefore, the effects of the flow regulations and water withdrawals were evaluated for deriving naturalized flood frequency estimates.

The natural and naturalized flood flows for Belly River near Stand Off were derived by removing the effect of major irrigation diversions into and out of the river and adding return flows from irrigation districts as shown in Figure 3. Daily releases to Belly-St. Mary Diversion Canal (Station No. 05AD021), United Irrigation District Canal (Station No. 05AD013) and Mountain View Irrigation District Canal (05AD017) were added to the downstream discharge while daily inflows from the Waterton-Belly Diversion Canal (Station No. 05AD027) and return flows were subtracted. The time lag between the stations were considered by conducting the flow naturalization using daily runoff.

Based on the recorded flows for irrigation diversion (AEP, 1998), the maximum diversion rate to MVID is approximately 5.3 m^3/s (occurred on May 24, 1970) and the maximum diversion rate to UID is approximately 8.24 m^3/s (occurred on July 13, 1925). Therefore, the upstream diversions at the MVID and UID had small effects on the flood flows in Belly River. Nevertheless, the diversions by the irrigation districts were considered for flow naturalization. In addition, return flow adjustments were considered based on the percentages of return flows recommended by WSC as shown in Table 2.

Table 2: Percentages of Return Flows from Irrigation Districts Recommended by Water Survey Canada

Irrigation District	May	June	July	August	September	October	Receiving Point
United Irrigation District	100%	100%	35%	30%	25%	20%	61.25% to the Belly River and 38.75% to the Waterton River
Mountain View Irrigation District	100%	100%	40%	35%	20%	35%	27% to the Belly River and 73% to the St. Mary River

For some of the small diversion or return flows (e.g., diversion from the Waterton-Belly Canal), there is limited or no data available and the historic water uses cannot be determined with any degree of reliability. Therefore, the effects of water diversions by the small projects cannot be accurately estimated.

The naturalized daily flow series derived for Belly River at the various locations were used to generate the naturalized annual maximum daily flow series for Belly River at Stand Off as follows:

- Naturalized annual maximum daily flow series for Belly River at Stand Off for the period 1909 to 1930, 1936, and 1949 to 1985, were derived based on the recorded flows for Belly River a Stand Off and considering the various upstream diversions and return flows as described above and shown in Figure 3.
- Naturalized annual maximum daily flow series for Belly River at Stand Off for the period 1985 to 2020 were derived from the naturalized annual maximum daily flow series of Belly River at Glenwood using the relationship presented in Figure A-3(c), Appendix A.

- Data gaps for the periods 1931 to 1935 and 1937 to 1948 were filled in using the following two methods:
  - **Method 1**: Using the flow relationship between Belly River at Stand Off and Lee Creek at Cardston [Figure A-3(b), Appendix A]
  - **Method 2**: Using the flow relationship between Belly River at Stand Off and Belly River near Mountain View [Figure A-2(b), Appendix A].

Belly River at Stand Off data series shows better relationship with Lee Creek at Cardston than the relationship with Belly River near Mountain View. The resulting flood flow series are provided in Table A-1 in Appendix A.

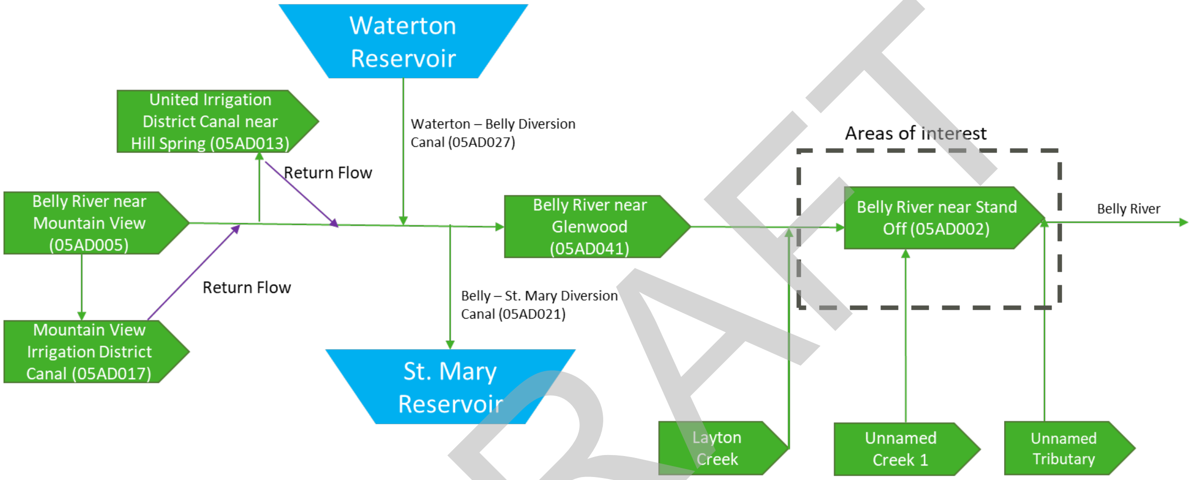

Figure 3: Schematic for Naturalization Model Setup for the Belly River Basin

2.3 Historic Data

There are no additional historic flow data available for the study area before systematic gauging and monitoring by the WSC around the study area.

2.4 Previous Studies

This study included a review of a number of background documents, including previous hydrology and flood studies. Several hydrology studies were completed over the last two decades. Some of these studies included assessments of open water hydrology. These studies include the following:

- Hydrology of the 1995 Flood in Southern Alberta, Alberta Environment, 1996.
- Storm Event Assessment: 2010 Spring South-Eastern Alberta Disaster Recovery Program (April 15 to May 31, 2010) and 2010 Southern Alberta Disaster, Alberta Environment. 2011.
- Planning Study for Upgrading and Rehabilitation of the Diversion Structures- Phase I and II Final Report. Klohn and Crippen Berger, 2013.

The review involved documentation of the assumptions, limitations, and understanding of the hydrologic techniques applied in the past studies. The results of these past studies provided a frame of reference for interpretation of the results and comparison to this study. The review helped identify data gaps and apparent discrepancies in the data that may affect their use in subsequent analyses.

3.0 PREPARATION OF FLOOD FLOW DATA SERIES

3.1 Introduction

Preparation of the flood flow series involved consideration of a large number of factors, including unequal and non-overlapping record lengths, and incomplete flow records. The methods used to compile the flood flow series and to address the data gaps are described in Section 2.2 and the following sections.

3.2 Flood Flow Series for the Gauged Location

The flood frequency estimates for the gauged locations were derived based on the recorded natural and naturalized annual maximum instantaneous discharge series, and where there is missing data, the annual maximum daily discharges that were used to estimate the instantaneous flood peak flows.

The flood flow series for Belly River near Stand Off were derived by accounting for the effect of the operation of the Waterton-Belly Diversion Canal (WSC 05AD027, 1968 to 2020), the Belly-St. Mary Diversion Canal diversion (WSC 05AD021, 1959 to 2020), the diversion to United Irrigation District Canal (1923 to 2020), and the Mountain View Irrigation District Canal (1935 to 2020). Derivation of the naturalized flow series for the period from 1909 to 2020 is described in Section 2.2.

The following method was used for estimating the annual maximum instantaneous discharges based on the annual maximum daily discharges to fill the data gaps in the record:

- Annual maximum daily discharge series were developed using the recorded natural and naturalized daily flow series.
- A relationship was established between event-based annual maximum daily and annual maximum instantaneous discharges in the record. If the reported annual maximum daily and annual maximum instantaneous discharges for the same year were not coincident (i.e., from the same flood event), the former values were replaced by the daily flow values for the events corresponding to the annual maximum instantaneous discharges. This relationship was used to estimate the annual maximum instantaneous discharges based on the recorded annual maximum daily discharges.

3.3 Flood Flow Series for the Ungauged Locations

Empirical relationships between drainage areas and flood peak discharges were established based on the available regional flow records (see Table 3) and for the return periods ranging from 2 to 1,000 years. The relationships were then used to derive the flood frequency estimates for the Unnamed Tributary of Belly River in the study area.

Table 3: Summary of Gauged Stations Considered in the Regional Study

WSC/USGS Station Number	WSC Station Name	Latitude	Longitude	Approximate Distance from the Study Area (km)	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Period of Record	Length of Record (years)
05AE005	Rolph Creek	49°07'30"	113°08'33"	41	222.4	186.6	1911-2019	88
05AE009	Pinepound Creek	49°19'57"	113°03'52"	24	207	173	1914-1950	37
05AE011	Pothole Creek	49°22'36"	112°53'21"	32	374	351	1914-1951	37
05AD016	Drywood Creek near Twin Butte(1)	49°18'00"	114°00'20"	54	29.30	29.30	1920 - 2019	96
05AD010	Drywood Creek near the Mouth	49°17'39"	113°47'39"	40.5	238.6	238.60	1920 - 2019	96
05AD035	Prairie Blood Creek	49°33'58"	112°57'15"	27.7	223.5	223.5	1970-2019	45
06098700	Powell Coulee	48°45'1.24"	112°45'24.28"	90	32.6	32.6	1974-2019	46
06101520	Favot Creek	48°15'46.66"	111°42'12.08"	179	1.97	1.97	1974-2019	32
06133500	North Fork Milk River	48°57'48.70"	113°03'44.48"	59	157	157	1911-2019	81
05AE002	Lee Creek at Cardston	49°11'58"	113°17'47"	32	312	312	1909 – 2019	100

The flood frequency estimates for the Unnamed Tributary were obtained as follows:

- The drainage areas at the WSC stations were compiled. The gross drainage area at the ungauged location of the Unnamed Tributary was estimated in a GIS analysis.
- The flood frequency estimates for the WSC stations (Appendix B) were obtained based on the annual maximum instantaneous flow series.
- Regional relationships between drainage area and peak discharge for a range of return periods (i.e., 2 to 1,000 years) were developed, as shown in Figure 4.
- The resulting regional relationships were then used to estimate the flood peak discharges for the Unnamed Tributary for the various return periods and the 95% confidence intervals.

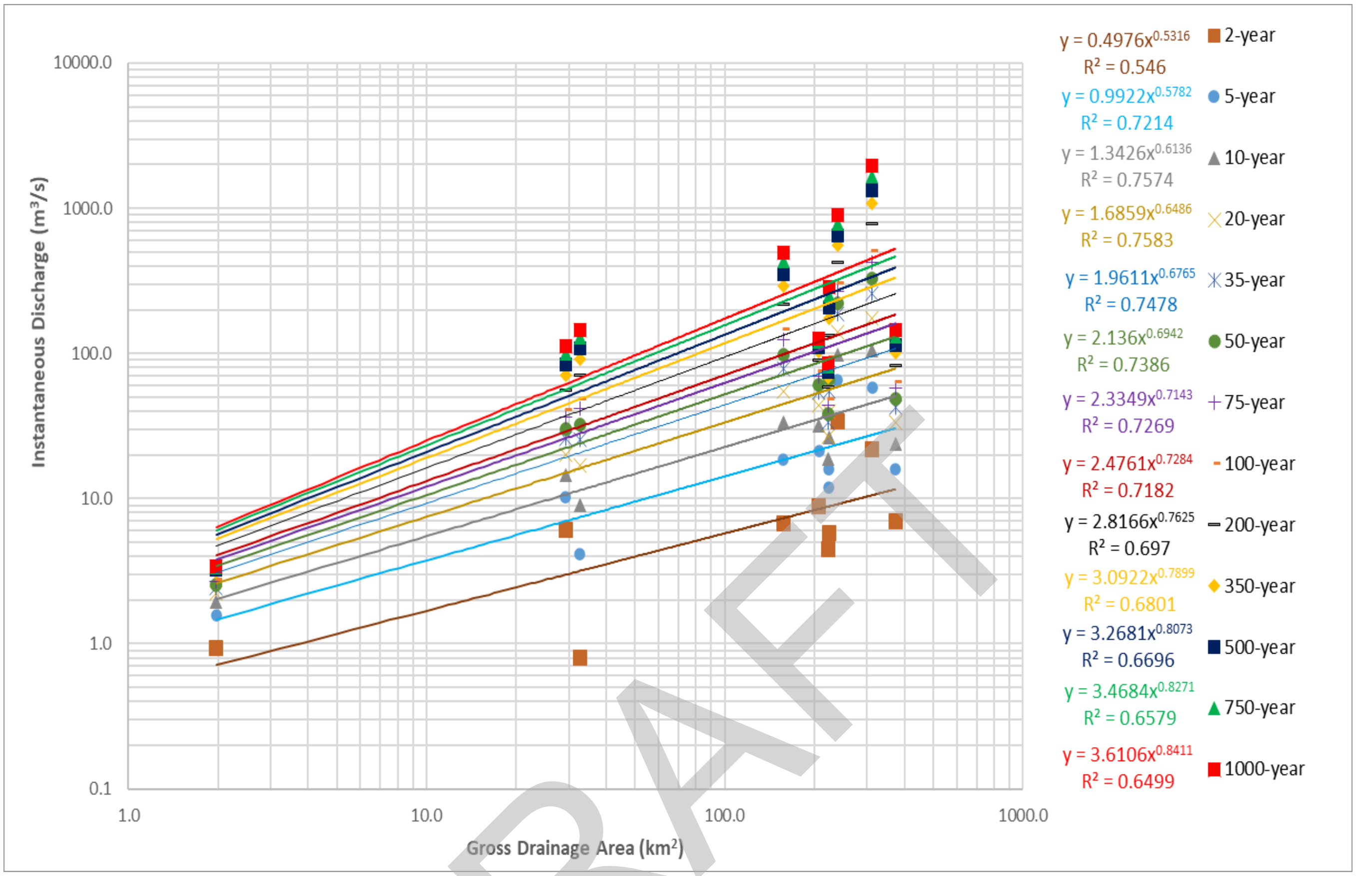

Figure 4: Empirical Relationships between Flood Peak Flows and Drainage Areas for the Regional Stations

4.0 FLOOD FREQUENCY ANALYSIS

4.1 Statistical Tests

4.1.1 Methodology

Prior to fitting the appropriate frequency distribution to the flood flow data, a number of statistical tests were performed to determine the quality of the developed annual maximum instantaneous discharge series. Software developed by Golder that is similar to Environment Canada's Consolidated Frequency Analysis (CFA), but with enhanced methodology, was used for: (i) flood frequency analyses and statistical tests for independence (not serially correlated); and (ii) trend, randomness, and homogeneity tests. Golder's software includes modern boot-strapping method and estimation of confidence intervals.

The following probability distributions were analyzed with select parameter estimation methods (i.e., method of moments [Moment], maximum likelihood estimation [MLH], and Method of L-moments [MLM]):

- Three-parameter Log Normal distribution (3P, Moment and MLH)
- Generalized Extreme Value distribution, which includes Extreme Value 1, 2, and 3 distributions (EV, MLM)
- Log-Pearson Type III distribution (LP3, Moment, and MLH)
- Weibull distribution (Moment)

Numerical goodness-of-fit tests were performed using the non-parametric Anderson-Darling test (Stephens 1974).

4.1.2 Results

The results of statistical analysis for the regional stations are provided in Tables A-2 and A-5 in Appendix A. The results show that the annual maximum instantaneous discharge series are independent, random, homogeneous, and do not display any significant trends at both the 5% and 1% level of significance.

4.2 Flood Frequency Estimates

Flood frequency analyses of the annual maximum instantaneous discharge series for Belly River near Stand Off and regional analysis, were conducted to estimate the flood peak discharges of various return periods of floods (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods). The annual maximum instantaneous discharge series used in the flood frequency analyses, the various frequency distributions, and the best-fit distributions along with their 95% confidence intervals, are provided in Appendix B.

The flood frequency estimates for Belly River near Stand Off were derived using the natural and naturalized flood series described in Section 2.2. The differences in flood frequency estimates derived based on the data series generated using Method 1 and Method 2, described in Section 2.2, are relatively small (e.g., approximately 6% for 100-year flood and approximately 10% for 1000-year flood). The flood frequency estimates (Table 4) derived based on the data series generated using Method 1 is recommended, because filling of the data gaps (i.e., for the periods 1931 to 1935 and 1937 to 1948) was based on the flow relationship with the data for Lee Creek at Cardston station, which is better than the relationship with the data for Belly River near Mountain View.

The flood frequency estimates for the Unnamed Tributary of Belly River were derived using the regional analysis described in Section 3.3. The upper and lower 95% limits estimates were derived using the factors calculated based on confidence intervals of Lee Creek at Cardston. The resulted flood discharge estimates and the associated upper and lower 95% confidence intervals are summarized in Table 4.

Table 4: Flood Frequency Estimates for Belly River near Stand Off

Return Periods (years)	Annual Probability of Exceedance (%)	Belly River near Stand Off (using EV2 Distribution)			Unnamed Tributary to Belly River		
		Value (m^3/s)	Lower 95% Limit (m^3/s)	Upper 95% limit (m^3/s)	Value (m^3/s)	Lower 95% Limit (m^3/s)	Upper 95% limit (m^3/s)
2	50	70.6	64.2	80.2	4.5	3.5	5.6
5	20	115	98	138	10.8	8.0	14.0
10	10	160	130	194	16.8	12.0	23.3
20	5.0	220	171	271	24.4	16.1	37.8
35	2.9	283	212	353	31.9	19.7	56.0
50	2.0	332	242	418	37.4	22.1	71.6
75	1.3	399	280	505	44.4	24.8	94.0
100	1.0	454	312	580	49.9	26.8	115
200	0.50	619	401	814	65.3	31.9	185
350	0.29	796	482	1,067	80.2	36.4	272
500	0.20	934	547	1,274	91.1	39.7	346
750	0.13	1,120	627	1,567	105	43.0	457
1,000	0.10	1,275	689	1,807	116	45.7	557

4.3 Comparison to Previous Studies

The naturalized flows derived in this study using the water balance analysis and those derived in the AEP (1996) study were compared and the results are provided in Figure B-13 in Appendix B. The comparison indicates that annual maximum instantaneous discharges derived in this study and in the AEP (2006) study are comparable.

A comparison of the flood frequency estimates obtained in this study for Belly River at Stand Off with the studies previously completed by AEP(1996 and 2011) as well as KCB (2013), is provided in Table 5.

The flood frequency estimates for Belly River at Stand Off in the AEP (1996) study combined the records from Belly River stations near Stand Off and near Glenwood. The AEP (1996) study included the consideration that the prairie catchment between the two stations would produce little runoff and have a negligible effect on annual maximum flows. Flows were naturalized by adding and subtracting the upstream diversions out of and into the river. Gaps in the record were filled by correlation with Belly River near Mountain View and Lee Creek at Cardston, and the missing instantaneous peak flows were filled by correlation with daily maximum discharges. Six frequency distributions were examined, and the modified Pearson III distribution was selected.

The AEP (2011) study involved use of the published values without explicitly accounting for diversions and extending the station records. A modified Pearson III distribution was applied.

Klohn Crippen Berger (KCB, 2013) study used naturalized data up to 2011. Flow naturalization and filling of missing data followed similar procedure as in this study. The log Pearson III distribution was selected as the best distribution fit to the data.

The result of flood frequency estimates for this study are consistent with AEP (1996) and KCB (2013) estimates for return periods up to 100 years. The 200-year and 1000-year estimates in the AEP (1996) study were lower than those in this study, likely because the data series did not include some of the large floods in 2002, 2010 and 2014. The comparison in Table 5 shows that the main differences in the flood frequency estimates are due to the different lengths of the recorded data used in the flood frequency analyses as well as the selections of different frequency curve distributions and approaches used to naturalize the flow series

Table 5: Comparison of the Flood Frequency Estimates of Various Studies

Return Period (years)	Belly River near Glenwood (m^3/s)			Belly River at Stand Off (m^3/s)		
	AEP(1) (1996)	AEP(2) (2011)	KCB(3) (2013)	AEP(1) (1996)	AEP(2) (2011)	This Study
2	139	40.6	70.5	139	40.6	70.9
5	-	-	-	-	-	115
10	203	223	166	203	223	160
20	268	316	227	268	316	220
50	354	446	340	354	446	332
100	421	547	456	421	547	453
200	487	650	608	487	650	619
1,000	642	894	1,160	642	894	1,276

Notes:
1. The AEP (1996) study involved use of the recorded data up to 1995 and combined the recorded data from Glenwood and Stand Off stations.
2. The AEP (2011) study involved use of the recorded data without explicitly accounting for diversions (i.e., flow not naturalized).
3. The KCB (2013) study involved use of the recorded data up to 2011.

5.0 POTENTIAL EFFECTS OF CLIMATE CHANGE ON FLOOD PEAK DISCHARGES AND FLOOD FREQUENCY ESTIMATES

Recent studies on the effect of climate change (e.g., Martz et al. 2007; Valeo et al. 2007) indicate that climate change could result in increased air temperature, more frequent drought and water shortages, increased precipitation in some areas, and increased flooding. As a result of climate change and variability, many regions of Canada, including the Prairies, could experience warmer air temperatures and changes in stream flow magnitude and timing (e.g., higher winter stream flows and lower summer stream flows).

Prediction of future scenarios depends on the climate model used for the prediction. Precipitation is projected to increase in Alberta, with less precipitation falling as snow and more rainfall-on-snow events (Valeo et al. 2007). Such changes in precipitation patterns could increase the frequency and intensity of extreme events (i.e., flood, drought, hail, and windstorms). In Alberta, for example, the Bow River watershed, it is predicted that if rain-on-snow events occur more frequently and the snowpack begins to melt earlier, then flood events could occur earlier in the spring than in the past.

Using the predictions from the Canadian Regional Climate Model, Valeo et al. (2007) showed that May precipitation could increase by more than 35 percent under a 2xCO_2 scenario. The resulting increases in precipitation in May could nearly double spring peak flows.

Droppo et al. (2018) review of several studies indicates with high confidence that projected increases in extreme precipitation are expected to increase the potential for future urban flooding. There is medium confidence that projected higher temperatures will result in a shift toward earlier floods associated with spring snowmelt, ice jams, and rain-on-snow events. However, it is uncertain how projected higher temperatures and reductions in snow cover will affect the frequency and magnitude of future snowmelt-related flooding.

Assessment of future climate scenarios depends on the climate model used for the prediction. Regardless, precipitation is projected to increase in Alberta, with less precipitation falling as snow and more rainfall-on-snow precipitation events (Valeo et al. 2007). Therefore, it is anticipated that such changes in precipitation patterns could increase the frequency and intensity of extreme events (i.e., flood, drought, hail, and windstorms). It is also predicted that the flood events for the Belly River watershed could occur earlier in the spring than in the past if rain-on-snow events occur more frequently and the snowpack begins to melt earlier.

Golder (2010) completed an assessment of the effect of climate change using five selected representative GCMs and scenarios outputs from Alberta Climate Model for Belly River near Stand Off. The five selected scenarios represent climate conditions that were cooler and drier (CGCM2-B23), cooler and wetter (NCARPCM-A1B), warmer and wetter (HADCM3-A2A), and warmer and drier (CCSRNIES-A1F1) than median conditions (HADCM3-A2A).

The forecasted climate change is between the modelled baseline period (1961 to 1990) as represented by its 30-year average and the modelled future period (i.e., the period of 2040 to 2069 called the 2050s) as represented by its 30-year average. The results indicate that the changes in flood peaks for the Belly River watershed will vary from no change for the 2-year flood to a slight decrease (i.e., less than 5%) for the 25-year flood for the median climate change conditions. Therefore, the changes in the flood peak discharges for Belly River are expected to be small for the median climate change projections.

Approximately 96 percent of the recorded annual peak flows in Belly River occurred between May 12 and end of June (Figure 8). The frequency of annual peak flows occurring outside this time window (earlier or later) does not appear to be changing with time. The recent patterns in the timing of these peak flows are similar to what were observed at the beginning of the century. There is no clear evidence that the patterns in magnitude or timing of annual peak flows have changed significantly over the past hundred years.

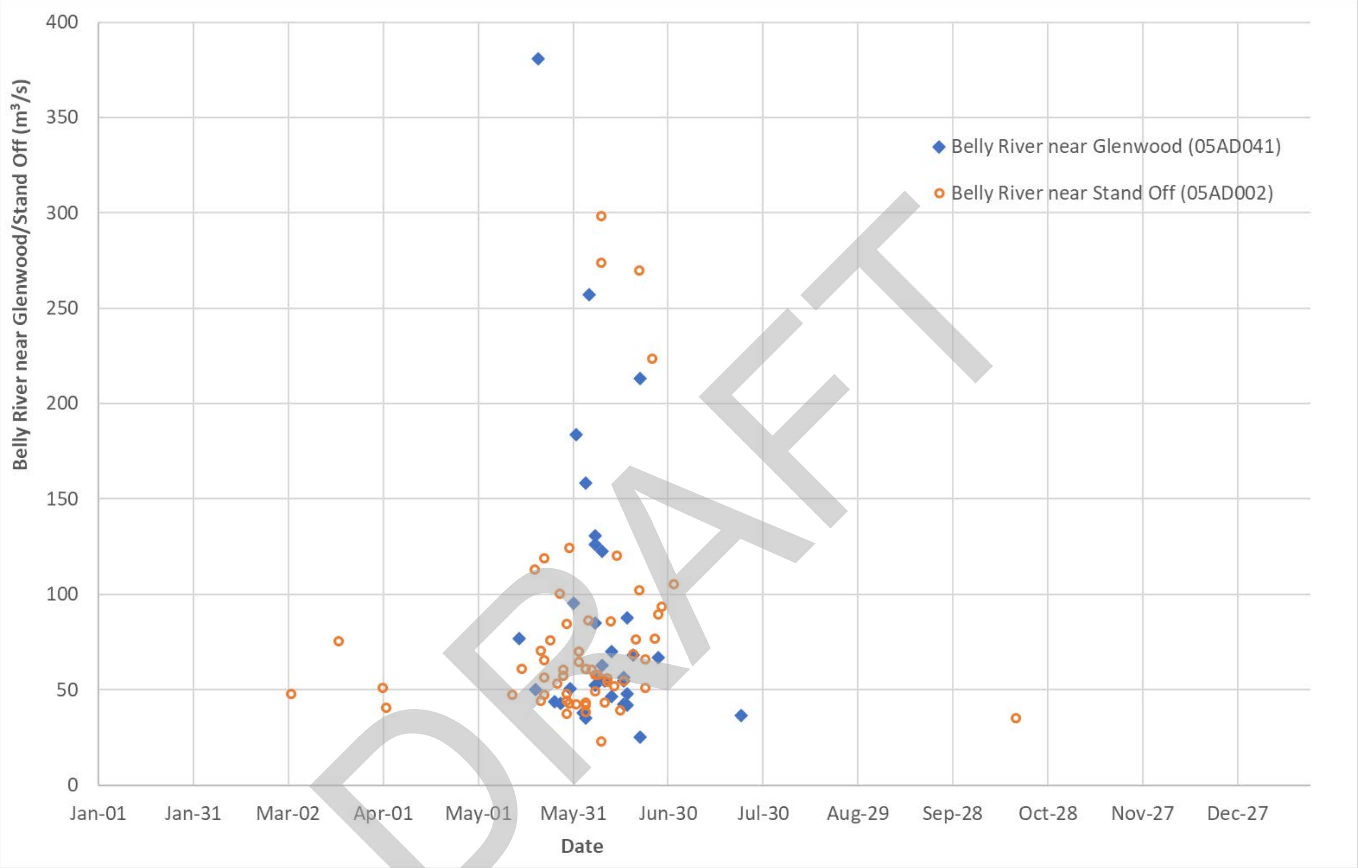

Figure 5: Timings of Belly River Flood Peak Occurrences

6.0 CONCLUSIONS

The results of this hydrology assessment support the following conclusions:

- The flood frequency estimates obtained in this study are the most up to date for Belly River at Stand Off and for the Unnamed Tributary to Belly River. These estimates provide the updated flood hydrology information as inputs to the other components of the study (e.g., hydraulic modelling). A summary of the estimates of flood peak discharges for the various return periods ranging from 2 to 1,000 years, and the 95% upper and lower confidence intervals, is provided in Table 4.
- The length of time period of the recorded flood flow data available and used in the flood frequency analyses is approximately 111 years. Therefore, there are large uncertainties (i.e., the confidence intervals are large) with flood frequency estimates for return periods greater than 100 years.

7.0 CLOSURE

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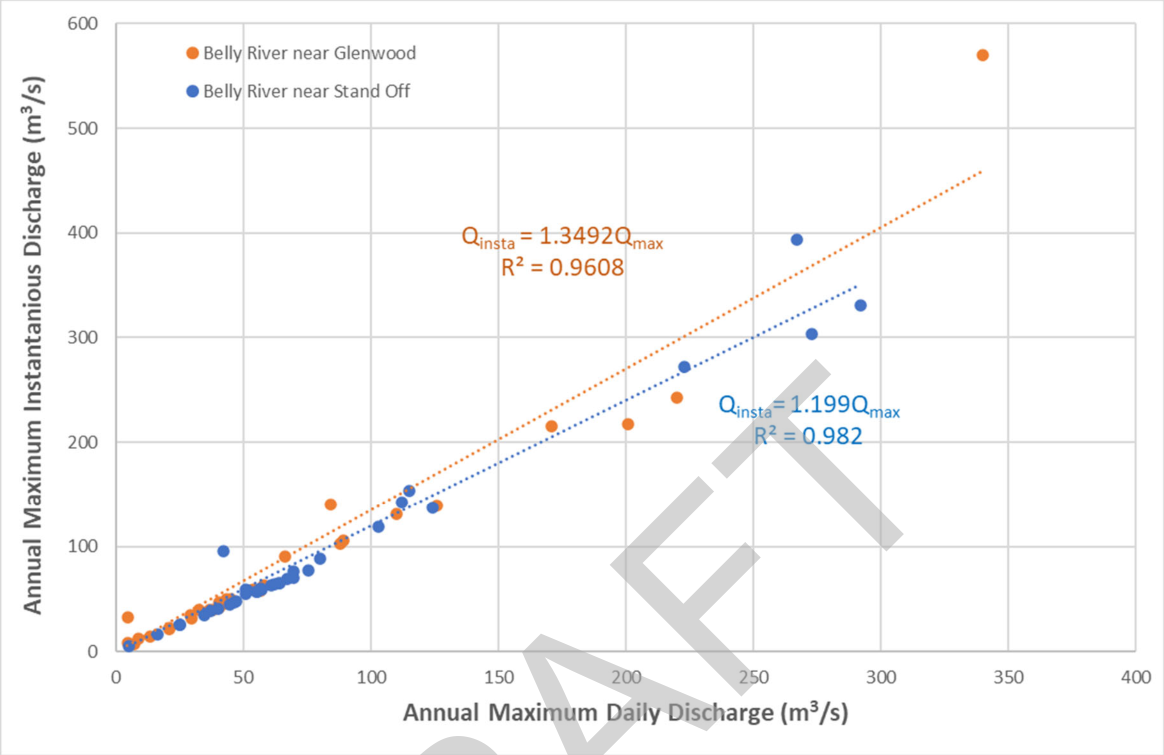
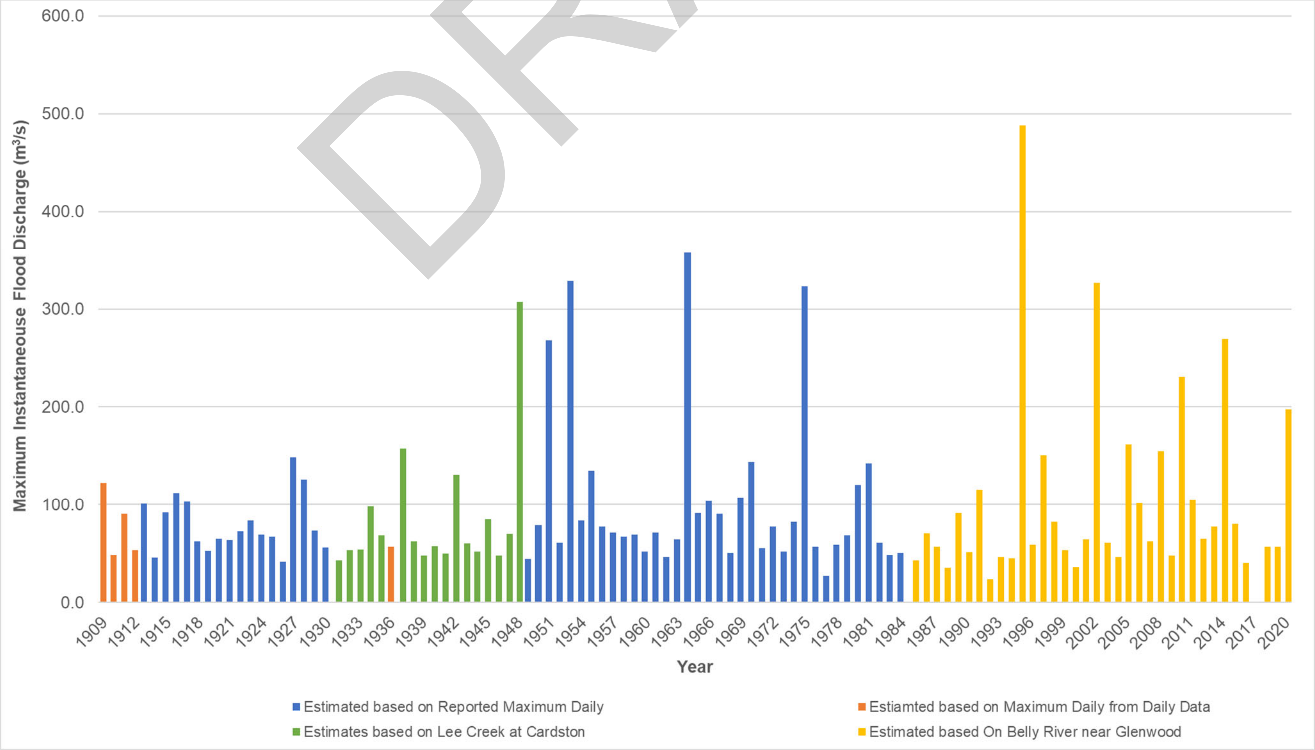
APPENDIX A

Graphical and Tabulated Summaries of Flood Flow Series at Gauged Stations

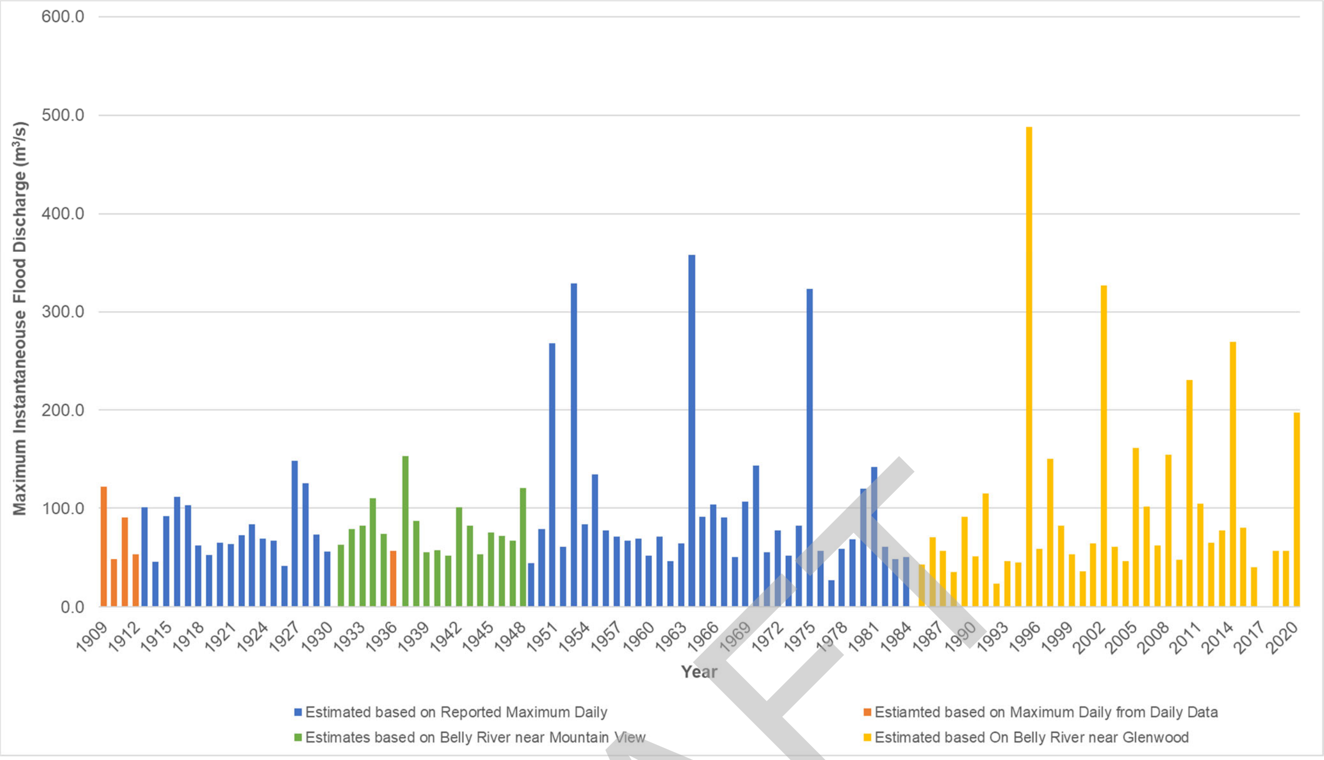
Figure A-1: Belly River Near Glenwood (WSC Stations No. 05AD0041) and Belly River near Stand Off (WSC Station No. 05AD002)



Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges for Belly River



Maximum Instantaneous Flood Flow Series for Belly River near Stand Off (WSC Station No. 05AD002) – Method 1



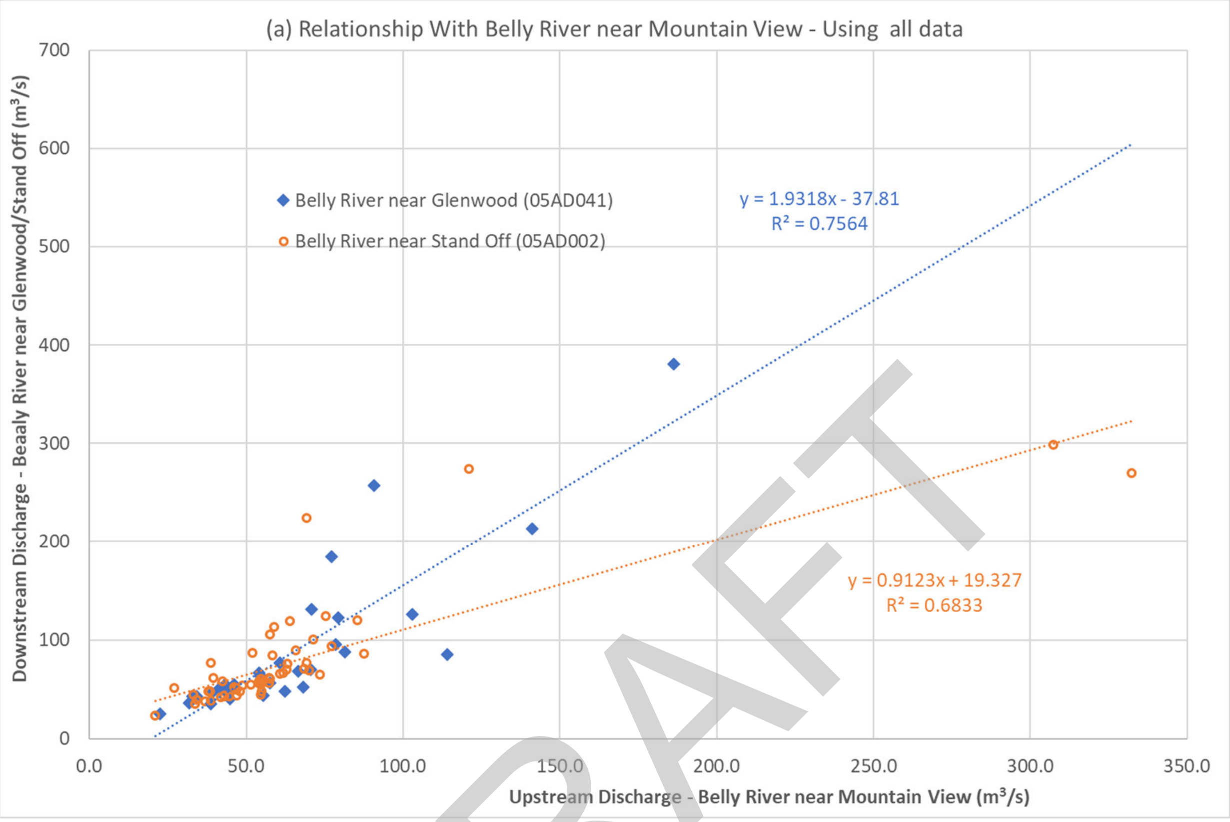
Maximum Instantaneous Flood Flow Series for Belly River near Stand Off (WSC Station No. 05AD002) – Method 2

<u>Note:</u>

Method 1 – used Lee Creek at Cardston data to fill data gaps for Belly River near Stand Off from 1931 to 1935 and 1937 to 1948.

Method 2 – used Belly River near Mountain View data to fill data gaps for Belly River near Stand Off from 1931 to 1935 and 1937 to 1948.

Figure A-2: Relationship of Belly River near Mountain View with Belly River Near Glenwood (WSC Stations No. 05AD0041) and Belly River near Stand Off (WSC Station No. 05AD002)



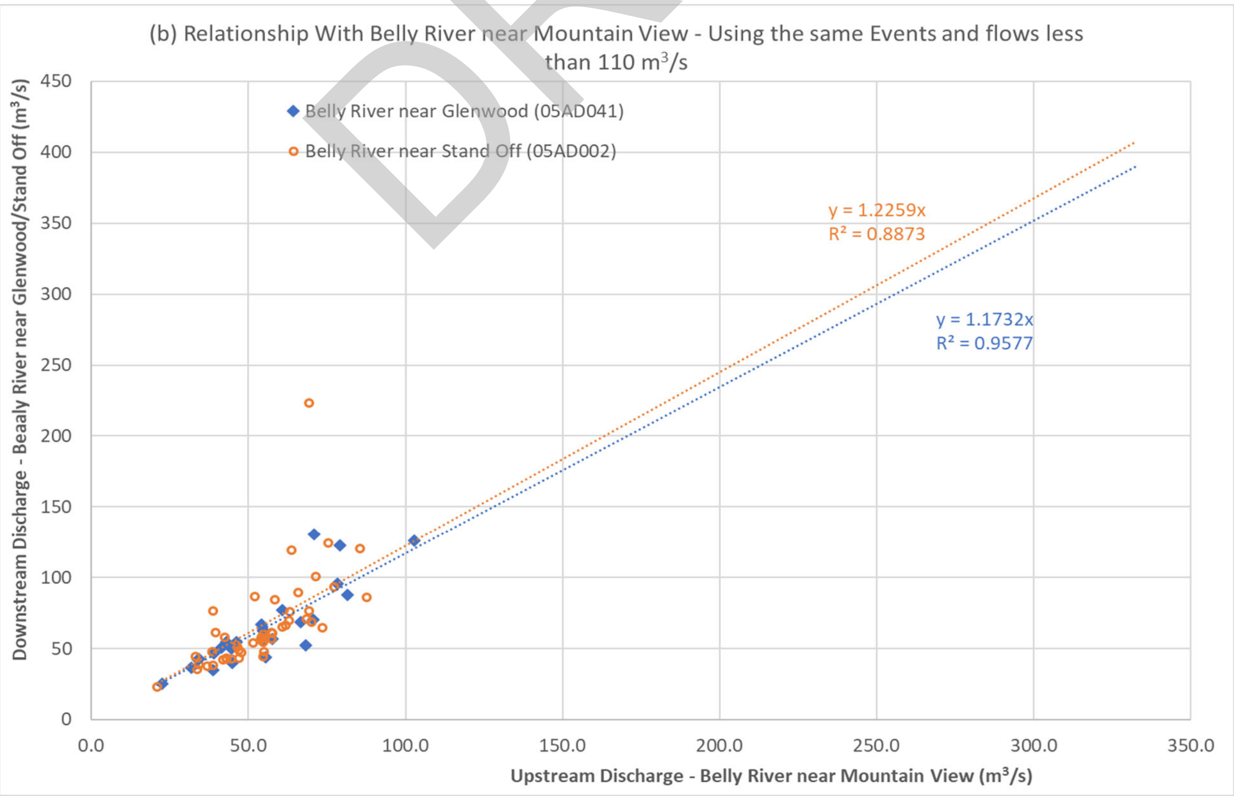
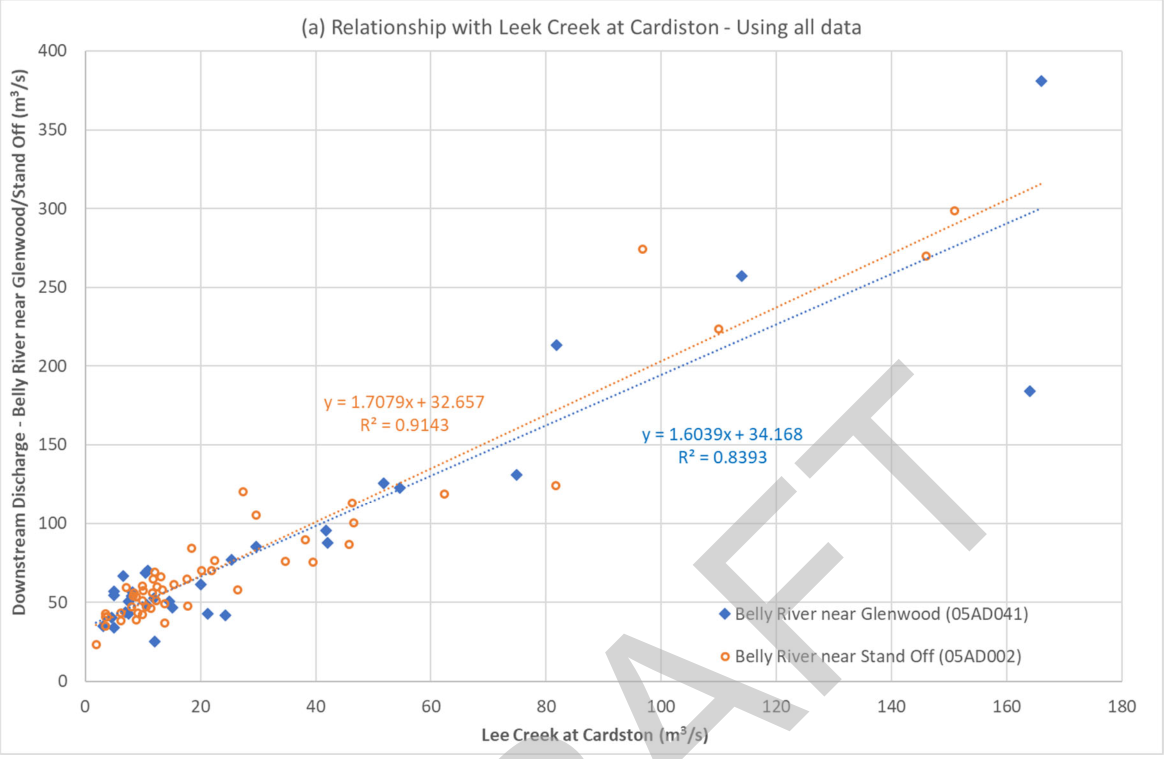
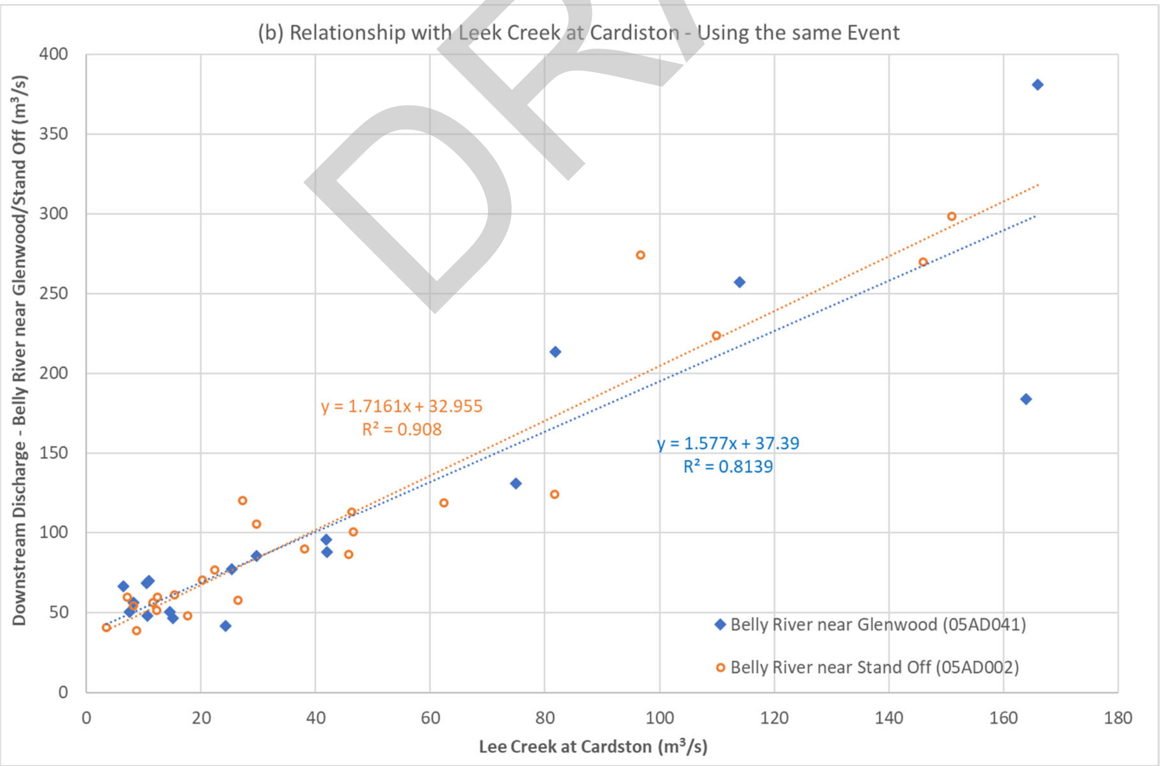


Figure A-3: Relationship of Belly River Near Glenwood (WSC Stations No. 05AD0041) and Belly River near Stand Off (WSC Station No. 05AD002) with Lee Creek





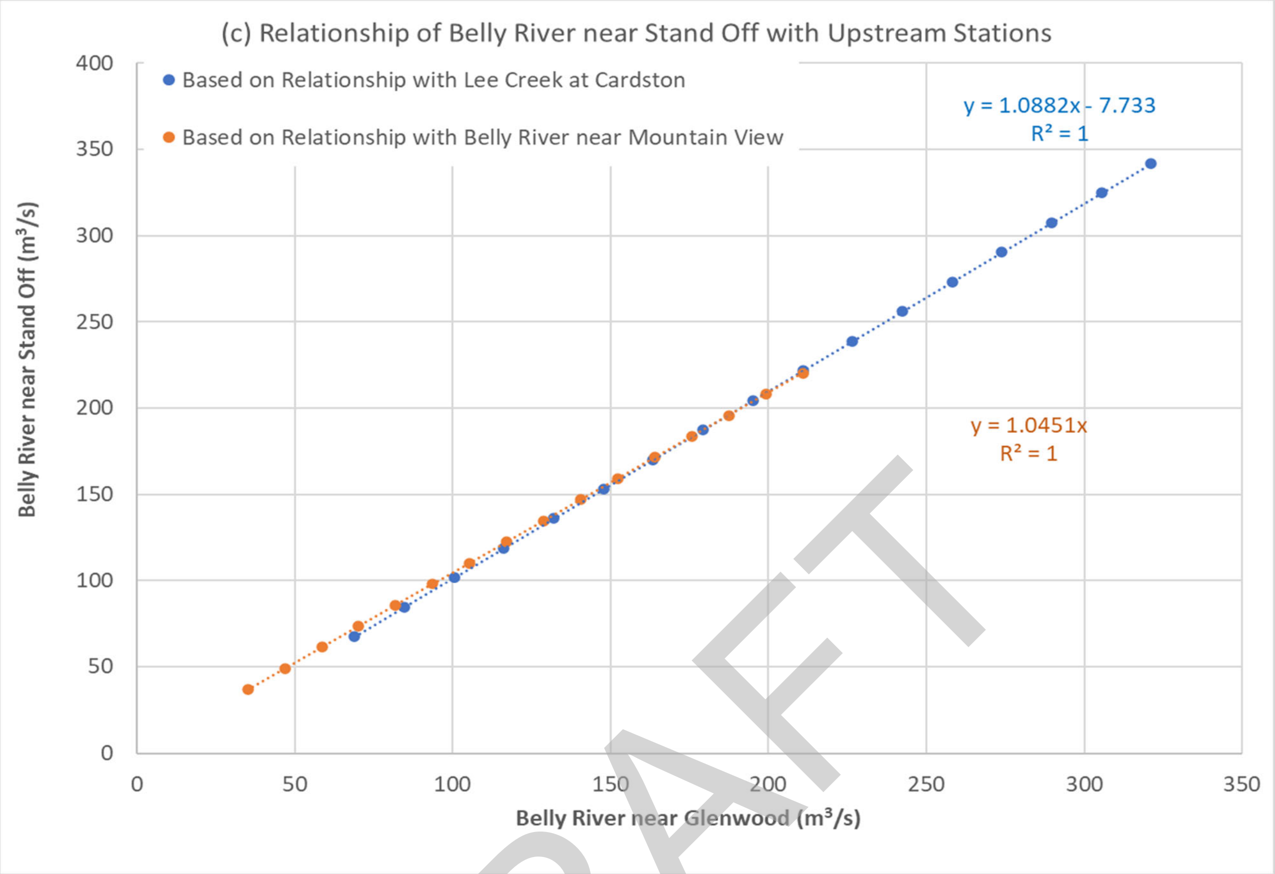
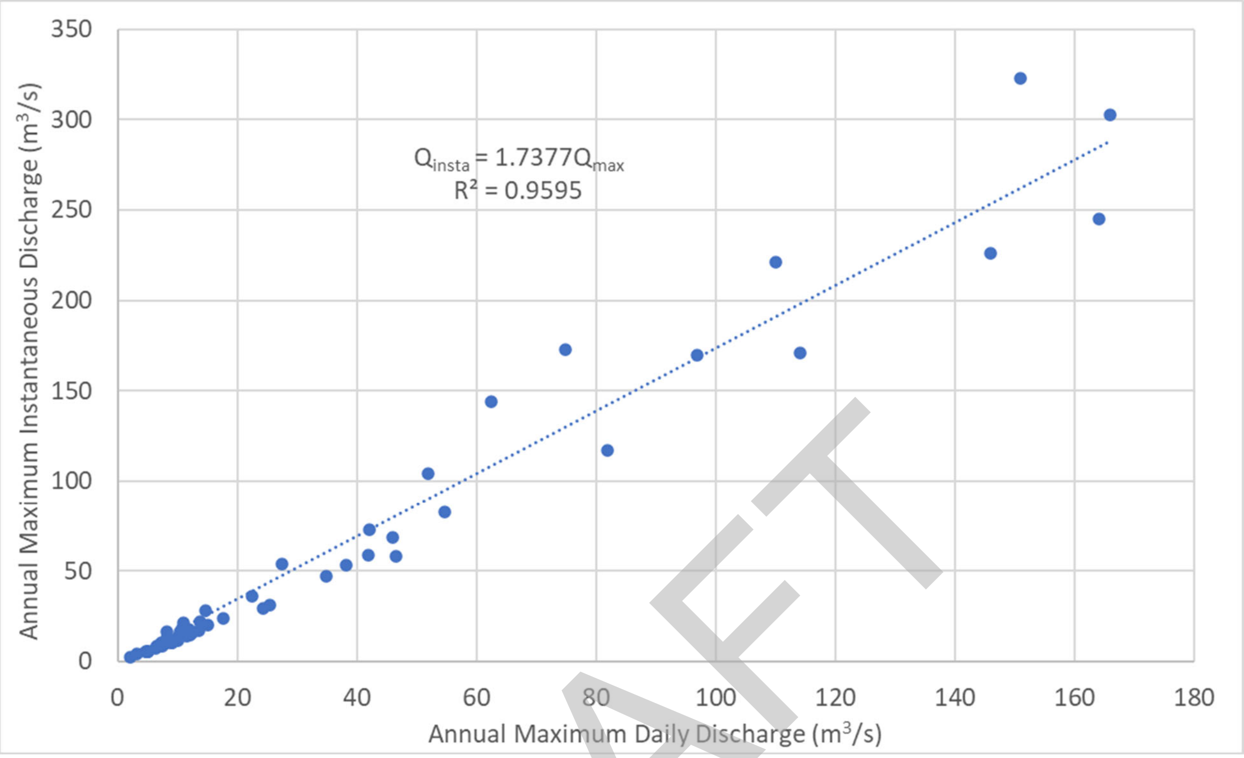
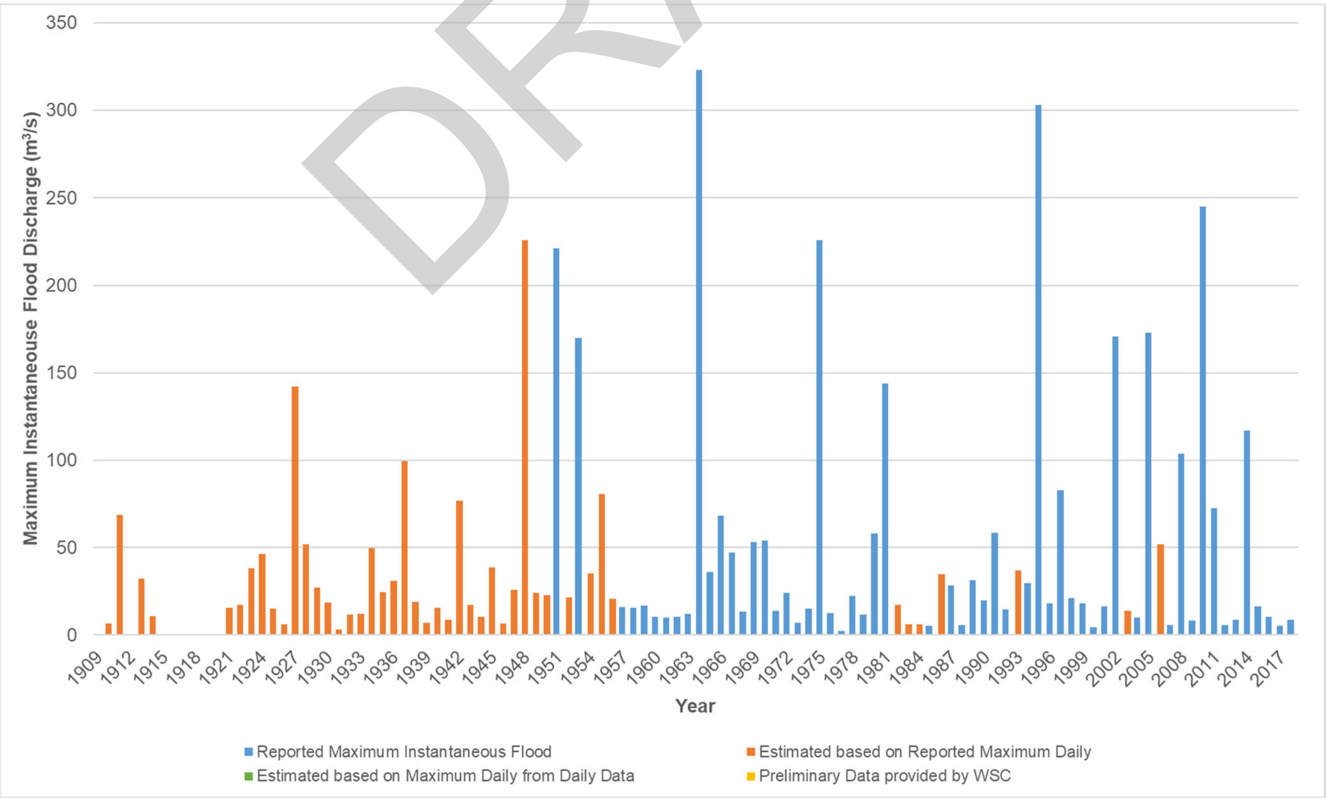

(c) Relationship of Belly River near Stand Off with Upstream Stations
● Based on Relationship with Lee Creek at Cardston
● Based on Relationship with Belly River near Mountain View
y = 1.0882x - 7.733
R² = 1
y = 1.0451x
R² = 1
Belly River near Stand Off (m³/s)
Belly River near Glenwood (m³/s)
0
50
100
150
200
250
300
350
400

Figure A-4: WSC Station No. 05AE002, Lee Creek at Cardston

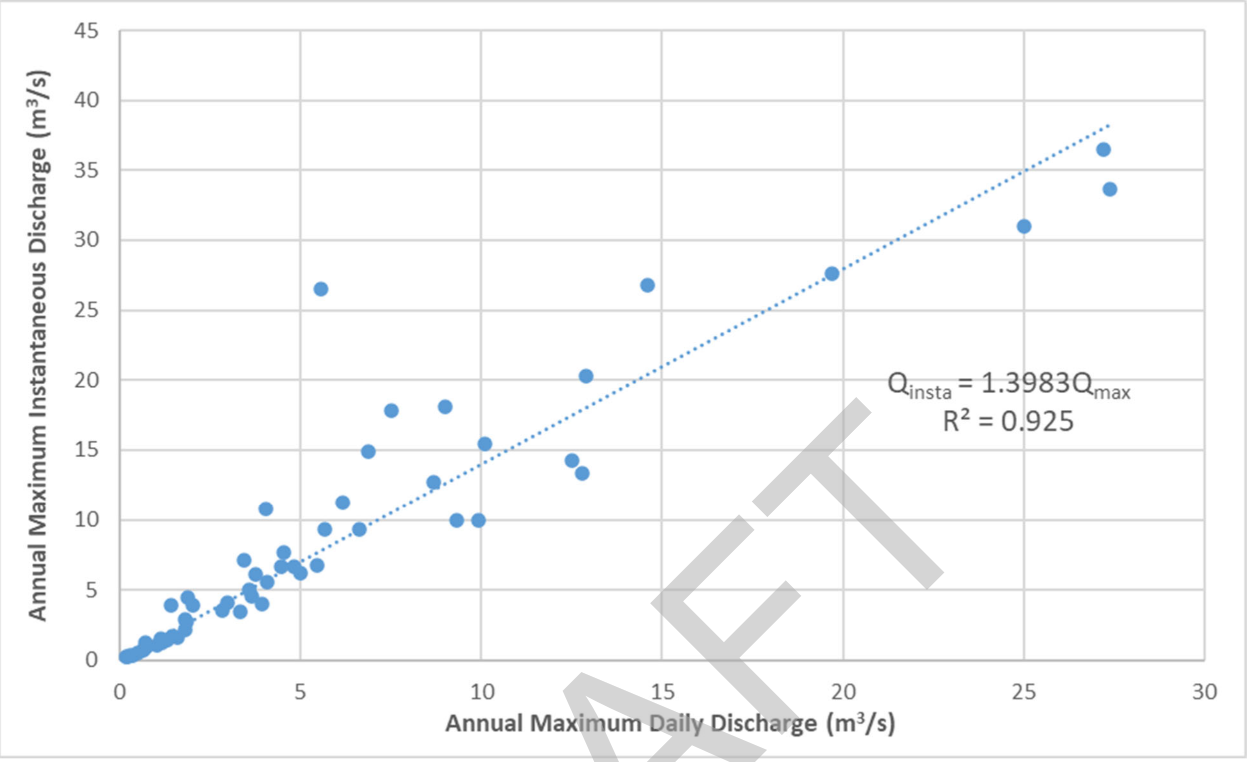


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Lee Creek at Cardston (WSC Station No. 05AE002)

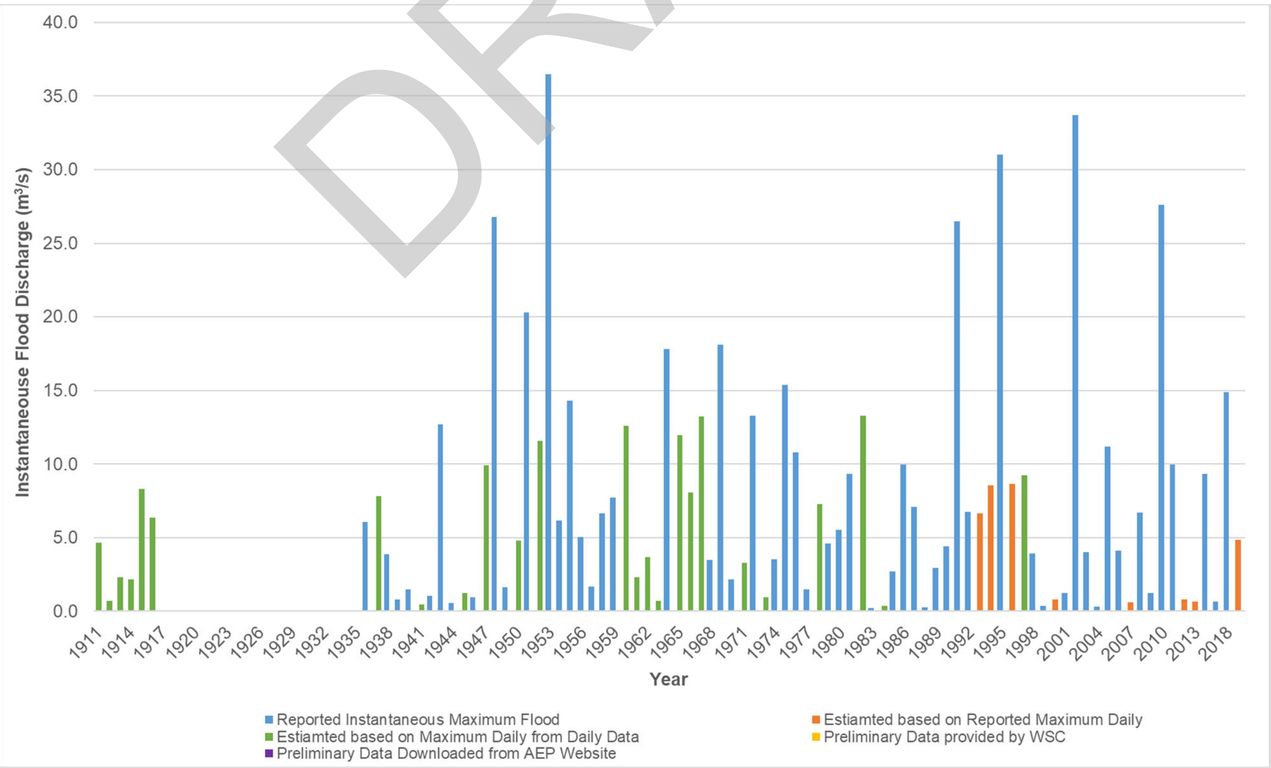


Maximum Instantaneous Flood Flow Series at Lee Creek at Cardston (WSC Station No. 05AE002)

Figure A-5: WSC Station No. 05AE005, Rolph Creek

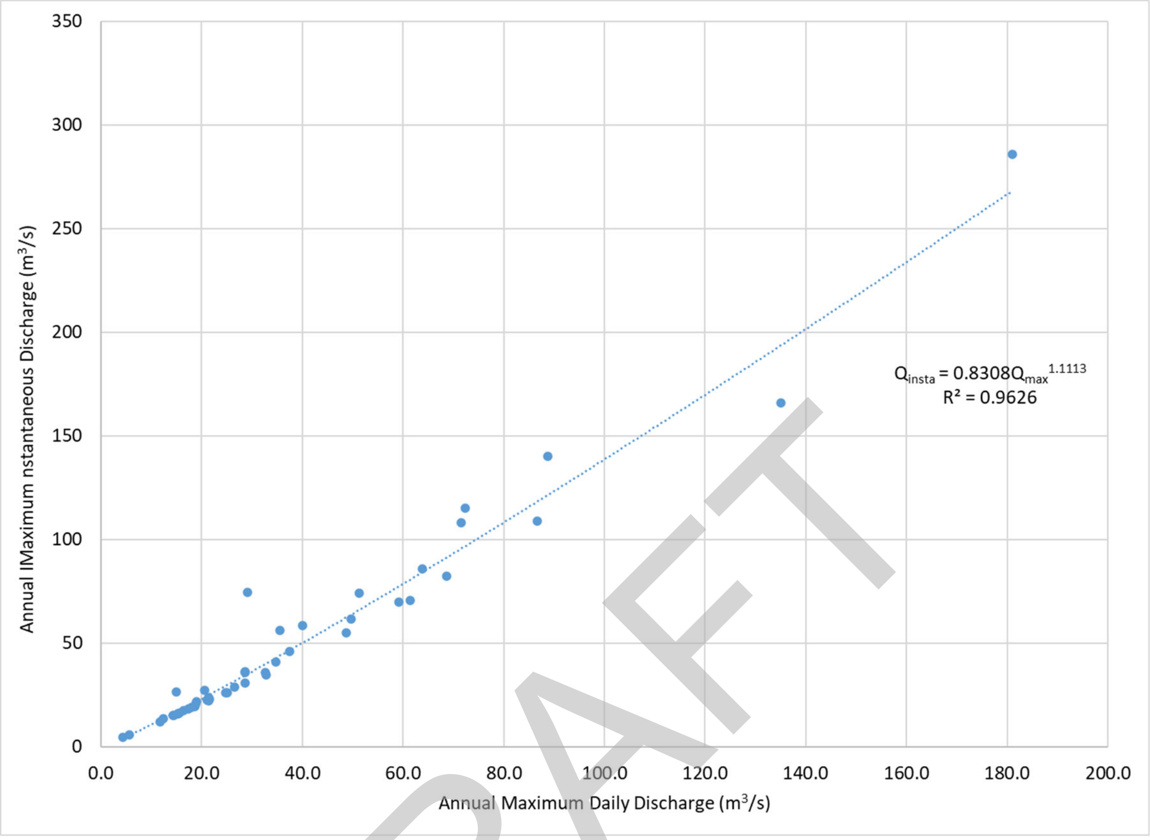


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Rolph Creek (WSC Station No. 05AE005)

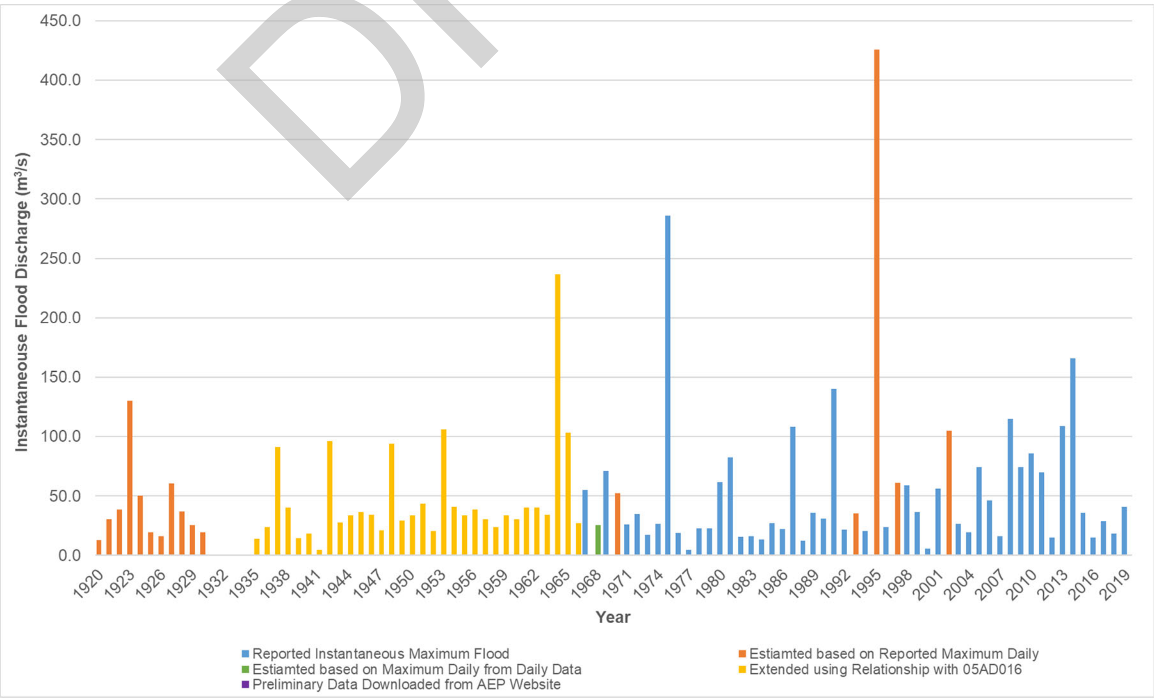


Maximum Instantaneous Flood Flow Series at Rolph Creek (WSC Station No. 05AE005)

Figure A-6: WSC Station No. 05AD010, Drywood Creek near the Mouth

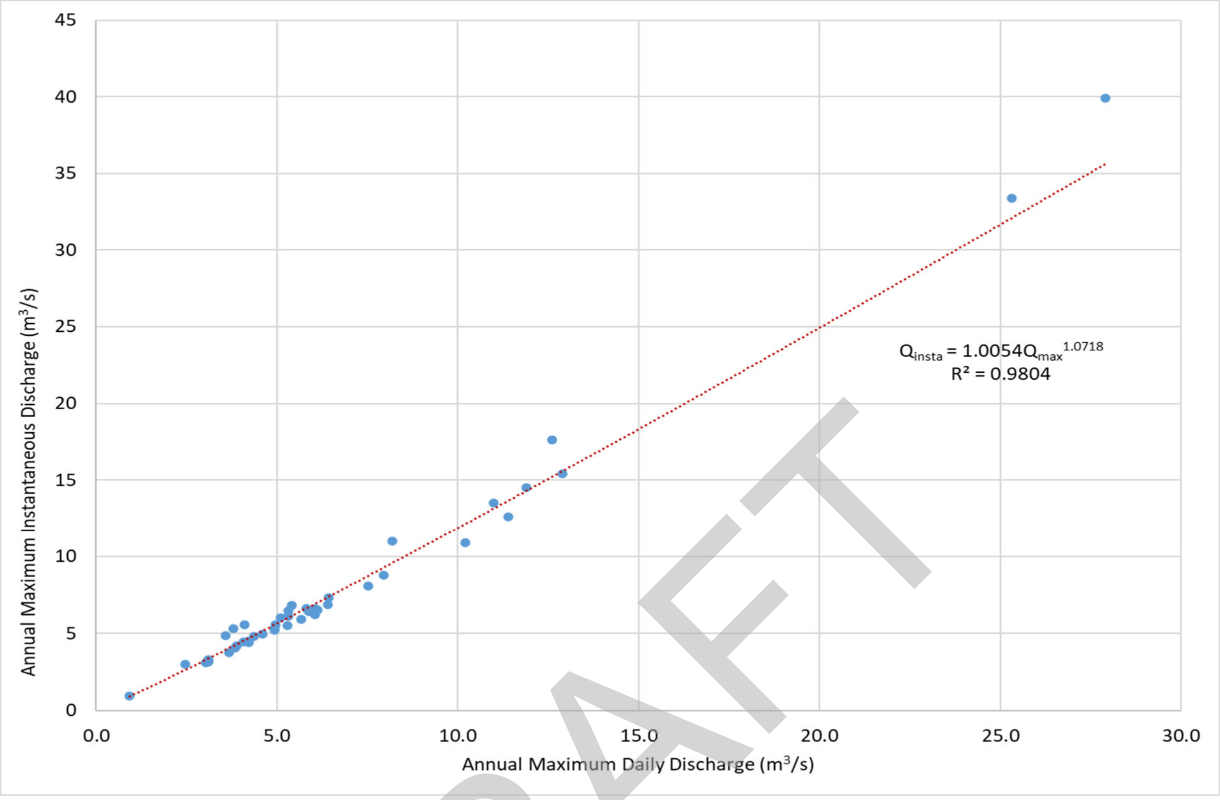


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Drywood Creek near the Mouth (WSC Station No. 05AD010)

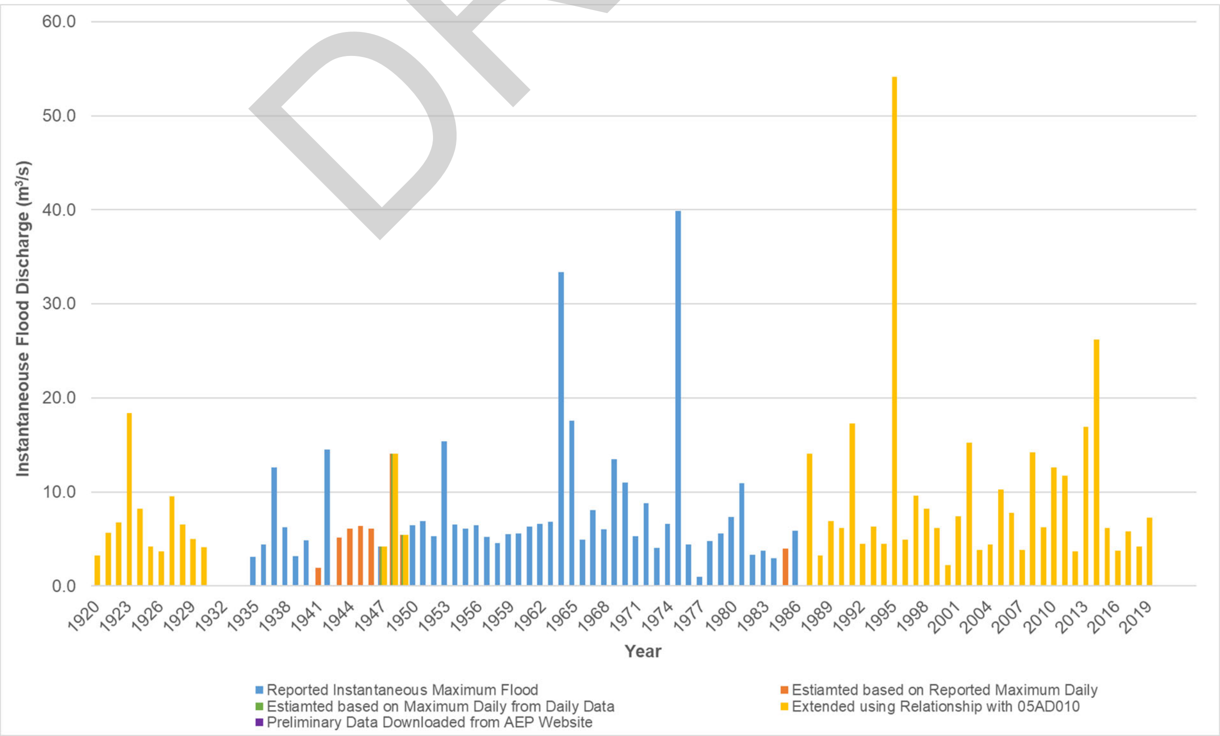


Maximum Instantaneous Flood Flow Series at Clearwater River at Drywood Creek near the Mouth (WSC Station No. 05AD010)

Figure A-7: WSC Station No. 05AD016, Drywood Creek near Twin Butte

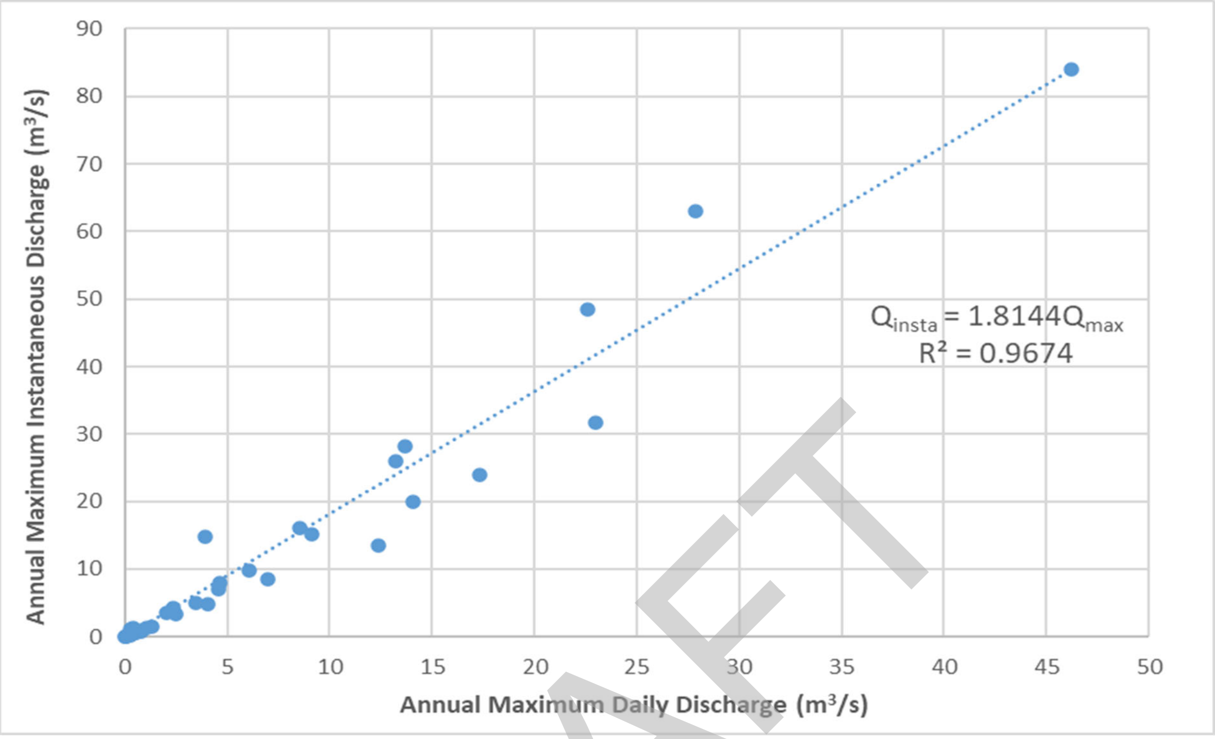


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Drywood Creek near Twin Butte(WSC Station No. 05AD016)

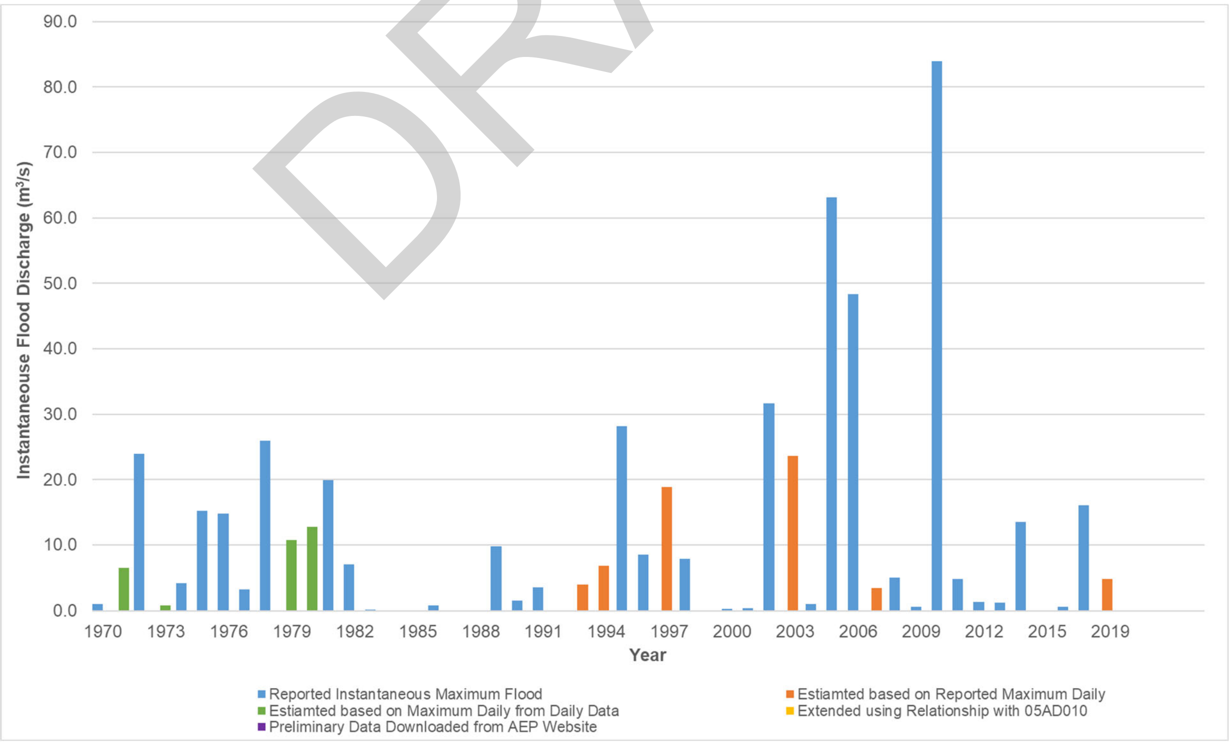


Maximum Instantaneous Flood Flow Series at Clearwater River at Drywood Creek near Twin Butte(WSC Station No. 05AD016)

Figure A-8: WSC Station No. 05AD035, Prairie Blood Creek

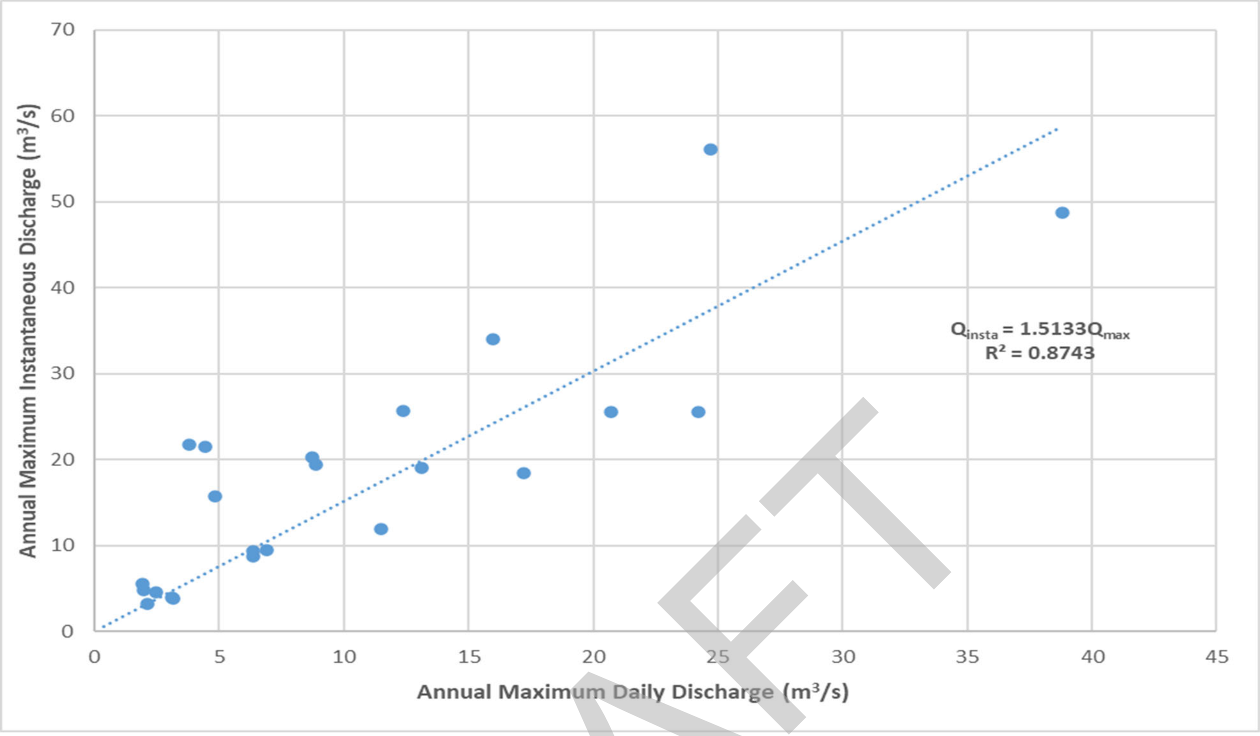


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Prairie Blood Creek (WSC Station No. 05AD035)

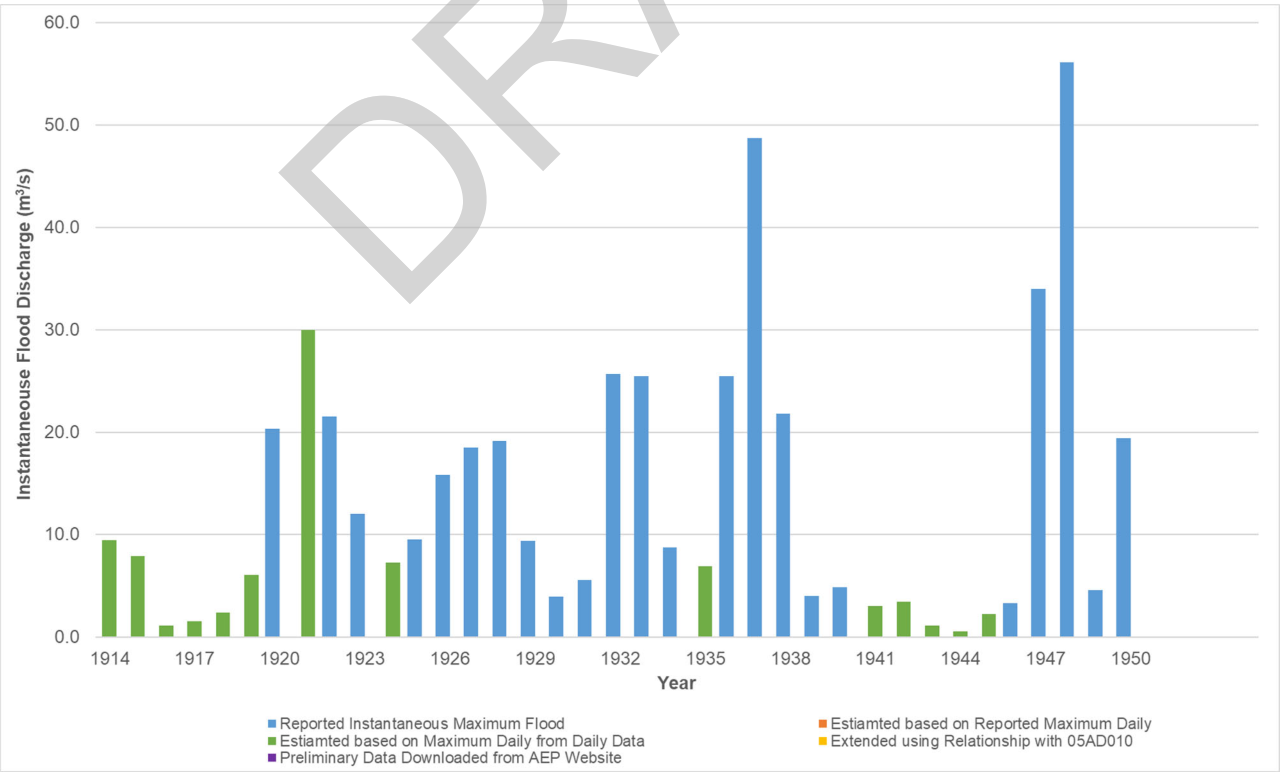


Maximum Instantaneous Flood Flow Series at Prairie Blood Creek (WSC Station No. 05AD035)

Figure A-9: WSC Station No. 05AE009, Pinepound Creek

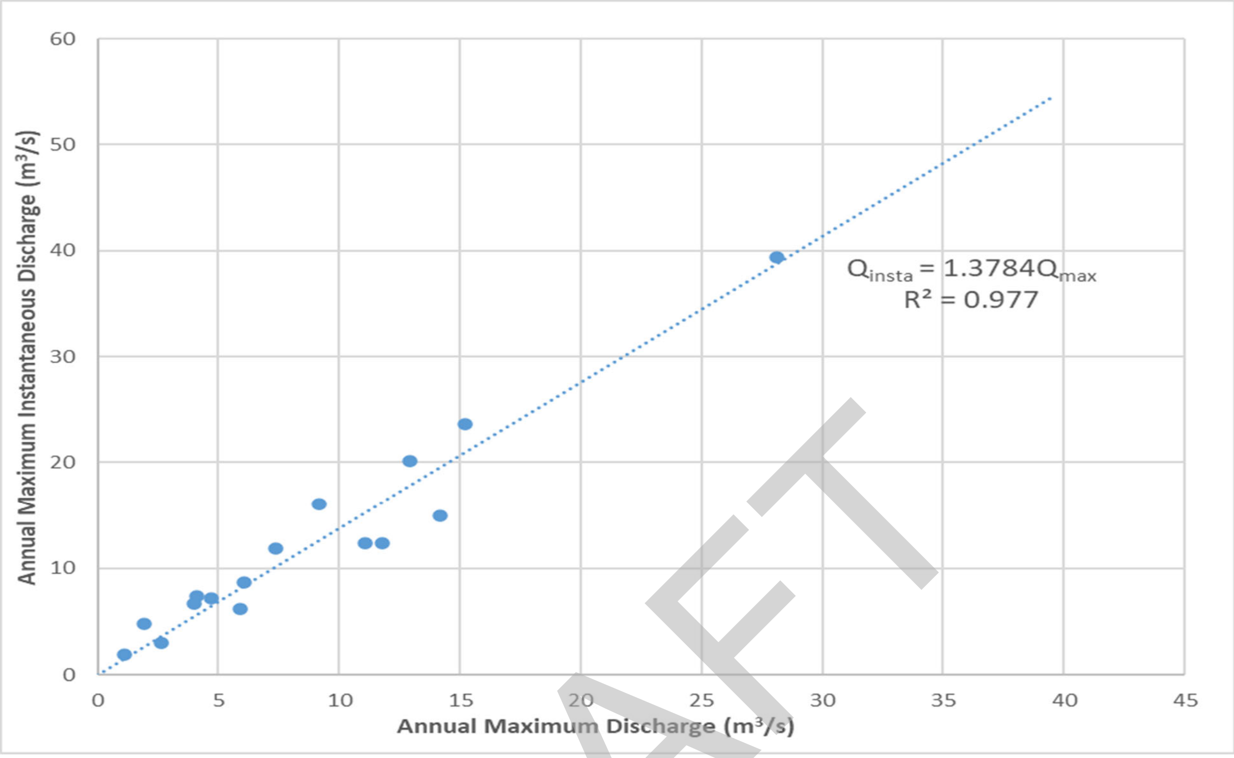


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Pinepound Creek (WSC Station No. 05AE009)

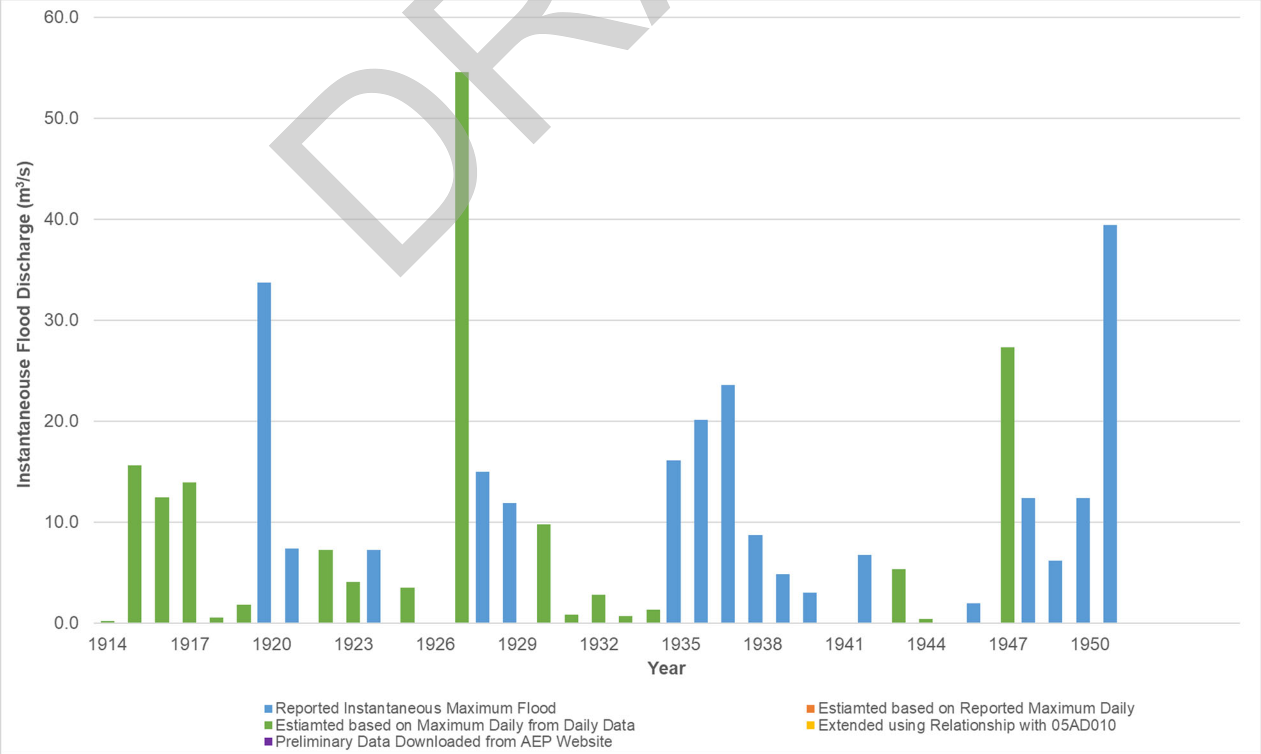


Maximum Instantaneous Flood Flow Series at Pinepound Creek (WSC Station No. 05AE009)

Figure A-10: WSC Station No. 05AE011, Pothole Creek

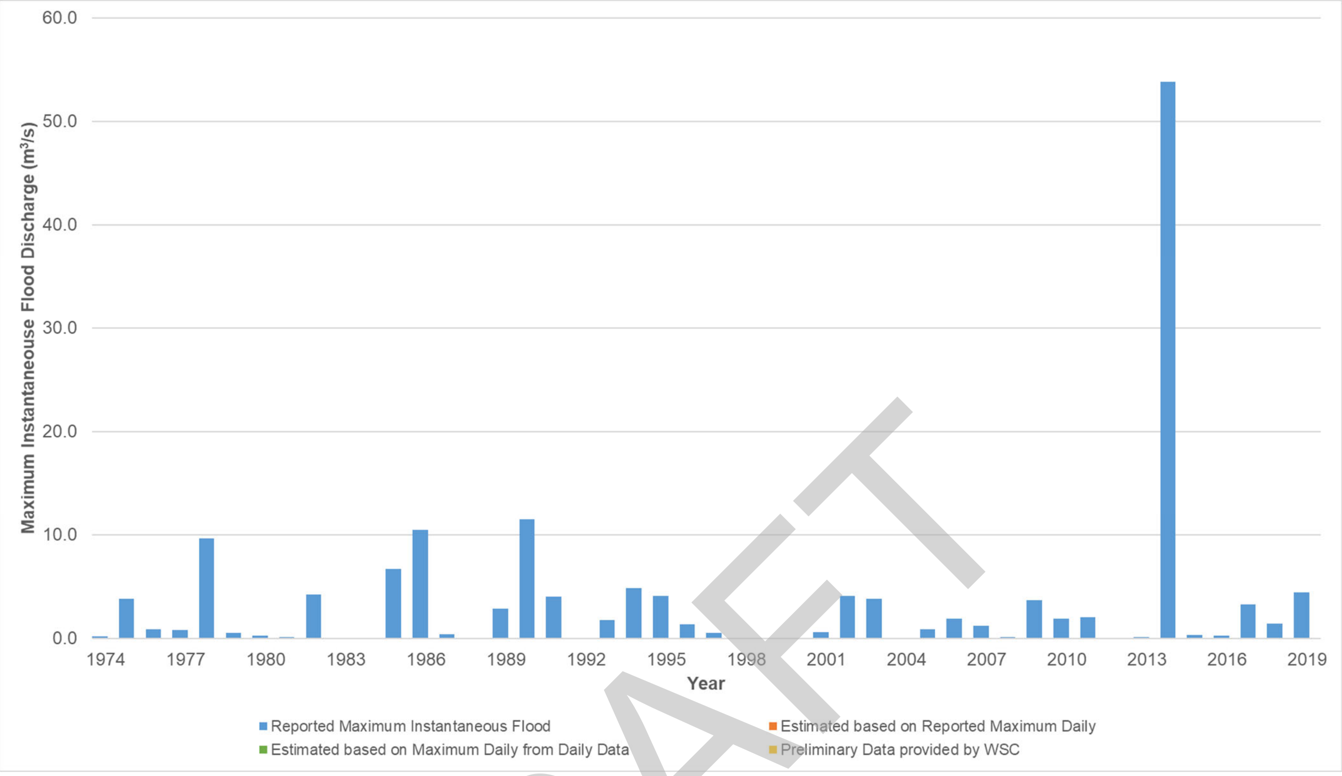


Relationship between Annual Maximum Daily and Annual Maximum Instantaneous Discharges at Pothole Creek (WSC Station No. 05AE011)



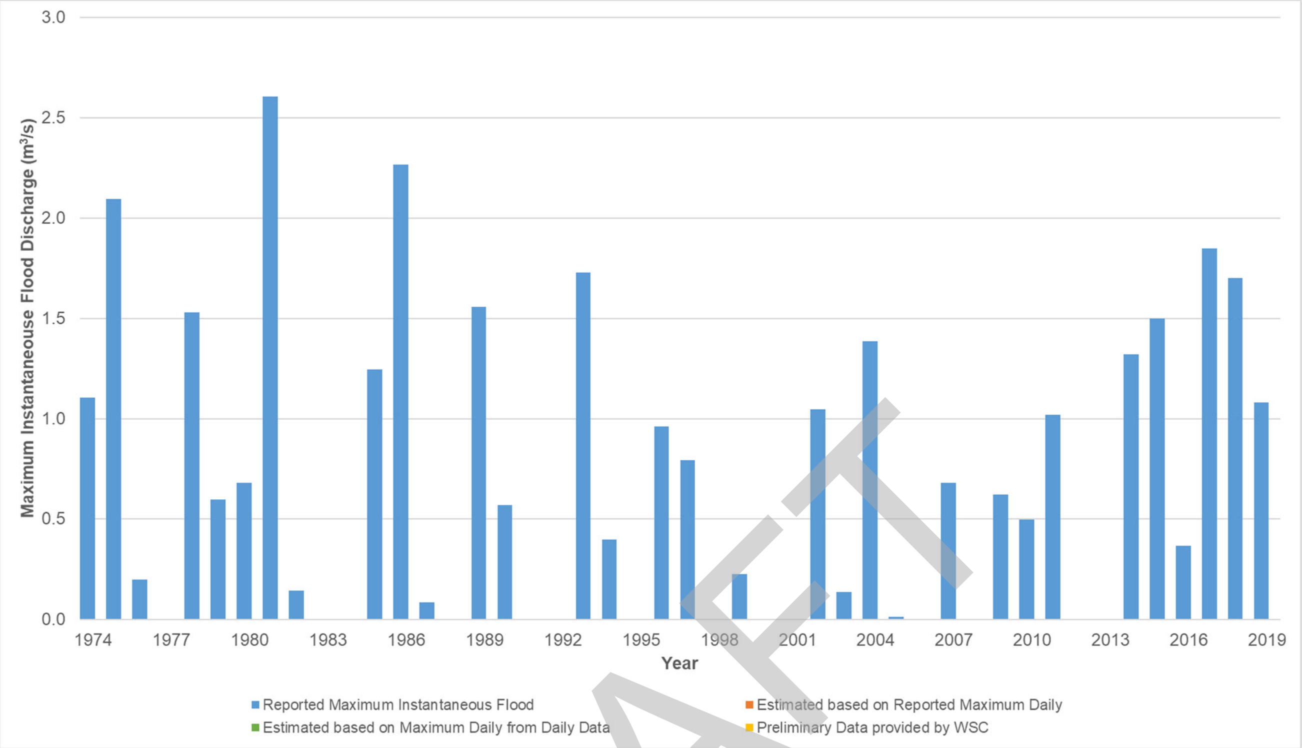
Maximum Instantaneous Flood Flow Series at Pothole Creek (WSC Station No. 05AE011)

Figure A-11: USGS Station No. 0698700, Powell Coulee



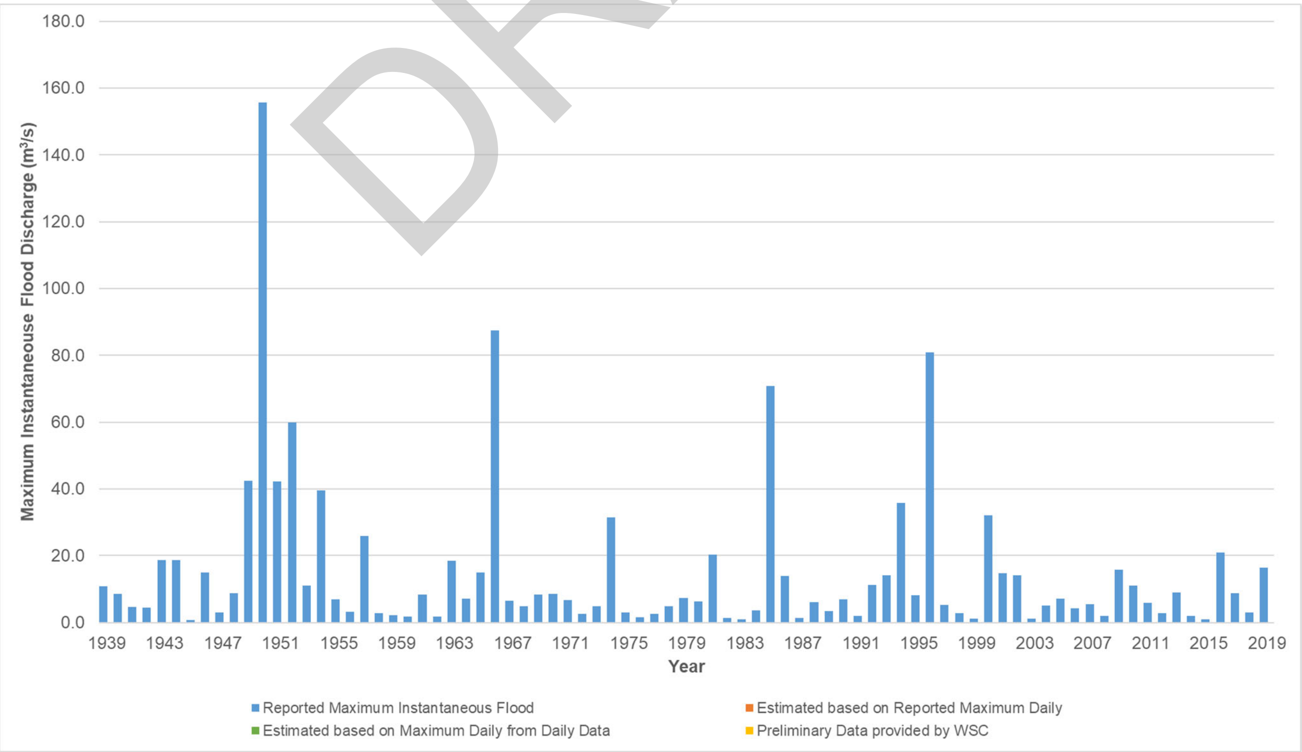
Maximum Instantaneous Flood Flow Series at Powell Coulee (USGS Station No. 0698700)

Figure A-12: USGS Station No. 06101520, Favot Creek



Maximum Instantaneous Flood Flow Series at Favot Creek (USGS Station No. 06101520)

Figure A-13: USGS Station No. 06133500, North Fork Milk River



Maximum Instantaneous Flood Flow Series at North Fork Milk River (USGS Station No. 06133500)

Table A-1: Data Used for the Flood Frequency Analysis – Belly River and Lee Creek

Year	Annual Maximum Daily Flow Belly River near Mountain View (05AD005)						Annual Maximum Daily Flow Belly River near Glenwood (05AD041)						Annual Maximum Daily Flow Belly River near Stand off (05AD002)						Annual Maximum Daily Flow Lee Creek at Cardston (05AE002)			Belly River near Stand Off Derived Annual Maximum Daily Series		Belly River near Stand Off Derived Annual Maximum Instantaneous Series	
	Date		Recorded	Date		Naturalized	Date		Recorded	Date		Naturalized	Date		Recorded	Date		Naturalized	Date		Recorded	Method 1	Method 2	Method 1	Method 2
	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
1909	-	-	-	-	-	-	-	-	-	-	-	-	6	21	102	6	21	102.0	-	-	-	102.0	102.0	122.3	122.3
1910	-	-	-	-	-	-	-	-	-	-	-	-	4	2	40.5	4	2	40.5	5	19	3.91	40.5	40.5	48.6	48.6
1911	-	-	-	-	-	-	-	-	-	-	-	-	3	18	75.3	3	18	75.3	5	15	39.6	75.3	75.3	90.3	90.3
1912	5	17	33.4	5	17	33.4	-	-	-	-	-	-	5	21	44.2	5	21	44.2	-	-	-	44.2	44.2	53.0	53.0
1913	5	29	58.6	5	29	58.6	-	-	-	-	-	-	5	29	84.1	5	29	84.1	4	8	18.5	84.1	84.1	100.8	100.8
1914	6	14	38.8	6	14	38.8	-	-	-	-	-	-	6	4	37.9	6	4	37.9	3	29	6.26	37.9	37.9	45.4	45.4
1915	6	3	38.8	6	3	38.8	-	-	-	-	-	-	6	26	76.5	6	26	76.5	-	-	-	76.5	76.5	91.7	91.7
1916	6	21	77.3	6	21	77.3	-	-	-	-	-	-	6	28	93.2	6	28	93.2	-	-	-	93.2	93.2	111.7	111.7
1917	6	11	87.8	6	11	87.8	-	-	-	-	-	-	6	12	85.8	6	12	85.8	-	-	-	85.8	85.8	102.9	102.9
1918	6	11	46.4	6	11	46.4	-	-	-	-	-	-	6	13	51.8	6	13	51.8	-	-	-	51.8	51.8	62.1	62.1
1919	5	29	54.7	5	29	54.7	-	-	-	-	-	-	5	29	43.9	5	29	43.9	-	-	-	43.9	43.9	52.6	52.6
1920	6	16	54.7	6	16	54.7	-	-	-	-	-	-	6	16	54.4	6	16	54.4	-	-	-	54.4	54.4	65.2	65.2
1921	6	8	49	6	8	49.0	-	-	-	-	-	-	6	7	53.2	5	26	53.2	4	2	8.95	53.2	53.2	63.8	63.8
1922	6	6	57.8	6	6	57.8	-	-	-	-	-	-	6	6	60.3	6	6	60.3	4	29	10	60.3	60.3	72.3	72.3
1923	6	2	63.1	6	2	63.1	-	-	-	-	-	-	6	2	69.7	6	2	69.7	6	22	22	69.7	69.7	83.6	83.6
1924	6	16	42.5	6	16	42.5	-	-	-	-	-	-	6	8	56.6	6	8	57.7	6	7	26.5	57.7	57.7	69.2	69.2
1925	5	23	57.5	5	23	57.5	-	-	-	-	-	-	5	22	55.5	5	22	55.8	5	3	8.58	55.8	55.8	66.9	66.9
1926	10	17	33.7	10	17	33.7	-	-	-	-	-	-	10	18	34.8	10	18	34.9	6	21	3.54	34.9	34.9	41.9	41.9
1927	6	11	75.6	6	11	75.6	-	-	-	-	-	-	5	30	124	5	30	124.0	5	31	81.8	124.0	124.0	148.7	148.7
1928	5	25	57.8	5	25	57.8	-	-	-	-	-	-	7	2	105	7	2	105.0	7	1	29.7	105.0	105.0	125.9	125.9
1929	6	3	39.6	6	3	39.6	-	-	-	-	-	-	6	4	60.9	6	4	60.9	6	3	15.5	60.9	60.9	73.0	73.0
1930	5	22	38.5	5	22	38.5	-	-	-	-	-	-	5	22	46.7	5	22	46.9	5	4	10.7	46.9	46.9	56.3	56.3
1931	5	16	36.8	5	16	36.8	-	-	-	-	-	-	-	-	-	-	-	-	5	30	1.81	36.1	52.8	43.2	63.3
1932	5	22	51	5	22	51.0	-	-	-	-	-	-	-	-	-	-	-	-	5	21	6.82	44.7	65.7	53.5	78.8
1933	6	17	54.4	6	17	54.4	-	-	-	-	-	-	-	-	-	-	-	-	5	14	7.08	45.1	68.8	54.1	82.5
1934	6	7	79.9	6	7	79.9	-	-	-	-	-	-	-	-	-	-	-	-	6	7	28.6	82.0	92.1	98.4	110.4
1935	5	24	46.4	5	24	46.4	-	-	-	-	-	-	-	-	-	-	-	-	1	25	14.2	57.3	61.5	68.7	73.8
1936	5	15	36.8	5	15	37.8	-	-	-	-	-	-	3	3	47.6	3	3	47.6	3	2	17.8	47.6	47.6	57.1	57.1

Table A-1: Data Used for the Flood Frequency Analysis – Belly River and Lee Creek

Year	Annual Maximum Daily Flow Belly River near Mountain View (05AD005)						Annual Maximum Daily Flow Belly River near Glenwood (05AD041)						Annual Maximum Daily Flow Belly River near Stand off (05AD002)						Annual Maximum Daily Flow Lee Creek at Cardston (05AE002)			Belly River near Stand Off Derived Annual Maximum Daily Series		Belly River near Stand Off Derived Annual Maximum Instantaneous Series	
	Date		**Recorded**	**Date**		**Naturalized**	Date		Recorded	**Date**		**Naturalized**	Date		Recorded	**Date**		**Naturalized**	Date		Recorded	**Method 1**	**Method 2**	**Method 1**	**Method 2**
	Month	**Day**	**(m^3/s)**	**Month**	**Day**	**(m^3/s)**	Month	Day	(m^3/s)	**Month**	**Day**	**(m^3/s)**	Month	Day	(m^3/s)	**Month**	**Day**	**(m^3/s)**	Month	Day	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
1937	6	13	118	6	13	119.4	-	-	-	-	-	-	-	-	-	-	-	-	6	13	57.2	131.1	128.2	157.2	153.7
1938	5	26	58.6	5	26	58.7	-	-	-	-	-	-	-	-	-	-	-	-	5	2	11	51.8	72.7	62.1	87.2
1939	5	30	28.6	5	30	29.6	-	-	-	-	-	-	-	-	-	-	-	-	3	21	3.96	39.8	46.2	47.7	55.4
1940	5	12	30.6	5	12	31.7	-	-	-	-	-	-	-	-	-	-	-	-	3	16	8.86	48.2	48.1	57.7	57.7
1941	6	29	26.5	6	29	26.7	-	-	-	-	-	-	-	-	-	-	-	-	6	2	4.93	41.4	43.5	49.7	52.2
1942	6	6	71.1	6	6	71.1	-	-	-	-	-	-	-	-	-	-	-	-	6	5	44.2	108.8	84.1	130.5	100.8
1943	6	18	54.1	6	18	54.3	-	-	-	-	-	-	-	-	-	-	-	-	6	9	9.88	49.9	68.8	59.8	82.4
1944	5	18	26.6	5	18	27.6	-	-	-	-	-	-	-	-	-	-	-	-	6	27	6.09	43.4	44.4	52.0	53.2
1945	6	4	47.6	6	4	48.0	-	-	-	-	-	-	-	-	-	-	-	-	6	6	22.2	71.1	63.0	85.2	75.6
1946	5	28	43.6	5	28	44.5	-	-	-	-	-	-	-	-	-	-	-	-	5	28	3.88	39.6	59.8	47.5	71.7
1947	5	3	40.2	5	3	40.3	-	-	-	-	-	-	-	-	-	-	-	-	5	3	14.8	58.4	56.0	70.0	67.1
1948	6	17	88.1	6	17	89.4	-	-	-	-	-	-	-	-	-	-	-	-	6	17	130	256.0	100.8	307.0	120.8
1949	5	28	37.1	5	28	37.1	-	-	-	-	-	-	5	29	36.5	5	29	36.8	5	22	13.8	36.8	36.8	44.1	44.1
1950	6	22	61.2	6	22	61.9	-	-	-	-	-	-	6	23	62	6	23	65.9	5	13	13.2	65.9	65.9	79.0	79.0
1951	6	24	69.1	6	24	69.3	-	-	-	-	-	-	6	25	223	6	25	223.3	6	24	110	223.3	223.3	267.8	267.8
1952	5	20	27	6	12	27.3	-	-	-	-	-	-	4	1	51	4	1	51.0	3	27	12.4	51.0	51.0	61.1	61.1
1953	6	4	120	6	4	121.0	-	-	-	-	-	-	6	9	273	6	9	273.9	6	4	96.8	273.9	273.9	328.4	328.4
1954	5	20	68.5	5	20	68.6	-	-	-	-	-	-	5	21	69.7	5	21	70.0	5	19	20.3	70.0	70.0	83.9	83.9
1955	6	25	58.9	6	25	59.1	-	-	-	-	-	-	5	19	112	5	19	112.6	5	18	46.4	112.6	112.6	135.0	135.0
1956	5	22	60.9	5	22	60.9	-	-	-	-	-	-	5	22	64.3	5	22	64.7	7	4	11.8	64.7	64.7	77.5	77.5
1957	5	14	55.2	5	14	56.8	-	-	-	-	-	-	5	15	57.2	5	15	59.4	5	14	12.5	59.4	59.4	71.3	71.3
1958	6	10	51.3	6	10	54.1	-	-	-	-	-	-	6	11	51	6	11	55.8	6	10	11.7	55.8	55.8	67.0	67.0
1959	6	6	54.1	6	6	54.2	-	-	-	-	-	-	6	7	56.6	6	7	57.8	5	19	13.5	57.8	57.8	69.3	69.3
1960	6	4	43	6	4	43.1	-	-	-	-	-	-	6	4	42.2	6	4	43.2	5	13	9.15	43.2	43.2	51.9	51.9
1961	5	27	54.7	5	27	54.8	-	-	-	-	-	-	5	31	51.8	5	28	59.2	5	31	7.25	59.2	59.2	71.0	71.0
1962	6	14	31.4	6	14	34.3	-	-	-	-	-	-	4	26	22	6	15	38.8	6	14	8.89	38.8	38.8	46.5	46.5
1963	6	10	47.9	6	10	51.7	-	-	-	-	-	-	7	8	16.2	6	11	53.9	6	10	8.33	53.9	53.9	64.6	64.6
1964	6	8	303	6	8	307.6	-	-	-	-	-	-	6	9	292	6	9	298.3	6	8	151	298.3	298.3	357.6	357.6

Table A-1: Data Used for the Flood Frequency Analysis – Belly River and Lee Creek

Year	Annual Maximum Daily Flow Belly River near Mountain View (05AD005)						Annual Maximum Daily Flow Belly River near Glenwood (05AD041)						Annual Maximum Daily Flow Belly River near Stand off (05AD002)						Annual Maximum Daily Flow Lee Creek at Cardston (05AE002)			Belly River near Stand Off Derived Annual Maximum Daily Series		Belly River near Stand Off Derived Annual Maximum Instantaneous Series	
	Date		Recorded	Date		Naturalized	Date		Recorded	Date		Naturalized	Date		Recorded	Date		Naturalized	Date		Recorded	Method 1	Method 2	Method 1	Method 2
	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
1965	6	19	69.1	6	19	69.3	-	-	-	-	-	-	6	20	67.1	6	20	76.2	6	17	22.5	76.2	76.2	91.3	91.3
1966	6	4	50.1	6	4	52.2	-	-	-	-	-	-	6	5	77.9	6	5	86.3	6	4	45.9	86.3	86.3	103.5	103.5
1967	5	23	62.9	5	23	63.2	-	-	-	-	-	-	5	24	75.3	5	24	75.6	6	9	34.8	75.6	75.6	90.6	90.6
1968	6	4	41.9	6	4	41.9	-	-	-	-	-	-	6	4	34.5	6	4	41.9	9	25	10	41.9	41.9	50.2	50.2
1969	6	26	64.3	6	26	65.9	-	-	-	-	-	-	6	27	80.1	6	27	89.4	6	26	38.2	89.4	89.4	107.2	107.2
1970	6	14	85.2	6	14	85.6	-	-	-	-	-	-	6	14	124	6	14	119.9	6	13	27.4	119.9	119.9	143.7	143.7
1971	5	28	53.5	5	28	54.7	-	-	-	-	-	-	5	29	44.5	5	29	46.2	5	6	11.5	46.2	46.2	55.3	55.3
1972	6	2	73.6	6	2	73.7	-	-	-	-	-	-	6	2	63.7	6	2	64.4	5	26	17.7	64.4	64.4	77.3	77.3
1973	6	9	43.6	6	9	47.1	-	-	-	-	-	-	5	20	24.9	6	10	43.0	5	18	6.26	43.0	43.0	51.6	51.6
1974	6	18	69.9	6	18	70.1	-	-	-	-	-	-	6	18	60.9	6	19	68.6	5	1	12.1	68.6	68.6	82.3	82.3
1975	6	20	331	6	20	332.5	-	-	-	-	-	-	6	21	267	6	21	269.4	6	20	146	269.4	269.4	323.0	323.0
1976	5	11	47.9	5	11	48.0	-	-	-	-	-	-	5	12	47	5	12	47.1	5	6	8.18	47.1	47.1	56.4	56.4
1977	6	9	17.8	6	9	21.0	-	-	-	-	-	-	4	8	5.15	6	9	22.9	4	9	1.99	22.9	22.9	27.4	27.4
1978	6	6	46.7	6	6	47.0	-	-	-	-	-	-	6	7	39.9	6	7	48.8	6	1	13.8	48.8	48.8	58.5	58.5
1979	5	27	55.1	5	27	55.2	-	-	-	-	-	-	5	28	55	5	28	57.0	5	16	10.1	57.0	57.0	68.3	68.3
1980	5	26	70.5	5	26	71.2	-	-	-	-	-	-	5	27	103	5	27	100.1	5	26	46.6	100.1	100.1	120.0	120.0
1981	5	22	62.9	5	22	63.7	-	-	-	-	-	-	5	22	115	5	22	118.6	5	22	62.4	118.6	118.6	142.2	142.2
1982	6	16	44.6	6	16	46.5	-	-	-	-	-	-	6	15	46.2	6	23	50.8	4	13	10	50.8	50.8	60.9	60.9
1983	5	27	41.5	5	27	42.6	-	-	-	-	-	-	5	27	37.3	5	30	40.4	5	25	3.56	40.4	40.4	48.4	48.4
1984	5	31	43.3	5	31	44.4	-	-	-	-	-	-	6	30	25.1	6	1	42.4	6	22	3.62	42.4	42.4	50.8	50.8
1985	6	8	42.7	6	8	44.9	5	26	22.5	6	9	40.2	-	-	-	-	-	-	9	12	4.62	36.0	36.0	43.2	43.2
1986	5	30	53.2	5	30	54.3	5	30	56.5	5	30	61.1	-	-	-	-	-	-	2	24	20	58.8	58.8	70.4	70.4
1987	7	23	40.2	7	23	41.2	7	23	45.1	7	23	50.4	-	-	-	-	-	-	7	23	14.6	47.1	47.1	56.5	56.5
1988	5	13	30.5	5	13	31.4	10	19	7	5	14	34.2	-	-	-	-	-	-	5	8	4.92	29.5	29.5	35.4	35.4
1989	6	11	60.6	6	11	60.7	6	12	53.9	6	12	77.0	-	-	-	-	-	-	6	11	25.4	76.1	76.1	91.2	91.2
1990	5	31	38.9	5	31	39.0	5	31	40.3	5	31	46.5	-	-	-	-	-	-	5	29	15.1	42.8	42.8	51.4	51.4
1991	6	21	77.7	6	21	78.4	6	21	88	6	21	95.5	-	-	-	-	-	-	6	21	41.8	96.1	96.1	115.3	115.3
1992	5	1	20.3	5	1	22.0	10	12	8.68	6	16	25.1	-	-	-	-	-	-	7	1	12.1	19.6	19.6	23.5	23.5

Table A-1: Data Used for the Flood Frequency Analysis – Belly River and Lee Creek

Year	Annual Maximum Daily Flow Belly River near Mountain View (05AD005)						Annual Maximum Daily Flow Belly River near Glenwood (05AD041)						Annual Maximum Daily Flow Belly River near Stand off (05AD002)						Annual Maximum Daily Flow Lee Creek at Cardston (05AE002)			Belly River near Stand Off Derived Annual Maximum Daily Series		Belly River near Stand Off Derived Annual Maximum Instantaneous Series	
	Date		Recorded	Date		Naturalized	Date		Recorded	Date		Naturalized	Date		Recorded	Date		Naturalized	Date		Recorded	Method 1	Method 2	Method 1	Method 2
	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	Month	Day	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
1993	5	17	32.8	5	17	32.9	6	17	32.8	6	17	42.6	-	-	-	-	-	-	7	13	21.3	38.6	38.6	46.3	46.3
1994	5	13	33.9	5	13	34.0	5	20	32.7	5	20	41.8	-	-	-	-	-	-	5	20	24.3	37.7	37.7	45.2	45.2
1995	6	7	184	6	7	186.2	6	7	340	6	7	381.0	-	-	-	-	-	-	6	7	166	406.8	406.8	487.8	487.8
1996	6	9	68	6	9	68.1	6	10	38	6	9	52.4	-	-	-	-	-	-	5	23	11.9	49.3	49.3	59.1	59.1
1997	6	1	79.1	6	1	79.3	6	12	126	6	12	122.6	-	-	-	-	-	-	5	26	54.6	125.7	125.7	150.7	150.7
1998	6	17	70.2	6	16	70.6	6	17	66.2	6	17	70.1	-	-	-	-	-	-	6	17	10.9	68.6	68.6	82.2	82.2
1999	11	14	62.3	11	14	62.3	11	15	43.2	6	4	48.1	-	-	-	-	-	-	6	3	10.7	44.6	44.6	53.4	53.4
2000	6	16	36	6	16	38.7	10	20	4.55	6	16	35.0	-	-	-	-	-	-	4	22	3.16	30.3	30.3	36.3	36.3
2001	6	4	54.1	6	4	54.9	6	5	4.49	6	5	56.4	-	-	-	-	-	-	6	4	8.21	53.7	53.7	64.3	64.3
2002	6	18	89.9	6	18	90.8	6	10	220	6	10	257.3	-	-	-	-	-	-	6	10	114	272.3	272.3	326.5	326.5
2003	5	27	45.9	5	27	46.0	5	27	44.8	5	27	54.0	-	-	-	-	-	-	3	13	8	51.0	51.0	61.1	61.1
2004	6	6	34.1	6	6	34.1	7	2	13.5	6	7	42.8	-	-	-	-	-	-	5	22	7.47	38.8	38.8	46.5	46.5
2005	6	4	70.6	6	4	70.9	6	7	91.3	6	7	130.8	-	-	-	-	-	-	6	7	74.9	134.6	134.6	161.4	161.4
2006	11	8	114	11	8	114.0	11	9	84.1	6	16	85.2	-	-	-	-	-	-	6	14	29.7	85.0	85.0	101.9	101.9
2007	6	7	43	6	7	43.1	6	7	43.1	6	7	54.7	-	-	-	-	-	-	5	29	4.98	51.8	51.8	62.1	62.1
2008	5	25	102	5	25	102.6	5	25	110	5	25	125.8	-	-	-	-	-	-	6	12	51.8	129.2	129.2	154.9	154.9
2009	5	31	55.5	5	31	55.5	6	1	20.9	6	1	43.7	-	-	-	-	-	-	5	5	7.03	39.8	39.8	47.8	47.8
2010	6	17	77.2	6	17	77.2	6	17	171	6	17	183.9	-	-	-	-	-	-	6	17	164	192.3	192.3	230.6	230.6
2011	6	8	81.5	6	8	81.5	6	8	89.1	6	8	87.6	-	-	-	-	-	-	6	8	42	87.6	87.6	105.0	105.0
2012	6	6	57.3	6	6	57.6	6	27	40.5	6	27	56.8	-	-	-	-	-	-	4	27	5.03	54.1	54.1	64.8	64.8
2013	6	20	53.2	6	20	54.2	6	21	58	6	21	66.7	-	-	-	-	-	-	6	20	6.52	64.9	64.9	77.8	77.8
2014	6	19	141	6	19	141.0	6	19	201	6	19	213.3	-	-	-	-	-	-	6	19	81.8	224.3	224.3	269.0	269.0
2015	6	3	66.4	6	3	66.6	6	3	36.7	6	3	68.4	-	-	-	-	-	-	6	3	10.5	66.7	66.7	80.0	80.0
2016	-	-	-	-	-	-	10	16	21	6	9	37.9	-	-	-	-	-	-	-	-	-	33.5	33.5	40.1	40.1
2017	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2018	5	18	44.4	5	18	44.4	5	19	29.2	5	19	50.5	-	-	-	-	-	-	5	19	7.54	47.6	47.6	57.0	57.0
2019	6	3	44.2	6	3	44.5	6	4	29.7	6	4	50.3	-	-	-	-	-	-	-	-	-	47.3	47.3	56.7	56.7
2020	-	-	-	-	-	-	7	1	97.2	7	1	158.2	-	-	-	-	-	-	-	-	-	164.5	164.5	197.2	197.2

Table A-2: Results of Statistical Tests of Annual Maximum Instantaneous Discharges and Goodness-of-Fit of Probability Distribution Functions

WSC/USGS Station ID	**05AD002**		**05AD016**
WSC Station Name or Location of Interest	**Belly River near Stand Off**		**Lee Creek at Cardston**
	Method 1	**Method 2**	
Anderson-Darling statistic, A² = - N -S			
3 Parameter Log-normal	1.791	1.506	0.552
Extreme Value	0.643	0.448	1.480
Log-Pearson III	1.309	1.051	0.322
Weibull	4.642	4.422	7.026
Serial correlation coefficient test for independence			
S_1	-0.0419	-0.0406	0.0055
t	-0.4353	-0.4221	0.0546
t(α=0.05)	-1.6591	-1.6591	1.6607
t(α=0.01)	-2.3614	-2.3614	2.3654
Spearman rank order correlation coefficient test for no-trend			
r_s	-0.0100	0.0390	-0.0001
t	-0.1044	0.4071	-0.0007
t(α=0.05)	-1.9820	1.9820	-1.9845
t(α=0.01)	-2.6217	2.6217	-2.6269
Mann-Whitney split sample test for homogeneity			
Size of earlier sample	55	55	50
z	-0.1121	-0.4365	-0.3309
z(a=0.05)	-1.6449	-1.6449	-1.6449
z(a=0.01)	-2.3263	-2.3263	-2.3263
Test of general randomness (Runs for above or below the median)			
Median	68.3	71.0	20.3
N1(for Q>=Median)	56	56	50
N2(for Q<Median)	55	55	50
Run_ab	61	57	47
z	0.8591	0.0962	0.8041
z(a=0.05)	1.9600	1.9600	1.9600
z(a=0.01)	2.5758	2.5758	2.5758

Notes:

Selected distribution based on best statistical fit	0.647

Table A-3: Data Used for the Flood Frequency Analysis – Regional Stations

Year	05AE005 Rolph Creek	05AD010 Drywood Creek near the Mouth	05AD016 Drywood Creek near Twin Butte	05AD035 Prairie Blood Creek	05AE009 Pinepound Creek	05AE011 Pothole Creek	06098700 Powell Coulee	06101520 Favot Creek	06133500 North Fork Milk River
1911	4.6	-	-	-	-	-	-	-	-
1912	0.7	-	-	-	-	-	-	-	-
1913	2.3	-	-	-	-	-	-	-	-
1914	2.2	-	-	-	9.4	0.2	-	-	-
1915	8.3	-	-	-	7.8	15.6	-	-	-
1916	6.4	-	-	-	1.1	12.4	-	-	-
1917	-	-	-	-	1.5	13.9	-	-	-
1918	-	-	-	-	2.4	0.5	-	-	-
1919	-	-	-	-	6.0	1.8	-	-	-
1920	-	13.0	3.3	-	20.3	33.7	-	-	-
1921	-	30.4	5.6	-	30.0	7.4	-	-	-
1922	-	38.7	6.7	-	21.5	7.2	-	-	-
1923	-	130.2	18.4	-	12.0	4.1	-	-	-
1924	-	50.0	8.2	-	7.2	7.2	-	-	-
1925	-	19.6	4.2	-	9.5	3.5	-	-	-
1926	-	16.0	3.7	-	15.8	-	-	-	-
1927	-	60.4	9.6	-	18.5	54.6	-	-	-
1928	-	37.2	6.5	-	19.1	15.0	-	-	-
1929	-	25.5	5.0	-	9.3	11.9	-	-	-
1930	-	19.4	4.2	-	3.9	9.8	-	-	-
1931	-	-	-	-	5.5	0.8	-	-	-
1932	-	-	-	-	25.7	2.8	-	-	-
1933	-	-	-	-	25.5	0.7	-	-	-
1934	-	-	-	-	8.7	1.3	-	-	-
1935	-	14.0	3.1	-	6.9	16.1	-	-	-
1936	6.1	24.0	4.4	-	25.5	20.1	-	-	-
1937	7.8	91.3	12.6	-	48.7	23.6	-	-	-
1938	3.9	40.4	6.2	-	21.8	8.7	-	-	-
1939	0.8	14.6	3.2	-	4.0	4.8	-	-	11
1940	1.5	18.5	4.9	-	4.8	3.0	-	-	9
1941	0.5	4.9	2.0	-	3.0	0.0	-	-	5
1942	1.1	96.2	14.5	-	3.4	6.7	-	-	5
1943	12.7	27.5	5.2	-	1.1	5.3	-	-	19

Table A-3: Data Used for the Flood Frequency Analysis – Regional Stations

Year	05AE005 Rolph Creek	05AD010 Drywood Creek near the Mouth	05AD016 Drywood Creek near Twin Butte	05AD035 Prairie Blood Creek	05AE009 Pinepound Creek	05AE011 Pothole Creek	06098700 Powell Coulee	06101520 Favot Creek	06133500 North Fork Milk River
1944	0.5	33.9	6.1	-	0.6	0.4	-	-	19
1945	1.2	36.3	6.4	-	2.2	0.1	-	-	1
1946	1.0	34.2	6.1	-	3.3	2.0	-	-	15
1947	9.9	21.1	4.2	-	34.0	27.3	-	-	3
1948	26.8	94.2	14.0	-	56.1	12.4	-	-	9
1949	1.6	29.2	5.4	-	4.5	6.2	-	-	42
1950	4.8	33.7	6.5	-	19.4	12.4	-	-	156
1951	20.3	43.5	6.9	-	-	39.4	-	-	42
1952	11.6	20.3	5.3	-	-	-	-	-	60
1953	36.5	106.2	15.4	-	-	-	-	-	11
1954	6.2	40.9	6.5	-	-	-	-	-	40
1955	14.3	33.7	6.1	-	-	-	-	-	7
1956	5.0	38.8	6.4	-	-	-	-	-	3
1957	1.7	30.2	5.2	-	-	-	-	-	26
1958	6.6	24.0	4.5	-	-	-	-	-	3
1959	7.7	33.5	5.5	-	-	-	-	-	2
1960	12.6	30.5	5.6	-	-	-	-	-	2
1961	2.3	40.4	6.3	-	-	-	-	-	8
1962	3.7	40.4	6.6	-	-	-	-	-	2
1963	0.7	34.5	6.8	-	-	-	-	-	18
1964	17.8	236.4	33.4	-	-	-	-	-	7
1965	12.0	103.2	17.6	-	-	-	-	-	15
1966	8.1	27.2	5.0	-	-	-	-	-	87
1967	13.2	54.9	8.1	-	-	-	-	-	7
1968	3.5	25.5	6.0	-	-	-	-	-	5
1969	18.1	70.8	13.5	-	-	-	-	-	8
1970	2.2	52.4	11.0	1.0	-	-	-	-	8
1971	3.3	26.2	5.3	6.5	-	-	-	-	7
1972	13.3	34.8	8.8	23.9	-	-	-	-	3
1973	1.0	17.4	4.1	0.8	-	-	-	-	5
1974	3.5	26.3	6.6	4.2	-	-	0	1	31
1975	15.4	286.0	39.9	15.2	-	-	4	2	3
1976	10.8	19.1	4.5	14.8	-	-	1	0	2

Table A-3: Data Used for the Flood Frequency Analysis – Regional Stations

Year	05AE005 Rolph Creek	05AD010 Drywood Creek near the Mouth	05AD016 Drywood Creek near Twin Butte	05AD035 Prairie Blood Creek	05AE009 Pinepound Creek	05AE011 Pothole Creek	06098700 Powell Coulee	06101520 Favot Creek	06133500 North Fork Milk River
1977	1.5	4.8	1.0	3.3	-	-	1	-	3
1978	7.3	22.8	4.8	26.0	-	-	10	2	5
1979	4.6	22.6	5.6	10.7	-	-	1	1	7
1980	5.6	61.7	7.3	12.8	-	-	0	1	6
1981	9.3	82.3	10.9	19.9	-	-	0	3	20
1982	13.3	15.8	3.3	7.1	-	-	4	0	1
1983	0.2	16.3	3.8	0.1	-	-	0	-	1
1984	0.4	13.6	3.0		-	-	0	-	4
1985	2.7	27.3	3.9	0.0	-	-	7	1	71
1986	10.0	22.1	5.9	0.8	-	-	10	2	14
1987	7.1	108.0	14.0		-	-	0	0	1
1988	0.3	12.2	3.3		-	-	0	-	6
1989	2.9	36.0	6.9	9.8	-	-	3	2	3
1990	4.4	30.9	6.2	1.6	-	-	11	1	7
1991	26.5	140.0	17.3	3.6	-	-	4	-	2
1992	6.8	21.7	4.5	0.0	-	-	0	-	11
1993	6.6	35.4	6.3	4.0	-	-	2	2	14
1994	8.6	20.7	4.5	6.8	-	-	5	0	36
1995	31.0	426.0	54.1	28.2	-	-	4	-	8
1996	8.7	23.8	4.9	8.6	-	-	1	1	81
1997	9.2	61.2	9.6	18.9	-	-	1	1	5
1998	3.9	58.7	8.2	7.9	-	-	0	-	3
1999	0.4	36.4	6.2	0.1	-	-	0	0	1
2000	0.8	6.0	2.2	0.3	-	-	0	-	32
2001	1.3	56.0	7.4	0.4	-	-	1	-	15
2002	33.7	105.1	15.2	31.7	-	-	4	1	14
2003	4.0	26.6	3.8	23.6	-	-	4	0	1
2004	0.3	19.4	4.4	1.1	-	-	0	1	5
2005	11.2	74.2	10.3	63.1	-	-	1	0	7
2006	4.1	46.1	7.8	48.4	-	-	2	-	4
2007	0.6	15.9	3.9	3.4	-	-	1	1	5
2008	6.7	115.0	14.2	5.0	-	-	0	-	2
2009	1.2	74.4	6.3	0.6	-	-	4	1	16

Table A-3: Data Used for the Flood Frequency Analysis – Regional Stations

Year	05AE005 Rolph Creek	05AD010 Drywood Creek near the Mouth	05AD016 Drywood Creek near Twin Butte	05AD035 Prairie Blood Creek	05AE009 Pinepound Creek	05AE011 Pothole Creek	06098700 Powell Coulee	06101520 Favot Creek	06133500 North Fork Milk River
2010	27.6	85.8	12.6	84.0	-	-	2	0	11
2011	10.0	69.9	11.7	4.9	-	-	2	1	6
2012	0.8	15.0	3.7	1.3	-	-	0	-	3
2013	0.6	109.0	16.9	1.3	-	-	0	-	9
2014	9.4	166.0	26.2	13.5	-	-	54	1	2
2015	0.7	36.0	6.2	-	-	-	0	1	1
2016	-	15.2	3.7	0.6	-	-	0	0	21
2017	-	28.8	5.8	16.0	-	-	3	2	9
2018	14.9	18.5	4.2	4.8	-	-	1	2	3
2019	4.8	40.9	7.3	84.0	-	-	4	1	16
Maximum	36.5	426.0	54.1	12.0	56.1	54.6	53.8	2.6	155.8
Mean	7.5	51.8	8.3	0.0	13.5	10.6	3.3	1.0	14.8
Minimum	0.2	4.8	1.0	17.1	0.6	0.0	0.0	0.0	0.8
Standard Deviation	7.9	59.4	7.7	1.0	13.2	12.1	8.1	0.7	23.5

Table A-4: Results of Statistical Tests of Annual Maximum Instantaneous Discharges and Goodness-of-Fit of Probability Distribution Functions – Regional Stations

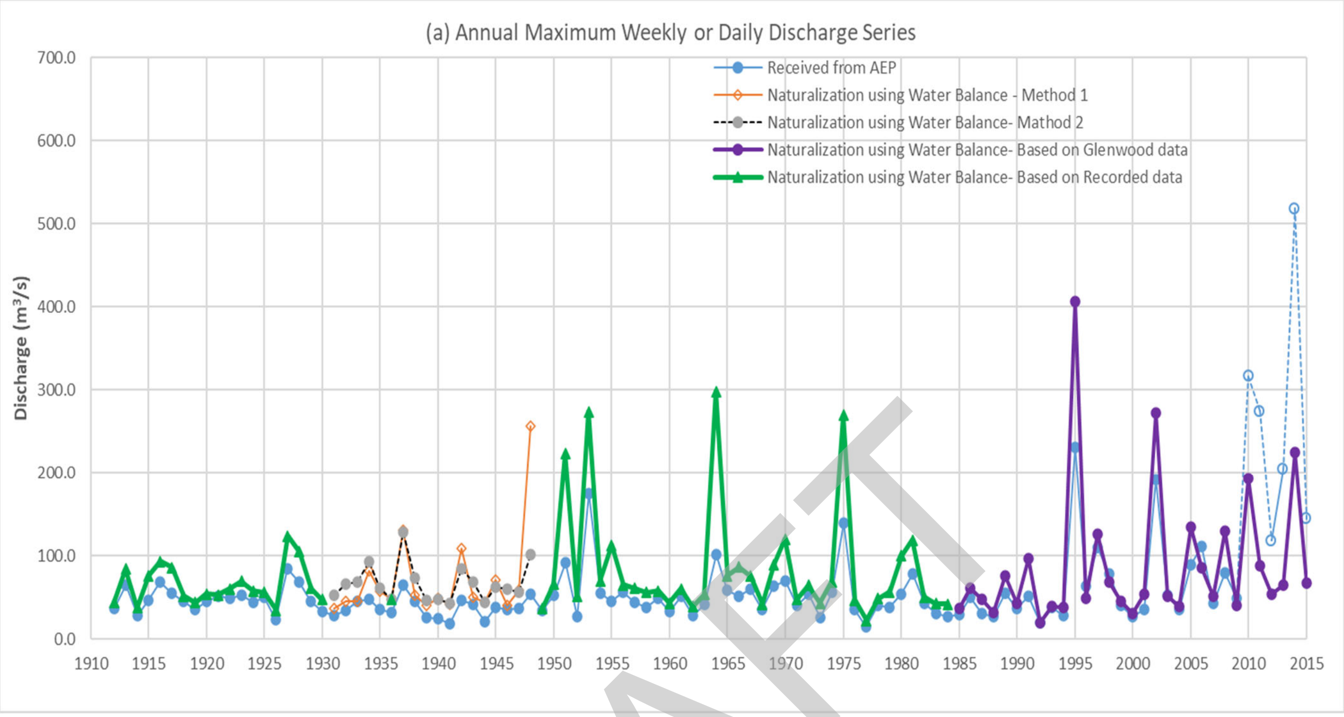
WSC/USGS Station ID	05AE005	05AD010	05AD016	05AD035	05AE009	05AE011	06098700	06101520	06133500
WSC Station Name or Location of Interest	**Rolph Creek**	**Drywood Creek near the Mouth**	**Drywood Creek near Twin Butte**	**Prairie Blood Creek**	**Pinepound Creek**	**Pothole Creek**	**Powell Coulee**	**Favot Creek**	**North Fork Milk River**
Anderson-Darling statistic, $A^2 = - N -S$									
3 Parameter Log-normal	1.231	0.868	1.775	2.068	0.318	0.537	1.504	0.255	0.199
Extreme Value	0.939	0.435	0.792	1.028	0.609	0.364	1.165	0.234	0.552
Log-Pearson III	0.641	0.640	1.775	3.635	0.251	1.210	0.858	1.303	0.170
Weibull	0.998	2.754	4.345	1.953	0.614	0.476	-	0.194	4.876
Serial correlation coefficient test for independence									
S_1	0.0785	-0.0109	0.0025	0.2690	0.5599	0.3069	0.0499	-0.4338	0.1090
t	0.7261	-0.1052	0.0245	1.8100	3.9404	1.8800	0.3278	-2.5924	0.9687
t(α=0.05)	1.6630	-1.6614	1.6614	1.6820	1.6909	1.6909	1.6811	-1.6991	1.6646
t(α=0.01)	2.3710	-2.3671	2.3671	2.4185	2.4411	2.4411	2.4163	-2.4620	2.3751
Spearman rank order correlation coefficient test for no-trend									
r_s	-0.0215	-0.1062	-0.0990	-0.0655	0.0124	0.0138	-0.0172	0.0273	0.1543
t	-0.1998	-1.0355	-0.9648	-0.4304	0.0736	0.0814	-0.1141	0.1496	1.3882
t(α=0.05)	-1.9879	-1.9855	-1.9855	-2.0167	2.0301	2.0301	-2.0154	2.0423	1.9905
t(α=0.01)	-2.6342	-2.6291	-2.6291	-2.6951	2.7238	2.7238	-2.6923	2.7500	2.6395
Mann-Whitney split sample test for homogeneity									
Size of earlier sample	44	48	49	23	19	19	23	16	42
z	-0.2253	-0.1392	-0.2309	-1.4534	-0.3039	0.0000	-0.9472	-0.6973	-0.8933
z(a=0.05)	-1.6449	-1.6449	-1.6449	-1.6449			-1.6449		-1.6449
z(a=0.01)	-2.3263	-2.3263	-2.3263	-2.3263			-2.3263		-2.3263
Test of general randomness (Runs for above or below the median)									
Median	4.9	33.8	6.2	4.9	8.7	7.2	1.0	1.0	6.9
N1(for Q>=Median)	44	48	49	23	19	19	23	16	42
N2(for Q<Median)	44	48	47	22	18	18	23	16	39
Run_ab	39	52	50	20	13	14	22	19	39
z	1.2866	0.6156	0.2096	1.0527	2.1646	1.8309	0.5964	0.7188	0.5474
z(a=0.05)	1.9600	1.9600	1.9600	1.9600			1.9600		1.9600
z(a=0.01)	2.5758	2.5758	2.5758	2.5758			2.5758		2.5758

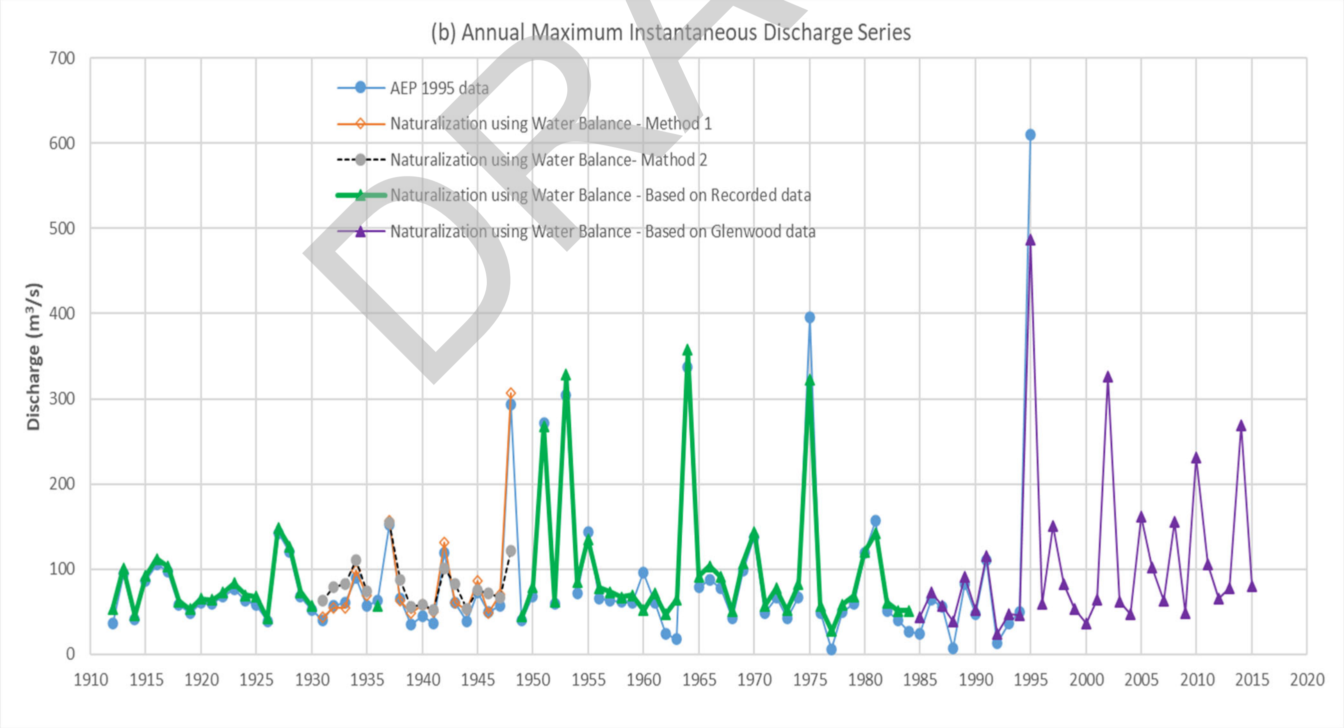
Notes:

Selected distribution based on best statistical fit *0.641*

Criteria for the respective statistical tests were not met *1.6820*

Figure A-14: Comparison of Different Data Sources





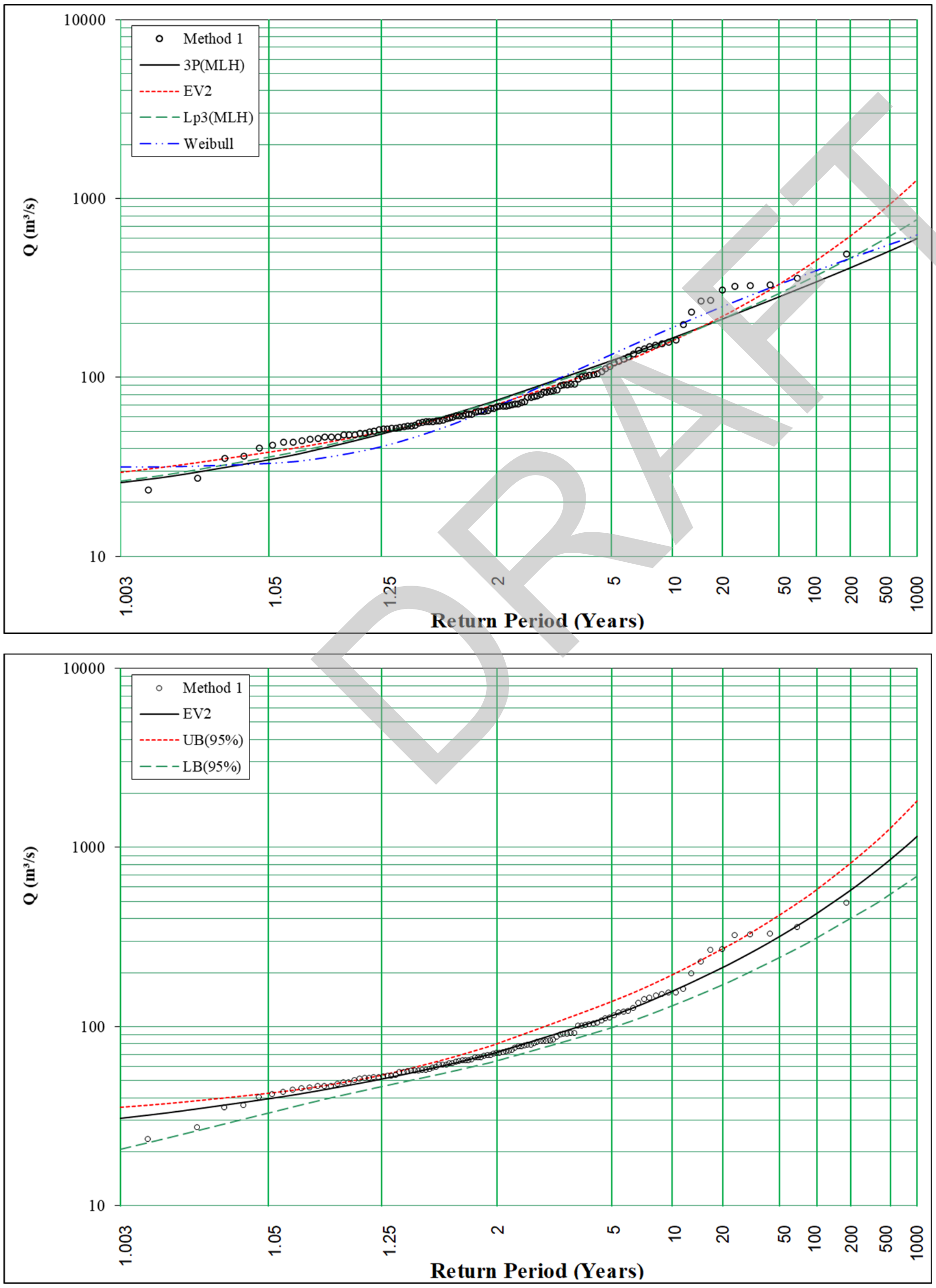
APPENDIX B

Frequency Analyses - Graphs and Tables

This appendix includes the graphs and results from the frequency analysis of the compiled/derived maximum instantaneous flood flow series at either the gauged stations or locations of interest within the study area. For each flood flow series, the following information is presented:

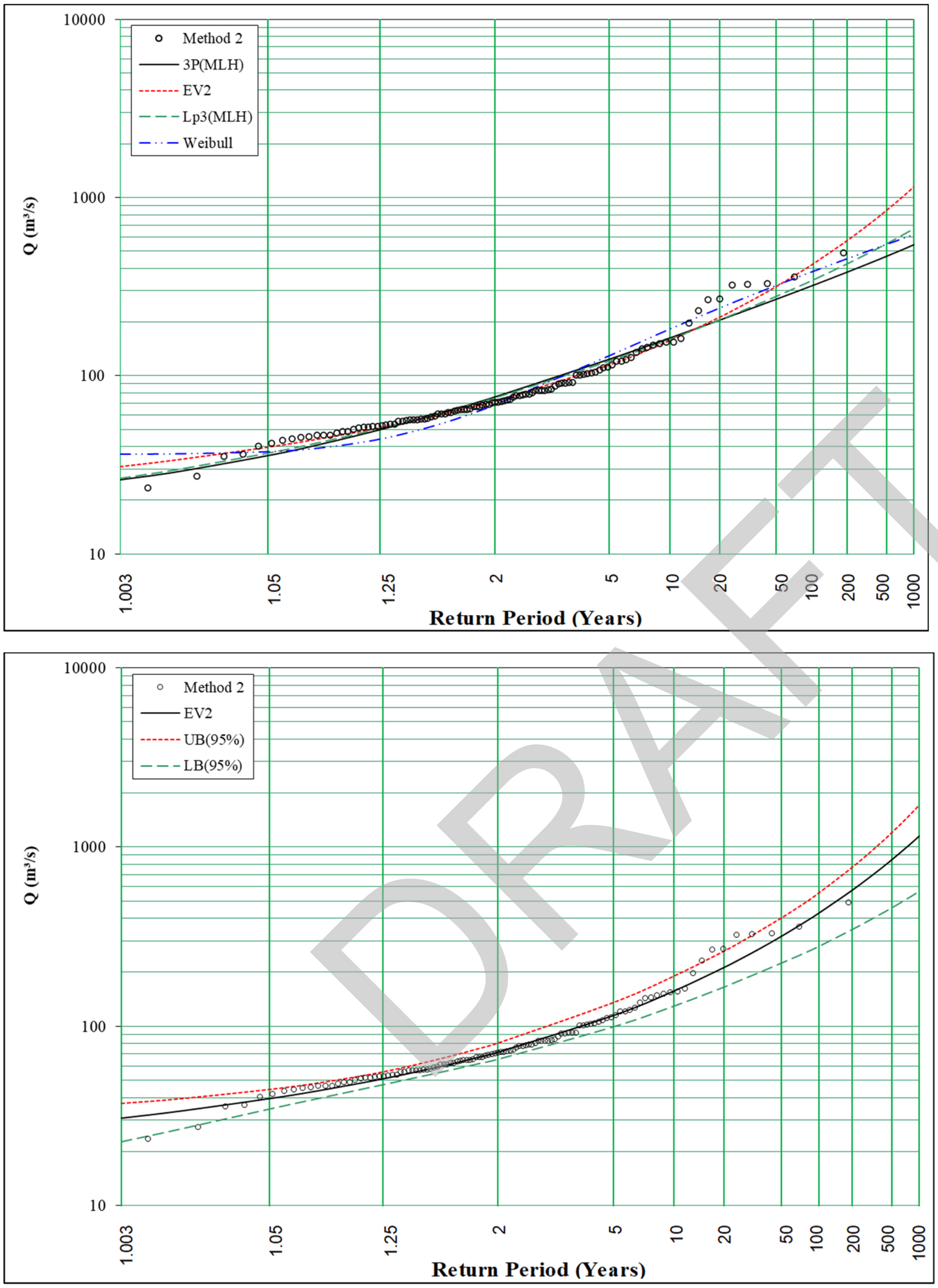
- Frequency distribution graph – all distributions
- Frequency distribution graph – best fit graph with confidence interval
- Flood flow estimates – all distributions

Figure B-1: WSC Station No. 05AD002, Belly River near Stand Off – Method 1



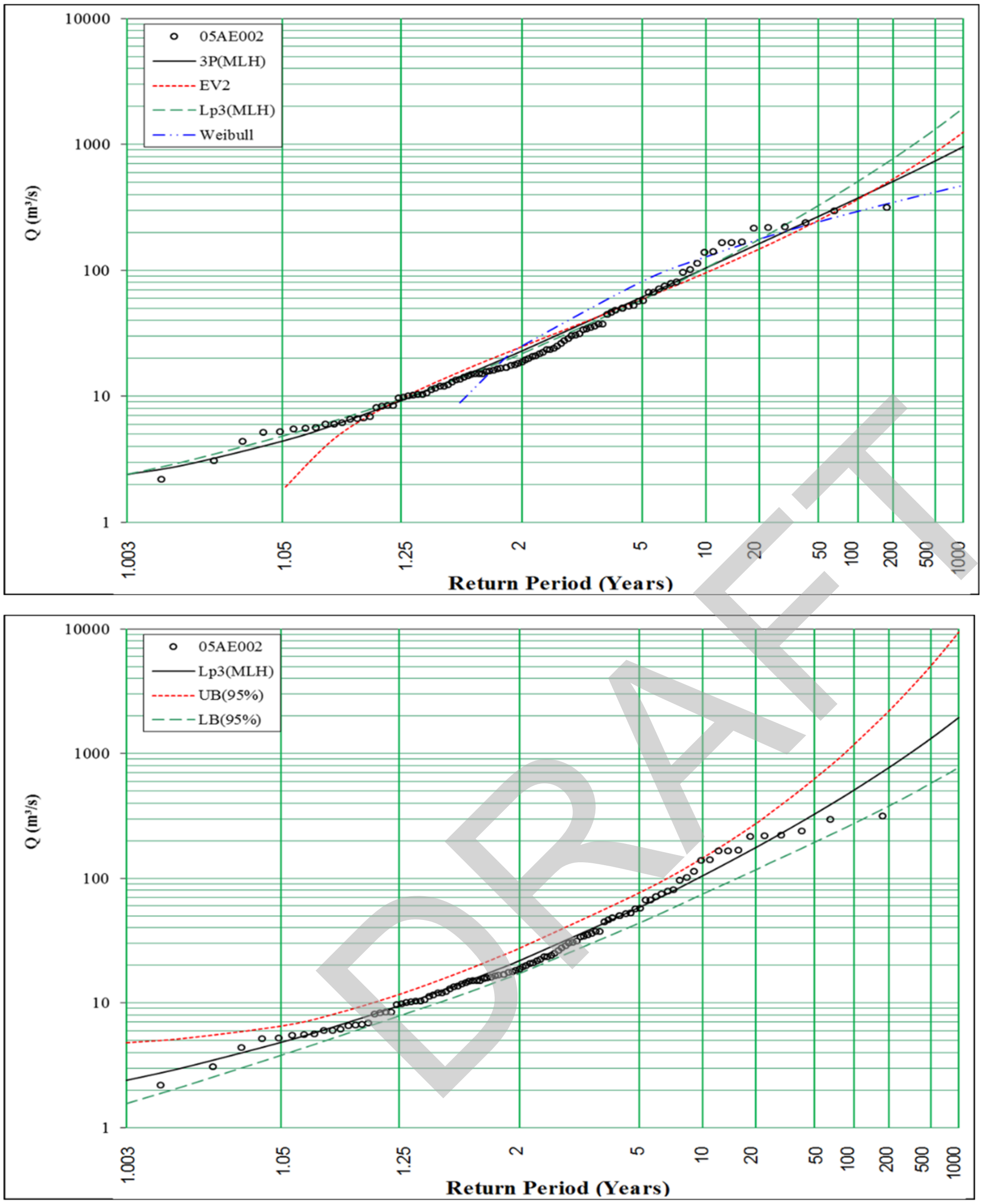
Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	75	71	73	69
5	124	115	121	134
10	166	160	163	189
20	212	220	213	248
35	254	283	261	298
50	282	332	295	330
75	317	399	339	368
100	343	454	373	395
200	410	619	467	462
350	470	796	556	518
500	511	934	621	553
750	560	1120	703	595
1000	597	1275	766	624

Figure B-2: WSC Station No. 05AD002, , Belly River near Stand Off – Method 2



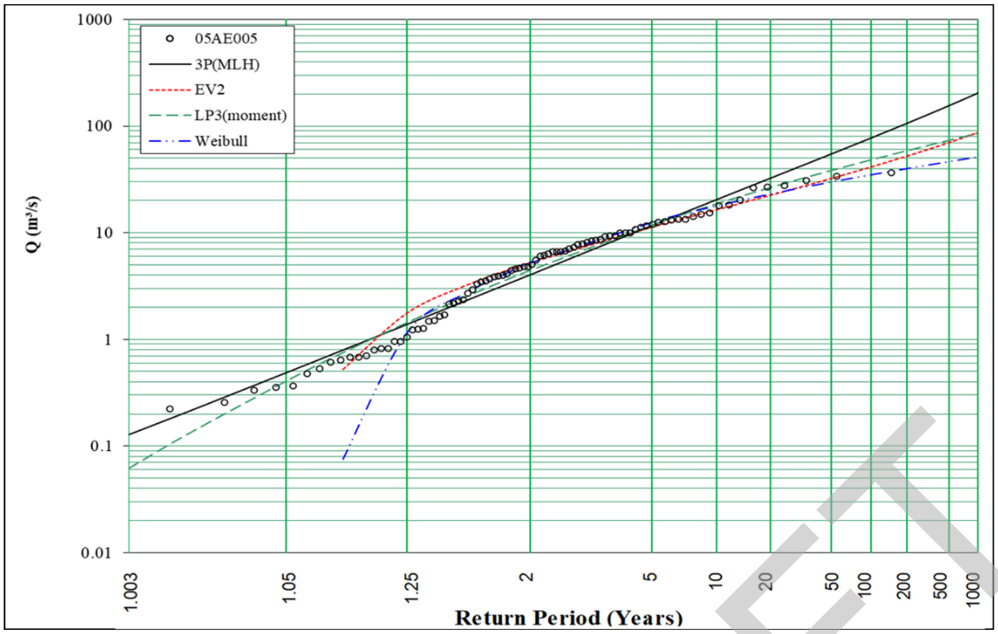
Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	76	72	75	69
5	124	115	121	130
10	163	158	160	183
20	205	214	206	240
35	243	272	248	289
50	268	317	278	322
75	299	378	316	359
100	322	427	345	387
200	381	575	424	454
350	433	731	498	510
500	468	852	551	547
750	510	1015	616	589
1000	541	1148	667	619

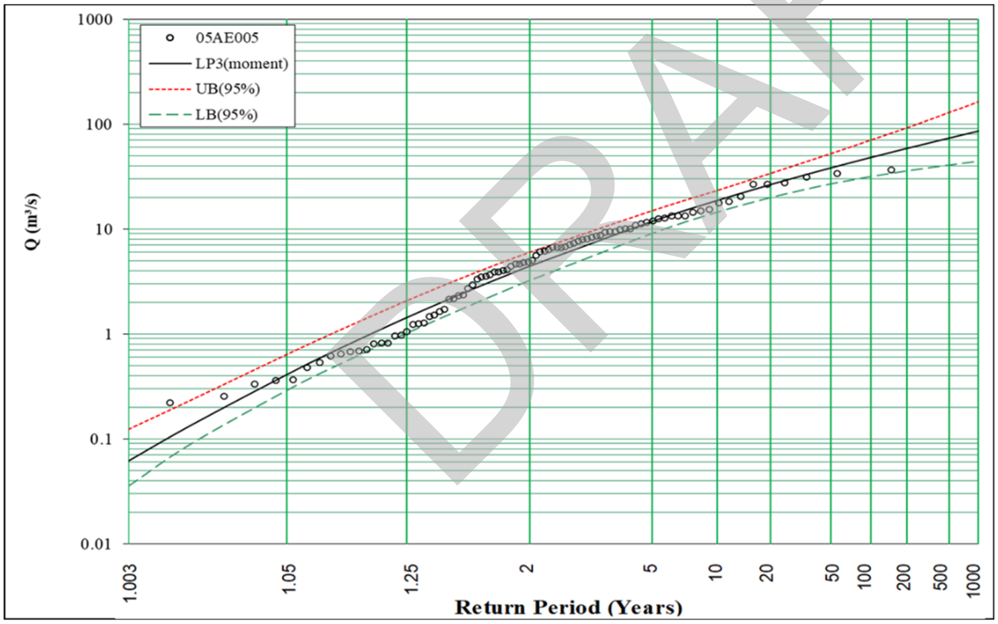
Figure B-3: WSC Station No. 05AE002, Lee Creek at Cardston



Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	23	25	22	25
5	62	59	59	82
10	105	96	105	128
20	163	147	176	177
35	223	203	259	217
50	269	249	328	243
75	328	312	425	273
100	375	365	509	295
200	510	531	775	348
350	642	715	1076	391
500	739	864	1320	419
750	862	1070	1660	451
1000	959	1244	1948	474

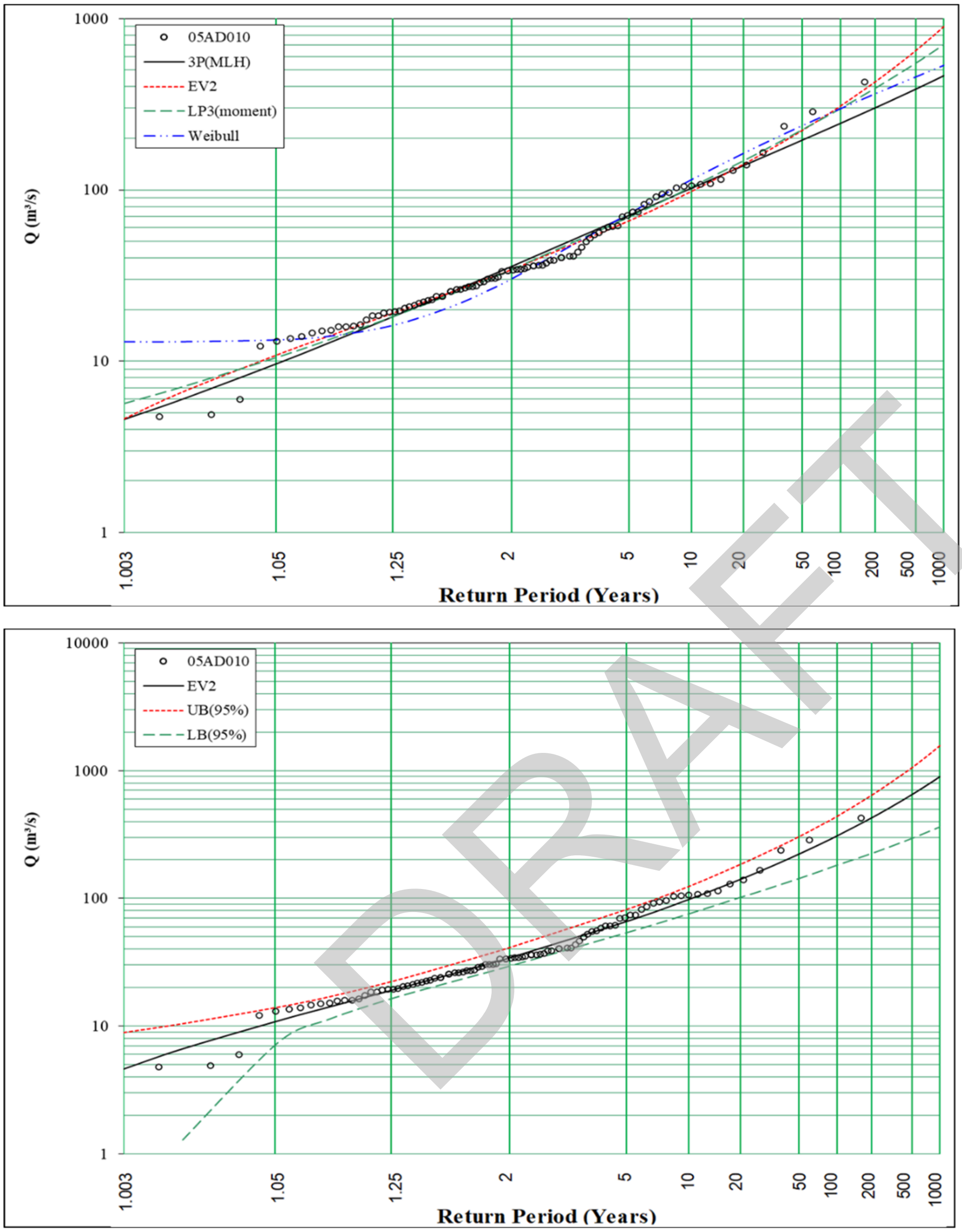
Figure B-4: WSC Station No. 05A005, Rolph Creek





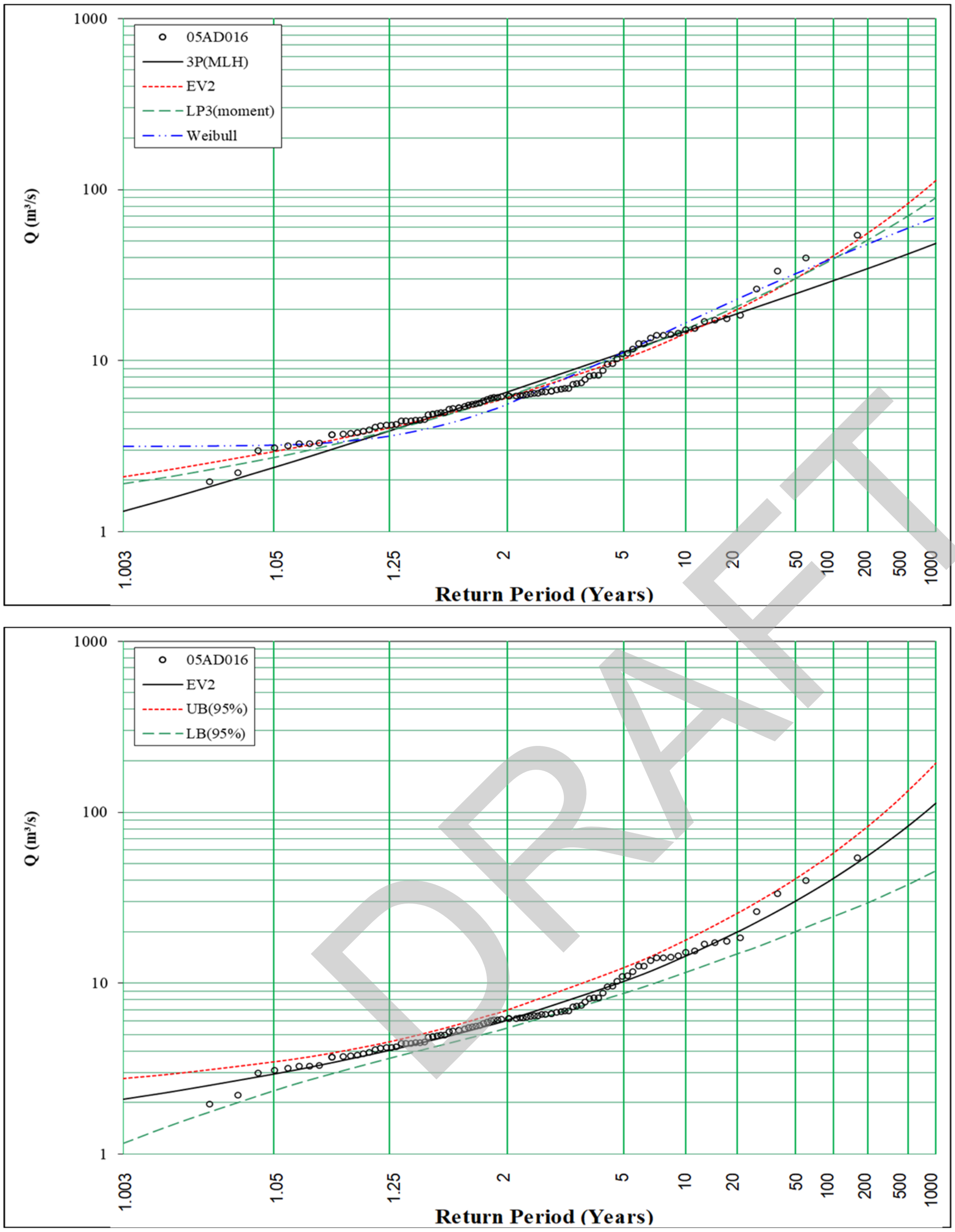
Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	4	5	4	5
5	12	11	12	13
10	20	16	19	18
20	32	22	27	23
35	45	28	34	27
50	54	32	38	30
75	67	37	44	33
100	77	41	48	35
200	106	52	59	40
350	134	63	68	44
500	155	70	74	47
750	182	80	81	50
1000	203	87	86	52

Figure B-5: WSC Station No. 05AD010, Drywood Creek near the Mouth



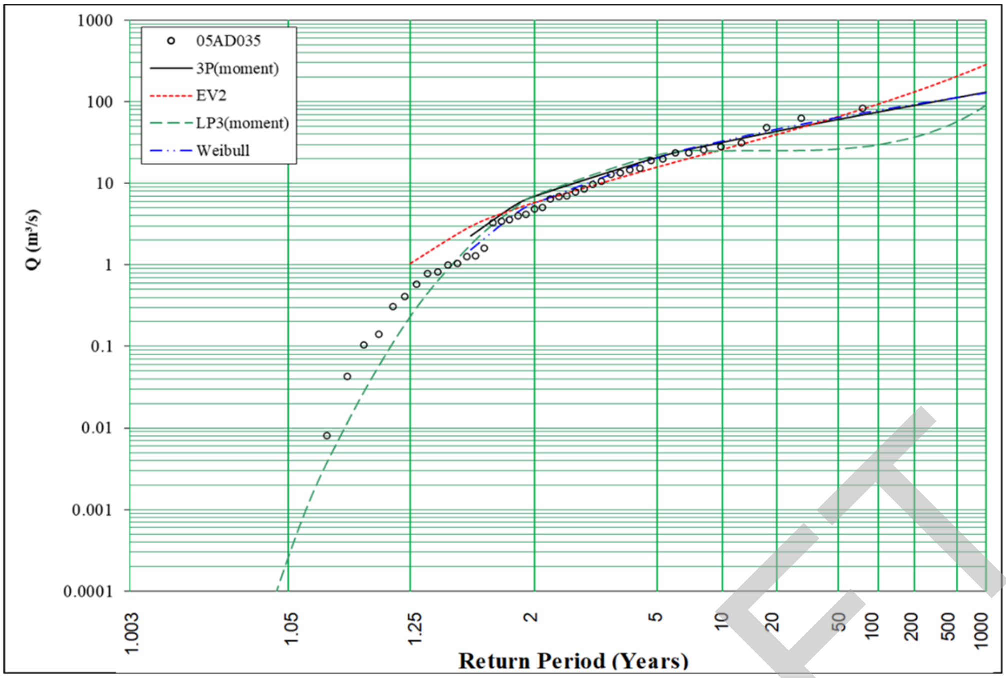
Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	36	34	34	30
5	71	66	70	73
10	103	98	104	115
20	139	141	148	164
35	172	186	192	207
50	195	221	225	237
75	224	269	266	272
100	245	308	300	298
200	302	426	393	364
350	354	552	485	420
500	389	651	553	458
750	432	784	639	501
1000	465	894	707	533

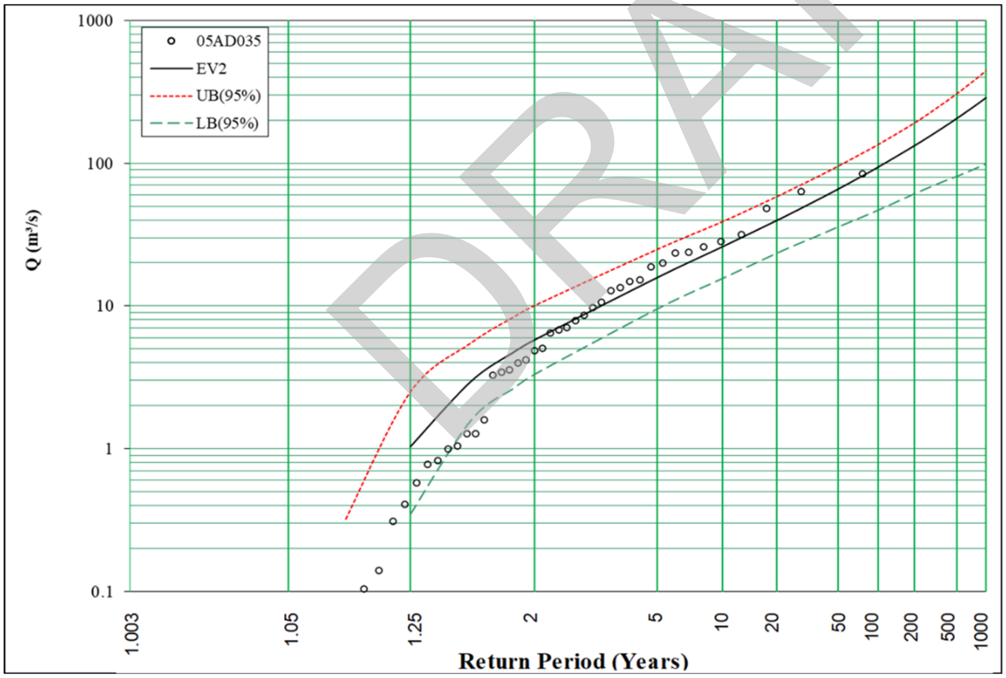
Figure B-6: WSC Station No. 05AD016, Drywood Creek near Twin Butte



Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	7	6	6	6
5	11	10	11	11
10	15	14	15	17
20	19	20	21	23
35	22	26	26	28
50	25	30	30	32
75	27	36	35	37
100	29	41	39	40
200	35	56	51	48
350	39	71	62	55
500	42	83	70	60
750	46	100	81	65
1000	49	113	89	69

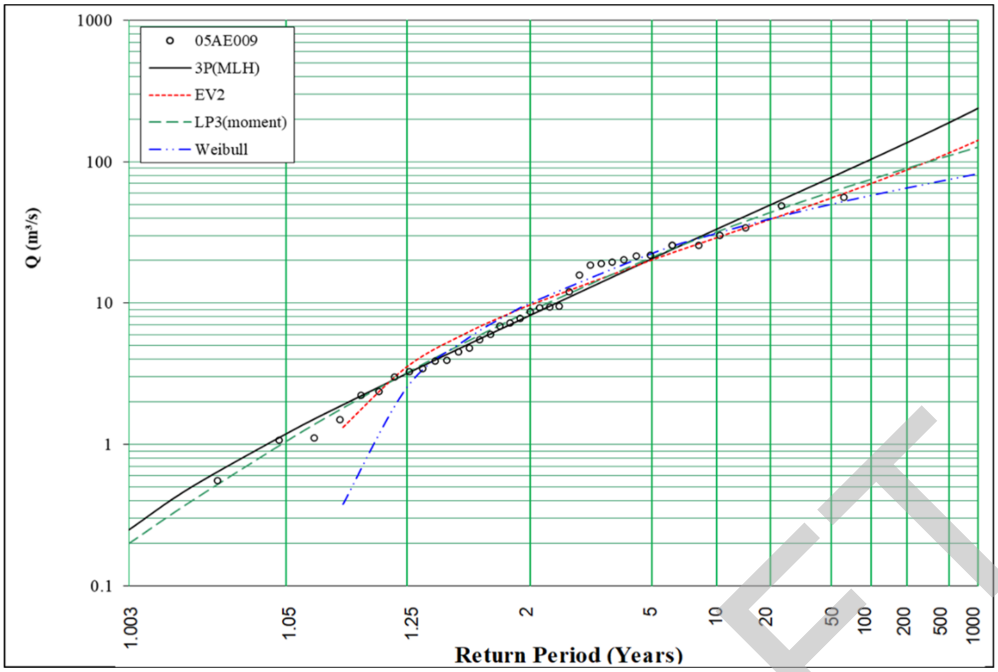
Figure B-7: WSC Station No. 05AD035, Prairie Blood Creek

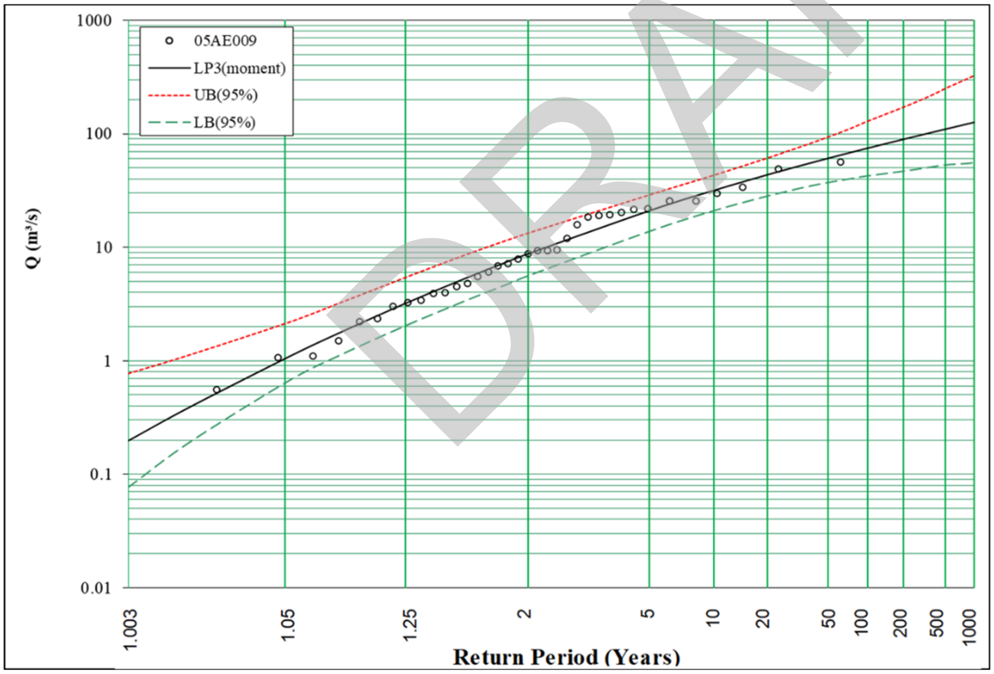




Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	7	6	7	6
5	21	16	22	20
10	32	26	25	33
20	44	40	25	46
35	54	55	25	57
50	61	66	26	64
75	69	81	28	72
100	75	94	29	78
200	91	133	37	92
350	104	175	47	104
500	113	207	57	112
750	124	252	73	121
1000	132	288	90	127

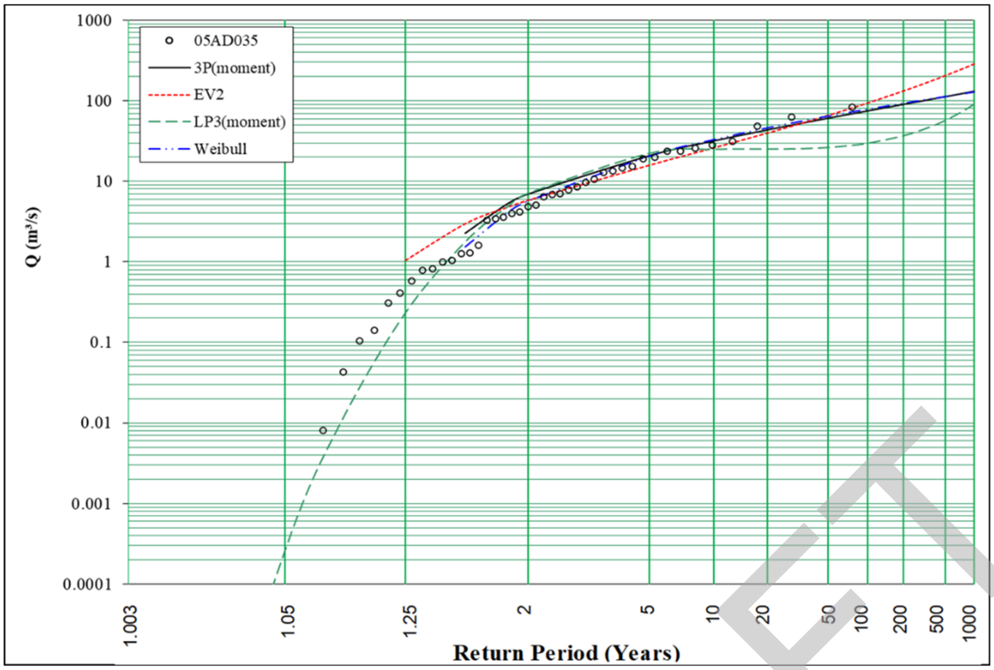
Figure B-8: WSC Station No. 05AD009, Pinepound Creek

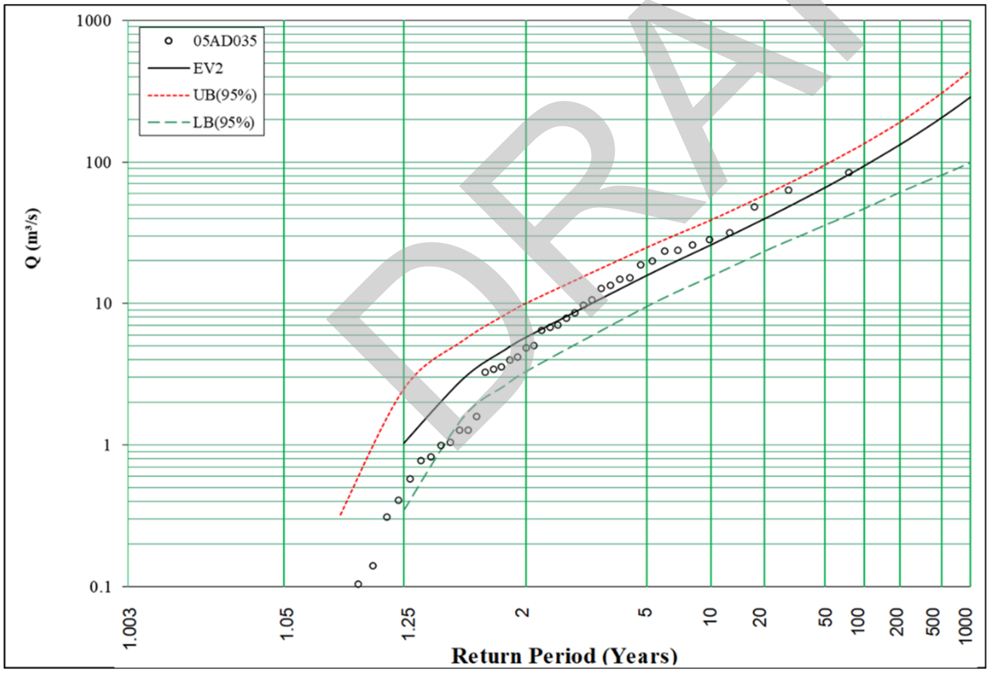




Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	8	10	9	10
5	21	20	21	23
10	33	29	32	31
20	50	39	44	40
35	66	49	54	46
50	78	55	61	50
75	93	64	69	55
100	105	70	75	58
200	137	88	90	65
350	168	104	102	71
500	190	116	111	75
750	218	130	120	79
1000	240	142	127	82

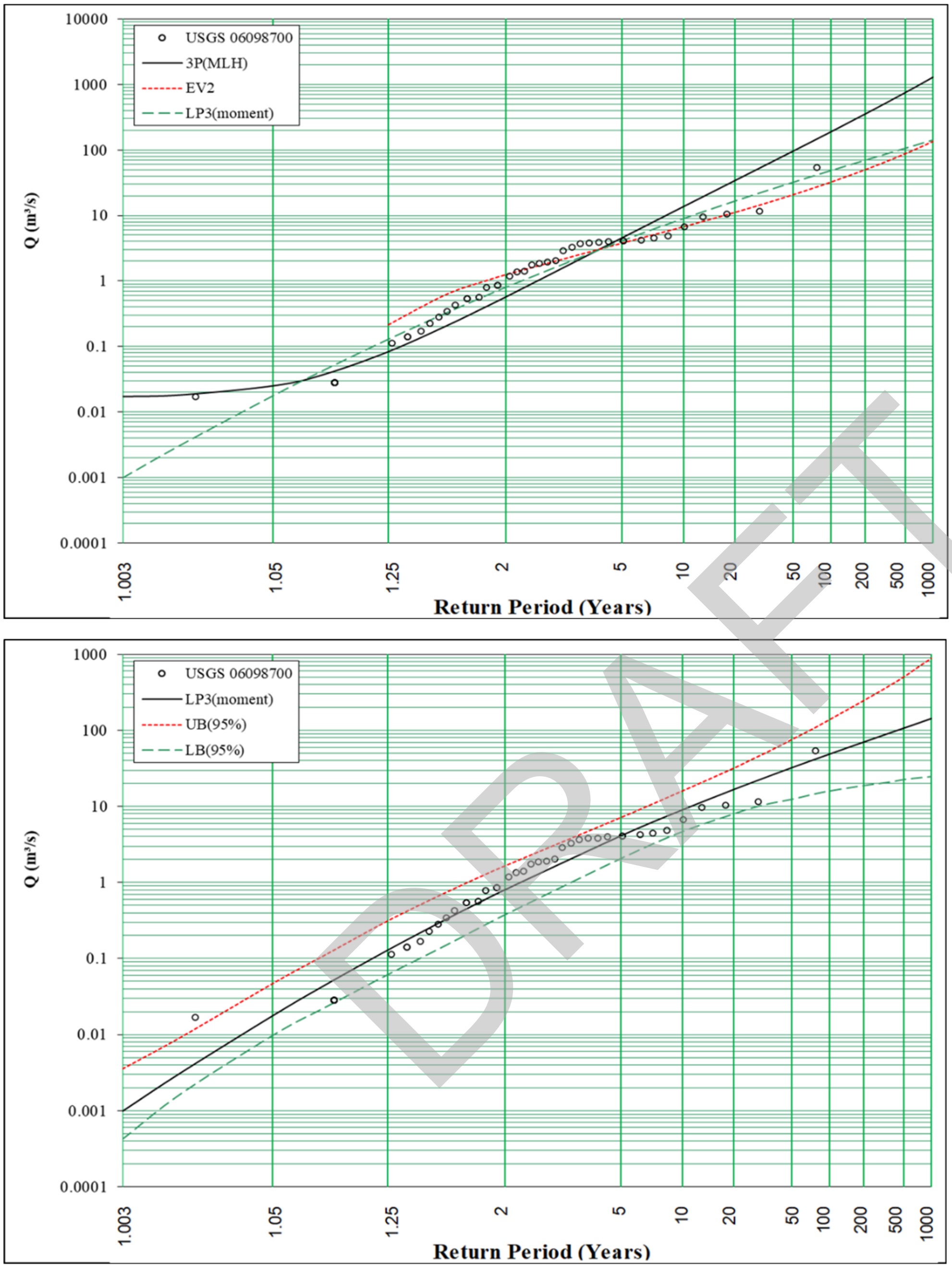
Figure B-9: WSC Station No. 05AD011, Pothole Creek





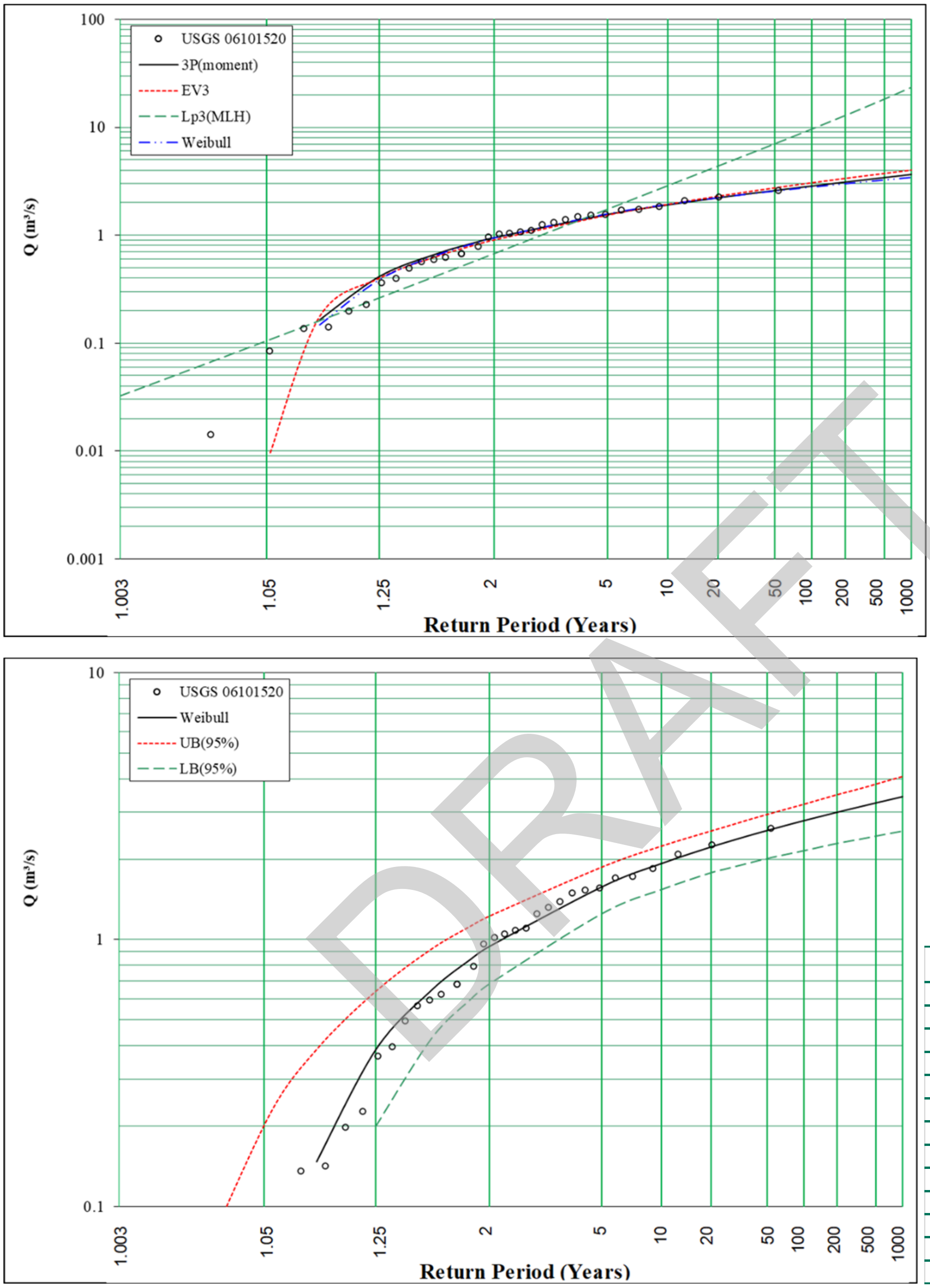
Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	7	6	7	6
5	21	16	22	20
10	32	26	25	33
20	44	40	25	46
35	54	55	25	57
50	61	66	26	64
75	69	81	28	72
100	75	94	29	78
200	91	133	37	92
350	104	175	47	104
500	113	207	57	112
750	124	252	73	121
1000	132	288	90	127

Figure B-10: USGS Station No. 06098700, Powell Creek



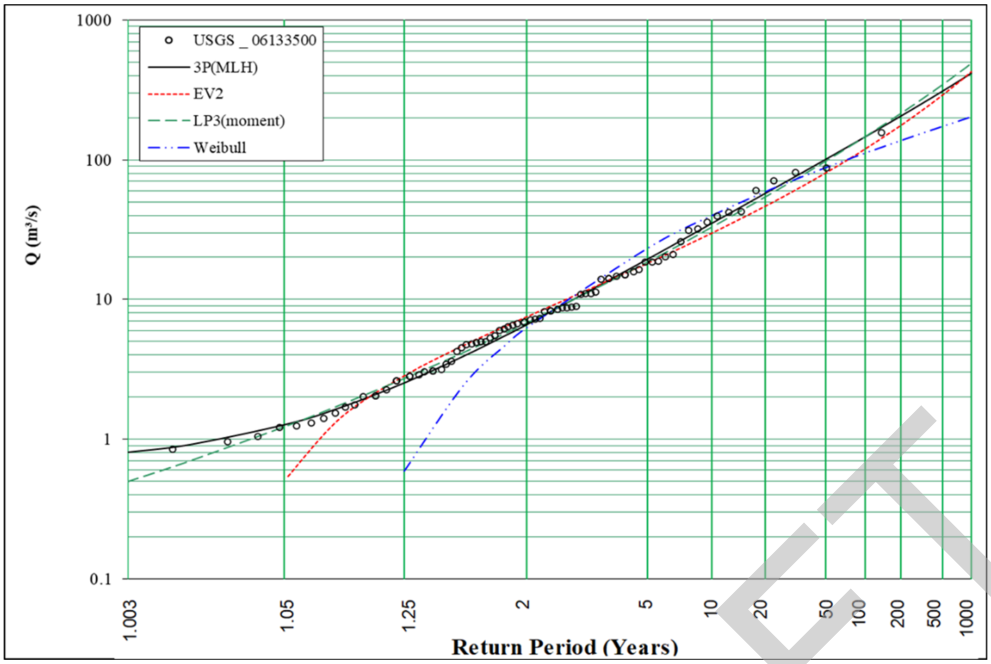
Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	1	1	1	
5	5	4	4	
10	14	7	9	
20	34	11	17	
35	65	16	25	
50	95	21	32	
75	143	27	41	
100	188	32	49	
200	352	50	70	
350	564	71	92	
500	752	88	108	
750	1031	113	128	
1000	1280	135	143	

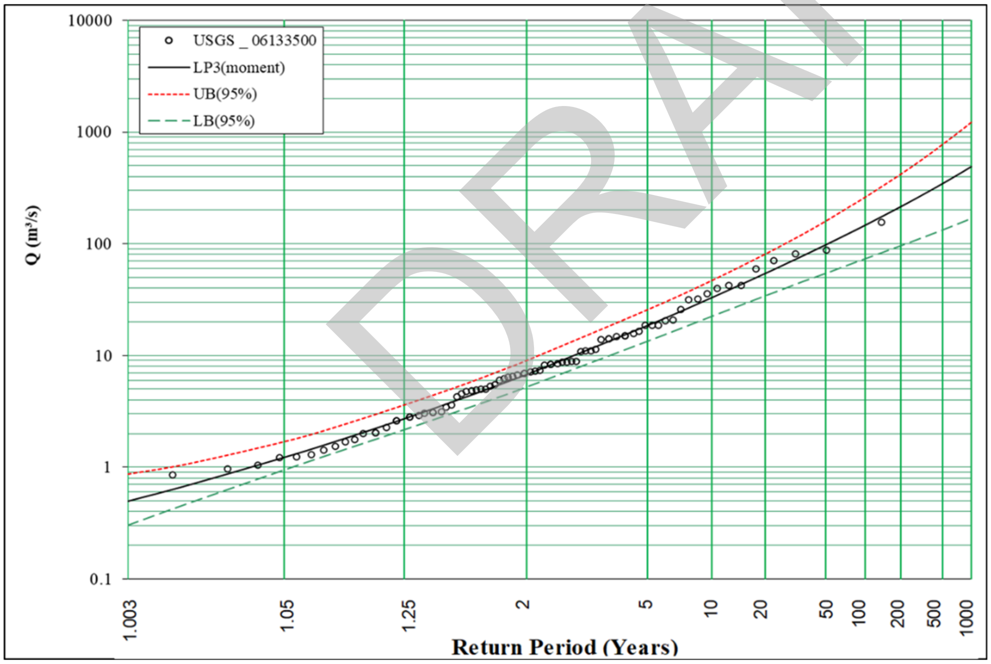
Figure B-11: USGS Station No. 06101520, Favot Creek



Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	0.9	0.9	0.7	0.9
5	1.6	1.5	1.7	1.6
10	1.9	1.9	2.9	1.9
20	2.2	2.3	4.4	2.2
35	2.4	2.6	5.9	2.4
50	2.6	2.8	7.0	2.6
75	2.7	2.9	8.5	2.7
100	2.8	3.1	9.7	2.8
200	3.1	3.4	12.9	3.0
350	3.3	3.6	16.1	3.2
500	3.4	3.8	18.4	3.3
750	3.5	3.9	21.3	3.4
1000	3.6	4.0	23.6	3.4

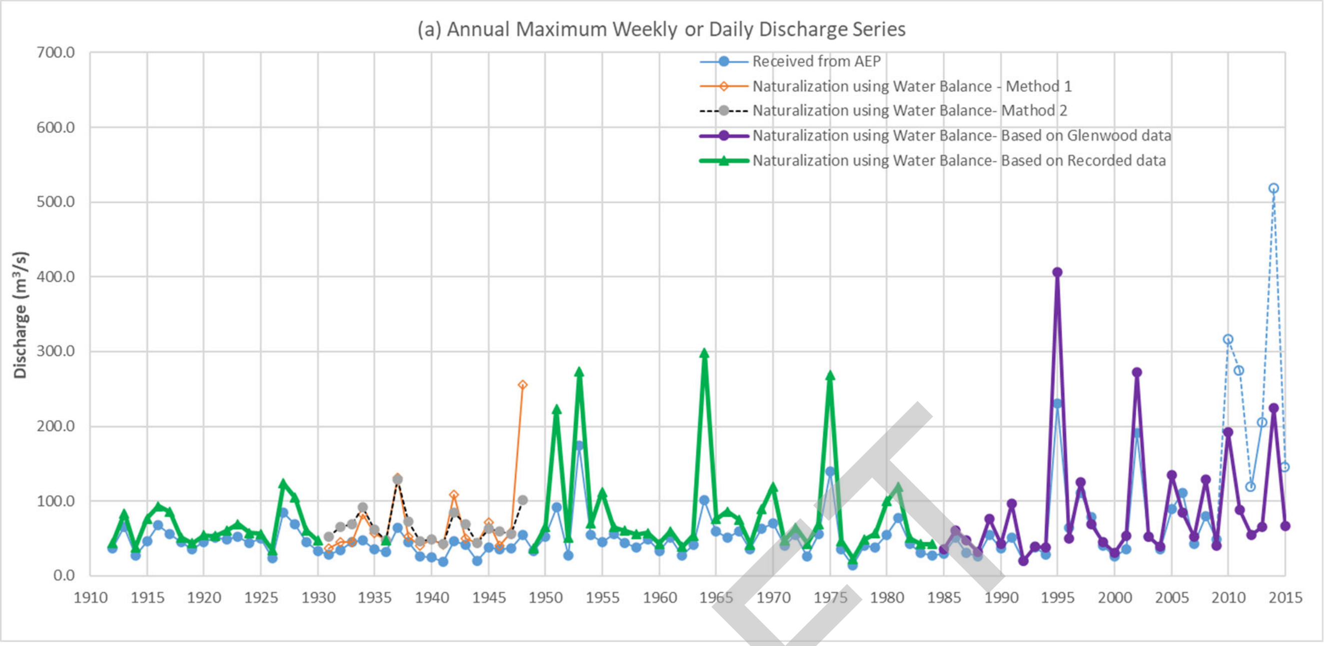
Figure B-12: USGS Station No. 06133500, North Fork Milk River

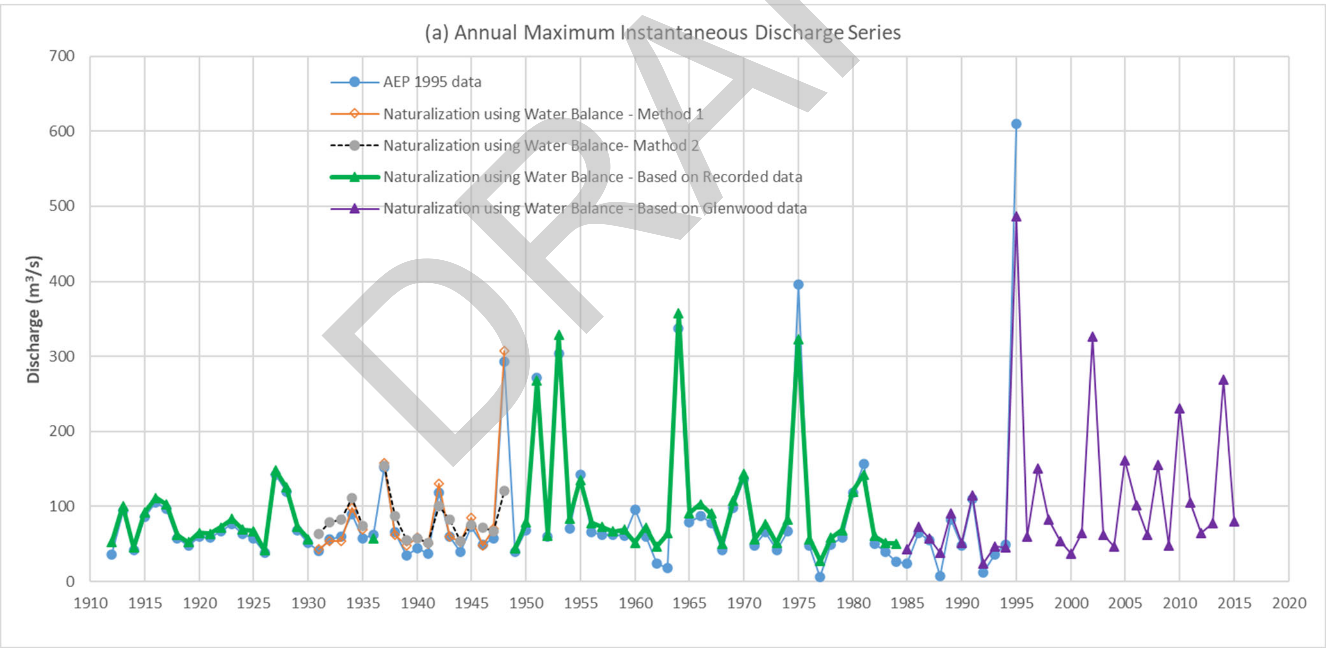




Return Period	3P(MLH)	EV2	LP3 (MLH)	Weibull
2	7	7	7	6
5	20	18	19	23
10	35	30	33	40
20	58	46	55	59
35	82	65	79	76
50	101	80	98	88
75	126	101	125	102
100	147	119	147	112
200	206	176	216	137
350	267	240	290	159
500	312	292	349	174
750	371	365	427	191
1000	418	427	492	203

Figure B-13: Comparison of Naturalized Flood Flows for Belly River near Stand Off

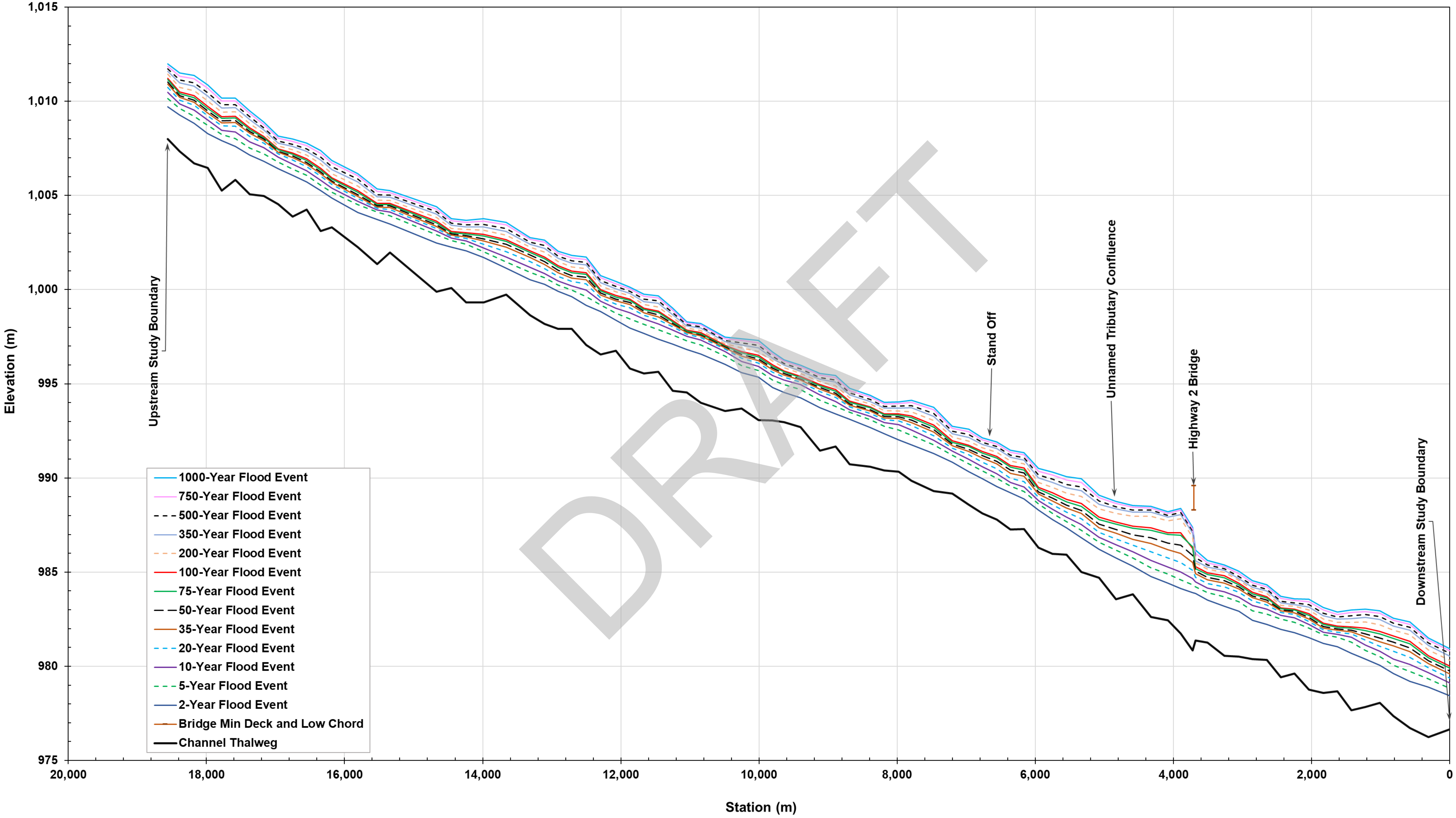

(a) Annual Maximum Weekly or Daily Discharge Series


(a) Annual Maximum Instantaneous Discharge Series

APPENDIX E

Open Water Flood Profiles

Figure E-1: Simulated Water Surface Profiles along the Belly River Study Reach



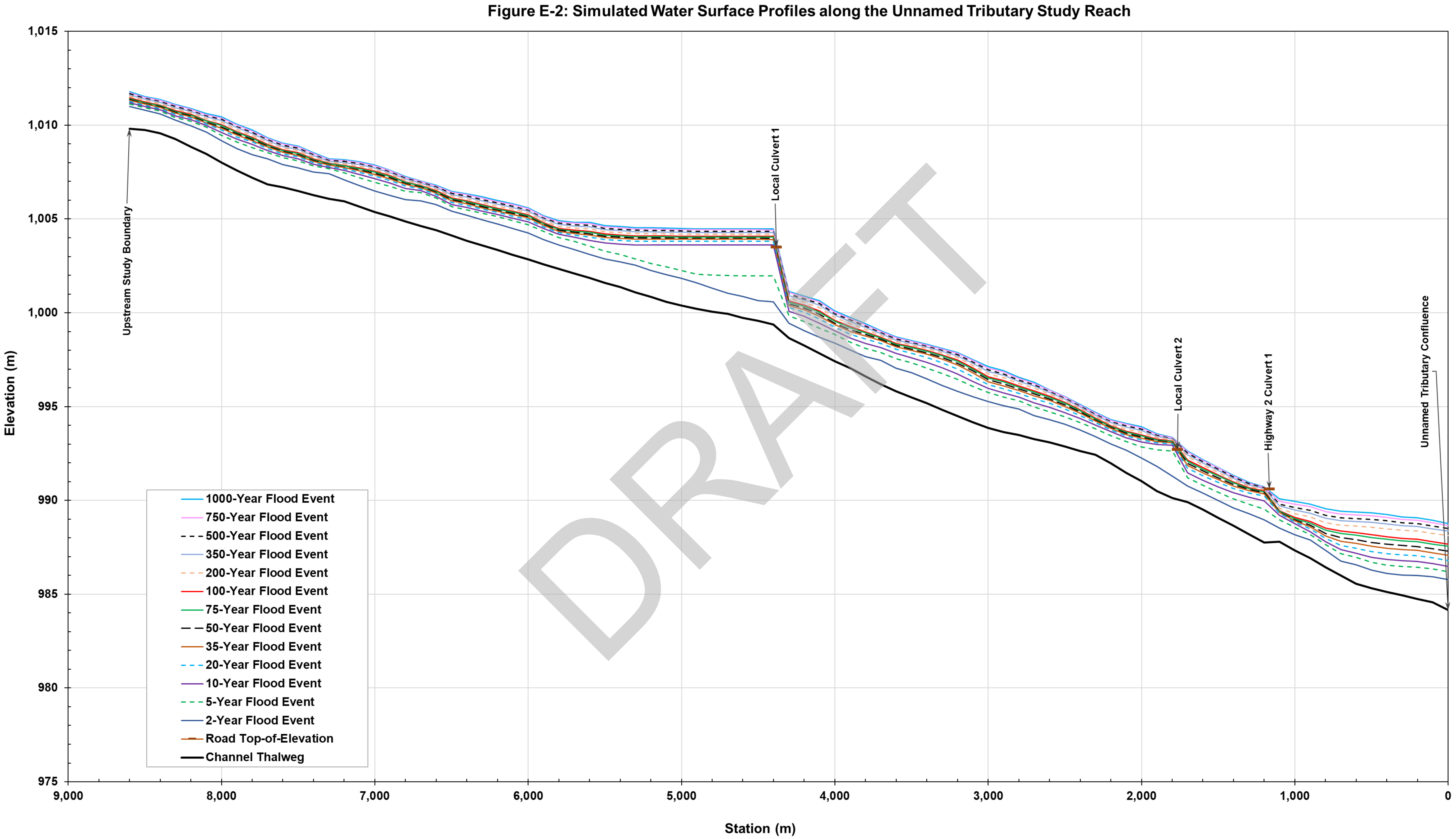


Figure E-2: Simulated Water Surface Profiles along the Unnamed Tributary Study Reach
Elevation (m)
Station (m)
1,015
1,010
1,005
1,000
995
990
985
980
975
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Upstream Study Boundary
Local Culvert 1
Local Culvert 2
Highway 2 Culvert 1
Unnamed Tributary Confluence
1000-Year Flood Event
750-Year Flood Event
500-Year Flood Event
350-Year Flood Event
200-Year Flood Event
100-Year Flood Event
75-Year Flood Event
50-Year Flood Event
35-Year Flood Event
20-Year Flood Event
10-Year Flood Event
5-Year Flood Event
2-Year Flood Event
Road Top-of-Elevation
Channel Thalweg

Table E-1: Belly River Flood Profiles

River	Cross Section	River Station	Channel Thalweg (m)	Simulated Water Level (m)												
				2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
Belly River	1	18563	1007.99	1009.71	1010.14	1010.47	1010.74	1010.92	1011.03	1011.15	1011.23	1011.43	1011.60	1011.72	1011.86	1011.98
Belly River	2	18386	1007.34	1009.26	1009.63	1009.87	1010.07	1010.22	1010.30	1010.41	1010.50	1010.74	1010.97	1011.13	1011.34	1011.51
Belly River	3	18178	1006.70	1008.83	1009.21	1009.53	1009.79	1009.96	1010.07	1010.20	1010.30	1010.56	1010.81	1010.98	1011.20	1011.37
Belly River	4	17984	1006.46	1008.29	1008.73	1009.01	1009.22	1009.38	1009.49	1009.62	1009.73	1010.01	1010.27	1010.45	1010.69	1010.86
Belly River	5	17779	1005.25	1007.91	1008.24	1008.46	1008.69	1008.86	1008.97	1009.09	1009.19	1009.42	1009.65	1009.81	1010.01	1010.17
Belly River	6	17581	1005.84	1007.61	1008.03	1008.38	1008.67	1008.87	1008.98	1009.11	1009.20	1009.45	1009.67	1009.82	1010.02	1010.17
Belly River	7	17371	1005.07	1007.14	1007.52	1007.85	1008.13	1008.30	1008.40	1008.51	1008.59	1008.82	1009.03	1009.18	1009.36	1009.50
Belly River	8	17172	1004.97	1006.82	1007.22	1007.55	1007.79	1007.92	1007.99	1008.07	1008.13	1008.31	1008.48	1008.60	1008.76	1008.89
Belly River	9	16962	1004.54	1006.42	1006.78	1007.03	1007.20	1007.30	1007.35	1007.42	1007.47	1007.63	1007.78	1007.89	1008.04	1008.15
Belly River	10	16753	1003.88	1006.07	1006.40	1006.67	1006.88	1007.01	1007.09	1007.19	1007.25	1007.43	1007.60	1007.72	1007.87	1007.99
Belly River	11	16548	1004.26	1005.72	1006.07	1006.31	1006.52	1006.66	1006.75	1006.86	1006.94	1007.14	1007.34	1007.47	1007.65	1007.78
Belly River	12	16348	1003.11	1005.27	1005.55	1005.80	1006.02	1006.16	1006.25	1006.36	1006.44	1006.68	1006.89	1007.04	1007.23	1007.38
Belly River	13	16186	1003.30	1004.86	1005.18	1005.40	1005.58	1005.70	1005.77	1005.87	1005.94	1006.16	1006.38	1006.53	1006.73	1006.87
Belly River	14	15809	1002.26	1004.10	1004.51	1004.70	1004.84	1004.96	1005.05	1005.17	1005.27	1005.51	1005.73	1005.87	1006.04	1006.16
Belly River	15	15531	1001.36	1003.73	1004.11	1004.24	1004.31	1004.39	1004.45	1004.52	1004.58	1004.75	1004.92	1005.05	1005.21	1005.34
Belly River	16	15344	1001.98	1003.48	1003.93	1004.13	1004.26	1004.37	1004.44	1004.52	1004.58	1004.74	1004.90	1005.02	1005.16	1005.27
Belly River	17	14670	999.90	1002.48	1002.92	1003.11	1003.25	1003.36	1003.45	1003.56	1003.64	1003.84	1004.01	1004.14	1004.28	1004.40
Belly River	18	14452	1000.09	1002.25	1002.61	1002.74	1002.82	1002.89	1002.95	1003.02	1003.08	1003.25	1003.41	1003.52	1003.66	1003.76
Belly River	19	14238	999.32	1002.06	1002.42	1002.58	1002.71	1002.80	1002.87	1002.96	1003.03	1003.19	1003.34	1003.45	1003.58	1003.68
Belly River	20	13990	999.33	1001.70	1002.01	1002.22	1002.41	1002.59	1002.70	1002.84	1002.93	1003.16	1003.34	1003.47	1003.64	1003.76
Belly River	21	13660	999.74	1001.13	1001.47	1001.73	1002.02	1002.26	1002.41	1002.56	1002.66	1002.89	1003.09	1003.24	1003.43	1003.58
Belly River	22	13312	998.63	1000.53	1000.91	1001.19	1001.49	1001.71	1001.84	1001.98	1002.06	1002.26	1002.42	1002.53	1002.67	1002.77
Belly River	23	13103	998.19	1000.28	1000.63	1000.86	1001.12	1001.34	1001.48	1001.64	1001.74	1001.99	1002.20	1002.34	1002.51	1002.64
Belly River	24	12907	997.92	999.91	1000.25	1000.47	1000.69	1000.90	1001.03	1001.18	1001.27	1001.48	1001.66	1001.77	1001.92	1002.03
Belly River	25	12709	997.92	999.62	999.97	1000.20	1000.43	1000.62	1000.75	1000.89	1000.98	1001.21	1001.40	1001.53	1001.69	1001.82
Belly River	26	12500	997.07	999.17	999.63	999.98	1000.30	1000.52	1000.65	1000.80	1000.90	1001.12	1001.32	1001.45	1001.60	1001.72
Belly River	27	12294	996.56	998.84	999.18	999.38	999.57	999.72	999.82	999.93	1000.01	1000.20	1000.37	1000.49	1000.63	1000.74
Belly River	28	12074	996.76	998.38	998.76	999.01	999.24	999.41	999.50	999.61	999.69	999.88	1000.05	1000.17	1000.31	1000.43
Belly River	29	11868	995.81	997.95	998.45	998.78	999.03	999.20	999.31	999.42	999.49	999.67	999.81	999.91	1000.04	1000.14
Belly River	30	11668	995.55	997.68	998.15	998.45	998.64	998.77	998.86	998.95	999.02	999.21	999.37	999.50	999.64	999.76
Belly River	31	11457	995.64	997.37	997.87	998.19	998.41	998.56	998.67	998.79	998.87	999.08	999.27	999.40	999.55	999.68
Belly River	32	11251	994.62	997.11	997.59	997.86	998.03	998.13	998.20	998.29	998.35	998.51	998.66	998.77	998.90	999.01
Belly River	33	11048	994.54	996.83	997.28	997.52	997.64	997.71	997.75	997.81	997.85	997.96	998.06	998.13	998.22	998.30
Belly River	34	10843	994.00	996.57	997.06	997.32	997.45	997.54	997.59	997.66	997.71	997.84	997.95	998.03	998.13	998.21
Belly River	35	10491	993.56	996.03	996.48	996.71	996.84	996.91	996.95	997.00	997.03	997.13	997.23	997.30	997.40	997.48
Belly River	36	10250	993.68	995.59	995.97	996.19	996.36	996.48	996.55	996.65	996.72	996.91	997.07	997.18	997.31	997.40
Belly River	37	10010	993.08	995.35	995.70	995.92	996.09	996.22	996.32	996.43	996.51	996.71	996.90	997.03	997.18	997.30
Belly River	38	9804	993.06	994.81	995.19	995.45	995.62	995.75	995.83	995.93	996.01	996.20	996.36	996.47	996.59	996.68

Table E-1: Belly River Flood Profiles

River	Cross Section	River Station	Channel Thalweg (m)	Simulated Water Level (m)												
				2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
Belly River	39	9636	992.97	994.55	994.96	995.21	995.36	995.46	995.54	995.63	995.69	995.85	995.99	996.08	996.20	996.28
Belly River	40	9400	992.71	994.25	994.69	994.95	995.09	995.19	995.25	995.33	995.39	995.54	995.68	995.79	995.90	995.99
Belly River	41	9118	991.45	993.74	994.12	994.40	994.59	994.71	994.80	994.89	994.95	995.11	995.25	995.34	995.46	995.55
Belly River	42	8892	991.66	993.40	993.79	994.05	994.27	994.41	994.50	994.61	994.69	994.90	995.08	995.20	995.34	995.45
Belly River	43	8691	990.73	993.11	993.48	993.63	993.77	993.86	993.93	994.02	994.08	994.25	994.40	994.51	994.64	994.75
Belly River	44	8388	990.59	992.68	993.09	993.27	993.42	993.55	993.63	993.72	993.78	993.93	994.07	994.17	994.29	994.38
Belly River	45	8189	990.40	992.35	992.75	992.94	993.09	993.19	993.27	993.35	993.41	993.57	993.71	993.80	993.92	994.01
Belly River	46	7976	990.34	992.02	992.55	992.83	993.03	993.16	993.24	993.33	993.40	993.56	993.71	993.82	993.94	994.04
Belly River	47	7793	989.84	991.75	992.27	992.55	992.78	992.95	993.07	993.20	993.29	993.52	993.72	993.85	994.01	994.13
Belly River	48	7469	989.31	991.29	991.75	992.00	992.24	992.44	992.57	992.71	992.82	993.05	993.27	993.43	993.61	993.75
Belly River	49	7202	989.17	990.84	991.22	991.43	991.59	991.71	991.80	991.90	991.97	992.17	992.36	992.48	992.63	992.75
Belly River	50	6965	988.59	990.34	990.75	990.99	991.23	991.41	991.52	991.66	991.74	991.96	992.16	992.30	992.47	992.60
Belly River	51	6767	988.12	989.97	990.37	990.60	990.84	991.05	991.19	991.32	991.41	991.60	991.77	991.88	992.03	992.14
Belly River	52	6558	987.79	989.55	989.98	990.23	990.49	990.74	990.89	991.06	991.15	991.37	991.55	991.67	991.81	991.92
Belly River	53	6358	987.27	989.21	989.56	989.76	989.99	990.24	990.41	990.57	990.67	990.90	991.09	991.21	991.36	991.48
Belly River	54	6163	987.28	988.88	989.28	989.52	989.80	990.09	990.26	990.43	990.53	990.76	990.95	991.08	991.23	991.34
Belly River	55	5953	986.31	988.29	988.62	988.79	988.97	989.14	989.27	989.42	989.51	989.77	990.00	990.16	990.35	990.51
Belly River	56	5749	985.97	987.78	988.12	988.33	988.57	988.78	988.92	989.09	989.21	989.50	989.76	989.93	990.15	990.31
Belly River	57	5550	985.93	987.35	987.69	987.92	988.18	988.41	988.56	988.74	988.87	989.20	989.48	989.66	989.89	990.07
Belly River	58	5334	985.01	986.83	987.23	987.53	987.84	988.11	988.28	988.49	988.64	989.02	989.32	989.53	989.77	989.95
Belly River	59	5080	984.69	986.21	986.59	986.84	987.11	987.36	987.56	987.80	987.93	988.36	988.61	988.77	988.95	989.09
Belly River	60	4831	983.57	985.75	986.17	986.46	986.77	987.06	987.27	987.54	987.65	988.12	988.35	988.48	988.64	988.76
Belly River	61	4585	983.83	985.32	985.76	986.09	986.43	986.74	986.99	987.32	987.44	987.97	988.19	988.30	988.44	988.54
Belly River	62	4326	982.61	984.76	985.23	985.63	986.09	986.51	986.83	987.23	987.36	987.96	988.18	988.29	988.41	988.49
Belly River	63	4079	982.45	984.42	984.89	985.28	985.76	986.20	986.55	987.00	987.10	987.73	987.92	988.01	988.12	988.20
Belly River	64	3893	981.75	984.13	984.59	985.00	985.52	986.00	986.43	986.96	987.09	987.83	988.06	988.16	988.29	988.39
Belly River	65	3722	980.85	983.91	984.32	984.66	985.09	985.51	985.88	986.35	986.56	986.85	987.06	987.16	987.28	987.37
Belly River	66	3682	981.37	983.86	984.22	984.48	984.73	984.92	985.05	985.19	985.29	985.48	985.60	985.78	986.00	986.16
Belly River	67	3505	981.26	983.52	983.92	984.16	984.40	984.59	984.72	984.87	984.97	985.17	985.27	985.37	985.50	985.61
Belly River	68	3265	980.55	983.18	983.69	983.96	984.22	984.42	984.55	984.70	984.80	984.99	985.09	985.18	985.30	985.39
Belly River	69	3055	980.52	982.93	983.43	983.67	983.94	984.10	984.22	984.33	984.41	984.56	984.65	984.76	984.92	985.06
Belly River	70	2859	980.38	982.45	982.95	983.24	983.48	983.64	983.74	983.85	983.93	984.09	984.20	984.30	984.43	984.55
Belly River	71	2651	980.33	982.23	982.77	983.04	983.26	983.41	983.51	983.62	983.69	983.87	983.99	984.09	984.22	984.33
Belly River	72	2443	979.42	981.97	982.51	982.71	982.85	982.94	982.99	983.06	983.11	983.24	983.36	983.46	983.60	983.71
Belly River	73	2251	979.62	981.79	982.34	982.57	982.74	982.84	982.92	982.99	983.04	983.18	983.28	983.37	983.49	983.59
Belly River	74	2041	978.75	981.53	982.03	982.22	982.37	982.50	982.60	982.71	982.79	982.99	983.14	983.27	983.43	983.56
Belly River	75	1831	978.58	981.22	981.67	981.81	981.93	982.03	982.12	982.22	982.29	982.50	982.69	982.82	982.98	983.12
Belly River	76	1629	978.68	981.05	981.55	981.69	981.81	981.91	981.98	982.07	982.14	982.34	982.50	982.62	982.76	982.88
Belly River	77	1427	977.66	980.68	981.29	981.54	981.71	981.82	981.92	982.03	982.10	982.34	982.54	982.68	982.85	982.99

Table E-1: Belly River Flood Profiles

River	Cross Section	River Station	Channel Thalweg (m)	Simulated Water Level (m)												
				2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
Belly River	78	1222	977.85	980.38	980.85	981.13	981.38	981.57	981.72	981.90	982.02	982.35	982.59	982.74	982.91	983.04
Belly River	79	1015	978.06	980.05	980.51	980.79	981.06	981.30	981.50	981.71	981.85	982.21	982.48	982.64	982.82	982.95
Belly River	80	818	977.36	979.61	980.05	980.38	980.79	981.09	981.28	981.48	981.60	981.91	982.14	982.28	982.44	982.56
Belly River	81	578	976.72	979.20	979.72	980.09	980.48	980.77	980.98	981.19	981.32	981.67	981.92	982.07	982.23	982.36
Belly River	82	311	976.24	978.90	979.34	979.65	979.93	980.14	980.29	980.45	980.56	980.87	981.10	981.24	981.39	981.51
Belly River	83	0	976.65	978.43	978.82	979.11	979.38	979.59	979.74	979.90	980.01	980.31	980.54	980.68	980.82	980.94

Table E-2: Unnamed Tributary Flood Profiles

River	River Station[a]	Channel Thalweg (m)	Simulated Water Level (m)												
			2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
Unnamed Tributary	8600	1009.82	1010.99	1011.13	1011.20	1011.27	1011.33	1011.37	1011.42	1011.45	1011.54	1011.62	1011.67	1011.73	1011.78
Unnamed Tributary	8500	1009.75	1010.80	1010.92	1010.99	1011.06	1011.12	1011.16	1011.20	1011.23	1011.32	1011.39	1011.43	1011.49	1011.53
Unnamed Tributary	8400	1009.56	1010.61	1010.75	1010.83	1010.90	1010.95	1010.99	1011.03	1011.06	1011.15	1011.22	1011.27	1011.33	1011.37
Unnamed Tributary	8300	1009.26	1010.27	1010.41	1010.49	1010.58	1010.64	1010.69	1010.74	1010.77	1010.86	1010.94	1010.99	1011.06	1011.10
Unnamed Tributary	8200	1008.84	1009.96	1010.20	1010.30	1010.39	1010.45	1010.49	1010.54	1010.57	1010.66	1010.73	1010.78	1010.84	1010.89
Unnamed Tributary	8100	1008.47	1009.63	1009.91	1010.00	1010.07	1010.13	1010.17	1010.22	1010.26	1010.35	1010.44	1010.49	1010.56	1010.62
Unnamed Tributary	8000	1008.02	1009.18	1009.47	1009.61	1009.74	1009.84	1009.91	1009.98	1010.03	1010.15	1010.25	1010.32	1010.39	1010.45
Unnamed Tributary	7900	1007.59	1008.75	1009.10	1009.25	1009.38	1009.48	1009.54	1009.61	1009.66	1009.77	1009.87	1009.93	1010.01	1010.06
Unnamed Tributary	7800	1007.19	1008.43	1008.81	1008.98	1009.10	1009.18	1009.24	1009.30	1009.34	1009.45	1009.55	1009.61	1009.68	1009.74
Unnamed Tributary	7700	1006.84	1008.20	1008.54	1008.65	1008.76	1008.83	1008.88	1008.94	1008.98	1009.08	1009.17	1009.22	1009.29	1009.33
Unnamed Tributary	7600	1006.70	1007.89	1008.27	1008.38	1008.48	1008.55	1008.60	1008.65	1008.69	1008.79	1008.88	1008.93	1009.00	1009.05
Unnamed Tributary	7500	1006.50	1007.72	1008.10	1008.21	1008.31	1008.39	1008.44	1008.49	1008.54	1008.64	1008.72	1008.78	1008.84	1008.89
Unnamed Tributary	7400	1006.27	1007.50	1007.84	1007.93	1008.01	1008.08	1008.12	1008.17	1008.21	1008.30	1008.37	1008.42	1008.48	1008.53
Unnamed Tributary	7300	1006.08	1007.41	1007.68	1007.75	1007.82	1007.87	1007.90	1007.94	1007.96	1008.03	1008.08	1008.12	1008.16	1008.20
Unnamed Tributary	7200	1005.94	1007.08	1007.46	1007.59	1007.68	1007.74	1007.78	1007.83	1007.86	1007.94	1008.02	1008.07	1008.13	1008.17
Unnamed Tributary	7100	1005.65	1006.77	1007.20	1007.36	1007.48	1007.57	1007.62	1007.67	1007.71	1007.81	1007.89	1007.94	1008.00	1008.05
Unnamed Tributary	7000	1005.38	1006.49	1006.96	1007.15	1007.28	1007.38	1007.43	1007.50	1007.54	1007.64	1007.72	1007.78	1007.84	1007.88
Unnamed Tributary	6900	1005.13	1006.26	1006.74	1006.91	1007.04	1007.13	1007.19	1007.26	1007.30	1007.39	1007.47	1007.51	1007.56	1007.60
Unnamed Tributary	6800	1004.86	1006.03	1006.48	1006.63	1006.75	1006.83	1006.89	1006.94	1006.98	1007.07	1007.14	1007.18	1007.23	1007.26
Unnamed Tributary	6700	1004.62	1005.97	1006.40	1006.52	1006.61	1006.67	1006.72	1006.76	1006.79	1006.86	1006.92	1006.95	1007.00	1007.03
Unnamed Tributary	6600	1004.41	1005.76	1006.11	1006.22	1006.31	1006.38	1006.43	1006.48	1006.52	1006.60	1006.67	1006.71	1006.76	1006.80
Unnamed Tributary	6500	1004.11	1005.41	1005.67	1005.77	1005.88	1005.97	1006.02	1006.08	1006.12	1006.22	1006.31	1006.36	1006.43	1006.48
Unnamed Tributary	6400	1003.84	1005.20	1005.49	1005.61	1005.72	1005.81	1005.86	1005.93	1005.97	1006.07	1006.16	1006.22	1006.30	1006.35
Unnamed Tributary	6300	1003.60	1004.95	1005.31	1005.42	1005.52	1005.60	1005.66	1005.72	1005.76	1005.88	1005.98	1006.04	1006.12	1006.18
Unnamed Tributary	6200	1003.35	1004.73	1005.13	1005.24	1005.34	1005.42	1005.47	1005.53	1005.58	1005.69	1005.78	1005.85	1005.92	1005.98
Unnamed Tributary	6100	1003.09	1004.49	1004.92	1005.04	1005.15	1005.24	1005.30	1005.36	1005.41	1005.52	1005.62	1005.69	1005.76	1005.82

Table E-2: Unnamed Tributary Flood Profiles

River	River Station[a]	Channel Thalweg (m)	Simulated Water Level (m)												
			2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
Unnamed Tributary	6000	1002.84	1004.26	1004.69	1004.85	1004.97	1005.06	1005.11	1005.17	1005.21	1005.32	1005.41	1005.47	1005.54	1005.60
Unnamed Tributary	5900	1002.59	1003.91	1004.34	1004.49	1004.59	1004.66	1004.71	1004.76	1004.80	1004.90	1004.99	1005.05	1005.13	1005.19
Unnamed Tributary	5800	1002.35	1003.61	1004.02	1004.18	1004.28	1004.35	1004.40	1004.46	1004.50	1004.61	1004.71	1004.77	1004.85	1004.91
Unnamed Tributary	5700	1002.10	1003.38	1003.81	1004.03	1004.15	1004.23	1004.29	1004.35	1004.40	1004.52	1004.62	1004.69	1004.77	1004.83
Unnamed Tributary	5600	1001.86	1003.10	1003.55	1003.87	1004.04	1004.15	1004.22	1004.29	1004.34	1004.48	1004.59	1004.66	1004.75	1004.82
Unnamed Tributary	5500	1001.59	1002.87	1003.29	1003.72	1003.91	1004.02	1004.08	1004.15	1004.20	1004.33	1004.43	1004.50	1004.59	1004.65
Unnamed Tributary	5400	1001.38	1002.71	1003.11	1003.66	1003.86	1003.96	1004.03	1004.10	1004.15	1004.27	1004.37	1004.45	1004.53	1004.60
Unnamed Tributary	5300	1001.09	1002.53	1002.87	1003.62	1003.82	1003.93	1003.99	1004.06	1004.11	1004.22	1004.33	1004.40	1004.48	1004.54
Unnamed Tributary	5200	1000.85	1002.25	1002.62	1003.62	1003.82	1003.93	1003.99	1004.05	1004.10	1004.22	1004.32	1004.39	1004.47	1004.53
Unnamed Tributary	5100	1000.58	1002.03	1002.46	1003.61	1003.82	1003.92	1003.98	1004.05	1004.09	1004.21	1004.31	1004.38	1004.46	1004.52
Unnamed Tributary	5000	1000.38	1001.83	1002.24	1003.61	1003.81	1003.91	1003.97	1004.04	1004.08	1004.19	1004.29	1004.35	1004.43	1004.49
Unnamed Tributary	4900	1000.20	1001.61	1002.07	1003.61	1003.81	1003.91	1003.97	1004.04	1004.08	1004.19	1004.29	1004.35	1004.43	1004.48
Unnamed Tributary	4800	1000.05	1001.32	1002.01	1003.61	1003.81	1003.91	1003.97	1004.04	1004.08	1004.19	1004.29	1004.35	1004.43	1004.48
Unnamed Tributary	4700	999.95	1001.05	1001.99	1003.61	1003.81	1003.91	1003.97	1004.04	1004.08	1004.19	1004.29	1004.35	1004.43	1004.48
Unnamed Tributary	4600	999.73	1000.86	1001.97	1003.61	1003.81	1003.91	1003.97	1004.03	1004.08	1004.19	1004.28	1004.35	1004.42	1004.48
Unnamed Tributary	4500	999.57	1000.66	1001.97	1003.61	1003.81	1003.91	1003.97	1004.03	1004.08	1004.19	1004.28	1004.34	1004.42	1004.48
Unnamed Tributary	4400	999.38	1000.58	1001.96	1003.61	1003.81	1003.91	1003.97	1004.03	1004.08	1004.19	1004.28	1004.34	1004.42	1004.47
Unnamed Tributary	4300	998.66	999.44	999.84	1000.08	1000.27	1000.39	1000.47	1000.56	1000.62	1000.78	1000.91	1000.99	1001.08	1001.14
Unnamed Tributary	4200	998.25	999.04	999.53	999.81	1000.03	1000.16	1000.25	1000.34	1000.40	1000.55	1000.67	1000.75	1000.83	1000.89
Unnamed Tributary	4100	997.84	998.70	999.19	999.44	999.65	999.81	999.91	1000.02	1000.10	1000.28	1000.41	1000.49	1000.58	1000.65
Unnamed Tributary	4000	997.43	998.39	998.84	999.05	999.24	999.37	999.45	999.54	999.60	999.76	999.88	999.96	1000.04	1000.10
Unnamed Tributary	3900	997.04	998.01	998.42	998.65	998.85	999.01	999.10	999.19	999.26	999.41	999.53	999.61	999.69	999.75
Unnamed Tributary	3800	996.61	997.67	998.11	998.37	998.60	998.76	998.85	998.93	998.99	999.12	999.22	999.28	999.36	999.42
Unnamed Tributary	3700	996.18	997.47	997.89	998.15	998.37	998.52	998.59	998.66	998.70	998.80	998.88	998.94	999.00	999.05
Unnamed Tributary	3600	995.82	997.04	997.56	997.83	998.06	998.20	998.26	998.33	998.37	998.47	998.55	998.60	998.67	998.71
Unnamed Tributary	3500	995.48	996.80	997.33	997.59	997.84	998.00	998.07	998.14	998.18	998.28	998.36	998.41	998.47	998.51
Unnamed Tributary	3400	995.17	996.47	997.06	997.35	997.61	997.79	997.87	997.94	997.99	998.09	998.17	998.22	998.27	998.32
Unnamed Tributary	3300	994.83	996.13	996.75	997.06	997.33	997.53	997.62	997.70	997.76	997.87	997.95	998.00	998.06	998.11
Unnamed Tributary	3200	994.49	995.83	996.44	996.74	997.00	997.22	997.32	997.42	997.48	997.61	997.70	997.76	997.83	997.88
Unnamed Tributary	3100	994.16	995.54	996.07	996.35	996.61	996.80	996.91	997.01	997.07	997.20	997.31	997.37	997.45	997.51
Unnamed Tributary	3000	993.85	995.27	995.76	995.98	996.17	996.32	996.42	996.52	996.59	996.75	996.87	996.96	997.05	997.12
Unnamed Tributary	2900	993.65	995.05	995.51	995.73	995.94	996.10	996.21	996.32	996.39	996.54	996.67	996.75	996.84	996.91
Unnamed Tributary	2800	993.48	994.87	995.32	995.51	995.70	995.85	995.94	996.04	996.10	996.24	996.34	996.41	996.50	996.55
Unnamed Tributary	2700	993.27	994.52	994.97	995.20	995.42	995.58	995.67	995.77	995.84	995.99	996.09	996.16	996.24	996.29
Unnamed Tributary	2600	993.10	994.29	994.72	994.96	995.18	995.33	995.41	995.50	995.55	995.66	995.74	995.79	995.85	995.89
Unnamed Tributary	2500	992.88	994.05	994.45	994.67	994.87	995.01	995.09	995.17	995.22	995.33	995.40	995.45	995.50	995.54
Unnamed Tributary	2400	992.63	993.75	994.15	994.36	994.53	994.65	994.71	994.78	994.82	994.91	994.98	995.03	995.08	995.11
Unnamed Tributary	2300	992.44	993.40	993.81	994.02	994.14	994.23	994.29	994.34	994.38	994.47	994.54	994.59	994.64	994.69

Table E-2: Unnamed Tributary Flood Profiles

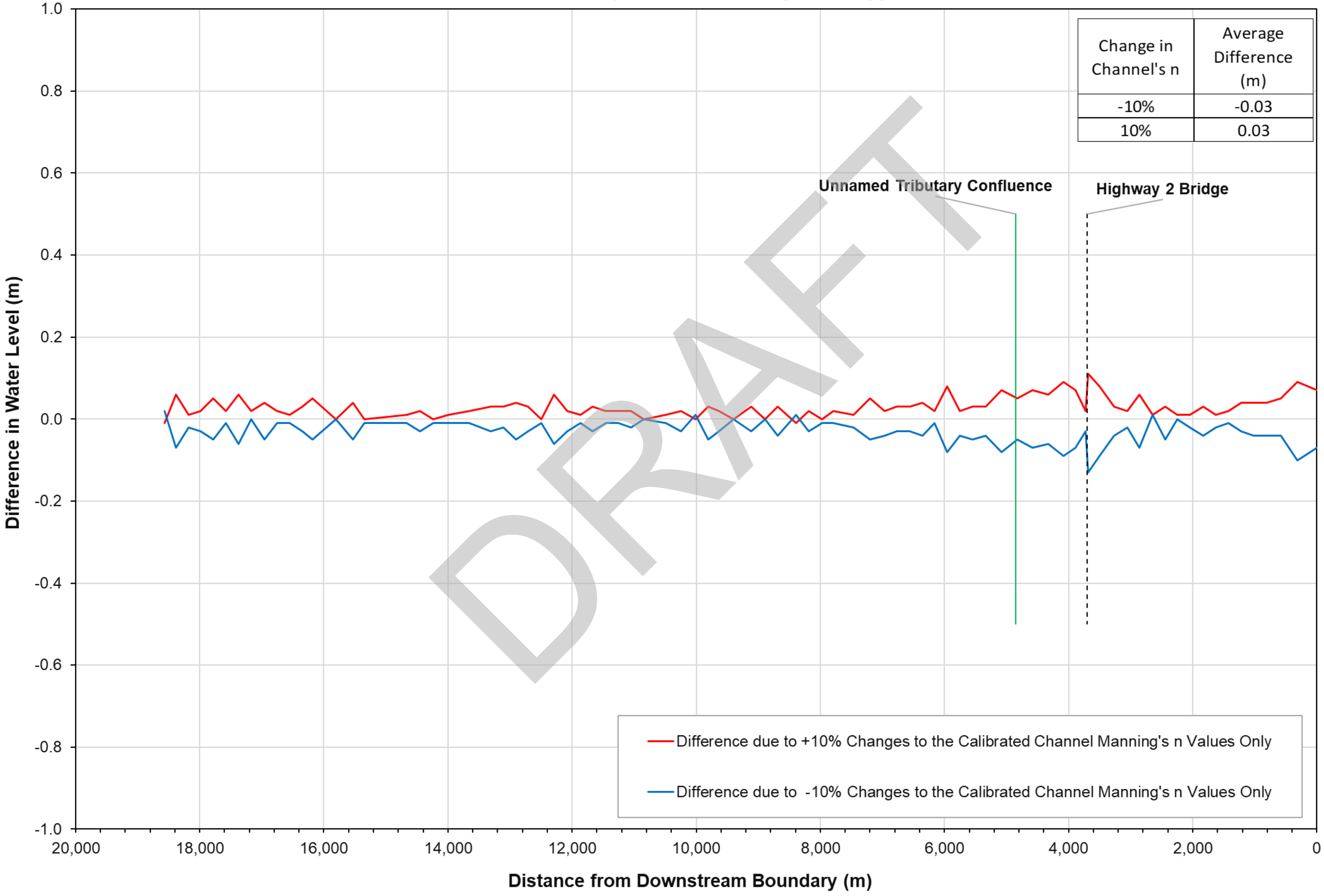
River	River Station[(a)]	Channel Thalweg (m)	Simulated Water Level (m)												
			2-Year Flood Event	5-Year Flood Event	10-Year Flood Event	20-Year Flood Event	35-Year Flood Event	50-Year Flood Event	75-Year Flood Event	100-Year Flood Event	200-Year Flood Event	350-Year Flood Event	500-Year Flood Event	750-Year Flood Event	1000-Year Flood Event
Unnamed Tributary	2200	991.98	993.01	993.45	993.65	993.75	993.83	993.88	993.93	993.97	994.06	994.14	994.19	994.26	994.30
Unnamed Tributary	2100	991.46	992.67	993.13	993.34	993.44	993.52	993.57	993.63	993.68	993.80	993.91	993.97	994.05	994.10
Unnamed Tributary	2000	991.02	992.25	992.86	993.12	993.23	993.31	993.37	993.44	993.49	993.62	993.72	993.79	993.86	993.92
Unnamed Tributary	1900	990.50	991.82	992.70	992.99	993.08	993.14	993.18	993.23	993.26	993.35	993.42	993.46	993.52	993.56
Unnamed Tributary	1800	990.13	991.29	992.64	992.94	993.02	993.07	993.10	993.13	993.16	993.22	993.26	993.29	993.33	993.35
Unnamed Tributary	1700	989.91	990.77	991.20	991.46	991.70	991.86	991.97	992.08	992.15	992.32	992.43	992.51	992.59	992.64
Unnamed Tributary	1600	989.51	990.39	990.81	991.08	991.31	991.47	991.57	991.67	991.74	991.89	991.99	992.06	992.12	992.16
Unnamed Tributary	1500	989.07	990.00	990.44	990.72	990.95	991.11	991.20	991.30	991.37	991.50	991.60	991.67	991.72	991.76
Unnamed Tributary	1400	988.66	989.60	990.09	990.41	990.64	990.77	990.84	990.93	990.98	991.09	991.19	991.25	991.30	991.33
Unnamed Tributary	1300	988.20	989.29	989.80	990.17	990.40	990.52	990.58	990.64	990.68	990.76	990.84	990.89	990.93	990.95
Unnamed Tributary	1200	987.76	988.96	989.53	989.98	990.24	990.36	990.41	990.46	990.49	990.56	990.63	990.67	990.70	990.73
Unnamed Tributary	1100	987.80	988.53	988.96	989.20	989.31	989.35	989.38	989.42	989.45	989.57	989.70	989.80	989.95	990.09
Unnamed Tributary	1000	987.34	988.17	988.57	988.76	988.86	988.92	988.97	989.04	989.10	989.29	989.48	989.62	989.80	989.94
Unnamed Tributary	900	986.91	987.89	988.17	988.33	988.47	988.59	988.67	988.78	988.87	989.11	989.32	989.47	989.66	989.81
Unnamed Tributary	800	986.45	987.33	987.64	987.81	987.96	988.11	988.23	988.40	988.51	988.81	989.04	989.20	989.40	989.55
Unnamed Tributary	700	986.00	986.77	987.17	987.38	987.61	987.83	988.01	988.23	988.36	988.68	988.92	989.07	989.27	989.42
Unnamed Tributary	600	985.55	986.56	986.96	987.18	987.44	987.71	987.91	988.15	988.29	988.63	988.87	989.03	989.22	989.37
Unnamed Tributary	500	985.31	986.29	986.69	986.96	987.26	987.55	987.76	988.03	988.17	988.56	988.83	988.99	989.19	989.34
Unnamed Tributary	400	985.13	986.11	986.55	986.85	987.16	987.45	987.66	987.93	988.07	988.49	988.75	988.91	989.10	989.24
Unnamed Tributary	300	984.94	986.03	986.48	986.79	987.10	987.38	987.59	987.85	987.98	988.40	988.65	988.80	988.98	989.11
Unnamed Tributary	200	984.75	986.00	986.44	986.75	987.06	987.34	987.54	987.79	987.92	988.36	988.61	988.77	988.95	989.08
Unnamed Tributary	100	984.56	985.93	986.36	986.64	986.93	987.21	987.41	987.67	987.79	988.24	988.49	988.63	988.81	988.95
Unnamed Tributary	0	984.15	985.77	986.19	986.48	986.79	987.07	987.28	987.55	987.67	988.13	988.36	988.50	988.65	988.77

Notes: a) The locations of these stations are shown in the Inundation Maps in Appendix G.

APPENDIX F

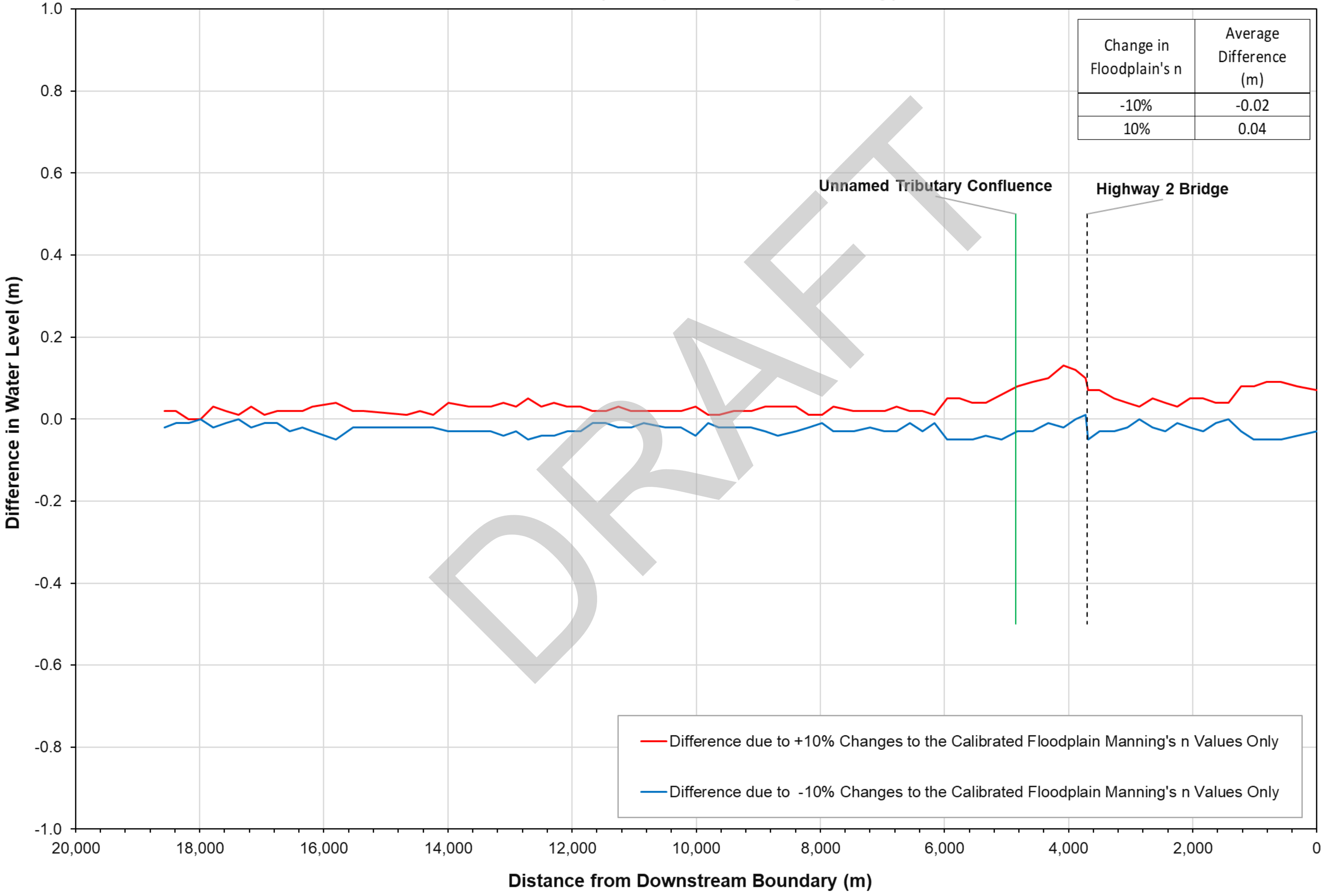
Open Water Sensitivity Analysis

Figure F-1: Sensitivity of Simulated Water Level along the Belly River Study Reach for the 100 - Year Flood Event (Channel Manning's n Only)



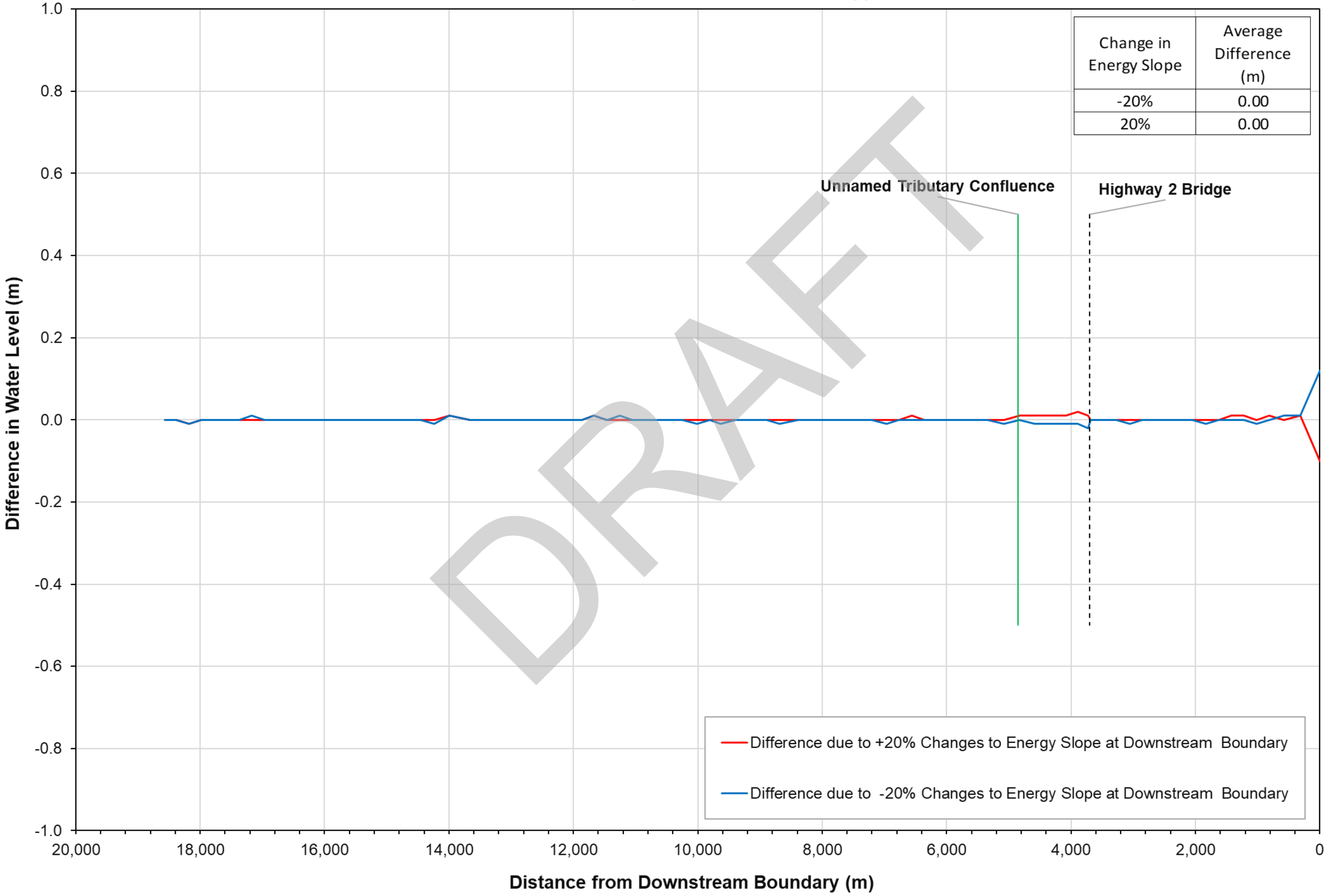
Change in Channel's n	Average Difference (m)
-10%	-0.03
10%	0.03

Figure F-2: Sensitivity of Simulated Water Level along the Belly River Study Reach for the 100 - Year Flood Event (Floodplain Manning's n Only)



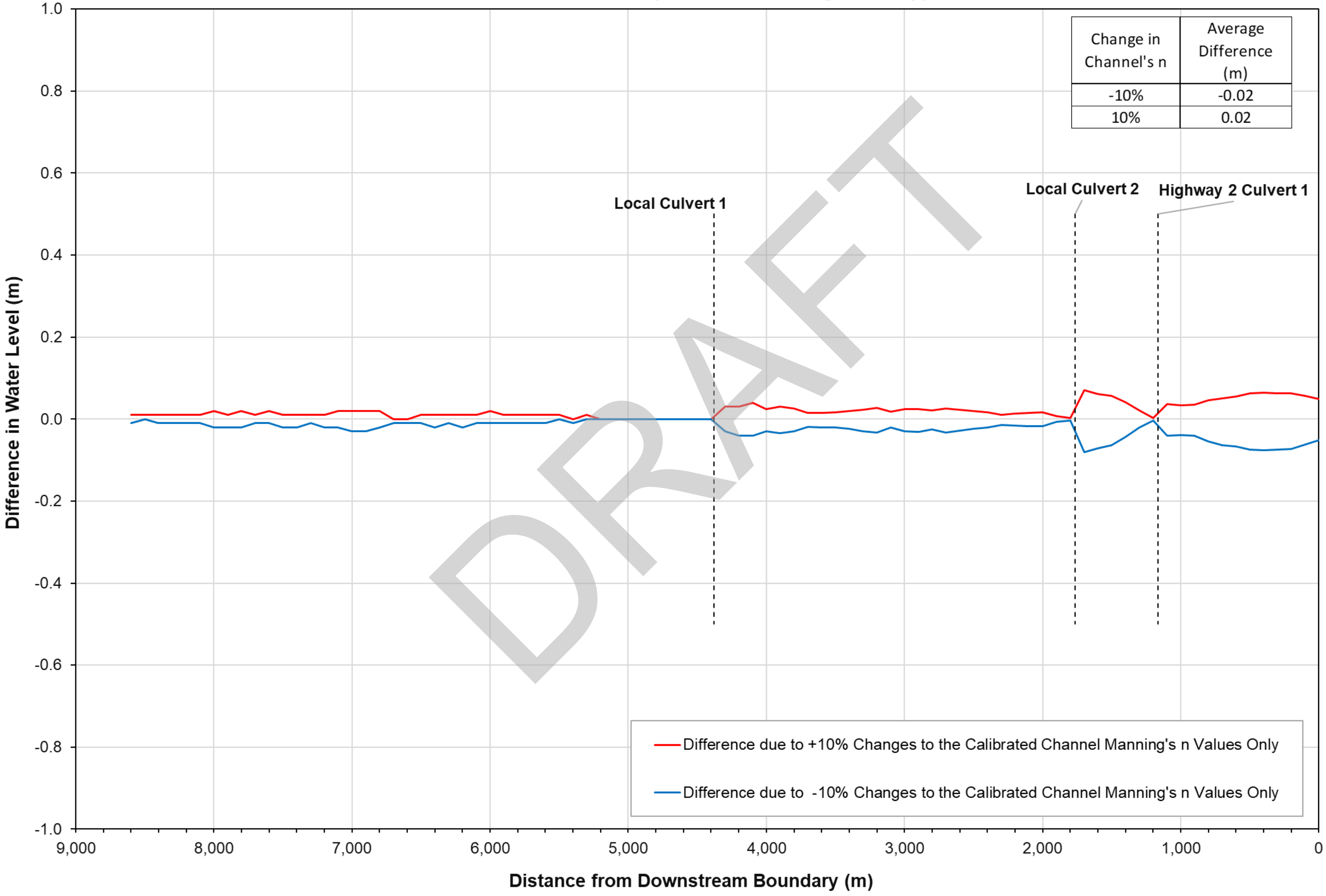
Change in Floodplain's n	Average Difference (m)
-10%	-0.02
10%	0.04

Figure F-3: Sensitivity of Simulated Water Level along the Belly River Study Reach for the 100 - Year Flood Event (Downstream Boundary)



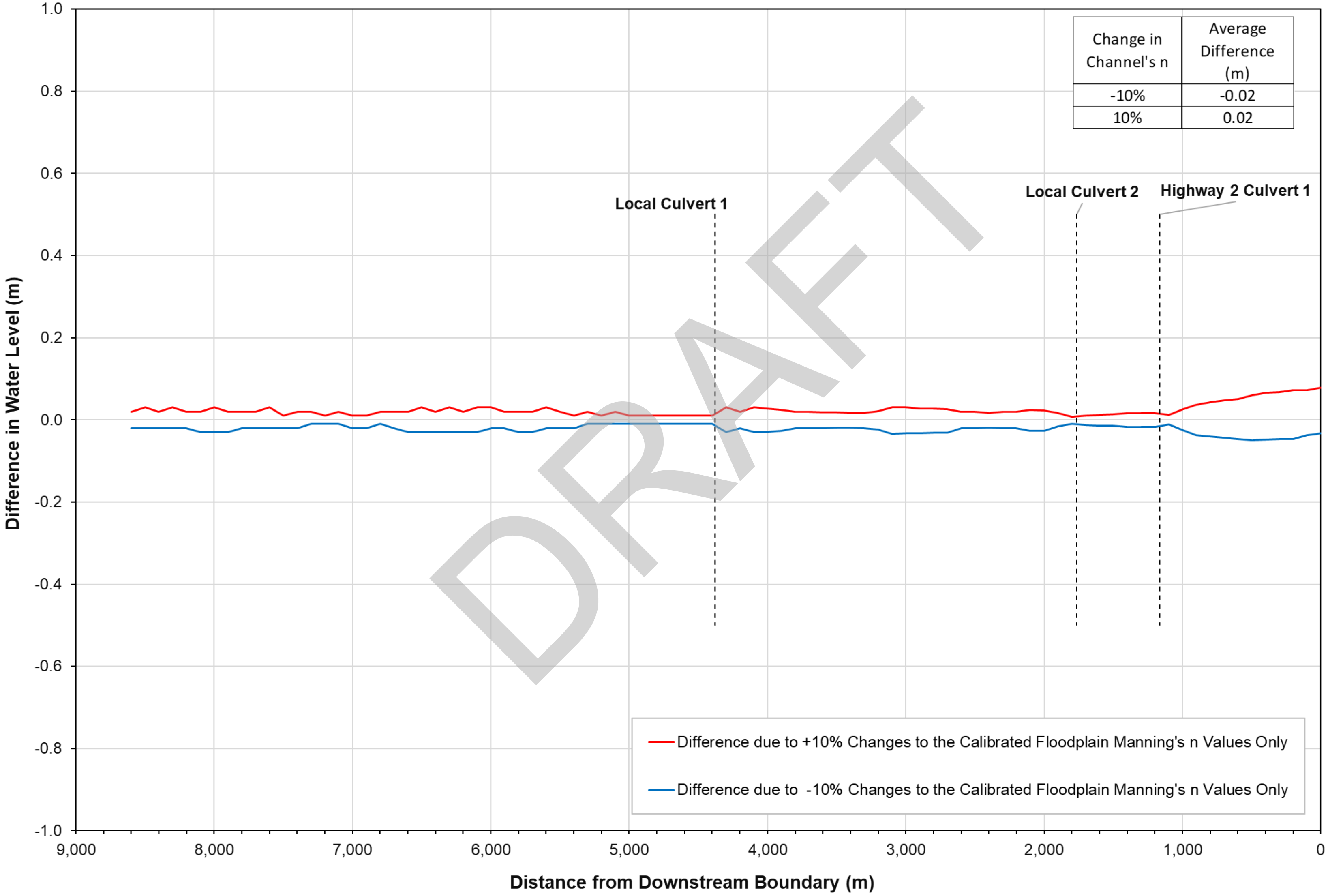
Change in Energy Slope	Average Difference (m)
-20%	0.00
20%	0.00

Figure F-4: Sensitivity of Simulated Water Level along the Unnamed Tributary Study Reach for the 100 - Year Flood Event (Channel Manning's n Only)



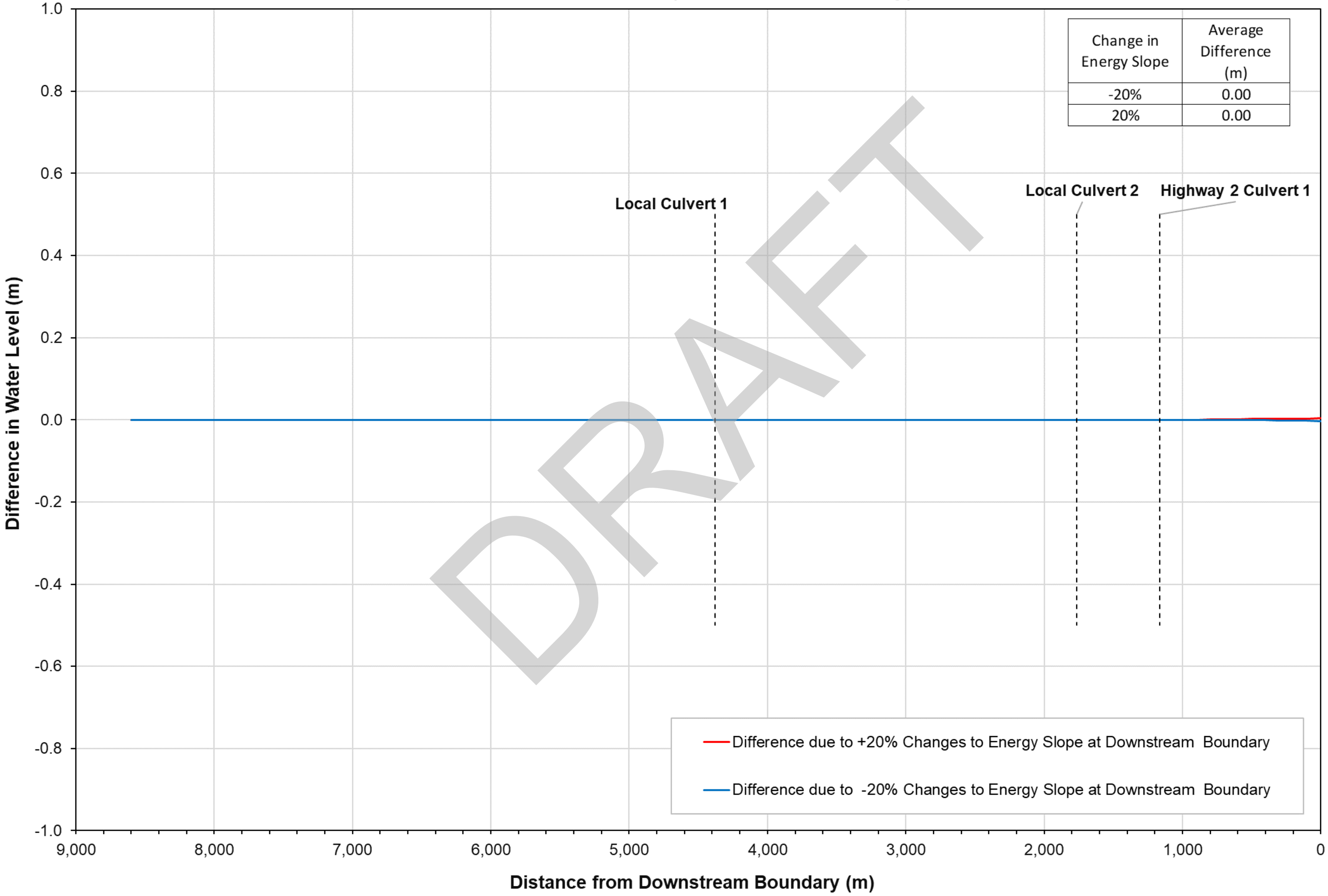
Change in Channel's n	Average Difference (m)
-10%	-0.02
10%	0.02

Figure F-5: Sensitivity of Simulated Water Level along the Unnamed Tributary Study Reach for the 100 - Year Flood Event (Floodplain Manning's n Only)



Change in Channel's n	Average Difference (m)
-10%	-0.02
10%	0.02

Figure F-6: Sensitivity of Simulated Water Level along the Unnamed Tributary Study Reach for the 100 - Year Flood Event (Downstream Boundary)



Change in Energy Slope	Average Difference (m)
-20%	0.00
20%	0.00

APPENDIX G

Open Water Inundation Maps

(PROVIDED SEPARATELY IN THE MAP LIBRARY)

APPENDIX H

Floodway Criteria Maps and Flood Hazard Maps

LEGEND

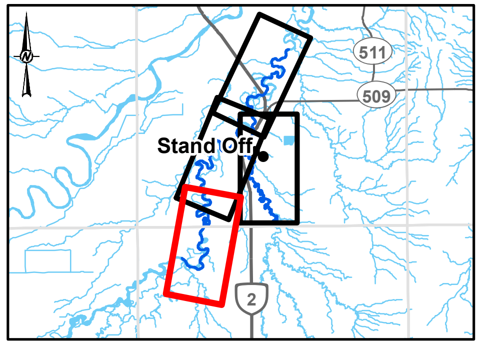
▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▪▪▪	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
▬	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
|||||||	FLOOD CONTROL STRUCTURE

▬	PROPOSED FLOODWAY BOUNDARY
○	BANK STATION
🟦	DEPTH ≥ 1 M
🟩	100-YEAR DESIGN FLOOD EXTENT
▬	VELOCITY ≥ 1 M/S

DISCHARGE
BELLY RIVER = 454 M³/S



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WSP GOLDER

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PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT
STAND OFF FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	1 of 4

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SHEET 4 ↓

LEGEND

▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▬▬▬	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
▬	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

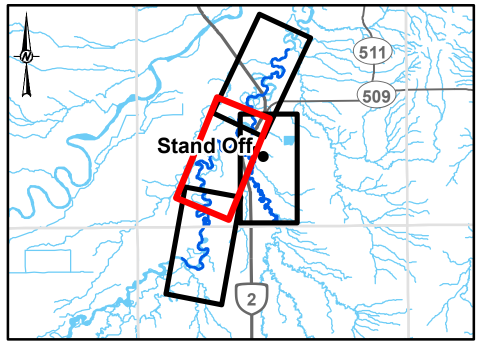
HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
▮▮▮▮	FLOOD CONTROL STRUCTURE

🟥	PROPOSED FLOODWAY BOUNDARY
●	BANK STATION
🟦	DEPTH ≥ 1 M
🟩	100-YEAR DESIGN FLOOD EXTENT
🟪	VELOCITY ≥ 1 M/S

DISCHARGE

BELLY RIVER = 454 M³/S
UNNAMED TRIBUTARY = 49.9 M³/S



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APPROVED	WP

TITLE
FLOODWAY CRITERIA MAP

PROJECT NO.	CONTROL	REV.	FIGURE
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LEGEND

▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▬▬▬	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

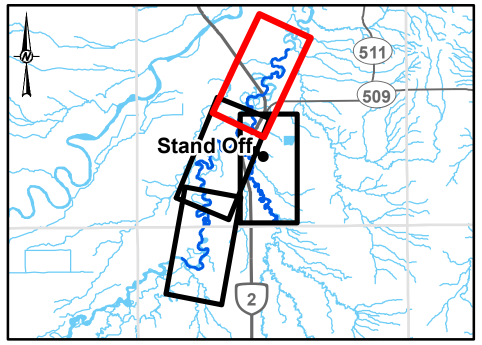
HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
▮▮▮▮	FLOOD CONTROL STRUCTURE

🟥	PROPOSED FLOODWAY BOUNDARY
○	BANK STATION
🟦	DEPTH ≥ 1 M
🟩	100-YEAR DESIGN FLOOD EXTENT
🟪	VELOCITY ≥ 1 M/S

DISCHARGE

BELLY RIVER = 454 M³/S
UNNAMED TRIBUTARY = 49.9 M³/S



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APPROVED	WP

PROJECT
STAND OFF FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

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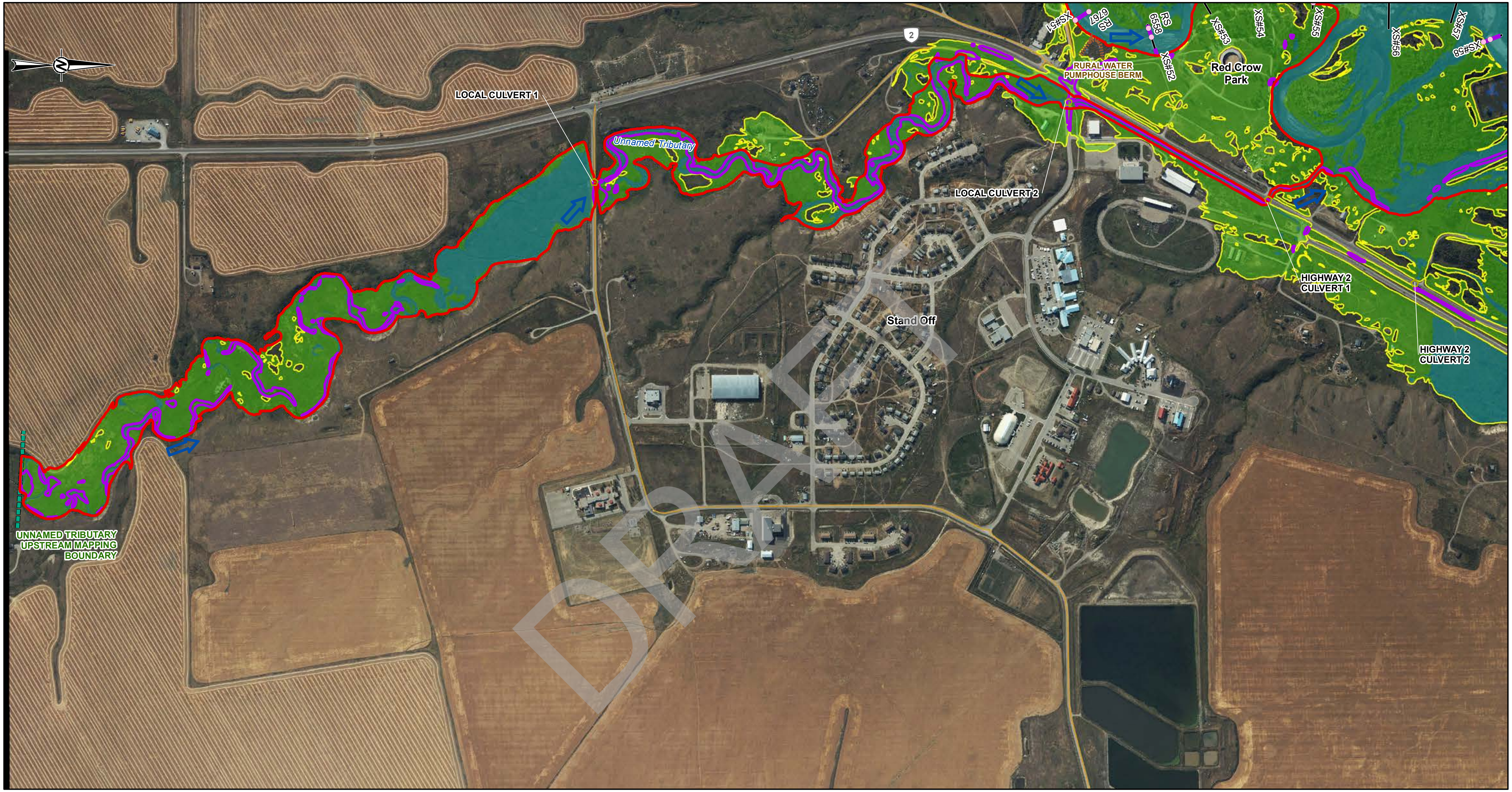

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LEGEND

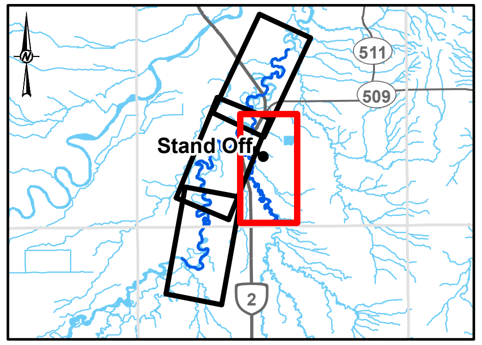
—	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▪▪▪	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
▥	FLOOD CONTROL STRUCTURE

🟥	PROPOSED FLOODWAY BOUNDARY
●	BANK STATION
🟦	DEPTH ≥ 1 M
🟩	100-YEAR DESIGN FLOOD EXTENT
🟪	VELOCITY ≥ 1 M/S

DISCHARGE
UNNAMED TRIBUTARY = 49.9 M³/S



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PROJECT
STAND OFF FLOOD STUDY

TITLE
FLOODWAY CRITERIA MAP

PROJECT NO.	CONTROL	REV.	FIGURE
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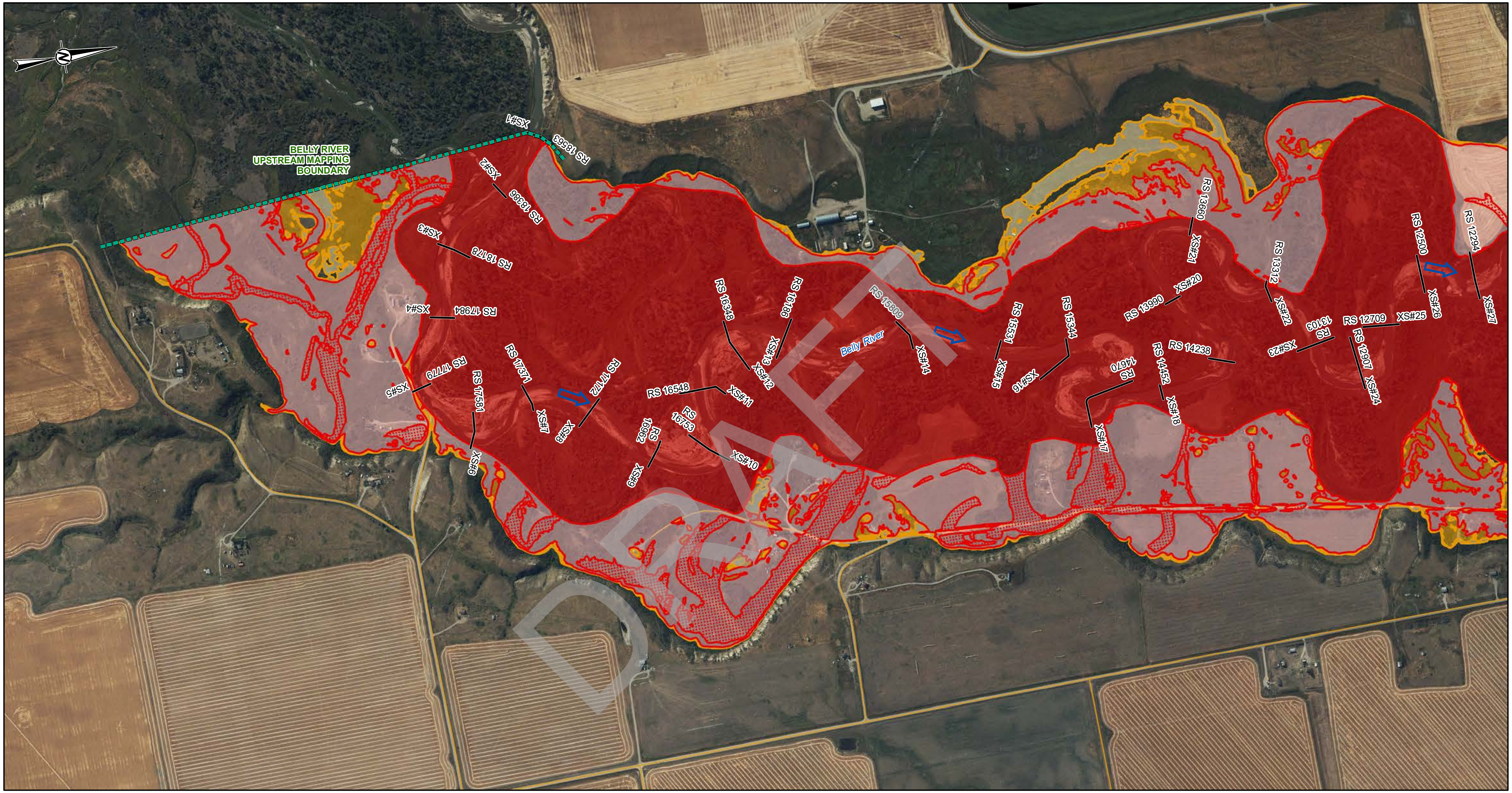


LEGEND

▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▪▪▪	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

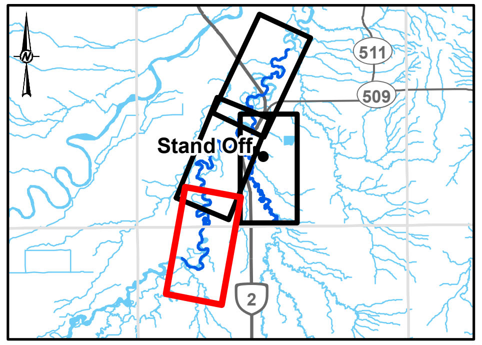
HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
⦙⦙⦙	FLOOD CONTROL STRUCTURE

🟥	FLOODWAY
▨	HIGH HAZARD FLOOD FRINGE
☐	FLOOD FRINGE
🟧	200-YEAR FLOOD EXTENT
🟨	500-YEAR FLOOD EXTENT

DISCHARGE

BELLY RIVER = 454 M³/S



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PROJECT
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PREPARED	NB
REVIEWED	JC
APPROVED	WP

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	1 of 4

SHEET 4 ↓

LEGEND

▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▪▪▪	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

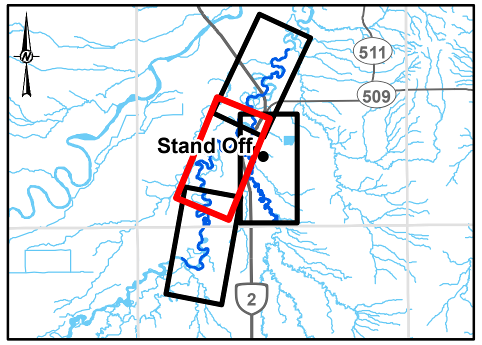
HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
▮▮▮	FLOOD CONTROL STRUCTURE

🟥	FLOODWAY
▨	HIGH HAZARD FLOOD FRINGE
☐	FLOOD FRINGE
🟧	200-YEAR FLOOD EXTENT
🟨	500-YEAR FLOOD EXTENT

DISCHARGE

BELLY RIVER = 454 M³/S
UNNAMED TRIBUTARY = 49.9 M³/S



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AND PARKS

PROJECT
STAND OFF FLOOD STUDY

CONSULTANT

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PREPARED	NB
REVIEWED	JC
APPROVED	WP

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	2 of 4

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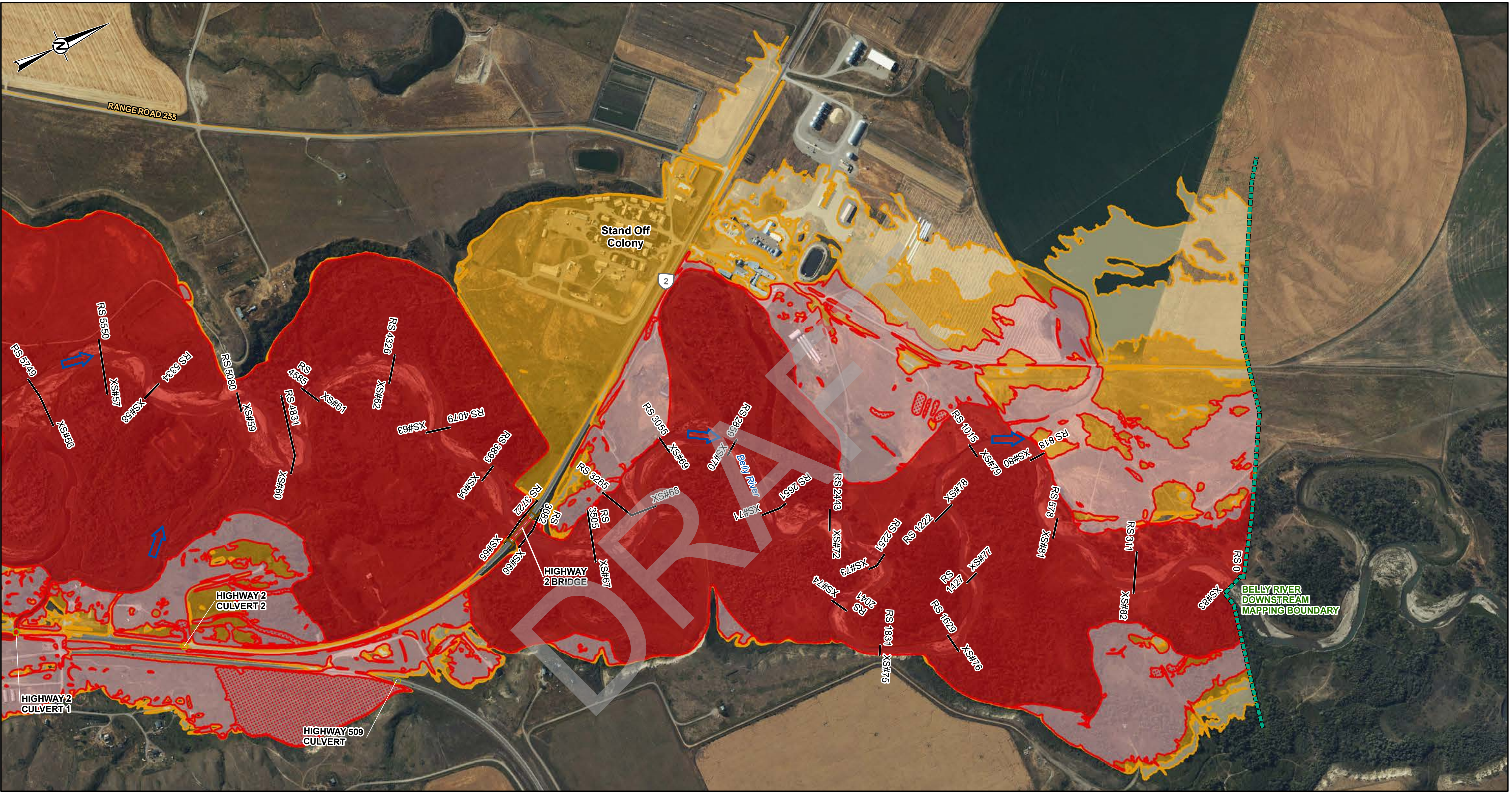


LEGEND

▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
▪▪▪	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

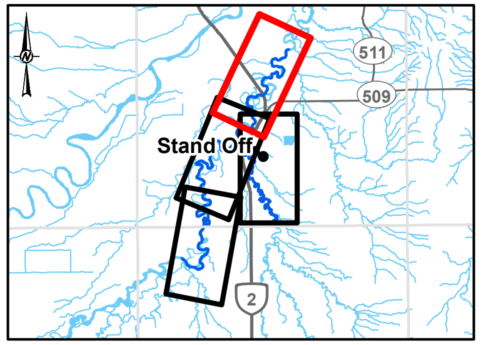
HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
⦙⦙⦙	FLOOD CONTROL STRUCTURE

🟥	FLOODWAY
▦	HIGH HAZARD FLOOD FRINGE
☐	FLOOD FRINGE
🟧	200-YEAR FLOOD EXTENT
🟨	500-YEAR FLOOD EXTENT

DISCHARGE

BELLY RIVER = 454 M³/S
UNNAMED TRIBUTARY = 49.9 M³/S



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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

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CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-22
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT
STAND OFF FLOOD STUDY

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	3 of 4

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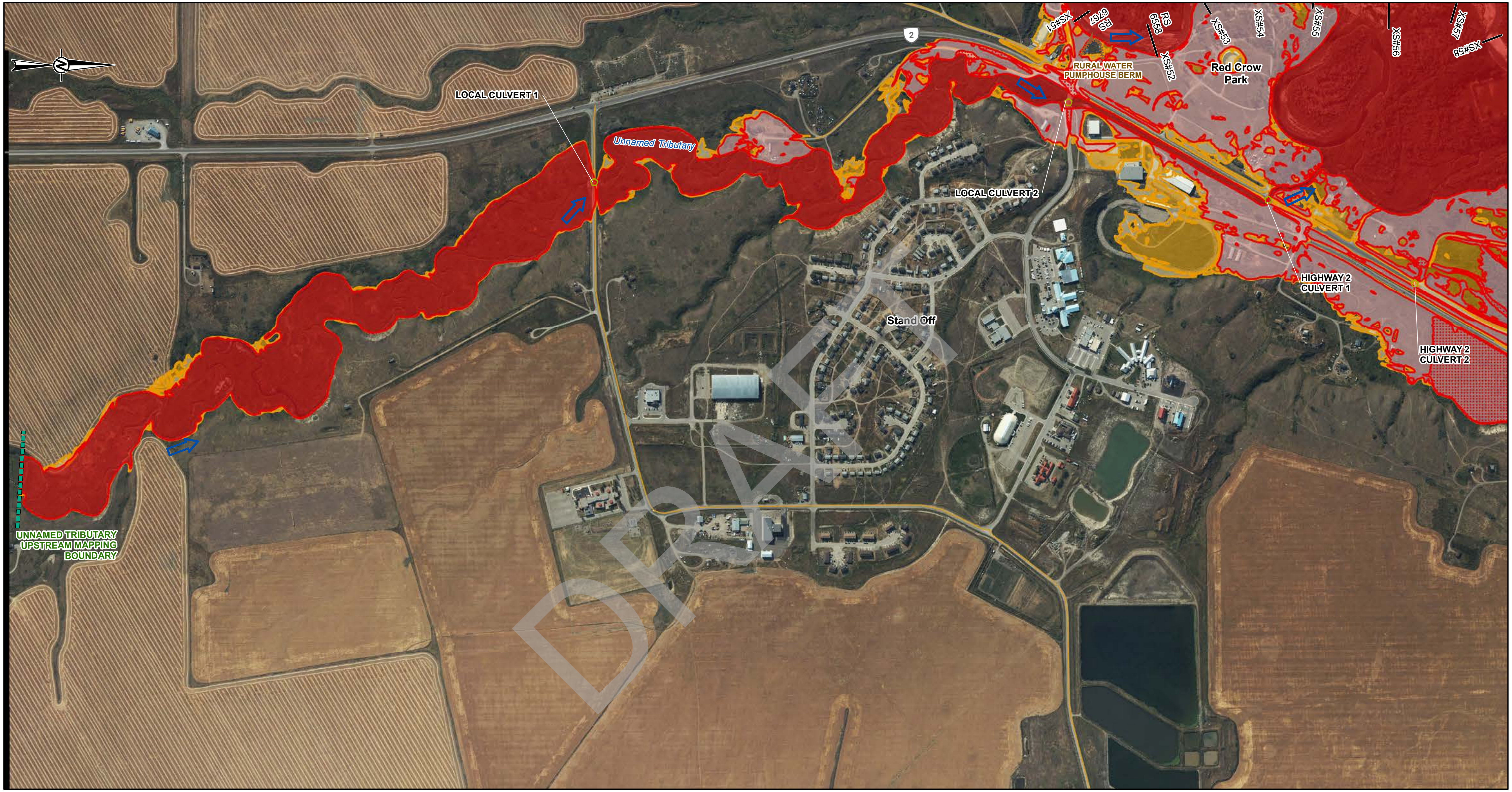
SHEET 2 ↑



SHEET 3 ↓

LEGEND

▬	CROSS SECTION
XS#1	CROSS SECTION NUMBER
RS 18178	RIVER STATION (M)
■■■	MAPPING BOUNDARY
⇨	FLOW DIRECTION
—	LOCAL ROAD
—	PRIMARY HIGHWAY
—	SECONDARY HIGHWAY

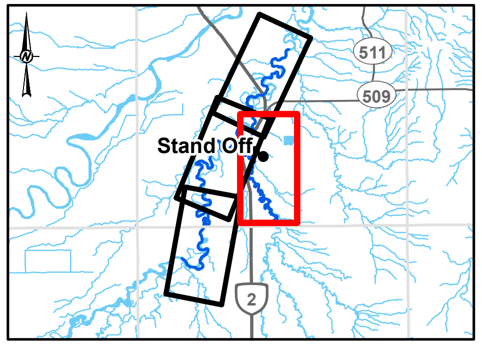
HYDRAULIC STRUCTURES

⌶	BRIDGE
⬠	CULVERT
IIIIIIII	FLOOD CONTROL STRUCTURE

🟥	FLOODWAY
▦	HIGH HAZARD FLOOD FRINGE
☐	FLOOD FRINGE
🟧	200-YEAR FLOOD EXTENT
🟨	500-YEAR FLOOD EXTENT

DISCHARGE

UNNAMED TRIBUTARY = 49.9 M³/S



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DATUM: NAD 83 CSRS PROJECTION: 3TM 114

CLIENT
ALBERTA ENVIRONMENT
AND PARKS

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-06-22
DESIGNED	TT
PREPARED	NB
REVIEWED	JC
APPROVED	WP

PROJECT
STAND OFF FLOOD STUDY

TITLE
FLOOD HAZARD MAP

PROJECT NO.	CONTROL	REV.	FIGURE
21467363	-	0	4 of 4

PATH: I:\CLIENTS\GOVERNMENT_OF_ALBERTA\21467363\Mapping\Products\Hydrology\05_Design Flood Hazard Mapping\21467363_Governing-Flood-Hazard_Rev0.mxd PRINTED ON: 2022-06-22 AT: 10:20:32 AM

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Classification: Public

APPENDIX I

Climate Change Flood Profiles

Table I-1: Water Levels along the Belly River due to Climate Change

River	Cross Section	River Station	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Belly River	1	18563	1011.23	1011.29	1011.35	0.06	0.12
Belly River	2	18386	1010.50	1010.57	1010.64	0.07	0.14
Belly River	3	18178	1010.30	1010.37	1010.45	0.07	0.15
Belly River	4	17984	1009.73	1009.81	1009.88	0.08	0.15
Belly River	5	17779	1009.18	1009.25	1009.32	0.07	0.14
Belly River	6	17581	1009.20	1009.27	1009.34	0.07	0.14
Belly River	7	17371	1008.59	1008.66	1008.72	0.07	0.13
Belly River	8	17172	1008.13	1008.18	1008.23	0.05	0.10
Belly River	9	16962	1007.47	1007.51	1007.56	0.04	0.09
Belly River	10	16753	1007.25	1007.31	1007.36	0.06	0.11
Belly River	11	16548	1006.94	1007.00	1007.06	0.06	0.12
Belly River	12	16348	1006.44	1006.51	1006.57	0.07	0.13
Belly River	13	16186	1005.94	1006.00	1006.06	0.06	0.12
Belly River	14	15809	1005.27	1005.34	1005.41	0.07	0.14
Belly River	15	15531	1004.58	1004.63	1004.67	0.05	0.09
Belly River	16	15344	1004.58	1004.63	1004.67	0.05	0.09
Belly River	17	14670	1003.64	1003.70	1003.75	0.06	0.11
Belly River	18	14452	1003.08	1003.13	1003.17	0.05	0.09
Belly River	19	14238	1003.03	1003.07	1003.12	0.04	0.09
Belly River	20	13990	1002.93	1003.00	1003.06	0.07	0.13
Belly River	21	13660	1002.66	1002.73	1002.80	0.07	0.14
Belly River	22	13312	1002.06	1002.13	1002.18	0.07	0.12
Belly River	23	13103	1001.74	1001.82	1001.89	0.08	0.15
Belly River	24	12907	1001.27	1001.34	1001.40	0.07	0.13
Belly River	25	12709	1000.98	1001.05	1001.11	0.07	0.13
Belly River	26	12500	1000.90	1000.97	1001.03	0.07	0.13

Table I-1: Water Levels along the Belly River due to Climate Change

River	Cross Section	River Station	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Belly River	27	12294	1000.01	1000.07	1000.12	0.06	0.11
Belly River	28	12074	999.69	999.75	999.80	0.06	0.11
Belly River	29	11868	999.49	999.55	999.60	0.06	0.11
Belly River	30	11668	999.02	999.08	999.13	0.06	0.11
Belly River	31	11457	998.87	998.94	999.00	0.07	0.13
Belly River	32	11251	998.35	998.40	998.45	0.05	0.10
Belly River	33	11048	997.85	997.88	997.91	0.03	0.06
Belly River	34	10843	997.71	997.75	997.78	0.04	0.07
Belly River	35	10491	997.03	997.06	997.08	0.03	0.05
Belly River	36	10250	996.72	996.78	996.83	0.06	0.11
Belly River	37	10010	996.51	996.57	996.63	0.06	0.12
Belly River	38	9804	996.01	996.07	996.12	0.06	0.11
Belly River	39	9636	995.69	995.73	995.78	0.04	0.09
Belly River	40	9400	995.39	995.44	995.48	0.05	0.09
Belly River	41	9118	994.95	995.00	995.05	0.05	0.10
Belly River	42	8892	994.69	994.75	994.81	0.06	0.12
Belly River	43	8691	994.08	994.13	994.17	0.05	0.09
Belly River	44	8388	993.78	993.82	993.86	0.04	0.08
Belly River	45	8189	993.41	993.45	993.50	0.04	0.09
Belly River	46	7976	993.40	993.45	993.49	0.05	0.09
Belly River	47	7793	993.29	993.36	993.42	0.07	0.13
Belly River	48	7469	992.82	992.89	992.96	0.07	0.14
Belly River	49	7202	991.97	992.03	992.08	0.06	0.11
Belly River	50	6965	991.75	991.81	991.87	0.06	0.12
Belly River	51	6767	991.41	991.47	991.53	0.06	0.12
Belly River	52	6558	991.15	991.22	991.28	0.07	0.13

Table I-1: Water Levels along the Belly River due to Climate Change

River	Cross Section	River Station	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Belly River	53	6358	990.67	990.74	990.80	0.07	0.13
Belly River	54	6163	990.53	990.61	990.67	0.08	0.14
Belly River	55	5953	989.51	989.59	989.66	0.08	0.15
Belly River	56	5749	989.21	989.30	989.38	0.09	0.17
Belly River	57	5550	988.87	988.97	989.06	0.10	0.19
Belly River	58	5334	988.64	988.76	988.86	0.12	0.22
Belly River	59	5080	987.93	988.07	988.21	0.14	0.28
Belly River	60	4831	987.65	987.81	987.97	0.16	0.32
Belly River	61	4585	987.44	987.63	987.81	0.19	0.37
Belly River	62	4326	987.36	987.58	987.79	0.22	0.43
Belly River	63	4079	987.10	987.34	987.56	0.24	0.46
Belly River	64	3893	987.10	987.37	987.62	0.27	0.52
Belly River	65	3722	986.25	986.48	986.69	0.23	0.44
Belly River	66	3682	985.29	985.36	985.43	0.07	0.14
Belly River	67	3505	984.97	985.05	985.12	0.08	0.15
Belly River	68	3265	984.80	984.87	984.94	0.07	0.14
Belly River	69	3055	984.41	984.46	984.52	0.05	0.11
Belly River	70	2859	983.93	983.99	984.04	0.06	0.11
Belly River	71	2651	983.69	983.75	983.81	0.06	0.12
Belly River	72	2443	983.11	983.15	983.19	0.04	0.08
Belly River	73	2251	983.04	983.09	983.13	0.05	0.09
Belly River	74	2041	982.79	982.85	982.91	0.06	0.12
Belly River	75	1831	982.29	982.35	982.42	0.06	0.13
Belly River	76	1629	982.14	982.20	982.26	0.06	0.12
Belly River	77	1427	982.10	982.17	982.24	0.07	0.14
Belly River	78	1222	982.02	982.12	982.22	0.10	0.20

Table I-1: Water Levels along the Belly River due to Climate Change

River	Cross Section	River Station	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Belly River	79	1015	981.85	981.95	982.07	0.10	0.22
Belly River	80	818	981.60	981.69	981.79	0.09	0.19
Belly River	81	578	981.32	981.43	981.54	0.11	0.22
Belly River	82	311	980.56	980.65	980.75	0.09	0.19
Belly River	83	0	980.01	980.10	980.19	0.09	0.18

Table I-2: Water Levels along the Unnamed Tributary due to Climate Change

River	River Station(a)	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Unnamed Tributary	8600	1011.45	1011.48	1011.51	0.03	0.06
Unnamed Tributary	8500	1011.23	1011.26	1011.29	0.03	0.06
Unnamed Tributary	8400	1011.06	1011.09	1011.12	0.03	0.06
Unnamed Tributary	8300	1010.77	1010.80	1010.83	0.03	0.06
Unnamed Tributary	8200	1010.57	1010.60	1010.63	0.03	0.06
Unnamed Tributary	8100	1010.26	1010.29	1010.32	0.03	0.06
Unnamed Tributary	8000	1010.03	1010.07	1010.11	0.04	0.08
Unnamed Tributary	7900	1009.66	1009.70	1009.74	0.04	0.08
Unnamed Tributary	7800	1009.34	1009.38	1009.41	0.04	0.07
Unnamed Tributary	7700	1008.98	1009.02	1009.05	0.04	0.07
Unnamed Tributary	7600	1008.69	1008.73	1008.76	0.04	0.07
Unnamed Tributary	7500	1008.54	1008.57	1008.60	0.03	0.06
Unnamed Tributary	7400	1008.21	1008.24	1008.27	0.03	0.06
Unnamed Tributary	7300	1007.96	1007.98	1008.00	0.02	0.04
Unnamed Tributary	7200	1007.86	1007.89	1007.92	0.03	0.06
Unnamed Tributary	7100	1007.71	1007.75	1007.78	0.04	0.07
Unnamed Tributary	7000	1007.54	1007.58	1007.61	0.04	0.07
Unnamed Tributary	6900	1007.30	1007.33	1007.36	0.03	0.06
Unnamed Tributary	6800	1006.98	1007.01	1007.04	0.03	0.06
Unnamed Tributary	6700	1006.79	1006.81	1006.84	0.02	0.05
Unnamed Tributary	6600	1006.52	1006.55	1006.57	0.03	0.05
Unnamed Tributary	6500	1006.12	1006.16	1006.19	0.04	0.07
Unnamed Tributary	6400	1005.97	1006.00	1006.04	0.03	0.07
Unnamed Tributary	6300	1005.76	1005.80	1005.84	0.04	0.08
Unnamed Tributary	6200	1005.58	1005.61	1005.65	0.03	0.07
Unnamed Tributary	6100	1005.41	1005.45	1005.49	0.04	0.08

Table I-2: Water Levels along the Unnamed Tributary due to Climate Change

River	River Station[(a)]	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Unnamed Tributary	6000	1005.21	1005.25	1005.29	0.04	0.08
Unnamed Tributary	5900	1004.80	1004.84	1004.87	0.04	0.07
Unnamed Tributary	5800	1004.50	1004.53	1004.57	0.03	0.07
Unnamed Tributary	5700	1004.40	1004.44	1004.47	0.04	0.07
Unnamed Tributary	5600	1004.34	1004.39	1004.43	0.05	0.09
Unnamed Tributary	5500	1004.20	1004.25	1004.29	0.05	0.09
Unnamed Tributary	5400	1004.15	1004.19	1004.23	0.04	0.08
Unnamed Tributary	5300	1004.10	1004.15	1004.18	0.05	0.08
Unnamed Tributary	5200	1004.10	1004.14	1004.18	0.04	0.08
Unnamed Tributary	5100	1004.09	1004.13	1004.17	0.04	0.08
Unnamed Tributary	5000	1004.08	1004.12	1004.16	0.04	0.08
Unnamed Tributary	4900	1004.08	1004.12	1004.15	0.04	0.07
Unnamed Tributary	4800	1004.08	1004.12	1004.15	0.04	0.07
Unnamed Tributary	4700	1004.08	1004.12	1004.15	0.04	0.07
Unnamed Tributary	4600	1004.08	1004.12	1004.15	0.04	0.07
Unnamed Tributary	4500	1004.08	1004.12	1004.15	0.04	0.07
Unnamed Tributary	4400	1004.08	1004.11	1004.15	0.03	0.07
Unnamed Tributary	4300	1000.62	1000.68	1000.73	0.06	0.11
Unnamed Tributary	4200	1000.40	1000.45	1000.50	0.05	0.10
Unnamed Tributary	4100	1000.10	1000.16	1000.22	0.06	0.12
Unnamed Tributary	4000	999.60	999.66	999.71	0.05	0.10
Unnamed Tributary	3900	999.26	999.31	999.36	0.06	0.11
Unnamed Tributary	3800	998.98	999.03	999.07	0.05	0.09
Unnamed Tributary	3700	998.70	998.74	998.77	0.03	0.07
Unnamed Tributary	3600	998.37	998.41	998.44	0.03	0.07
Unnamed Tributary	3500	998.18	998.22	998.25	0.04	0.07

Table I-2: Water Levels along the Unnamed Tributary due to Climate Change

River	River Station(a)	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Unnamed Tributary	3400	997.99	998.03	998.06	0.04	0.07
Unnamed Tributary	3300	997.76	997.80	997.84	0.04	0.08
Unnamed Tributary	3200	997.48	997.53	997.57	0.05	0.09
Unnamed Tributary	3100	997.07	997.12	997.16	0.05	0.09
Unnamed Tributary	3000	996.59	996.65	996.70	0.05	0.10
Unnamed Tributary	2900	996.39	996.45	996.49	0.05	0.10
Unnamed Tributary	2800	996.10	996.15	996.19	0.05	0.09
Unnamed Tributary	2700	995.84	995.89	995.94	0.05	0.10
Unnamed Tributary	2600	995.55	995.59	995.63	0.04	0.08
Unnamed Tributary	2500	995.22	995.26	995.29	0.04	0.07
Unnamed Tributary	2400	994.82	994.85	994.88	0.03	0.06
Unnamed Tributary	2300	994.38	994.41	994.44	0.03	0.06
Unnamed Tributary	2200	993.97	994.00	994.03	0.03	0.06
Unnamed Tributary	2100	993.68	993.72	993.76	0.04	0.08
Unnamed Tributary	2000	993.49	993.53	993.58	0.04	0.09
Unnamed Tributary	1900	993.26	993.29	993.32	0.03	0.06
Unnamed Tributary	1800	993.16	993.18	993.20	0.02	0.04
Unnamed Tributary	1700	992.15	992.21	992.27	0.06	0.11
Unnamed Tributary	1600	991.74	991.80	991.84	0.05	0.10
Unnamed Tributary	1500	991.37	991.42	991.46	0.05	0.09
Unnamed Tributary	1400	990.98	991.03	991.06	0.04	0.08
Unnamed Tributary	1300	990.68	990.71	990.73	0.03	0.06
Unnamed Tributary	1200	990.49	990.52	990.54	0.02	0.05
Unnamed Tributary	1100	989.45	989.48	989.51	0.03	0.06
Unnamed Tributary	1000	989.10	989.15	989.21	0.05	0.11
Unnamed Tributary	900	988.87	988.94	989.01	0.07	0.14

Table I-2: Water Levels along the Unnamed Tributary due to Climate Change

River	River Station[(a)]	Water Level for 100-Year (Base Case) (m)	Water Level for 10% Increase in Peak Flow (m)	Water Level for 20% Increase in Peak Flow (m)	Difference due to 10% increase in Peak Flow (m)	Difference due to 20% increase in Peak Flow (m)
Unnamed Tributary	800	988.51	988.60	988.69	0.09	0.18
Unnamed Tributary	700	988.36	988.46	988.56	0.10	0.20
Unnamed Tributary	600	988.29	988.40	988.50	0.11	0.21
Unnamed Tributary	500	988.17	988.30	988.42	0.13	0.25
Unnamed Tributary	400	988.07	988.21	988.34	0.14	0.27
Unnamed Tributary	300	987.98	988.12	988.26	0.14	0.28
Unnamed Tributary	200	987.92	988.07	988.21	0.14	0.29
Unnamed Tributary	100	987.79	987.94	988.09	0.15	0.30
Unnamed Tributary	0	987.67	987.82	987.98	0.16	0.31

Notes: a) The locations of these stations are presented in Appendix G.

Figure I-1: Water Level Difference along the Belly River due to Climate Change

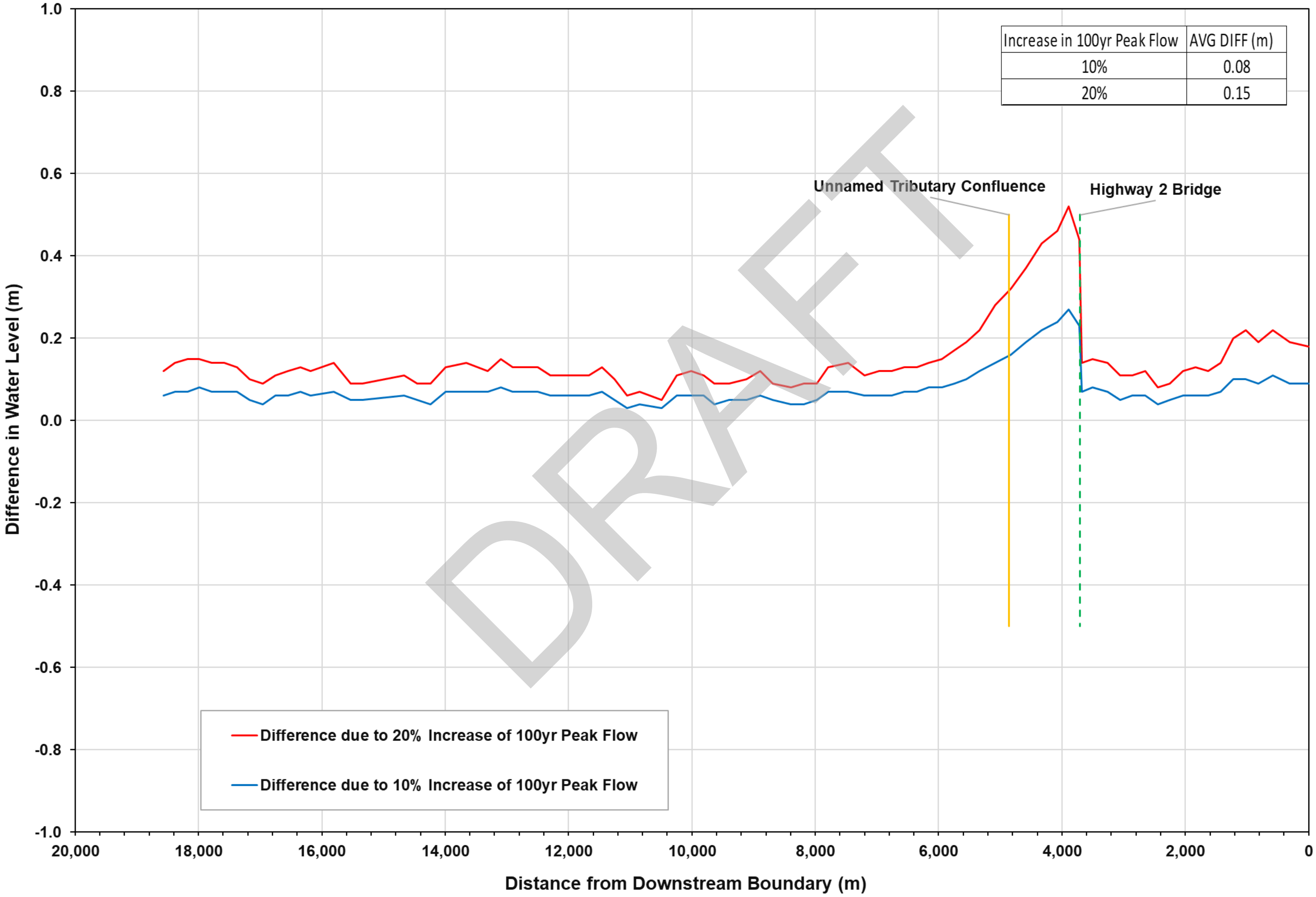
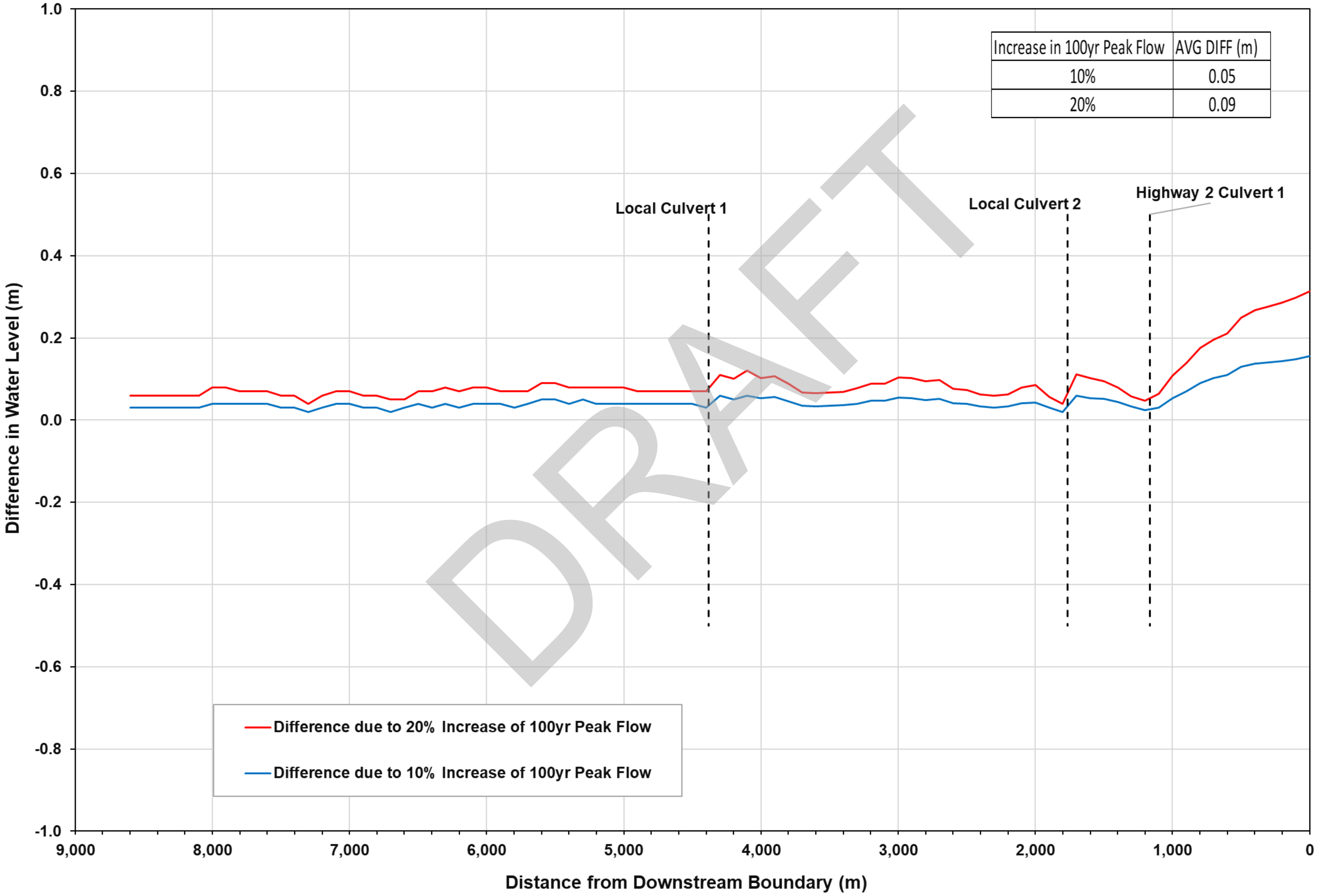


Figure I-2: Water Level Difference along the Unnamed Tributary due to Climate Change



Increase in 100yr Peak Flow	AVG DIFF (m)
10%	0.05
20%	0.09

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